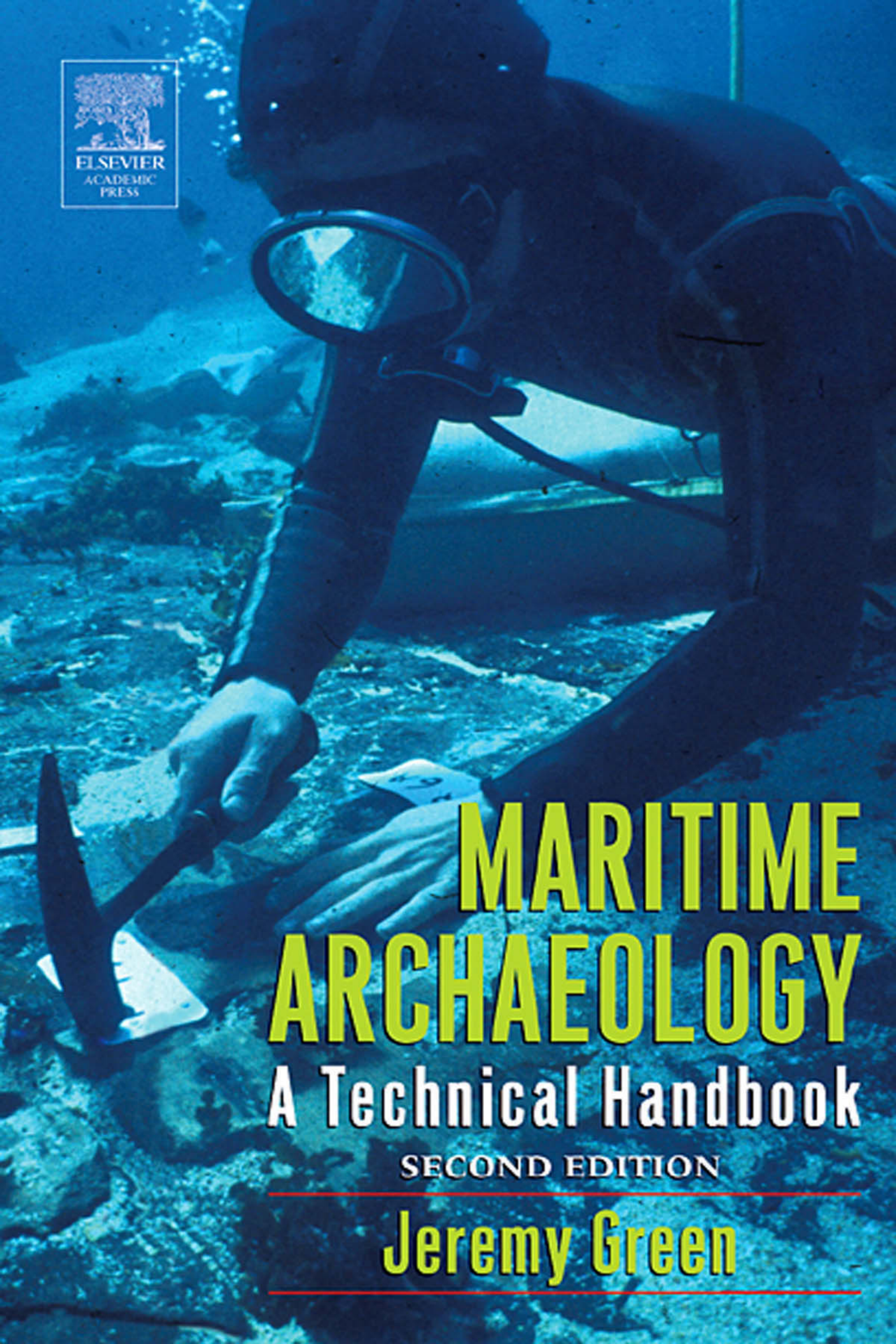
ELSEVIER
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MARITIME
ARCHAEOLOGY
A Technical Handbook
SECOND EDITION
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Maritime Archaeology

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A Technical Handbook

Jeremy Green

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Fremantle, Western Australia

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Preface

As with the first edition, the second edition of *Maritime Archaeology, A Technical Handbook* is intended as a guide and reference book for persons working in the field of maritime archaeology. As this is a technical handbook, the original concentration on technical matters has been maintained. However, since the first edition, many issues and emphases have changed and I have tried to incorporate these changes into the book as best as possible. As a result the second edition is almost twice as long as the first, even though some of the original parts have been excised from the work because they are no longer relevant.

This book is not meant to be a passport to become an instant maritime archaeologist. Rather, it is an aid or guide for those interested or involved in the field. The book is divided into five broad areas: searching for sites; recording sites; excavation; management; and study, research, and publication. I have tried to cover all the main subjects involved within these areas. It is interesting that in the last 10 years, methods of recording have become much more technical and, in many cases, much easier for the archaeologist. Although this technical handbook deals mainly with shipwreck archaeology, there is no reason why the techniques cannot be applied to other forms of cultural heritage underwater (or in some cases on land). There is no differentiation on approaches to sites of different ages; this, for a technical handbook, is irrelevant, since the archaeological methodology does not change simply because one site is very old and another modern.

The future of the field of maritime archaeology today is far more certain than it was in 1990. It still faces challenges in a number of areas, particularly the complex problem of legislation related to the protection of sites. The UNESCO Convention on Underwater Cultural Heritage will have an enormous impact on the attitudes and perceptions of governments to treasure hunting and cultural heritage management. There is also the need to encourage public support for this work. Cultural tourism and public participation has enormous implications for the future of the discipline. Unless we, as archaeologists, can interest and inspire the public, who usually in one way or another pays for us to do the work, we will have no grass roots support. It is therefore our responsibility to ensure that the public is involved and informed. Additionally, there is an equivalent need to involve and inform governments and government departments to ensure that sites are protected. Divers should be encouraged to assist in projects, and interested groups formed into associations. With guidance, such groups can be trained and encouraged to do survey work and assist in excavations. In this way the archaeologist can draw on a source of trained volunteers for excavation work, which by its nature is labour intensive. When the excavation is over, the volunteers can return to their normal occupations, leaving the archaeologist and staff to deal with the non-labour intensive day-to-day work. It is far better to channel divers' energy in this direction, rather than have the same people loot sites through ignorance and lack of direction.

It is also an essential part of an archaeologist's work to publish, and today there are numerous avenues for publication. It is important that material be published properly so that the work is recorded for others to see and utilise.

One minor point, the first edition of *Maritime Archaeology, A Technical Handbook*, published by Academic Press was written in British English. Unfortunately, the publishers of the second edition have insisted that this edition be written in American English, a language with subtleties, particularly in punctuation, with which I am unfamiliar. As a result, the process of editing on the part of the author has been problematic. However, as author, I accept full responsibility for errors and mistakes that will have almost inevitably crept into the text and I invite readers to forward suggestions and corrections so that one day they may be incorporated in a third edition (heaven forbid!).

Finally, I hope this handbook will encourage people to try new techniques and different approaches to the subject. I think one of the most enjoyable aspects of this field is the great variety of techniques and methods that are needed in order to be a good maritime archaeologist.

Please note that all the figures are the author's unless otherwise indicated in the source line in parentheses found at the end of the caption.

Jeremy Green
February 2004

Acknowledgments

In writing the second edition of *Maritime Archaeology, A Technical Handbook* I have drawn on experience gained over almost 40 years working in the field of maritime archaeology. During this time I have worked on many sites, both as a member of an excavation team under a project director; as a project director myself, working with others; or, as the head of the Department of Maritime Archaeology at the Western Australian Museum. Throughout this time I have benefited from advice, help, and assistance from a wide range of people. All of this has been stimulating and thought provoking. In writing this second edition, once again I owe a debt of gratitude to the people that have shared their knowledge and experience with me. In this section I attempt to acknowledge this and in doing so express my gratitude. Maritime archaeology is a discipline that is multi-faceted. One works in an extraordinarily diverse field where, happily, many people are willing to share their knowledge and experience. It is what makes the field such a joy to work in.

Much has changed since I wrote the first edition. Sadly, many old colleagues have died. Among them is Teddy Hall, founder of the Research Laboratory for Archaeology at Oxford, who died in 2002. It was Teddy who in the 1960s introduced me, a brash young physicist, to maritime archaeology, and whose mentorship during those heady years I owe a huge debt of gratitude. A generous and immensely enjoyable person to work with, Teddy taught me the importance of research while having fun at the same time. Others who are sadly missed include Michael Katzev, who directed the Kyrenia excavation in Cyprus in the 1960s—my first experience of a major archaeological project; Bas Kist of the Netherlands Rijksmuseum, who shared with me his great intellectual grasp of the historical dimension of the Dutch East India Company in my early attempts to understand its complexities; Frank Broeze of the University of Western Australia, whose outstanding scholarship in maritime history has an ongoing impact not only on my research but that of countless others; and Hassan Maizan Maniku, who as Director of the Fisheries Department of the Maldives, supported and worked with me on projects related to boat ethnography and heritage management.

I am indebted to many people who helped me in my early career, particularly Jan Piet Puype, late of the Leger Museum Leiden and the Scheepvaartmuseum, Amsterdam; R. Reinders of the University of Groenegen (late of the Kedelhaven Museum); and Gerrit vander Heide (retired)—all of whom have assisted me in my research in the Netherlands on numerous occasions. Willem Vos and Robert Parthesius of the Nederland Stichting Bouw VOC Retourschip, Lelystad, also opened up new opportunities for research on the *Batavia* for which I am grateful. In Sweden I received a great deal of support from the Wasavarvet, in particular from the then Director Lars Åke Kvarning and then chief maritime archaeologist Carl Olof Cederlund (both now retired). In the United Kingdom, the experience gained from working, initially with Syd Wignall and later with Colin Martin on a number of excavations and with Peter Marsden on the *Amsterdam* project also warrants my thanks.

Since writing the first edition of this book, some of my interests have diverged and my activities changed direction leading to new experiences and ideas. I am particularly grateful to George Bass who, in 1999, invited me to (once again) visit his operation in Turkey (I remember that within a few days of starting work at the Research Laboratory for Archaeology in 1967, I was sent by Teddy Hall to Turkey to work with George at Yassi Ada, my first startling introduction to maritime archaeology). Since 1999 I have returned each year, with the support of the Western Australian Museum, to work with the Institute for Nautical Archaeology (INA) in Bodrum, carrying out a research programme related to the development of underwater surveying techniques; this has been a fruitful and exciting programme. I would like to acknowledge the great contribution to my research made by colleagues at INA Bodrum, particularly my old friend and colleague Robin Piercy, and also to Xila Matthews, Tufan Turanli, Don Frey, Murat Tilev, Debora Carlson, and Faith Henschal.

In recent years I have also been fortunate to have the opportunity to work in Sicily, where Sebastiano Tusa and Gaetano Lino of the Servizo per il Coordiamento delle Ricerche Archeologiche Sottomarine (SCRAS), which is part of Departemento dei Beni Culturali ed Ambientali e dell'Educazione, have provided invaluable assistance and support. I want to thank them for allowing me to work with their organization.

In the United Kingdom, Pete Holt of 3H Computing, Portsmouth, helped enormously with the application of Site Surveyor and has my thanks for his part in developing our acoustic position fixing system. Another great source of support is Ray Sutcliff, an old friend and colleague who has helped in film projects, including the immensely successful BBC Chronicle programme on the *Batavia*, sadly the last program of the series that the BBC produced.

In the United States Thomas Wilcox, of Marine Sonic Technology, has been a constant source of advice and assistance in the operation of our side scan sonar.

In Sri Lanka I have been involved in a project developing a maritime archaeological programme in conjunction with the Sri Lankan Department of Archaeology, the Postgraduate Institute for Archaeological Research (PGIAR), and the Central Cultural Fund. Instigated by Professor Senake Bandaranayake of the PGIAR and Dr. Kenneth McPherson of the Indian Ocean Centre at Curtin University of Technology (now regrettably defunct), this programme has led to a long and fruitful collaboration with Somasiri Devendra, and continued a research program with Robert Parthesius, with whom I had worked earlier in the Netherlands on the *Batavia* project. Initially the work in Sri Lanka was funded by an Australian Research Council grant and later with Australian National Centre of Excellence funding which is explained below. This project now continues with funding from the Netherlands Government under direction of Robert Parthesius.

I would like to acknowledge the recognition given to the Western Australian Museum, when in 1995, the Australian Federal Government announced the *Creative Nation Statement*, in which the Museum was made a National Centre of Excellence for Maritime Archaeology and received a 3-year special purpose grant. This provided an opportunity for the Department of Maritime Archaeology to embark on an imaginative programme to develop maritime archaeology on a national and international level. It marked a time of immense activity for the Department. We were able to develop new technology and assist in numerous national and international projects and published numerous reports and technical works. It is hoped that in the future, similar schemes can be initiated; hopefully with longer term funding that will provide that 'quantum leap' that disciplines such as maritime archaeology need to maintain their cutting edge.

Much of the work of the Department has been supported by grant giving organisations. In particular I would like to thank the Australian Research Grant Scheme for long and continued support. The Australian Commonwealth Department Heritage and Environment, the Churchill Foundation, the Australian Academy of the Humanities, the Japan Foundation, the Western Australia-China Economic and Technical Research Fund Grant, the Australia China Council, and the Australia Japan Foundation that have all given me financial support for projects.

Governments have come and gone, as have museum directors—my colleague Graeme Henderson, once a member of staff in the Department, has gone on to become director of the Western Australian Maritime Museum, which in turn has enjoyed a new building and a revitalization of the work of the Maritime Museum. The State government has continued to support the work of the Department, as has the Federal government, through the Historic Shipwrecks Programme.

I would especially like to thank (long-time friend and associate) John Penrose and Alec Duncan from the Centre for Marine Science and Technology at Curtin University of Technology, and Bruce Montgomery and Jochen Franke at the Department of Spatial Sciences at Curtin University of Technology for their input to my work and ongoing support and assistance. The Western Australian companies Geosciences Australia and 3D Mapping has also been a great help on photogrammetric issues.

Geoff Glazier of Fugro Survey has over the years lent exceptional support for maritime archaeology in Western Australia and I am particularly grateful to him for the assistance Fugro has provided towards the work of the Department.

In 2001, the local Western Australian film company Prospero Productions sponsored a series of three documentary films entitled *The Shipwreck Detectives* which portrayed the work of the Western Australian Department of Maritime Archaeology and of maritime archaeology in general. The programs, which were totally funded by Prospero, enabled us to carry out further work in the *Batavia* grave sites, investigate the World War II seaplane wreck sites in Broome, and explore the Deepwater Graveyard off Rottnest (an episode that ultimately transformed into a program about the World War II wrecks of Truk Lagoon, Micronesia). This proved to be a dynamic and extremely successful collaboration and I am grateful to my friend and colleague, Ed Punchard, director of Prospero, for his support.

Teaching has played an important role in my work and is part of the reason for writing this handbook. Curtin University of Technology, through the auspices of Professor John Penrose, established the first Australian postgraduate diploma course in maritime archaeology. Initially a collaborative course between Curtin University of Technology, the University of Western Australia, Murdoch University, and the Western Australian Museum, it was a unique course that was run on an irregular basis (five courses between 1990 and 2001). In 2001, Curtin University was no longer prepared to run the course and with changes in tertiary education in Australia we negotiated to run the course in conjunction with James Cook University in Townsville and Flinders University in Adelaide. Currently I hold the unusual distinction of being an adjunct associate professor at two universities. The Department is now negotiating a new structure with the Department of Archaeology at the University of Western Australia, scheduled to start in 2005. Working with a wide range of students over the past 20 years has, again, been an intellectually stimulating process; it is always thought provoking to work with students fresh to the subject.

In 1982, I was part of a process that established the Australian Institute for Maritime Archaeology (AIMA, now Australasian rather than Australian), as foundation president. AIMA took on a wide range of responsibilities, particularly in supporting maritime archaeology in Australia. Numerous AIMA colleagues have helped me at various times: Bill Jeffery, Paul Clark, Terry Arnott, Mike Nash, Peter Gesner, Peter Harvey, Ross Anderson, David Nutley, and Tim Smith.

My greatest debt of gratitude lies with the numerous staff members with whom I have worked since 1971 as Head of the Department of Maritime Archaeology at the Western Australian Maritime Museum. In particular, I want to pay tribute to my colleagues Myra Stanbury, Mike McCarthy, Corioli Souter, Geoff Kimpton, Patrick Baker, Stuart Sevastos, Richenda Prall, Jennifer Rodrigues, and Matthew Gainsford for their outstanding professionalism and, in particular, Susan Cox, our tireless departmental secretary. Staff that have now left and moved on to other areas include: Scott Sledge, Colin Powell, Bob Richards, Brian Richards, Fairlie Sawday, Rosemary Harper, Paul Hundley, Catherina Ingleman-Sundberg, Lous Zuiderbaan, Warren Robinson, Tom Vosmer, and the late Jim Stewart. I have also benefited from the help and assistance of the Staff of the Department of Material Conservation and Restoration, Ian MacLeod, Ian Godfry, Vicki Richards, and Jon Carpenter. The success of my Department is a direct result of the enthusiasm and dedication of the staff working in it, together with the support of the Museum in general.

The public arm of maritime archaeology has been essential in establishing maritime archaeology in Australia. In 1963 a group of public-spirited Western Australians citizens, who had found important and significant 17th century Dutch East India Company shipwrecks, transferred their rights to the State Government on the condition that the government take responsibility for their protection; subsequently, the State Government enacted *The Museum* Act *1963* (the first international underwater cultural heritage legislation). As a result of all this, I am here writing this second edition, I have a department that has to be second to none (in my eyes), and Australia through a series of acts, now has one of the best examples of underwater cultural heritage legislation and public acceptance of the concept of protecting underwater cultural heritage in the world. All of this was a result of public concern. Graeme Henderson, from the Western Australian Museum was the founding chair of the UNESCO Convention on Underwater Cultural Heritage, reaffirming the seminal position

Australia has, and continues to have, in this process. This is all the result of public interest. I therefore acknowledge the enthusiastic contribution the public continues to play in our operation. I remind everyone that without public support one is doomed.

Many people have contributed one way or another to this book. I am grateful for everyone's help. I have always found it stimulating and enjoyable to work with others in this field, and I believe that in writing this book, what has been written is as much their work as mine.

Chapter 1

Introduction to Maritime Archaeology

Much has changed since I wrote the first edition of *Maritime Archaeology: A Technical Handbook* in 1989. Possibly the greatest change, at the technical level, has been the advance in the use of computers and their introduction to mainstream maritime archaeology. The development of the Internet, the amazing power of the computer, and the advent of reliable, cheap, and extremely accurate position fixing systems like the Global Positioning System (GPS) have provided opportunities that would have been unthinkable in 1980s. Now, with a small hand-held GPS, a position can be obtained anywhere on the surface of the Earth accurate to about a couple of meters. Although much has changed, surprisingly, a lot of things have not. So in revising the handbook there will be changes in some areas and very little in others. I have decided to omit the chapter on conservation as this subject is now well covered in the literature and there are several handbooks that can be used as references. Over the past ten years, maritime archaeology as a subject has become increasingly involved in cultural resource management, so I have introduced a new chapter dealing with this issue. In addition, the plethora of computer packages which are currently available now make it impossible to deal with each in detail. As a result, I have illustrated the general application with a program with which I am experienced. This is not to say there are better programs, or that the one discussed is the best, it is simply that I have used it and know how it works and know its limitations. Readers are encouraged to investigate other systems, particularly as there are always new systems being produced, that may well be better or more sophisticated.

When *Maritime Archaeology: A Technical Handbook* was first published there were few books that dealt with the practical application of maritime archaeology with Wilkes (1971) being the only notable work. Soon after the publication of *Maritime Archaeology: A Technical Handbook*, Dean (1992) published *Archaeology Underwater: The NAS Guide to Principles and Practice*, an excellent guide to maritime archaeology, particularly as it related to the very important Nautical Archaeology Society (NAS) courses developed in the UK.

In the first sentence of the first edition, I asked the question: "What is maritime archaeology?" The answer is still the same. There have been a number of attempts to define a term to describe all aspects of the field. Terms such as marine, nautical, and underwater all have slightly different meanings, and there is no one word that is really adequate. In 1978 Muckelroy (1978) defined a meaning of the various terms, but generally it has been accepted that the most suitable adjective is "maritime" (McGrail, 1984, 1987), and that it is possibly irrelevant to attempt to determine if, for example, a shipwreck found on reclaimed land is nautical, maritime, or marine archaeology. It is clearly not under water. Recently, Werz (1999) revisited this question and quoting Bass (1983) "archaeology under water, of course, should be called simply archaeology." This handbook deals with aspects of archaeology and the techniques that are used to conduct archaeology in an underwater environment. Although shipwrecks are particularly featured here, the techniques described can be applied just as readily to submerged land structures and research associated with sea level changes. See, for example, Blackman (1982) and Flemming (1971, 1978). The overall archaeological process is in fact no different from the process that takes place on land. It is therefore essential to understand that archaeology which is done under water requires the same elements and the same procedures as any other form of archaeology.

Because maritime archaeology is a relatively new discipline it has in the past at times suffered, understandably, from a lack of proper methodology. This was partially due to the fact that the procedures were not clearly understood then; this is no longer the case. A series of major and pioneering excavations demonstrated that even under the most difficult conditions, the highest archaeological standards can be maintained. Previously it was often difficult to determine what was proper archaeology. There was (and there still is) a lot of excavation work masquerading as maritime archaeology, when it was in reality simply treasure hunting carried out by individuals claiming to be maritime archaeologists who were driven by a profit motive or simply souvenir hunting. These factors were detrimental to the proper development of maritime archaeology in the early phases and resulted in some people, including professional archaeologists, to argue that maritime archaeology was not a discipline but merely an extension of treasure hunting. This is no longer true and many of these prejudices are long gone. There is, however, a new problem beginning to arise. Whereas in the 1970s and 1980s maritime archaeological excavations were quite common, this is no longer the case. Remarkably few excavation reports are seen today in the literature. This stems from the fact that there are limited funds and a philosophical approach to the whole issue of excavation that tends to eschew the process. Consequently, there are less and less maritime archaeologists with excavation experience. This whole subject will be dealt with later in Chapter 14, "Cultural Resource Management." But it is worth noting here that as a result of this, most recovery work being done today is by treasure hunters.

An early criticism of maritime archaeology involved questions related to the study of relatively modern sites such as shipwrecks from the post-medieval or later periods. This has led professional archaeologists and historians to suggest that this type of study is "an expensive way of telling us what we already know" (Sawyer's remark quoted by McGrail, 1984). Others maintained that maritime archaeology was a valid part of archaeology and that it had made important contributions to history, art, archaeology, the history of technology, and many other traditional areas of study. Today, this criticism is largely irrelevant. The advances over the past decade in post-medieval and modern maritime archaeology have been enormous. Both the Columbus centenary and the remarkable historical reconstructions that were initiated in Lelystad, The Netherlands by Willem Vos, starting with the *Batavia*, have lead to a series of other historical reconstructions. These have all had immense impact on the understanding of the construction and sailing of ships of this period and have stimulated archaeological, historical, and archival research. The development of iron and steam maritime archaeology has also created new areas of research, particularly the development of corrosion science and understanding of the disintegration process of iron shipwrecks.

It is also obvious that maritime archaeology is no longer purely an archaeological matter concerned with archaeological issues of excavation and research. There is a growing awareness that maritime archaeology is related to management of sites and that sites do not necessarily "belong" to archaeologists, but instead are a cultural resource that belongs to everyone. This does not necessarily mean that a site has to be defined as an ancient monument in order to involve maritime archaeologists, nor does it mean that if it is declared a monument it precludes archaeological excavation. It could, for example, be a recreational facility in a national park or a site used to train archaeologists. The management of sites also concerns legislation and procedures and decisions required to define sites in accordance with the legislation—all of which have archaeological assessment issues. These issues will be discussed in greater depth in Chapter 16.

Steffy (1994) published a groundbreaking work, *Wooden Ship Building and the Interpretation of Shipwrecks*, in which he discusses how shipwreck sites should be investigated and that "each wreck must be analyzed as accurately and as extensively as possible by means of a controlled discipline; we have come to know this discipline as ship reconstruction." Steffy's approach was to take the basic ship-related information from archaeological shipwreck sites and attempt to extrapolate from the evidence a reconstruction of the ship. This is a particularly important and scholarly work and possibly one of the most important theoretical contributions to the field in the last decade.

From an archaeological point of view the study of maritime sites and artifacts has opened up new fields of study. In part these have complemented existing fields of study, but in many cases the area of study is totally new. The hulls of ancient ships and their contents, apart from one or two examples, have not previously been available for study. The material from shipwrecks is unusual for several reasons including that the circumstances of the loss of a vessel in one instant of time often leaves a large quantity of material, much of which can be recovered or reconstructed. This may be contrasted with objects that survive today in museums and collections, which do so because they were rare or valuable and were therefore to be kept and collected. Thus, if one's view of the past is based solely on museum collections, there tends to be a bias toward luxury and there is often little of the mundane, day-to-day items that would have been found in the houses of the masses. This view has changed within the last decade as archaeology has opened up fields of study that relate to these issues. The Jorvik Viking Centre in York is a good example of this; a place where everyday life of the Vikings is shown. Another example of this shift in perspective is with the Egyptian excavations. Here the archaeology is probably driven by the fact that there are few remaining Pharaonic tombs to be found, but there is now a considerable emphasis on discovering who the builders of the pyramids were and what the life of the ordinary person was like in Egypt during the time of the Pharaohs.

There is a difference too in the nature of maritime archaeological sites. The material from terrestrial archaeological sites usually represents occupation over a period of time, often centuries, and the artifacts that survive do so in a complex pattern demanding great skill on the part of the archaeologist to understand and interpret. Often terrestrial sites have had a continual history of interference, both human and natural, and the continued occupation of sites make understanding them as a series of events extremely complicated. Underwater sites, on the other hand, particularly shipwreck sites, tend to be single events in time. Shipwreck sites usually contain all the material that was on board the ship at the moment of sinking, almost like a tomb on land (naturally some things tend to disappear). The artifacts, however, are usually simple domestic wares belonging to the common seaman, trade goods destined for the markets of the world, and the fittings of the vessel itself. As a result the collections provide new and different types of information through which we can study the past. The consequent disintegration of the site and the natural effects of the sea are thus the primary vectors that the archaeologist have to interpret.

The advent of underwater breathing equipment and early salvage work starting essentially in the 16th century had a minor effect on the archaeological record, but the advent of the aqualung had a major impact on underwater sites. More and more sites are being looted by treasure hunters so that the archaeological record, like that on land, is now slowly disappearing. These issues have been of concern to archaeologists and legislators, and there has been a long and bitter battle with the treasure-hunting community over this issue. The United Nations Educational, Scientific and Cultural Organization (UNESCO) Convention on the Protection of the Underwater Cultural Heritage was adopted in November 2001 by the Plenary session of the 31st General Conference thus becoming UNESCO's fourth heritage convention. This convention is a starting point in dealing with issues relating to sites that lie in international waters, but it also requires that countries abide by its principles. The conference underlines an international desire that underwater cultural heritage should be protected.

Underwater archaeology as a discipline had its beginnings in the 19th century when salvors, working on the then modern shipwrecks, and sponge divers seeking sponges occasionally came across ancient material. This attracted archaeological interest, however, the work that was undertaken was limited at best to an archaeologist directing divers from the surface (Frost, 1965; Taylor, 1965; Throckmorton, 1964). The advent of scuba equipment and the birth of sport diving rapidly altered this situation. The 1950s marked the start of two separate developments that were to affect the future of maritime archaeology: the diving archaeologist and, for want of a better word, the "looter". The former included a small number of archaeologists who learned to dive, and a large number of divers who became involved and interested in doing archaeology under water, many of whom (like myself) went on to become archaeologists. The looters were sports divers, who, in the Mediterranean, found that Greek and Roman amphora commanded high prices on the antiquities market. Even if there was no commercial motive, these artifacts from the sea made excellent souvenirs. In the United States, the seeds of a far greater problem were being sown. The discovery of the shipwrecks of the Spanish fleets that sailed from Central America to Spain, bringing the treasures of the Americas, attracted the growing interest of underwater treasure hunters. The treasure hunter operates differently from the looter, who usually finds sites by chance. The treasure hunter actively searches for sites as an occupation using sophisticated electronic search equipment, is motivated by profit, and usually works totally within the law. This was a time when the word gold was on every treasure hunter's lips. There is an apocryphal story that treasure hunters in their search for gold were ignoring sites that had just silver on board. The literature abounds with accounts of treasure-hunting groups that set up companies to search for famous treasure ships. Nearly all went bust, possibly some never had the intention to search for sites in the first place, and others were inept. Yet, even today the gullible investors sign up their hard-earned cash with the dream of gaining huge fortunes—most are sadly disappointed.

Once again the wheel turned and in 1983 Michael Hatcher started looking for the *Verenigde Oostindische Compagnie* (VOC) shipwreck *Geldermalsen* off the Riau Archipelago in Indonesia. His search started with the discovery of another wreck site, the so-called Transitional Wreck. This was a Chinese junk, dating from the mid-17th century, possibly in the employment of the VOC. There was no silver or gold on this site, but a remarkable collection of Chinese porcelain of the Transitional Period. The collection was sold at Christie's in Amsterdam, and made Hatcher a small fortune (Christie's Amsterdam, 1984, 1985; Sheaf and Kilburn, 1988). He went on and eventually found the *Geldermalsen* which contained a huge cargo of Nanking porcelain (Christie's Amsterdam, 1986; Jorg, 1986; Sheaf and Kilburn, 1988). There has never been an event quite like the sale of the Nanking cargo which was comprised of over 160,000 ceramic items and 126 gold ingots and sold for about £10 million. Indeed the *Geldermalsen* sale by itself exceeded in almost every conceivable way anything that Christie's had done before. For example: Lot 5105 included one thousand similar tea bowls and saucers, circa 1750 at £21,000–32,000 and Lots 5059–5066 included one thousand (each lot) tea bowls and saucers at £26,000–40,000. It was staggering. The sheer quantity must have created a nightmare in marketing for Christie's. Clearly, their approach was unconventional and successful. First, by selling off large lots it was possible for dealers to the resell, allowing for a financial speculation. The catch phrase was "Nanking for everyone." Even if is was mediocre quality, the buyers came in droves and bought at prices well above the expected or "suggested" price. Additionally, it was essential for Christie's to ensure that the sale did not cause a loss in confidence of people who use the antiquity market for investment purposes. Who wants to buy something for £1000 today and find tomorrow, because a wreck has been found with thousands of what were once unique items, that one's investment is worthless? This has happened with numismatic collections consisting of rare silver coins, which in the catalogs are worth a large amount, have often fooled the unwary treasure hunter (working on the theory that the numismatic value of a coin is say, £200, so because I have 10,000, this means I have £2,000,000). In the same way, the investor who has a coin worth £100,000, because there are only four in the world, is faced with the danger of a hitherto unknown wreck site which is found to have 10,000 of these coins. Christie's also sold dinner services as lots:

> A magnificent dinner service . . . four tureens and covers, 25.5 cm diameter. Four dishes, 42 cm diameter. Eight dishes, 39 cm diameter. Four deep dishes, 38 cm diameter. Six dishes, 35.5 cm diameter. Sixteen dishes, 32 cm diameter. Eighteen dishes, 29 cm diameter. Twelve saucer dishes, 26 cm diameter. Eight jars and covers, 11.5 cm wide. Twelve salt cellars, 8.5 cm wide. One hundred and forty-four soup plates, 23 cm diameter. One hundred and forty-four plates, 23 cm diameter £100,000 to 15,000.

There were about 17 dinner services auctioned, mostly smaller than those illustrated above. The suggested price in the catalog was generally far exceeded at the time of the auction, often by up to ten times. The auction was the second highest total for a Christie's sale and no doubt, for them, a very profitable operation. From this moment on, shipwreck treasure hunting was not just looking for gold and silver.

The whole problem of course started much earlier. It must be remembered that this started at a time when governments, academics, and archaeologists had no real interest in, or concept of, the extent of the underwater heritage. As a result, the looters made rapid inroads into shallow water sites (up to 40 m). By the mid-1960s, there were growing reports of sites in the Mediterranean being extensively looted. Countries bordering the eastern and western Mediterranean (France, Greece, and Turkey) started to take steps to protect these sites by enacting legislation. These countries, particularly Greece and Turkey, had suffered in the 19th century from terrestrial collectors. Because the underwater looters were more often than not visiting tourists (who could afford not only the holiday, but also the expensive diving equipment), the enactment of legislation came easily and was widely accepted by the local people who generally did not have access to this equipment, did not benefit from the process and, more significantly, had a growing interest and pride in their cultural heritage. The treasure hunters in the Caribbean were beginning to run out of really valuable sites and were running into more and more bureaucratic opposition to the process. This opposition gradually extended outside the United States, as international organizations such as UNESCO and the International Council on Monuments and Sites (ICOMOS) became concerned that valuable underwater heritage was being lost to a small, elite group of commercial operators. Naturally, the *Geldermalsen* opened up a huge new opportunity, particularly in Asia, where countries had little interest or ability in dealing with underwater cultural heritage. Additionally, as many of the sites belonged to their post-colonial masters there was an even greater lack of interest. The fact that these sites that had little to do with their indigenous heritage but had promised opportunities of access to a share of the fortunes, often resulted in arrangements where sites were salvaged for their financial resource, the material cataloged and then sold at auction, and the country taking a percentage of the proceeds, occasionally in artifacts, but often in straight cash. Even today Malaysia, Viet Nam, the Philippines, Indonesia, and other Southeast Asian countries make deals with treasure hunters. They license them to search and share in the proceeds. This is often against the wishes of the heritage managers, but the decisions are driven by the finance departments and the politicians. It is quite legitimate, a country has every right to decide how it wishes to dispose of its heritage. It is unfortunate that these decisions have short-term benefits and rarely result in a positive outcome. The UNESCO Convention will make this process more difficult.

In the past four decades, great developments have been seen in the maritime archaeological field. Pioneering this was the raising of the 17th century Swedish warship *Wasa* in Stockholm Harbor in 1961 (Franzen, 1961). This was a landmark for maritime archaeology. For the first time, an almost complete ship was brought to the surface, not for salvage, but for archaeology. This immense project brought home the impact of the past in that dramatic moment when the vessel first broke surface and floated into the dry dock. The raising of the *Mary Rose* in 1982 was also a landmark in maritime archaeology. However, strangely, neither projects have become springboards for advancement in the field. Admittedly both projects have stupendous displays, but between the *Wasa* and the *Mary Rose* there has been no more than a handful of academic papers, a fact that has to be deplored.

The work in the Mediterranean, popularized in the 1950s and 1960s by Jacques Cousteau, and later developed into a scientific discipline by George Bass (and other organizations in the Mediterranean), also stimulated the popular imagination. Here, it was not really the material, but more the great age of the sites. The fact that they dated from pre-Christian times amazed many and brought home the closeness of the past.

However, in the United States there was a different situation. First, the sites involved were relatively modern. It was therefore argued that they came under salvage laws and that the question of antiquities was irrelevant. Secondly, as mentioned above, there was little interest (in the beginning), either from government, academics, or institutions. Everyone, generally, either tried to avoid responsibility or was disinterested. Finally, the divers were usually locals, and the material, which was mainly sold for profit, attracted interest, tourism, and more divers. It was thus plain good business with the possibility of rich rewards. By the late 1960s, there was a twofold situation: recreational divers who collected souvenirs as a cottage industry and treasure hunters, who in the United States had become very big business, and this business began to spread out across the world.

While this was taking place, underwater archaeology was also beginning. George Bass pioneered a series of excavations in Turkey which have become the model for other archaeologists. For the first time the scientific principles of archaeology to the excavation of underwater sites was applied. At about this time centers began to develop in France, Israel, and Italy, all working on classical shipwreck archaeology. In Scandinavia, the Viking ship archaeology, pioneered on land through the archaeological excavation of ship burials was extended by the discovery of a number of Viking ships sunk in Roskilde Fjord in Denmark. In Sweden, the work of preserving the *Wasa* became a major conservation problem, but underwater archaeological work developed and continued there too. In The Netherlands, the reclamation of the IJsselmeer polders revealed many hundreds of shipwrecks. This region posed a land archaeological problem rather than an under water one and, until recently, little underwater work had been done in The Netherlands (Maarleveld, 1984). In the UK, underwater archaeological work was carried out by individuals or groups rather than organizations. and a number of important historic sites were investigated.

By the beginning of the 1970s maritime archaeology, which was still in its infancy, was encountering a growing number of problems, many of which still exist today: the crucial issue related to the ownership of underwater archaeological sites, the enactment of legislation to protect these sites, and the material from them. This problem today has become confused and complicated by international legislation, offshore seabed rights, and the interests of individuals, business organizations, and vested interests. These issues are discussed in Chapter 16, but the legal complexities are far beyond the scope of this work.

There has also been considerable debate within maritime archaeological circles over codes of ethics. Part of this debate relates to the question of dispersal of collections. Is it acceptable, for example, to excavate a site and then sell the collection? Is it acceptable for a museum to buy material on the auction market that has clearly come from a site that has not been excavated in an archaeological manner? In many situations the archaeologist is required by law to sell the collection. In other cases, the sale of the collection finances the excavation work, and by necessity the material must be sold in order to carry on working. It is quite clear that, in the last two decades, we have seen major and important wreck collections sold at auction. Although some material has gone to museums, the majority has been dispersed, and thus has been lost. Usually the only way that the material has been recorded is in an illustrated auction catalog which, for archaeological purposes, is totally inadequate. The issue has been addressed in a number of forums: the ICOMOS International Committee on the Underwater Cultural Heritage and the International Congress of Maritime Museums being the most significant.

As far as the question of artifacts from shipwreck sites is concerned, there are now several schools of thought holding widely divergent views on these issues. The purists argue that the collection is unique and, if dispersed, the information will be lost forever. Therefore, no excavation should take place unless the material can be conserved and then preserved. The pragmatists state that sites will be excavated or looted and, unless the material is recorded, it will be totally lost. Their approach is to work with the salvors and try to preserve and record as much as possible. The purists claim that this is self-defeating. By giving archaeological respectability to looting or salvage, it is legitimized and, in the long run, even more material will be lost. The treasure hunters argue that, but for them, the sites would never be found. In their eyes, archaeologists are incompetents who are trying to take away the right they have, as treasure hunters, to the rewards for their endeavors. Within this hotbed of dissent exist questions relating to the position of amateurs and nonprofessionals and who is to take responsibility for conservation, storage, and display of material. It is, therefore, not surprising that some terrestrial archaeologists find the maritime field difficult to accept as a fully fledged academic discipline. Sadly these words, written in 1989, are still largely true, although the situation is slowly changing for the better.

Maritime archaeology is a part of archaeology, and as such, is a scientific discipline. It has quite simple aims. First, archaeology should be systematic, and as much information as it is reasonably possible to record must be extracted, information must be properly recorded and documented, and finally, the work should be fully analyzed and published. Where one is involved in excavation, the material should be properly preserved so that it can be studied in the future and the work published, preferably as an excavation report. It is totally unacceptable to excavate, record the material, and then disperse the collection. The collection must be kept together, in a secure, long-term storage. This in reality means a museum of some sort. It is the responsibility of museums, by nature of their function, to take on this role. It is unfortunate that more museums have not done this and some that have done so have actually taken on collections that were, arguably, illegally obtained or, in many cases, not recovered using proper archaeological techniques. However, one must appreciate that taking on such a responsibility creates serious organizational, financial, and administrative problems. Sadly, few institutions have accepted the challenge of maritime archaeology and this has resulted both in a loss of cultural material and in a lack of institutional expertise in the field.

Today there are many sources of information on maritime archaeological work. There is little or no excuse for maritime archaeologists (or those who are working in this field) not to publish their material. The *International Journal of Nautical Archaeology* must hold the prime place as the leading journal in this field. It was through the foresight of the late Joan du Plat Taylor, who started the journal in 1971, that today we have a major source for publication of reports of projects spanning 30 years. The *Australasian Institute for Maritime Archaeology Bulletin for Maritime Archaeology* has a similar record of 24 years of publication. There are other journals and some annual conferences including the Society for Historical Archaeology annual conference and the international symposium on boat and ship archaeology. The recent encyclopedic publications by Delgado (1997) and Ruppé and Barstad (2002) are the most comprehensive review of the field of maritime archaeology on the international level.

Today the Internet is awash with information on all sorts of subjects related to maritime archaeology and of all sorts of quality. A cursory search on the Internet of the word maritime archaeology produced 38,000 hits. Publishing material on the Internet is easy and has a great number of advantages. First, and most important of all, it will get to a very wide public. It is cheap to produce and provided you can ensure its long-term maintenance, it must be one of the most effective ways of communicating information. It is possibly the most worrying aspect that, although there are literally tens of thousands of sites holding information, one wonders what will happen to these sites in the long term. Whereas museums and government institutions may be expected to have a long-term survival, what happens if they are closed, or the individual hosting information on a local Internet service provider (ISP) decides that the costs are too much? Although hardcover publications are not likely to be replaced in the near future, they are expensive to produce and it is difficult for authors to find publishers willing to accept anything but the more popular material. Notable exceptions are Plenum Press and British Archaeological Reports, the latter publishing both a British series and a much more extensive International series.

There is an educational dimension to this subject. Maritime archaeology is a subject that is now increasingly being taught at universities at both a degree level as part of a normal archaeology degree and at a postgraduate level. There are now a very large number of institutions teaching the subject, and this is producing a steady stream of trained individuals who are able to take on projects in a disciplined and competent manner. The introduction of the NAS course provides recreational divers with the opportunity to develop their skills and expertise and through this process obtain a better understanding of maritime archaeology. With trained and experienced volunteers it is then possible for organizations with responsibility for wreck sites and underwater archaeological sites to recruit these people as volunteers.

Finally, as in 1990, I hope this book will stimulate debate, provoke thought and questioning, and also help educate and encourage maritime archaeologists everywhere.

Chapter 2

Research

Some form of research must be carried out as a prerequisite to archaeological fieldwork, be it an initial field survey or excavation work on a site. Without this preliminary study, it is likely that a great deal of time will be wasted in the field solving problems that could have been solved much more easily and efficiently at the home base. This is often referred to as a research design, although that is a rather restrictive term and is often simply the basis or justification for conducting work, rather than the more encompassing research that provides all the available information before the field operations begin. The aim of this chapter is to give a broad overview of the complex problems associated with preparation for fieldwork. There are many different types of research work required to be done before going into the field, which should give information about the location of the site or the nature of the area and help in the planning of the fieldwork. These include such diverse fields such as archival research, site research and, finally, the detailed preparation for fieldwork. For further information on this general subject, see Alexander (1970), Flemming and Max (1988), and Palmer (1986).

I. PROJECT PLANNING

Before embarking on any archaeological project it is essential to have some sort of plan which should be made up of an assessment of the objectives, an outline of the methods that will be used to gather the data, and a careful analysis of how the collected data will be recorded, conserved, studied, and curated. It is important to understand that the process of planning and implementing fieldwork has to be considered together with the post-fieldwork research as an overall project. Every project should begin with a planning phase where the scope of the project, the methods of survey, excavation, sampling and recording methods, and strategies should be assessed. At the end of this phase a plan or research design, as it is sometimes called, should be prepared. This should summarize the following types of information:

- The objectives, which should include the reasons for doing the project and the archaeological problems the work will be addressing
- The methods, including the way that the archaeological problems will be dealt with and the methods of gathering the data; the logistics relating to how the fieldwork will be implemented and staffed
- The background data which consist of all available information which can be used to assist in the logistics and in the implementation of the project; the conservation strategies relating to how material that may be recovered should be handled and treated
- The identification of the storage or repository for the material
- The strategy for postexcavation research and publication

The preparation of this plan is essential and for many grant-providing organizations it is a prerequisite in the application process (for example, see English Heritage, 1989).

Other forms of research may be used to establish a site management program, catalogs of sites, or a theoretical framework related to archaeological site research. These latter areas of study, where discussion relates to the synthesis of information, are dealt with in Chapter 13.

II. ARCHIVAL RESEARCH

There are no shortcuts in archival research. Many long hours may be spent working in archives or reading through literature to find what one seeks. Depending on your approach to the subject, this can be an exciting or a tedious pastime. In this section some brief notes are given on the various aspects of archival research.

Starting at the bottom line, how does one institute research, say, to locate or identify a shipwreck? Obviously the methods will vary depending on the nature of the loss. The main objective, however, is to find some source of information that will give details related to the event that will help to locate the site or at the very least, provide some background knowledge. Records of shipwrecks, because they involve the loss of property and sometimes life, have always been of interest to the government and public alike. If a ship is wrecked in a relatively populated part of the world, there will usually be a record of the event. The problem is trying to find out if the record has survived. The further back in time the event occurred, naturally, the less likely it is that the record survived and the more difficult it will be to find. When a wreck has occurred in a remote or unpopulated location, the only hope is that there were either survivors who reached civilization and reported the event, or that someone saw the wreck site after the event and noted its location. The researcher, therefore, needs to use a fair amount of intuition and imagination in seeking sources of this information.

In the case of a more extensive research program related to a region or country, it is necessary to build up a complete record of all known sites in the region. This requires very detailed and ongoing research, and the results can be used not only to assist in field identification of sites but also as part of a site management program. An example of this type of approach, used in Western Australia by Henderson (1977a), developed into an extensive shipwreck register of all known losses on the coast. The register was compiled from archival sources such as Customs Department Volumes, Colonial Secretary's Office Files, Board of Trade Wreck Registers and Certificates, Lloyd's Survey Registers, newspapers, and other sources dating from European settlement in 1829 until the beginning of this century. This register now acts as the main reference for identification of wreck reports to the Department of Maritime Archaeology of the Western Australian Maritime Museum. Even with this register of more than 1000 losses, four sites dating from the first two decades of the 19th century have been reported since the register was started and five sites from the 17th and 18th centuries were identified in the 1960s. These sites, of course, would not have been discovered in the survey of 19th century Western Australian sources, but without the register, there would be an enormous problem in the identification of any site. There are some examples of research-based projects that will give the reader more depth in this field, in particular, Hargrove (1986).

Wreck registers have been established in other countries including Sweden (Cederlund, 1980) and the UK (Allen, 1994; Hydrographic Department London, 1950; Larne and Larne, 1997; Parker and Painter, 1979). In some cases, these registers only list sites that have been located, and thus cannot serve as an aid to identification.

There are many different levels at which this type of research can be done. In the case where a broad survey is being undertaken, it is not possible to do detailed systematic research on a particular wreck. Alternatively, if one plans to go out to look for a site, a very detailed study of all the available information is required. Often long periods of time are spent doing background archival research before anyone ventures into the field to search for a site. Such work is inevitably time well spent. It is cheaper to gather information in the archives and be fully equipped before going into the field, than to waste time and money in the field without the maximum information.

In carrying out archival research, there is the ever present problem of what to record. Flicking through page after page of documents, minor items often catch one's eye, a shipwreck or an interesting account of an incident. A large hard-backed record book, or, when working on archival material, a small laptop computer, is useful to have at hand. At the top of the page, the reference can be identified by recording the date, place, reference number, title, author, and place of publication of the reference. A brief note of anything of minor interest, together with what it is and the page or pages it occurs on is also useful. Thus, if necessary, a photocopy or microfilm of the information can be obtained at a later date. This is a very useful method of keeping records, and saves one from having to research or reread a whole set of documents all over again, but care should be taken to store this material properly in a systematic manner.

Inevitably the sources of information on ships and shipwrecks are archives. The Public Records Office in the UK and the Algemeen Rijksarchief in the Hague are examples of two such national archives (Figure 2.1). There are, of course, many others ranging from the large national institutions such as the British Library and the Library of Congress, to the small local libraries and archives (Hydrographic Department London, 1950; Still, 1981). The first challenge is to know where the information is likely to be. It could exist in some obscure archive or in an unexpected or undocumented location within an archive. The problem is then how to get to the material that is wanted. Here, another piece of preliminary research can be of help. Before starting work at the archives, check and see if there is a published handbook or guide detailing the use of the archive. If so, get a copy in order to find out the layout, how it is organized, and what areas are appropriate to work in for the particular project in hand. Another approach is to consult colleagues or experts in the field who may be able to help or advise on where to look.

The archive or library will have a catalog which is the key to the archive. Studying the catalog thoroughly is essential for effective archival work. It is worth remembering that archival research is long and tedious, so set reasonable goals. Do not try to work 12 hours nonstop if this is unaccustomed behavior. It is better to break up the time by doing different things. Always seek advice when in doubt. The librarians and archivists are there to help and they can often direct the researcher to unusual sources which can be of enormous help.

Figure 2.1 A view inside the old Algemeen Rijksarchief in Beijlenberg, The Hague. The colonial archive alone has over 20 km of records. These books are the *Overgekomen Brieven en Papieren* (returning correspondence from the *Batavia*) for the years 1630–1670. (Photograph courtesy of Algemeen Rijksarchief.)

For example, the *Verenigde Oostindische Compagnie* (VOC) records in the Algemeen Rijksarchief at Den Haag in The Netherlands are very extensive and include both primary and secondary sources (Meilink-Roelofsz *et al.*, 1992). The primary sources are the letters, papers, books, and documents, all handwritten, which were made at the time and have been bound together into Letter Books or Committee Minute Books, etc., or exist as loose papers. With documentary sources originating in the 17th century or an earlier period, there is the immediate problem of reading the handwriting. The handwriting, particularly in English, can be very difficult to read. Copperplate writing came into use toward the end of the 17th century. A useful introduction and guide to handwriting is Hector (1966). Adding to the complication are the changes that the language has undergone over the years. This may not be a problem in interpreting one's native language, but reading a foreign language can become a real difficulty, because the spelling of words has changed. Latin was often used in England in the 16th century for official records, creating more problems for those of us who lack the benefit of a classical education.

Notwithstanding the benefits, working for long periods in the archives carries its own problems. It is expensive to live in another town or in a foreign country and work in the archives. It is therefore a good idea to go to the archives and conduct a survey of what is required and then order microfilms of the material. In this way the documents can be read using a microfilm reader at home at a later date and the research is not limited by the opening and closing hours of the archives and libraries.

The secondary sources are where the primary sources have been compiled as, for example, in *Calendar of State Papers* (Sainsbury, 1870), the general letters of the VOC (Coolhaas, 1960–1968). In most cases the author, or editor, has read through the primary, handwritten manuscript sources, has selected the sections that are considered to be the most interesting (discarding the rest), and published them in a printed form. The result is easy to read and is very useful because it usually has extensive indices. Thus the secondary sources are often the easiest way to get to the primary source material. Inevitably, however, information is left out of these compilations, so for any serious study it is essential to refer to the primary source. It may well be that the compiler considered wrecks to be of no real importance, and therefore left them out of the edition. After all, something has to be discarded.

It is possible to employ archivists to do the research. There are advantages and disadvantages to this approach. It is often cheaper and quicker to employ someone who knows the archives intimately and knows how to read and translate the documents. However, the disadvantages are that researchers generally follow instructions to the letter and often miss important items because they do not have firsthand experience of the subject. Additionally, the investigator does not get to know the background information which will give a broader understanding of the subject. For example, if information is requested on the loss of a certain vessel, that is what will be given, but it may be that there was some peculiarity about the event that to the researcher may seem irrelevant, but to the investigator it may be crucial. By doing the work, other information may be learned that is related or is more significant. This is an important factor to remember, because the archivist will not be familiar with the investigator's particular interest. Possibly, one could get the researcher to do the initial research to locate the main references and then this could be followed by a period of firsthand study.

III. SITE RESEARCH

If underwater archaeological survey work is planned in a place where the investigator has not worked before, it is important to gather as much information about the area as possible. The obvious initial source is the Admiralty Chart of the area. However, often public works departments, lands departments, or ordinance survey maps give more detail, particularly with regard to access roads and topographical features. Generally, Admiralty Charts are less up-to-date than land maps. The latter tend to be kept updated at regular intervals as the features on land change more rapidly with building works, etc.

The Admiralty Charts give details about the type and nature of the seabed, currents, depths, etc. The Pilots should also be consulted. These are published by the Hydrographic Office in the UK and give details of wind, weather, and local information about the area. In particular, everyone should have access to a copy of the *Catalogue of Admiralty Charts and other Publications* (Hydrographer of the Navy, 1980) which lists all the charts of the world and is very reasonably priced.

The next line of approach is to locate aerial photographs of the region. In a number of countries aerial photographs are available at low cost from lands and survey departments. It is worth getting the best possible coverage and, in particular, stereo pairs are useful because they can be utilized to produce maps of the area, if none are available. It is worth getting a copy of the ground control data as well, as these can be used to identify trig stations and survey points.

Clearly, the person going into the field should be equipped with as much of the available information about the site and the area as possible. It is advisable to have, or to produce, a large-scale working map for survey purposes.

IV. PREPARATION

Preparing to go into the field can be a difficult exercise. It is necessary to have a clear idea of what is to be done and how it is to be executed. Make a list of objectives; this is often called the research design and can be a survey or excavation or some plan of what you intend to do. The plan will depend on a number of other factors like budget, staffing, equipment, location, etc. The aim will, to a large extent, be to determine a lot of the other factors.

For example, how would one go about a limited, exploratory excavation of a remote, but known site—that is the aim. Let us examine a real site, by way of illustration, the *Trial* wreck site, some 15 nautical miles off the Monte Bello Islands in the northwest of Western Australia. This site was investigated briefly in 1971 (Green, 1977a). In 1985 a further survey was undertaken in order to try to conclusively identify the site (Green, 1986b). The site lies in shallow water on the southwest corner of Trial Rocks, but is exposed to strong currents and heavy swells. The nearest land is the uninhabited Monte Bello Islands which are about 80 nautical miles from the nearest mainland port. Obviously, a base camp on the Monte Bello Islands is the most convenient place to work from, as there is no shelter around Trial Rocks. The area is subject to cyclones in the summer (which is the best time of the year to work), so a base camp at the Monte Bello Islands is also necessary as a good cyclone shelter. Additionally, a land base enables on-site conservation, drawing, and cataloging. It is anticipated that there will be periods when it would be too rough to dive, so some alternative projects for the rough weather periods will also be required.

The next consideration is the size of the team: either a large team so that a lot of work can be achieved or a small group working very intensively. On a deep site, apart from all the logistic backup required, a large team is usually necessary because the diving times are limited by the depth. In the case of the *Trial*, because it is likely that it will not be possible to dive on the site for periods of several days, a small team, say no more than eight people, seems more appropriate. Another question concerns the type of work boats to be used. The area is remote, so a reasonably large vessel is required to transport the crew and equipment. Also, because the work will involve raising a cannon (to attempt to identify the site conclusively) and possibly other heavy material, a vessel with heavy lifting capacity will be needed. Finally, because the site lies in shallow water, a dinghy or small work boat is necessary to get close in to the site to act as a working platform for the hookah, airlift, or water dredge. The length of time that the project will take is difficult to estimate. From previous experience on the site, the working conditions are difficult and there is a high probability of experiencing conditions on the site which will make diving impossible. Because the project is not a question of a major excavation, it will only be necessary to survey the site and attempt to locate material that will help to identify the site. Working on the basis that it will require 10 working days on the site, and with a ratio of 1 day on to 1.5 days off (due to bad weather), it will require 25 days together with 3 days to set up and 3 days to close down; so in all about 4 weeks.

The next phase is the budget. This is fairly simple if one has some experience. It is worth working out all the eventualities and requirements so that a maximum costing can be obtained. Usually the budget can be broken down into: travel, freight and hire, running costs, food, stores, allowances, etc. In this way, it should be possible to give a reasonably accurate forecast of the cost of the project.

V. STAFF

Staffing an archaeological project is usually not difficult. There are some obvious requirements, and it is the director's responsibility to select the team and to ensure that they work together as a team. A director can often get totally caught up in the archaeological aspects of an excavation or project and forget (or neglect) to ensure that there is a good team spirit. This, in my opinion, has the priority in any project. It is important to ensure that everyone is happy, contented and enjoying the work. In such a situation, better work will be done in an atmosphere of good will. Expeditions have often disintegrated, or progressed badly, because of endless bickering over trivial items like the quality of the food, the lack of proper toilets, or insufficient time off for recreation, etc. All these things can be resolved quickly and simply and thus dramatically change the atmosphere of the expedition if the leader or director is aware of the problems. Similarly, it is important that all expedition members become involved in their work. Regular formal meetings are essential, but it is also worth creating an environment where expedition members can sit and discuss the work in a relaxed atmosphere, for example, after the evening meal. A lot of thought should be given to the question of work and relaxation areas within a campsite or on an expedition. Areas should be arranged so that those who want to work can do so, without being interrupted. Similarly, those who wish to relax and socialize, should be able to, without disturbing people who are resting or working. While this may seem a trivial item, in my opinion, the best archaeological results are obtained where everyone has enjoyed the work and thus been enthusiastic about the project.

The project director has to delegate some responsibility, particularly if the team is large. Delegation is often a problem, and some people find it difficult to delegate. However, there is no doubt that by delegating responsibility, not only does it allow one to work more efficiently, but it also generates enthusiasm and interest in the person given the job. There are a number of responsibilities falling under the general headings of technical (diving, time-keeping, equipment maintenance, boats, machinery, safety, medical, underwater rigging and construction, communications); archaeological (surveying, artifact registration, underwater photography, artifact drawing and photography, conservation, recording, site plans, storage); and miscellaneous (catering, accommodation, travel, bar steward, treasurer, etc.). It is a wise director who ensures that most, if not all these jobs are delegated, allowing time to oversee the operation and to coordinate the work.

VI. SAFETY

It cannot be overemphasized that safety is of prime importance. Diving can be a dangerous occupation unless adequate precautions are not taken.

This handbook is not designed or intended to teach diving techniques. It is assumed that before carrying out archaeological work under water the archaeologists have learned how to dive and are reasonably experienced. It is therefore the responsibility of the project director to ensure that all diving staff is properly qualified or experienced and medically fit. This is best done by appointing someone to be diving officer. One person has to be responsible for diving safety, and, depending on the circumstances and numbers involved in the project, it is best to make that person responsible for the overall diving operations. The diving officer must ensure that everyone is medically fit to dive and it is best to insist on sighting a letter or a note from a doctor qualified to conduct a diving medical. This is an important point because doctors or general practitioners are often unaware of conditions that may make it dangerous to dive.

In situations where diving is planned in deep water, or where decompression diving is planned, it is essential to have access to a recompression chamber. Once an on-site recompression chamber is necessary, the whole nature of the operation changes. First, one must have an experienced chamber operator and a qualified doctor on hand at all times. Alternatively, when working without a chamber, it is vital to work out all emergency evacuation procedures and familiarize everyone with these procedures. One has to anticipate all possible eventualities and plan how to deal with these. One other important consideration is to ensure that staff is familiar with all forms of emergency resuscitation.

There are a number of good standard references which should be consulted on these aspects, in particular Edmonds *et al*. (1983), U.S. Navy Department (1978), Flemming and Max (1988), Miller (1975), and Standards Association of Australia (1992).

Chapter 3

Search and Survey

I. INTRODUCTION

When I wrote the first edition of this book in 1989, much of the chapter on search and survey had not changed fundamentally for over 20 years. Surveys were regularly conducted with sounding sextants (a system that had changed little from the mid-19th century) with all the complexities and difficulties of using these instruments. In most cases surveys were crude and the techniques were difficult to use. Who could have imagined, ten years later, that for a few hundred pounds one could have a hand-held instrument that could provide position, anywhere on the surface of the Earth, to a precision of a few meters? The introduction of the Global Positioning System (GPS) in the 1980s was the start of this revolution. However, in the early days of GPS, with Selected Availability switched on, positions could only be obtained to an accuracy of ±50 m. However, on May 1, 2000, NASA turned selective availability off and GPS was then able to give a position accurate to a few meters.

This chapter deals with methods of search and survey which require knowledge of position. Up until the availability of GPS, locating a position at sea was notoriously difficult. The first part of this chapter deals with position location and describes its largely redundant techniques and then concentrates on the GPS system. It then goes on to describe the methods used to search and survey for sites (the actual survey of sites is dealt with in the Chapter 4). Most of the techniques described are used in other fields, particularly the offshore oil industry. Although the equipment and resources that are generally used by maritime archaeologists are very modest in comparison. It is also worth noting that in spite of all the high-technology equipment that has been used over the years by maritime archaeologists, the majority of archaeological wreck sites have been found by chance, often by fishermen or sponge divers. A great deal of time, effort, and equipment can go into looking for a wreck site, but there are two essential components to conducting a successful survey: appropriate initial research must be carried out prior to the survey and the survey must be conducted in a systematic manner. Without this, a survey will most likely be a complete waste of time. So often searches have been conducted on totally illogical and unscientific principles, based simply on the idea that the site "ought" to be in a particular place (see, for example, Mathewson, 1986, in the search for the *Atocha*). This is not, one would have thought, how a commercial operation should work nor is it how a scientific archaeological project should be carried out.

II. POSITION FIXING

A. General Considerations

Two situations exist where it is necessary to locate a position at sea. The first is where a particular site has been located and its position needs to be determined accurately for future relocation. To locate the site as accurately as possible, a large number of position fixes should be taken because of the many small movements a boat makes as it rides over the site. The other situation is where one is moving over the surface of the water or through the water, for example, towing some form of search detector system. Here the search path needs to be known to ensure that the survey is providing adequate coverage. In this moving situation, position needs to be determined rapidly in order to keep pace with the survey, but extreme accuracy may not be necessary. A variety of means of fixing a position are available, ranging from the simplest technique, without any equipment, to the more sophisticated, electronic GPS systems with a data logger and track plotter.

B. Transits

A transit is the visual coincidence or alignment of two fixed features separated by a distance. This coincidence then provides the observer with a bearing or fixed line. By using two or more sets of transits, the coincidence of the bearings can be used to define a position precisely (Figure 3.1). While transits have largely been superseded by the GPS, in many cases earlier

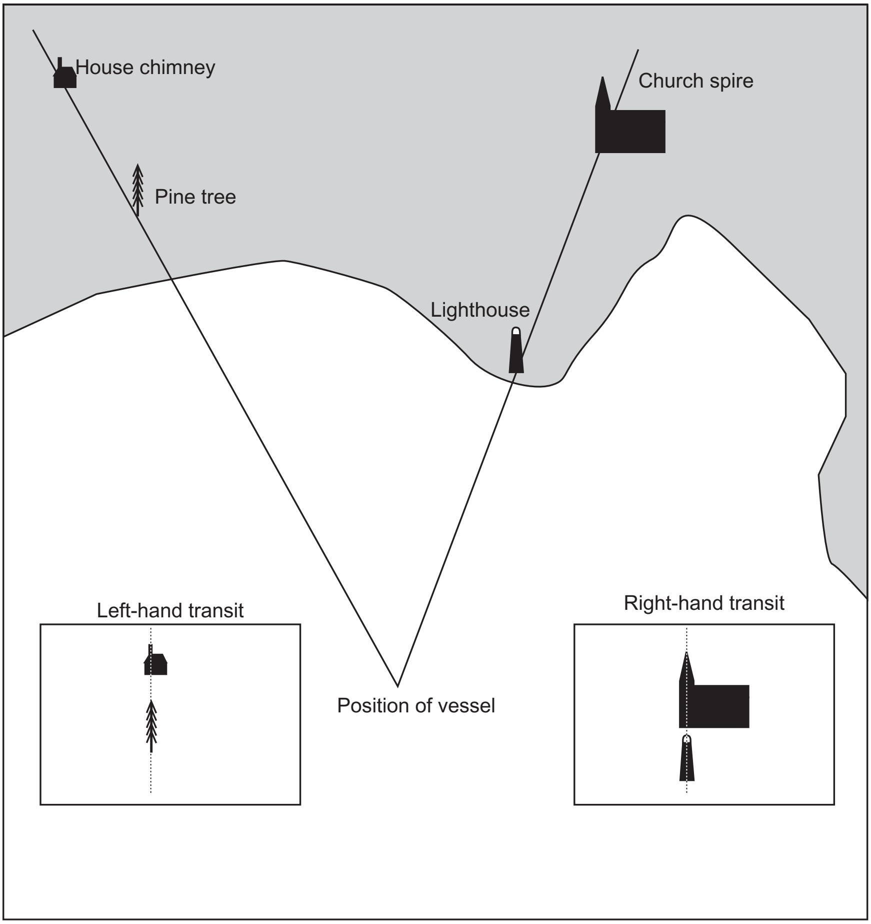


Figure 3.1 Diagram showing how two or more visual coincidences (transits) enable one to locate position. In some cases if the objects used in the transits can be identified on a map or aerial photograph, then it is possible to plot position on a map. However, in general, transits are used at sea to locate position.

surveys used transits and there is still a need to understand their application. Transits are still the best way of navigating a straight line course on a survey vessel. One of the best ways to record transits is to photograph them with a long focal length lens (Figure 3.2). Then, if this is possible, identify the transit features on a map, orthographic map, or aerial photograph and draw a line joining the coinciding features, which can be projected out to the location where the photograph was taken (Figure 3.2a). This is a

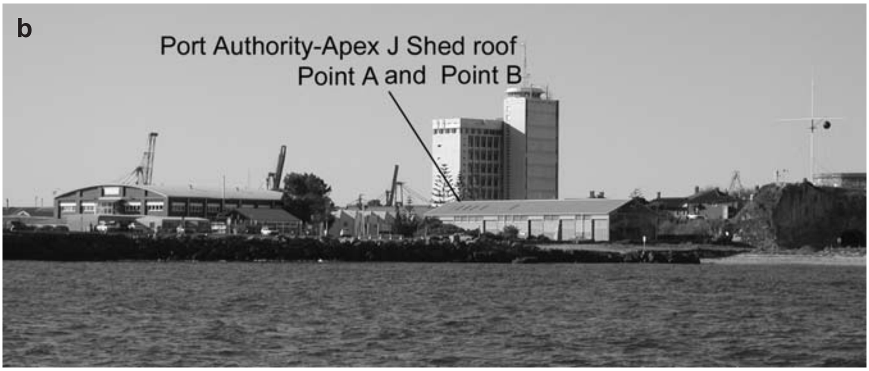
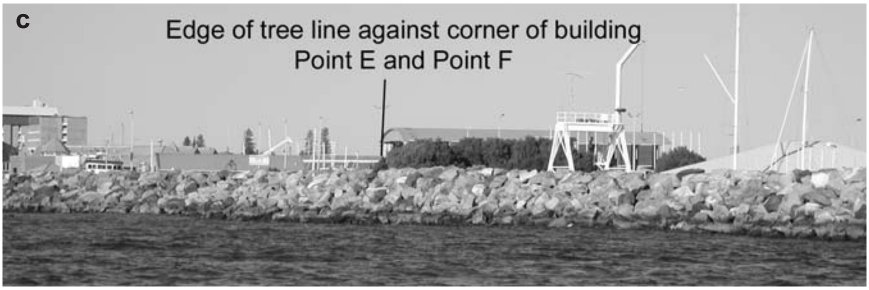


Figure 3.2 Photo transits and how they work. Four illustrations include an aerial photograph (a) and three transit photographs (b), (c), and (d). Figure 3.2b shows the alignment of the Port Authority Building (A) with the apex of the roof of J Shed (B). This line can be seen on Figure 3.2a.



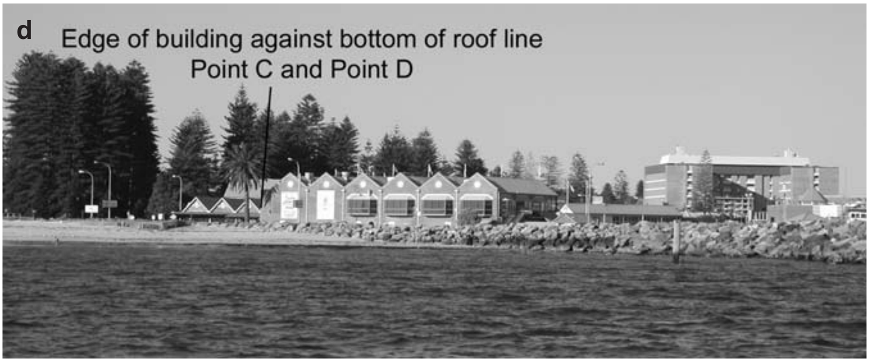


Figure 3.2 (*Continued*) Similarly, Figure 3.2c shows the edge of trees (E) against a building (F) shown in Figure 3.2a. Finally, in Figure 3.2d the edge of the building (C) against the bottom of the roofline (D) is shown. Provided the features can be identified on the aerial photograph, these are preferred to maps then the lines can be projected back to find the point where the photograph was taken. Aerial photographs are preferred to maps because they show more detail. (Figure 3.2a is courtesy of the Department of Land Administration, Western Australia.)

particularly useful method because you get a photographic record of the transit. Transits can also be used to relocate a fixed position by simple observation or to determine a course by using a single transit to provide a bearing. In the latter case the transit can be used to maintain a straight line course, provided the two features or marks are kept in visual coincidence while moving toward (or away) from the transit. It is preferable to select transits in which the two features are as far apart as possible. A good transit is one where the relative positions of the transits move out of coincidence rapidly as one moves out of alignment. Thus, a flagstaff separated from a house by a few tens of meters will make a poor transit at a distance of 1 km, whereas if they were 1 km apart, they would make an excellent transit at the same distance. A simple way of checking to see if a transit is good is to move about a meter at right angles to the transit line. If the transit moves out of alignment then it is good. If it hardly moves, then it is poor, and the distance that one has to move in order to make a noticeable difference to the transit gives an idea of its accuracy.

It should be noted that the more measurements that one takes to a point the more reliable the fix is. Take the example shown in Figure 3.3, where a point is resectioned or located by three distance measurements. It is almost certain that the the three measurements will not make a single intersection but create a "cocked-hat" (see upper left of illustration). In this situation it is not possible to determine which measurement is wrong, simply that there is an error in one of the measurements related to the size of the "cocked-hat". If one make four measurements, it is possible to determine which measurement has the largest error. This can be seen in the upper right of the figure. So the more measurements that can be made the more accurate the fix becomes.

A fixed position, such as a wreck site, can often be very easily relocated using two or more transits. Remarkably, wreck site positions are often not

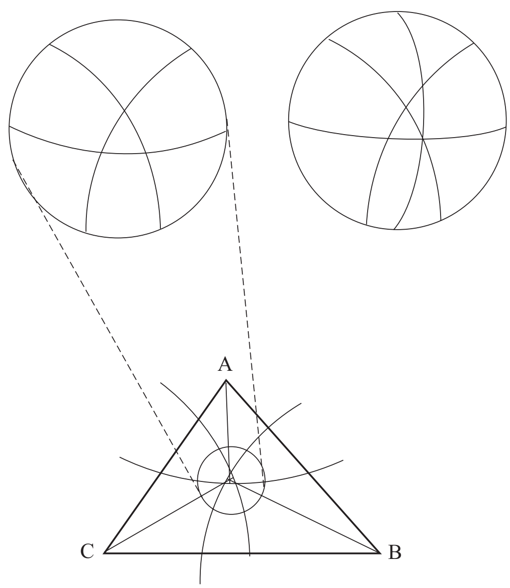


Figure 3.3 Resectioning showing the "cocked-hat" effect, where the arcs represent distance measurements from three fixed points A, B, and C. Because at least one measurement is slightly wrong, the result is a cocked hat. If four points were used and only one measurement was wrong, the result would be as shown in the second enlargement.

plotted on a chart. This neglect arises from the fact that at the time of location and during subsequent work on the site the position becomes familiar and can be relocated, using transits, on a day-to-day basis. Transits, however, are generally not associated with the use of a chart and, consequently, the position is often not properly recorded. Even after many thousands of hours have been spent on a site, the site can be completely lost in a few years, because the natural transits have disappeared or been forgotten. The transience of various landscape features must be considered and care exercised in selecting transits. Geographical features must be chosen for their durability. Thus, large public buildings, navigation aids such as lighthouses, etc., make better long-term transits than trees, walls, and flagstaffs, for example, which tend to disappear in time. A famous example of the loss of transits is the Mahdia site (Taylor, 1965), where the landmarks recorded in 1913 no longer existed in 1948. It required 6 days of searching to relocate the site.

If the surveyor chooses the junction of land with sea as a transit, there is another factor to be considered. Tides can often alter the position of the land–sea junction. The use of shoreline vegetation, such as growth of the foredunes, is best avoided, since over a period of time sand movement and patterns of growth can radically alter visual forms.

It is essential, even when transits have been recorded, that they should be identified on a topo- or orthographic map or an aerial photograph, and their intersection located to determine the position of the site. A good example of how transits can change in time is shown in Figure 3.4. The four illustrations show the appearance of a series of land transits over a number of years. Initially, the wreck site, which was found on the land during a mineral sands mining operation, was photographed against some buildings (a). The site was subsequently covered over. More than 20 years later the site could still be located by relocating the transits.

In order to determine an accurate geographical position of the site, the largest possible scale map of the area should be used for identifying the features used in the transits. Because of the photographic nature of an orthographic map, it is usually easier to identify the transits on this type of map rather than a conventional topographical map which may not show the particular transit feature. However, orthographic maps are often difficult to obtain or are not available. In such cases an aerial photograph can be used and features on the photograph can be linked to the map. If it is not possible to identify the transits on the map, there are two choices. One choice is to go out and survey the transit positions onto the map. Alternatively, and more simply, the photograph itself can be used to measure the angle, provided the lens is accurately calibrated (see Section II.D). It is also possible

Figure 3.4 Historical transits of the Bunbury whaler site. (a) Shows site in 1950s, (b) shows site in 1981, (c) shows site in 1986,

d

Figure 3.4 (*Continued*) and (d) shows site in 2003. Note that in all pictures some features are common, particularly the silos seen in (a). It should be noted that as the vegetation develops more and more features become obscure, and by 2003 most of the site is totally unrecognizable. (Figures 3.4b and c are courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

to utilize oblique photographs to locate position by rectification. One example is an aerial reconnaissance photograph of aircraft burning in Broome, Western Australia, after a Japanese raid during WW II (Figure 3.5). This was rectified to identify the locations of the aircraft (Green, 2002, p. 129). In this case there were features in the photograph that could be identified on a modern map. These features were used to calculate the orientation of the photograph and thus allowed the locations to be determined.

When surveying close to shore, it is sometimes possible to utilize natural transits to operate a systematic search pattern. However, as this requires the fortuitous location of regularly spaced features such as street lights or bridge railings, this situation is unusual. A far more common approach is to set up a transit network on the beach using a series of poles separated by the required lane width (Figure 3.6). A land survey party first places the back markers in a line at approximately right angles to the lanes required. The pole separation is measured with a tape and can be aligned by visual sighting. These back markers must be located as far up the beach as possible to give the greatest separation from the front markers. Using a simple optical square, or some other method of determining a right angle (theodolite, 3–4–5 triangle, etc.), the first pole of the front markers can be put in position. Using the optical square again, some place up the run the position

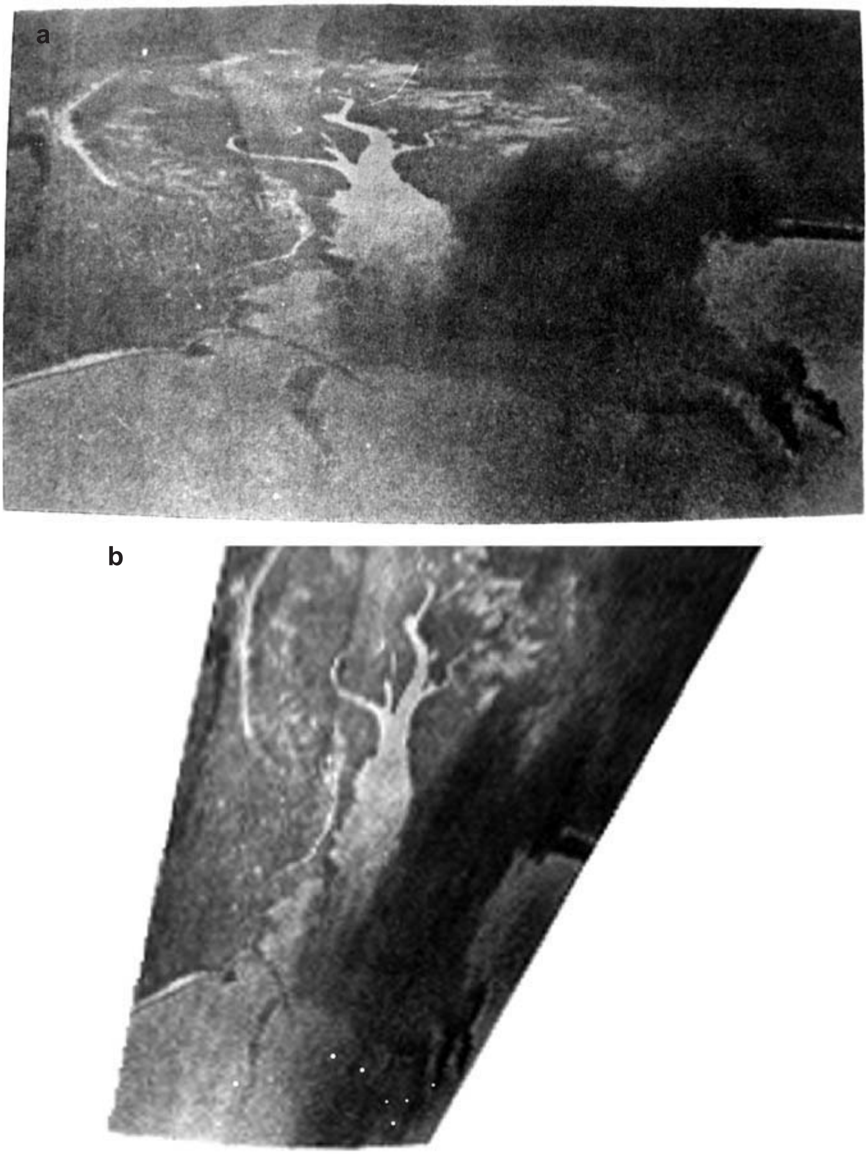


Figure 3.5 (a) Photograph taken during a Japanese raid on Broome during WW II. It shows a number of flying boats on fire in the bay and the town of Broome in the background. The objective was to obtain the geographical coordinates of the burning flying boats seen in the photo. Known points, with geographical coordinates that could be identified on the aerial photograph (a), were used to georeference the image. (b) The resulting rectified image obtained using the ArcMap Georeferencing facility. This image was used to determine the true coordinates of the sunken aircraft.

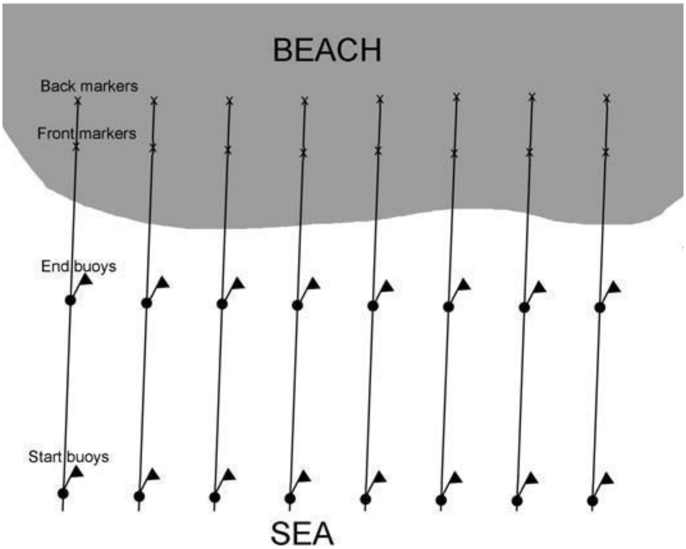


Figure 3.6 Artificial transit network on a beach. This is a schematic showing how control points can be set up on a beach to provide visual transits for a boat operator so that regular search lanes can be steered. It is a simple and easy system to implement provided one is not too far offshore.

of another front marker is measured off. The survey team then works onward using the first two survey poles as transits, and determines the positions of subsequent markers using a tape. The remaining first few markers can be put in place later. The onshore survey team, having set up the first survey section, can continue setting up more transits as the survey team at sea conducts the marine survey. The land team can also leapfrog survey markers after the initial lanes have been surveyed by the marine group, but care should be exercised to ensure the survey transit positions are plotted onto a topographical map before they are removed and their position lost. It is therefore necessary to leave at least some of the key markers in place (particularly the first pair) so that they can be accurately surveyed with a theodolite and transferred onto a topographical map of the area at a later date. It should be noted that locating the positions of the survey poles using a GPS may not be the best solution here, and this issue is discussed in Section II.J. The additional survey measurements can then be used to plot the positions of the other markers.

The marine survey team has an additional problem of locating the seaward and shoreward extent of their survey. This can best be solved using a GPS or by placing buoys at the start and finish of the first and last lanes of the survey. The start and finish buoys can be placed using a GPS at the locations, and these will serve the boat handler with a simple visual guide. In a simple operation, if the exact timings are obtained, these can be used to determine boat speed. If a chart recorder is used for the output of data, a fiducial mark can be made on the trace so that the output can be accurately correlated with position In a more complex operation a data logger can record the position of the vessel together with all the other remote sensing information, which can be used later in post processing (see Sections V.A and VI.D).

C. Sextant Survey

Although the sounding sextant is now virtually obsolete, it was the main instrument used in hydrographic surveying from the 19th century up to the advent of the GPS. The principles of the instrument are described in detail in the *Admiralty Manual of Hydrographic Surveying.* (Hydrographer of the Navy, 1965, Volume 2, Chapter 3). The sextant is accurate, portable, relatively inexpensive, and simple to use. Two instruments are generally needed to measure the angles included between three points (Figure 3.7). In this example, three land features, A, B, and C, can be observed from point O. The angles AOB and BOC are measured onboard the boat to define the position. This type of survey suffers from two major drawbacks: it requires considerable practice to become competent in using it, and it is only able to measure angles from 70 to 80° (beyond this the instrument can resolve angles up to about 110°, but with great difficulty). Given these two limitations, the sextant is very accurate (provided adequate consideration is given to the strength of fix, see next paragraph), and enables a position to be fixed onboard the vessel, rather than having to operate land survey stations. With practice, it can be operated quite easily in relatively rough seas; the skill lies in keeping the sextant horizontal while the boat is in motion.

One important theoretical issue relating to the use of the sextant is the strength of a fix or resection. This is a complex matter and is described in detail in a number of surveying handbooks, including, and possibly the best, *Admiralty Manual of Hydrographic Surveying* (Hydrographer of the Navy, 1965, Volume 1, pp. 357–360). Essentially, the strength of an intersection depends only on the receiving angles at the unknown point. The strength of resection on the chart, however, depends on the angles at which the position circles cut each other. These in turn depends not only on the observed angles, but also on the positions of the objects observed relative to the unknown point. In general, the sum of the two angles should not be less

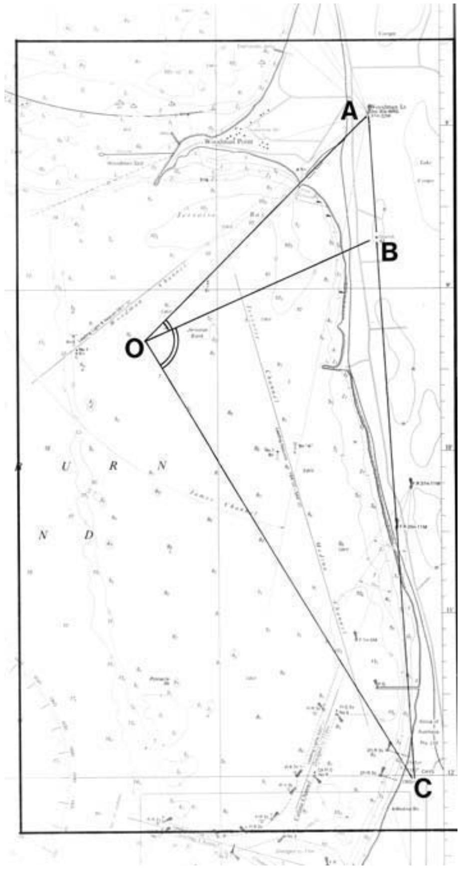


Figure 3.7 Sounding sextant fundamentals. This figure shows how the two included angles, AOB and BOC, which are the angles between Woodman Lighthouse (A) and the Obelisk (B) and the Obelisk and the 193-m high chimney (C) at the Alcoa Aluminum Refinery (all prominent features), are used to locate the position of the survey vessel.

than 60°. The central object should be either closest to, or much farther away from the surveyor than the other two objects. Other special considerations include: if the objects are in a straight line, the angle between any two objects should not be less than 30°; and where the observer is inside the triangle formed by the three objects, the angles should not be less than 60°. Figure 3.8 shows six types of resection. In each case A, B, and C are the known points and D is the point where the resected angles have been observed. In resections 1 and 2 the angles are exactly the same, with good

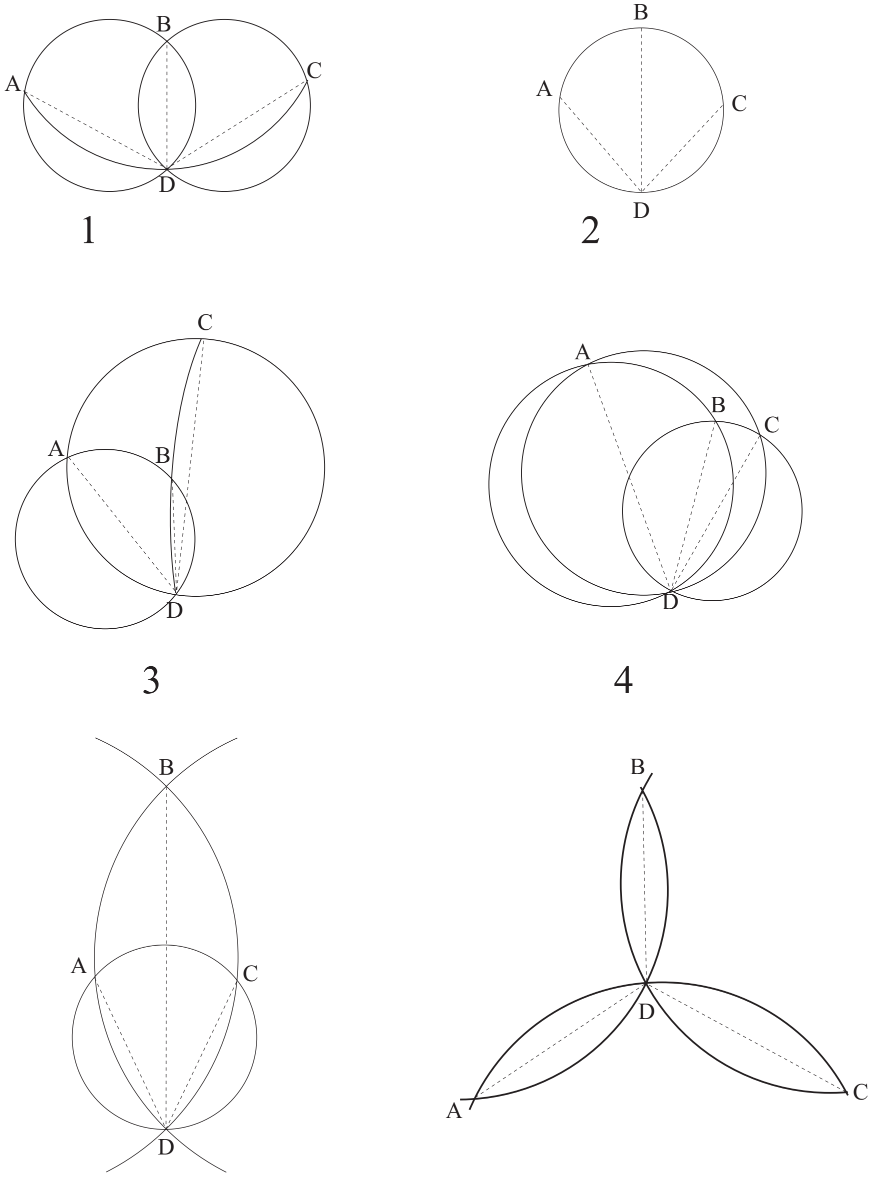


Figure 3.8 Here are six examples showing the strength of resection by showing how the angle of resection gives the best fix when the arc crosses at right angles. (From Hydrographer of the Navy (1965). *Admiralty Handbook of Hydrographic Surveying*, HMSO, London.) Note, in 1 and 2 the receiving angles are the same and 1 is an excellent fix, but in 2 there is a circular or no fix. 3 is a good fix because the position circles cut at good angles. 4 shows the condition where a small change in the angle BDC will have a large effect on the position of D. 5 and 6 are also good fixes.

receiving angles. In resection 1 the fix is excellent, whereas in resection 2 there is no fix at all because all three position circles coincide and the position could exist anywhere on that circle. In resection 3 the receiving angle BCD is very small, yet the fix is good, because the position angles cut at a good angle. In resection 4, two of the position circles are close together, and a small error in BDC will have a large effect on the position of D, thus making it a poor fix. In resection 5 the fix is good, but care must be taken to ensure that the fix is not approaching a circular fix as in resection 2. Finally resection 6 is a good fix provided that the smallest angle subtended by the three marks at D is not too small.

One looks back nostalgically to the days of sextant survey work. Especially in a small open boat during relocation of a site, with the operator driving the boat with one hand while holding the sextant, set at the correct angle, in the other, and thus maintaining the correct course (Figure 3.9). As the fix was approached the other operator would be calling "left hand down a bit, no, too far, back a bit," and so on. As one can imagine, it was of paramount importance when conducting a sextant survey to establish an atmosphere of good-natured cooperation, otherwise the whole operation could end in violence.

Figure 3.9 Operating a sounding sextant at sea.

D. Photographic Angle Measurement

If one can calibrate a camera lens so that the focal length is accurately determined (see Chapter 6), the camera can be used as an angle-measuring device and, thus, used as a surveying instrument. This technique is discussed in detail by Williams (1969), and now there are commercial programs that enable one to do this on a computer (see the Chapter 6, Section V.A). There are two methods to measure photographic angles: direct and photo resection. The direct method involves measuring the distance from the principal point on the photograph to one of the features and dividing this by the effective focal length of the print to give the tangent of the angle. This process is repeated for the other feature and the two angles subtracted to give the included angle between the two points. It should be obvious that if the angle to be measured crosses the principal point then the two angles have to be added together. In this way the camera works like a sextant and the two angles are calculated mathematically (Figure 3.10).

The alternative technique is photo resection, which consists of drawing the angles on tracing paper and then applying the tracing to a map of the area (Figure 3.11) in a similar manner to a Station pointer (see Figure 3.12). However, the ubiquitous GPS has largely replaced this time-consuming system.

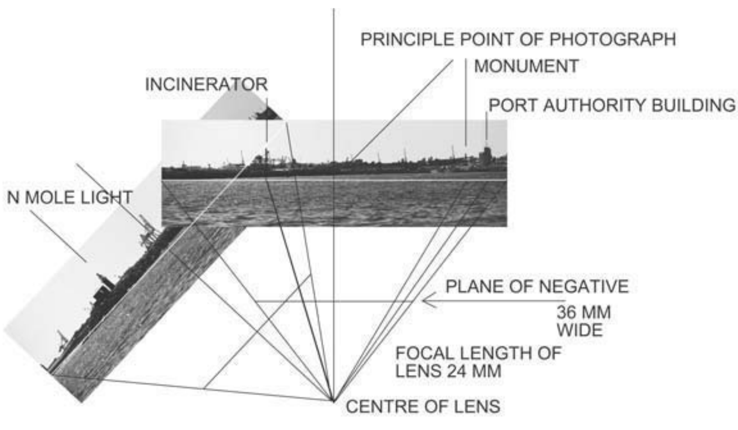


Figure 3.10 Photographic angle measurement. In this sequence, the camera has a previously calibrated lens with a focal length of 24.00 mm and the camera has a 36-mm wide format. Two points that are geographical features can be identified on the print (in this case the Port Authority Building and the incinerator chimney). It is possible to calculate the angle between the two points and the location of the camera. If common points on adjacent photographs can be identified, features on the prints can be linked together. In this case the incinerator chimney is common in both, making it possible to link the N Mole Light, incinerator chimney, and the Port Authority Building providing three angles from the two photographs.

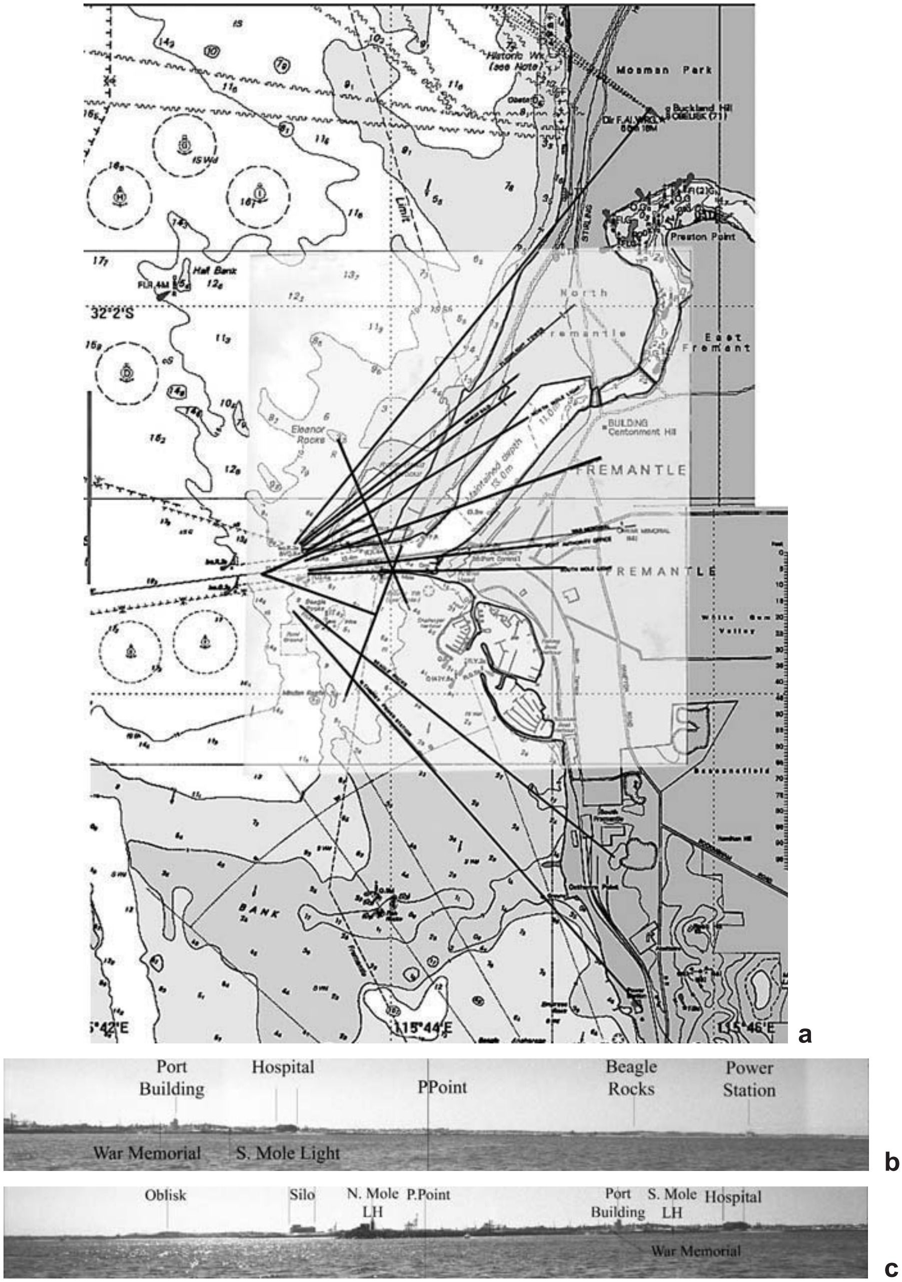


Figure 3.11 Photo resectioning using an overlay (a). This can be used to plot positions from photo triangulation or from any other angle-measuring system. Note that the angles that are used in (a) are obtained from figures (b) and (c). The angles are calculated from knowing the focal length of the camera lens and the frame format as shown in Figure 3.3. The calculated angles are drawn on a sheet of clear film and adjusted over the chart to obtain the position.

Comparison between a theodolite-based system and a photographic angle measurement system indicates that the theodolite had an accuracy of 1.5′ and was used on a baseline 2.5 km long with the site about 2.5 km offshore on a relatively featureless coastline. The resultant positions from triangulation (using the theodolite) and photo resection (using standard lens, film, and paper) were 130 m apart. It took a survey team a whole day to take the measurements, while the photograph took 1/125 of a second and about an hour of work to plot the data Today, with a GPS, that whole process can be done on the boat in less than a minute with the position accurate to ±2 m.

E. Double Theodolite

The theodolite or level is a very attractive instrument to use in survey work because it is easy to use and very accurate. Its application today is related to situations where sub-centimeter accuracy is required. In this area, the GPS is no longer a viable instrument unless one is prepared to hire or buy very expensive equipment. The theodolite cannot be used on a boat, however, it was widely used in the 1960s and 1970s in a double instrument system for locating a site or the position of a search vessel at sea. This was then superseded by electronic systems such as the MiniRanger and then the GPS. In the two-theodolite system, the two instruments are set up at either end of a baseline of known length and the two included angles are measured. Because one side and two angles of a triangle are known, the triangle and thus the position of the point to be surveyed can be calculated. A serious problem with this technique in a running fix situation was that of communication. The system relied on the two theodolite operators measuring their angles at the same moment in time, and ensuring that they did not miss a mark and get out of step. The theodolites had to be established on shore, requiring a shore landing party and had to maintain a two-way radio, which was an essential part of the system. The two operators zeroed their instruments on each other and then maintained the theodolite cross wires on a marked position on the survey vessel. If the absolute position was required, the distance between the two operators had to be determined. This was not a problem if the operators were on common ground, but if they were separated by water, for example, on different islands, the measurement was difficult to establish. Plotting was relatively simple by using either a protractor or a programmable calculator.

F. Theodolite and Distance Measuring System

Where it was impossible or impracticable to establish two stations, a land-based theodolite and distance-measuring system was sometimes used. At the crudest level an optical gun sight was used in conjunction with a theodolite, but the gun sights were hopelessly inaccurate. Other more accurate distance-measuring systems could be used. These included the tellurometer which used microwaves, and the geodimeter, which used a laser beam. These instruments were used to measure the distance to a reflector based on the vessel.

G. Electronic Position Fixing Systems

In 1989, I wrote:

> By far the most widely used systems for maritime survey work are the electronic distance-measuring systems. These systems are extremely expensive, and can generally only be justified for large-scale and well-funded operations. The unit cost is so high that it is only really practical for a maritime archaeological project to hire the system for the period of the survey, although it may be possible to negotiate with the hire company ways to offset the cost with publicity or a reduced hire rate during a period when the instrument is not required for commercial operations.

This, naturally, is no longer the case.

In this section I discussed various systems that fell into two broad categories: short-range systems (50–80 km) generally using microwaves in the 250–9000 MHz range and measuring distance from a mobile transmitter to a pair of shore stations; and medium-range systems (200–450 km) most commonly using three or more shore-based transmitters and any number of passive receivers operating in the 1–3 MHz or 420–450 MHz bands.

MiniRanger was perhaps one of the best known systems at that time for small-scale hydrographic work. The system consists of a master station onboard the vessel and two slave stations on shore. The master station interrogates the slave stations in turn and measures the time of flight of a radio signal from the master station to the slave station and back. It then calculates the distance by multiplying half this time by the speed of light to give the distance and displays the result. The accuracy was about ±1 m. In the Decca Navigator system, measurements were made of the phase between the signals, so that if the lock of the system was broken at any point, the survey vessel had to return to a known reference point to recalibrate. Neither system is commercially used today and is more of a reminder of the difficulties experienced in the past.

Figure 3.12 Station pointer used to resection sextant angles.

H. Total Station

The system described previously has now been transformed into an instrument called a Total Station (Figure 3.13). This is a combination of a precise electronic theodolite and electronic distance-measuring instrument. The fundamental measurements made by a Total Station are slope distance, horizontal angle, and vertical angle. Other values returned by the instrument, such as coordinates, are derived from these values. The instrument can give relative positions of points to millimeters, provided appropriate surveying procedures are used. Description of how the instrument works and its application are available in most surveying manuals.

I. Radar

In the ship-borne systems, prior to GPS, position could be determined by radar-ranging, which gave both bearing and distance, and was reasonably accurate in situations a long way from shore. Because radar is more accurate at measuring range than bearing, the range was measured by radar and the bearing by compass. This required that the fixed target was easily

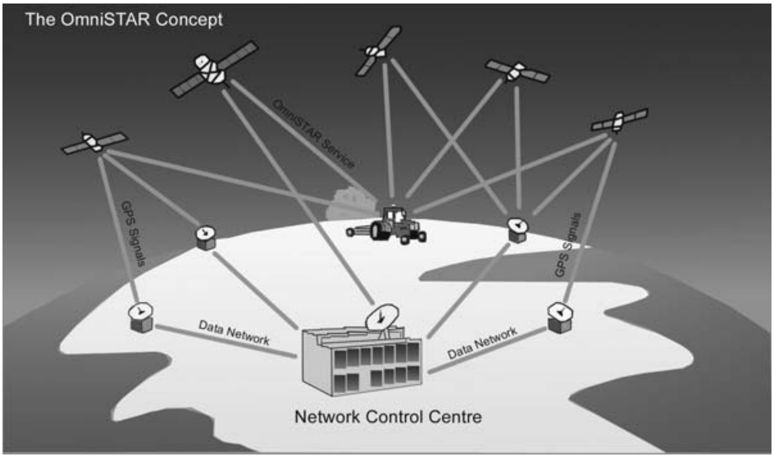
Figure 3.13 A Total Station in operation. Note the operator on the left is holding a reflector that has been placed over a position to be recorded. The Total Station determines the distance and the azimuth of this point, recording these data electronically for later downloading. (Courtesy of Jochen Franke.)

seen. This type of system was the best available for open-water searches where no land could be seen and, therefore, even the MiniRanger, which requires base stations, would not work. The target was usually a well-anchored buoy with radar reflectors on it. To improve the visibility of the buoy at extreme ranges, a small helium balloon was often used. This carried a radar reflector which was either painted black or had a large flag so that it could be easily seen.

J. Global Positioning System (GPS)

In 1989, the GPS was just becoming available and I wrote: "The latest system consists of a receiving instrument about the size of a small walkie-talkie set, which will provide position anywhere on the surface of the Earth within a period of a few minutes to a claimed accuracy of 30 m RMS at a cost of approximately $2000." Today, a hand-held GPS can be bought for around $100 and is accurate to ±2 m GPS (Figure 3.14a).

a



b

Figure 3.14 (a) A hand-held GPS unit. (b) A schematic showing how a DGPS system works, in this case the satellite-based OmniSTAR system. The OmniSTAR satellite (second on left) is sent data from the Network Control Center which are broadcast to the remote receiver. These satellite data provide the GPS system with information allowing the GPS to operate in differential mode. (Figure 3.14b is courtesy of OmniStar, Fugro International.)

1. The History of GPS

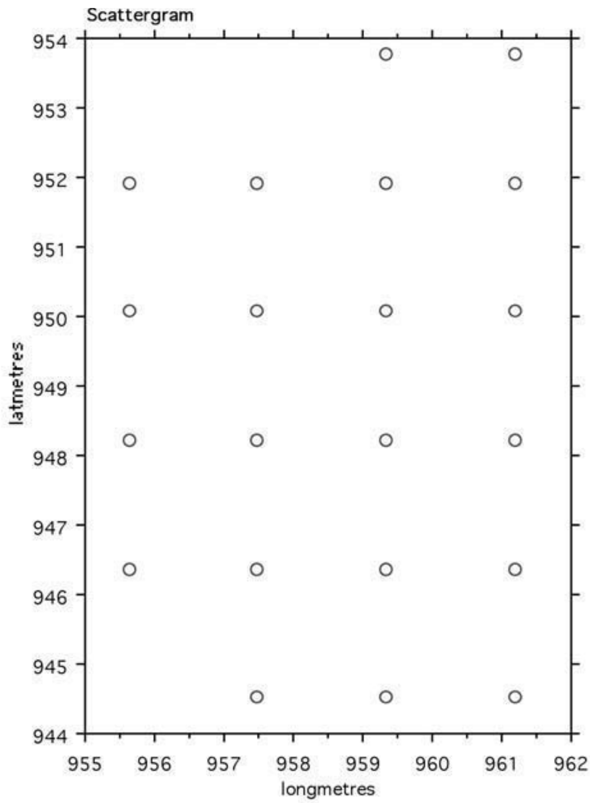
The history of the GPS is interesting. The first GPS satellite was launched in 1978. The first ten satellites were developmental satellites called Block I. From 1989 to 1994, 24 production satellites, called Block II, were launched. Each GPS satellite transmits data that indicate its location and the current time. All GPS satellites synchronize operations so that these repeating signals are transmitted at the same instant. The signals, moving at the speed of light, arrive at a GPS receiver at slightly different times because some satellites are farther away than others. The distance to the GPS satellites can be determined by estimating the amount of time it takes for their signals to reach the receiver. Basically, the instrument does a trilateration. A simple three-dimensional trilateration is done by knowing the precise positions of the satellites and the distance from the satellites to the GPS. When the first satellites were launched nobody realized the significance of GPS. As a result, it quickly became obvious that there were defense issues involved. This meant that the system, in the wrong hands, could be used to guide all sorts of weapon systems in real time. Theoretically, one could construct a missile guided by a GPS that could be targeted within a few meters of any site. Because of this concern, timing errors were inserted into GPS transmissions to limit the accuracy of the Block II so that nonmilitary GPS receivers were limited to an accuracy of about 100 m. This part of GPS operations was called selective availability (SA). During the Gulf War, because of the lack of military GPS receivers, the military bought a large number of commercial instruments and turned the SA off. So for the period of that conflict, ordinary operators had the possibility of an accurate GPS.

2. Differential GPS

Probably because of the various ways around SA using differential GPS (DGPS) and the growing commercial market for GPS in a huge range of applications, on May 1, 2000, the U.S. Department of Defense turned off SA for the worldwide GPS system. This effectively increased the accuracy of the GPS system to less than ±5 m. GPS accuracy is a complex issue (see the next section). Previously, with SA on, the GPS system was given an intentional "dither" or noise resulting in a minimum position accuracy of around ±50 to 100 m. This standard deviation of position would be a radius of 50 m. The artificial dither applied to the signal could be overcome by using the GPS in a differential mode or DGPS, where a base station records a fixed position and a mobile unit is used to do the recording (see Figure 3.14b). By comparing the signals, either in real time or in post survey, it was possible to cancel the effect of dither (as the dither at any moment would be the same for both units). Using DGPS with conventional GPS units it was possible to determine position with simple hand-held instruments to ±5 m. This is an accuracy acceptable for most maritime archaeological work, although it is expensive to do in real time and time-consuming to do post survey. When SA was turned off (thus canceling the dither) the accuracy of the system was then limited by instrumental errors introduced by atmospheric effects and the accuracy of the operational unit. This meant that to further increase the accuracy of the system, it was necessary to have more precise instrumentation and more control. For normal survey work, a hand-held instrument usually has a theoretical resolution of three decimal points in minutes (1.852 minutes). An experiment over an extended period of several hours showed that position converted to meters for GPS gave a standard deviation of 1.0 m and for the DGPS system a standard deviation of 1.5 m, indicating for some unknown reason that the DGPS quality was not quite as good as the GPS. In addition, the two systems gave slightly different positions in latitude (a difference of about 4 m). The most significant factor, however, is that the standard deviation of position in the GPS is about equal to the resolution of the system (Figure 3.15). Using a standard GPS system, over a period of time the position will tend to wander and standard deviations of 5 to 10 m over a period of a year are expected.

GPS accuracy can be reduced by the geometry of the constellation of the satellites. This is known as dilution of precision (DOP). All receivers have some form of DOP calculation to determine which of the satellites in view are the best ones to track. The most frequently used is position dilution of precision (PDOP). PDOP factors in elements of both horizontal DOP and vertical DOP, and degraded PDOP will occasionally occur somewhere on the Earth's surface. This area of degraded geometry is often referred to as a PDOP "spike." Thus it is important to monitor PDOP to ensure that the position has not been degraded. In many cases the GPS alerts the operator to this situation, but when tracking where the operator is not usually monitoring the system this can fail to be noticed.

The GPS usually has an option to output data and these data can contain a number of different types of information. For the purposes of survey work, the most relevant data will be latitude, longitude, and time. Other information may relate to what satellites are being used and what the PDOP is. Output options usually include an internal system used by the manufacturer and a system known as National Maritime Electronics Association (NMEA) sentences. These sentences have a variety of predetermined fields that the GPS outputs. You simply select the sentence that suits your needs and program that into the unit. From then on the unit will download data to a computer or data logger at the rate you specify for the unit.

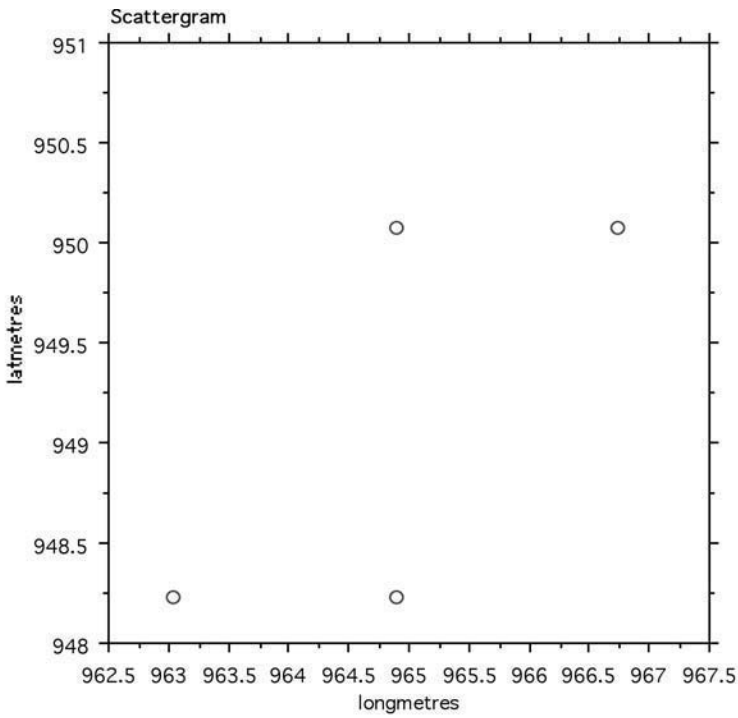


Descriptive Statistics

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
longmetres	959.055	1.534	.022	4846	955.632	961.188	0
latmetres	949.235	1.652	.024	4846	944.520	953.780	0

a

Figure 3.15 Position plots for DGPS (a) and GPS (b). The GPS and DGPS units were set up in the same position and the position recorded for a number of hours. Position was then plotted for each unit. Note the standard deviations with the slightly better GPS readings.



Descriptive Statistics

	Mean	Std. Dev.	Std. Error	Count	Minimum	Maximum	# Missing
longmetres	964.564	1.072	.017	4214	963.040	966.744	0
latmetres	949.133	.926	.014	4214	948.224	950.076	0

b

Figure 3.15 (*Continued*)

3. GPS Errors

There are a number of sources of error in the GPS, which may in some way reduce the accuracy of position. These are listed below with a note in parenthesis indicating if it can be corrected:

1. Ionosphere and troposphere delays. The satellite signal slows as it passes through the atmosphere. The GPS system uses a built-in model that calculates an average amount of delay to partially correct for this type of error (possible to correct with DGPS).
2. Signal multipaths. This occurs when the GPS signal is reflected off objects such as tall buildings or large rock surfaces before it reaches

the receiver. This increases the travel time of the signal, thereby causing errors (impossible to correct).
3. Receiver clock errors. The receiver's built-in clock is not as accurate as the atomic clocks onboard the GPS satellites resulting in very slight timing errors (can be improved using more sophisticated equipment).
4. Orbital errors, also known as ephemeris errors. These are inaccuracies in the satellite's reported location (probably not possible to correct).
5. Number of satellites visible. The more satellites that are visible to a GPS receiver the greater the accuracy (possible to correct manually).
6. Satellite geometry or shading. This refers to the relative position of the satellites at any given time. Ideal satellite geometry exists when the satellites are located at wide angles relative to each other. Poor geometry results when the satellites are located in a line or in a tight grouping (possible to correct manually).
7. Intentional degradation of the satellite signal. SA is an intentional degradation of the signal once imposed by the U.S. Department of Defense (now switched off and currently irrelevant).

4. Projections

One of the most important issues relating to the use of the GPS is understanding the projection method and the datum that is used for this. Many people quote GPS positions, and when one asks the fundamental question, "What datum did you use?," they have no idea to what you are referring. When the SA was on and positions were not particularly accurate, this issue probably did not matter. Today with GPS precision, it is very important. This whole projection method issue relates to the problem that the surface of the Earth is not flat, so to produce a map of its surface requires projection of the curved surface onto a flat surface. Nor is the surface of the earth spherical, it is in fact a complex ellipsoid (sometimes referred to as a spheroid, although this is not generally correct term). This ellipsoid is projected onto a flat surface to produce a map. Different ellipsoids apply in different areas and a GPS generally has a bewildering array of ellipsoids built into the system. All that is necessary, if one wishes to work with a GPS and an existing chart, is to look up ellipsoid or datum for the chart and set the GPS to this datum. The coordinates on the GPS will then plot correctly on the map. The map is a projection and by its nature a projection is a compromise. In the early days of navigation globes were often taken onboard ships to simplify navigational problems. It is not possible to make a map or a chart of a three-dimensional surface like an ellipsoid. Some projections, therefore, attempt to maintain the correct length of the meridians, while distorting areas close to the poles. The Mercator projection exaggerates the distance between meridians by the same degree as the lengths of the parallels in order to obtain an orthomorphic projection. A transverse Mercator is similar, but based on the transverse cylindrical projection. One needs to know how these projections affect the measurement of distance. For example, in the Universal Transverse Mercator (UTM) projections only work up to about 5° of longitude before they become inaccurate. So it is essential to check the limitations of any projection system used. In general, the larger the scale that one is working in the more complicated the problems.

5. Coordinate Systems

There are two basic and commonly known coordinate systems used with the GPS: a Cartesian coordinate system and the UTM. The former has its origin near the geographical center of the Earth, the Z-axis parallel to the terrestrial poles and the X-axis passes through the Equator at the intersection with the prime meridian. This system uses the World Geodetic System 1984 (WGS84) datum reference ellipsoid and usually uses degrees, minutes, and seconds; degrees and decimal minutes; or decimal degrees as units for latitude and longitude and a distance for altitude. The WGS84 system has universal application and is widely used in marine surveying. The UTM is a projection system which has different ellipsoids for different parts of the world and uses a linear measurement of easting and northing (usually in meters). The UTM is usually used in land survey work, but it has an especially useful application in marine work because of the ability to set lane spacing in north–south, or east–west directions to precise metric values. Because UTM is a projection, the datum it uses can be WGS84 (usually the choice for marine work) or other datum depending upon where you are and the local convention.

Because most GPSs have the ability to translate information from one system to another quite easily, there are often advantages in moving from one system to another. The most likely problem is that a GPS usually downloads position data in WGS84 in decimal degree format, so that basic survey data will need to be translated into UTM using some sort of software package.

III. VISUAL SEARCH TECHNIQUES

A. Introduction

Having determined a way of locating a position at sea, methods of locating sites now need to be considered. It is surprising how frequently one encounters or hears of searches that are carried out totally at random and without any recording of the area covered. The result is a waste of time. Before any type of search is undertaken, a number of factors need to be determined: most important is what sort of site is one looking for, what is known of the background information to the loss, and what does one know about the general locality (see Chapter 2 Research above). With some idea of these parameters it is possible to design a search plan which will define the area to be searched, the width of coverage of the search, the type and size of the object being searched for, and the velocity of search. These factors will indicate how long the search will take and thus its feasibility. For example, if a 1-km square area has to be searched for a large object in 10-m lanes at 5 km per hour, that will take about 20 hours and is thus quite a reasonable short-period survey (provided one is not somewhere like the White Sea in the middle of winter). A 10-km square being searched for a small object with 5-m lanes at 5 km per hour will take 400 hours, which is totally different and a major undertaking. Obviously, background research and study of the area will indicate the extent of the area to be searched. The search technique and the type of object or objects being looked for will decide the pattern of search system, the lane width, and the speed of operation. It is also prudent to build a large safety factor into the detection range, since it is better to ensure adequate coverage than have to repeat the survey. Even with quite simple searches, some method of recording the path of the search is essential. Often an initial enthusiasm leads to false optimism in the belief that the objective will be quickly and easily achieved. However, all too often the grim reality subsequently sets in when the site is not found. At this point, unless an accurate record has been made, it will be necessary to start all over again; this time in a more systematic manner. Naturally the GPS is a major factor in the operation of a search. Diver-operated GPS has been used for some time, particularly in shallow water. In these cases the hand-held instrument is usually encased in a water-tight container which the diver holds, and its antenna floats on the surface connected to the GPS by an aerial extension cord. Another option is towing divers behind a boat and recording the track of the boat and the position of the diver. This can be done knowing the layback (see Figure 3.28 below).

B. Swim-line

Any visual search technique requires a record of what area has been searched and what areas are still to be searched. Thus, it is of the utmost importance that the position of the diver or divers can be located at the surface and thus plotted on a chart. This is best done using a buoy on a line attached to the diver and a small boat can be used to plot the position of the buoy using a GPS. One of the most common and most effective search techniques is the swimline (Green, 1969, 1973; Martin, 1975; Wignall, 1968). A group of divers are spaced out on a line so that they are within sight of each other (see Figure 3.16). The divers swim in a particular direction keeping the line taut and at right angles to the direction of motion. The

Figure 3.16 Swimline being deployed from a boat. Note the diving team enters the water one by one as the vessel proceeds. Each diver holds the swimline at the fixed separation distance, the vessel proceeds slowly, and the swimline is deployed in the correct orientation and spacing ready to dive as a group.

divers observe the seabed and record and mark material as they proceed (Figure 3.17). The swimline, ideally, should be positioned some distance above, but within good visual sight of the seabed. As a very general rule, the height above the seabed should be half the diver separation. This way each diver searches half of the search area belonging to the diver on either side. This ensures that any particular area is visually searched by two divers, and thus there is a high certainty of sighting an object. In some cases, it may be necessary to alter the distances to improve efficiency. However, it should be emphasized that a diver can all too easily overlook the presence of an artifact, which is probably heavily encrusted with marine growth. Secondly, the distance of the search above the seabed should not be too great or the divers will not be able to spot the artifacts.

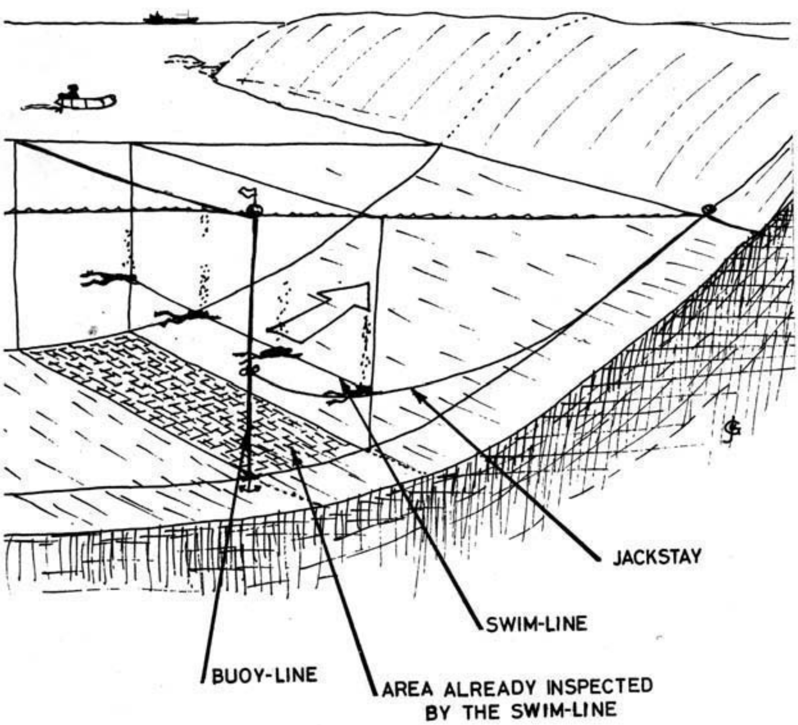


Figure 3.17 Swimline schematic at Cape Andreas, Cyprus, showing four divers holding the swimline and the first diver following the jackstay. The team has been deployed from the boat at the surface starting from the buoy at the buoy line.

The main concern with the swimline is that without some form of control there is no clear idea of the path of the search. Thus a survey of a defined area can be a hit-or-miss operation. One solution is to lay a jackstay on the seabed which the end diver of the swimline follows (see Figure 3.17). Using this system, the swimline has a direction and the survey can proceed regularly by laying successive jackstays. The beginning and end of the jackstay are marked with anchored buoys, and the jackstay runs from some point down the anchor line off to the other marker. Alternatively, divers on either end of the swimline can use compass bearings, but it is more difficult to maintain control this way. Both techniques were used by me at Cape Andreas in 1969 and 1970 (Green, 1973) and the resulting search areas can be seen in Figure 3.18. Although both systems had their relative merits, the compass-controlled swimlines, which were necessary because of currents, resulted in unpredictable search areas as seen in the Figure 3.18.

Poor visibility obviously creates problems and very careful planning of survey areas needs to be considered. Using a jackstay is probably only effective in places like rivers where it is possible to control the setting out of the search lines from either side of the river bank.

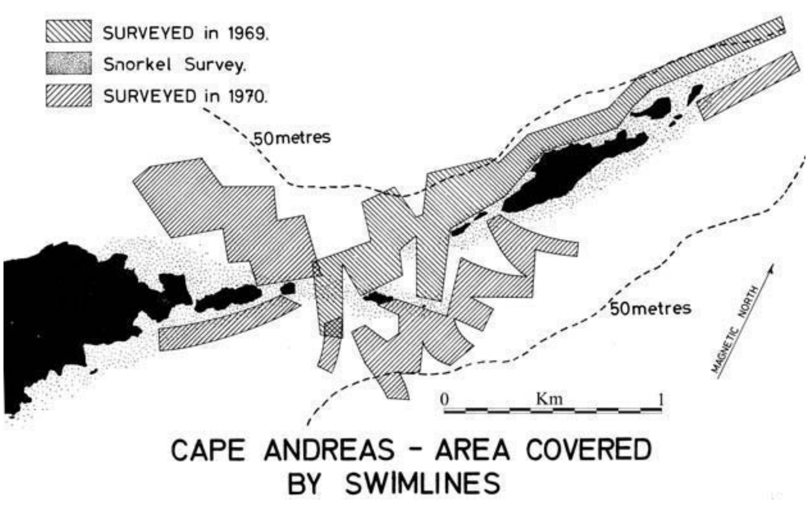


Figure 3.18 Area surveyed at Cape Andreas, Cyprus, during surveys in 1969 and 1970 using swimline search.

C. Circular Search

The circular search is well known to recreational divers as a simple and effective method of searching. For archaeological work it is probably only really useful in low visibility where a diver can conduct reasonably efficient searches around a marked point or where a quick identification of a known site is required. The real problem exists where one wishes to be systematic, because several overlapping circular searches are quite inefficient. As a technique it is very useful where one has low visibility and often two, or possibly three, divers can operate on a circular search, either feeling for sites or objects, or with limited visibility, maintaining visual contact with the adjacent diver. Obviously, lots of planning is required and underwater communications will increase the efficiency of this type of search system enormously.

D. Towed Search

The swimline requires a great deal of organization and preparation and proceeds slowly. An alternative to this is the towed search whereby one or two divers are towed on a board or sled behind a boat at a speed comfortable for the diver (about 2–3 knots). By means of diver-adjustable depressors and controls on the sled, the diver is able to adjust the height so that the seabed is kept in view. In this way, considerable distances can be surveyed quite quickly and the only real concerns are the diver's ability to withstand the cold, as almost no energy is expended sitting on the sled; the ability to keep the seabed in view over undulating topography; and to maintain a reasonable speed for the comfort of the diver. The sleds and boards vary in complexity, but it is advisable to avoid the so-called manta boards unless the diver has some form of support. The most comfortable system is one where the diver lies supported in a relaxed prone position on a form of saddle. If depressors are used they should be balanced so that strong depression or (more important) elevation can be achieved with only a small amount of effort. The sled should be arranged so that in a free condition it automatically rises and, for obvious reasons, the diver must be able to abandon the sled easily. Voice communication can be an advantage, but again it should be easy to ditch. The depth that the sled can reach will depend on its drag, which is a function of the speed of the tow and the length and the diameter of the tow rope. The cable equations (see Green, 1970) are quite complex, but in general it is preferable to keep the cable diameter as small as possible, because, for a given velocity, it has a significant effect on the drag. For this reason it is worth considering using wire, although it is extremely difficult to handle and needs to be used with caution as it has a high breaking strain and it is not easy to cut.

Obviously, using a GPS track plot of the search would have immense advantages. In situations where systematic searches are not possible because of underwater obstructions such as reefs and coral heads, the ability to record where one has been is essential. This system was used in Ningaloo Reef in a search for the wreck site of the *Correio da Azia*. Because of the difficult nature of the terrain and the complex reef system, searches were conducted over a number of days. At the end of each day the track of the search was laid down on a geographic information system (GIS) to record the path of the vessel and thus the area visually searched (see Figure 3.19). It was

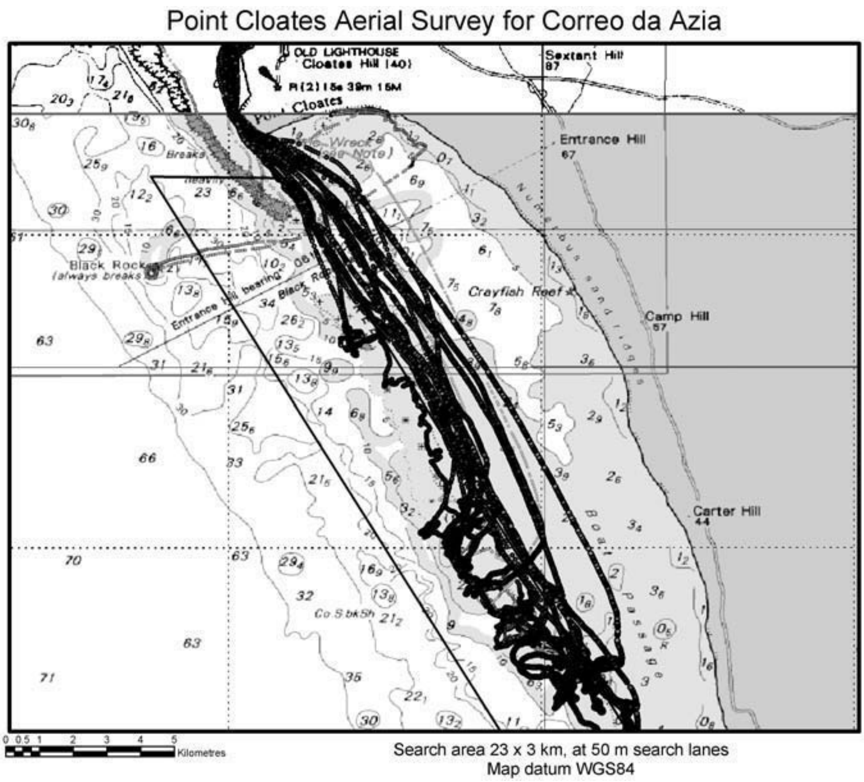


Figure 3.19 *Correio da Azia* towed search in the Ningaloo Reef, Western Australia, showing the track of the search vessel recorded by GPS and then plotted on a chart using a GIS. Because the area consists of large coral heads (bommies), it is very difficult to search the area systematically. The GPS provides a good record of what areas have been covered and what need to be covered.

immediately possible to see area that had been missed and to plan the following day's survey to take this into account.

E. GPS Search

In shallow water there is no reason why an underwater GPS system could not be used. All that is necessary is that the system should be waterproof, the diver should have access to the controls, and the antenna should float on the surface. In places where there is not a strong current it would be possible to maintain the antenna on a cable running from the surface to the diver unit within a 5-m radius of the operator's position. This would give access to reasonably accurate underwater location and, more important, the ability to utilize the simple tracking systems that most GPSs have.

IV. OTHER VISUAL TECHNIQUES

Several techniques are available to search for deep-water wreck sites. It must be pointed out immediately that the cost and logistic problems of working in deep water have to be carefully considered along with the objectives of the exercise. It may well be that even if a site is discovered in deep water, it may not be feasible to study it properly, let alone excavate it. With the advent of mixed gases and technical diving, the operational threshold of conventional archaeology is slowly extending into deeper water. For example, Bass *et al.* (1984) operated with conventional SCUBA to a depth up to 70 m in Ulu Burun, Turkey. Similarly, his work at Tektash was conducted at 42 m for three seasons. Naturally this requires resources and infrastructure, so if sites are going to be worked at this depth the ability to search for them is also necessary. Although the logistics of a survey are quire different from a full-scale excavation, they are, nevertheless, serious. So any system that reduces the logistics of divers is worth considering.

A. Submersibles

Several systems have been used that involve putting a person in some form of submersible. At the simplest level, a single, manned, one-atmosphere capsule, towed behind a boat, has been used in deep-water searches in the Mediterranean off Turkey (Bass and Katzev, 1968) and elsewhere in the Mediterranean (Frey *et al.*, 1978). Otherwise, a number of exotic manned submarines and one-atmosphere diving suits have been deployed, although in most cases this has been after the location of a site. Bass developed the submersible *Ishara.* Currently, he is working with the small, self-contained submarine *Caroline* (Figure 3.20), which is being used to investigate the feasibility of submarine survey work (Bass, 2002). In most cases submersibles carrying individuals have now, for obvious reasons, been largely superseded by remotely operated vehicles (ROVs). COMEX has a range of submarines including the REMORA 2000, which combines the functions and instrumentation of an oceanographic subsea vessel with the built-in amenities and design of a recreational submarine.

B. ROVs

Towed video cameras and ROVs (Figures 3.21 and 3.22) are widely used in the investigation of sites that are beyond the operational depths of divers

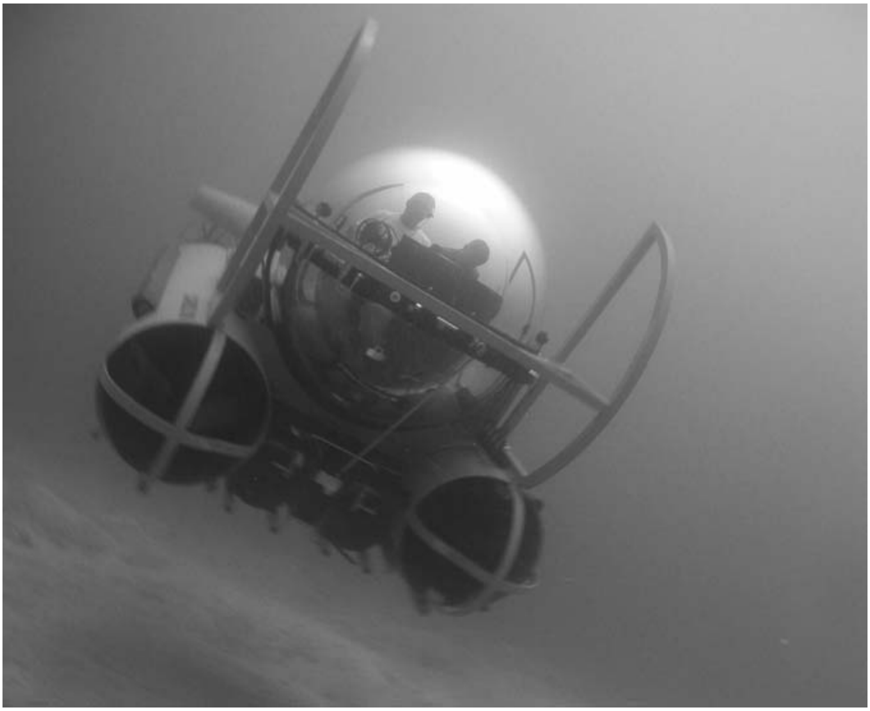


Figure 3.20 Underwater two-person submarine *Caroline* in operation on the Tektash Brunu site in Turkey. The submarine is used for survey work and observation during excavations by the Institute of Nautical Archaeology, which is based in Bodrum. It is particularly useful for deep-water survey because there is almost unlimited time as it is at normal atmospheric pressure. (Courtesy of Jeremy Green, Department of Maritime Archaeology, Western Australian Maritime Museum and the Institute of Nautical Archaeology, Bodrum, Turkey.)

Figure 3.21 Large-scale ROV, the Nomad, produced by Total Marine Technology. (Courtesy of Tom Pado, Total Marine Technology.)

Figure 3.22 Small-scale ROV, the Navigator, produced by Total Marine Technology. (Courtesy of Tom Pado, Total Marine Technology.)

(Bass and Joline, 1968), although they are somewhat difficult to use in locating sites. Obviously these systems are unlikely to be effective in deep-water searches over large areas of the seabed due to their limited field of view, the difficulty in controlling a search pattern in deep water, and the limited range. Such systems are more likely to be useful in the final location and inspection phase of a deep-water search and in the survey of these deep-water sites.

The use of the ROV is also an interesting development for maritime archaeology. In the majority of cases video cameras are placed onboard an ROV and used in deep-water site inspection. Recent examples of the use of this type of system were with the discovery of the *Titanic* (Ballard and Crean, 1988), the *Bismark* (Ballard and Archbold, 1991), HMS *Hood* (Means, 2002) in the mid-Atlantic, and the discovery of HMS *Breadalbane* (McInnis, 1982) in northern Canada. Not only can deep-water sites be investigated in a nonlife-threatening situation, but the instrument also can be deployed for long periods of time allowing leisurely inspection of sites. Obviously, there would be little justification to use a large-scale ROV in very shallow water, but from depths beyond 20 m, depending on the nature of the work, such systems could be very useful. It seems that the ROV is most likely to be used in the predisturbance survey of a site, because they usually have limited mechanical ability. In these searches, a towed acoustic and visual vehicle (*Argo*) was used to produce detailed information about the seabed.

The advent of the autonomous underwater vehicle (AUV) ROV is a new development. AUVs are unmanned, untethered submersible ROVs that are capable of carrying out work autonomously. Examples of AUVs include: the EAVE-III vehicles of the Marine Systems Engineering Laboratory (part of the Autonomous Undersea Systems Institute), the Ocean Voyager and Ocean Explorer vehicles of Florida Atlantic University, the Odyssey vehicles at MIT Sea Grant, and the Phoenix AUV at the Naval Postgraduate School. These vehicles are capable of being programmed to conduct an autonomous search of the seabed, gathering a range of data, and then returning to the mother vessel where the unit is recovered and these data downloaded and analyzed. A recent technical problem with the AUV system has been described by Hocker (personal communication 2002). He indicated that during the time taken to conduct an extensive AUV survey, there is generally no feedback of data from the unit to the operator, consequently, targets of interest that need to be re-examined have to undertaken after the survey. Where one is looking for a particular site or where the AUV produces a poor quality image, the system has to be reprogrammed and sent on a further mission, all of which is time consuming and expensive.

C. Aerial Photography

A technique which is sometimes used for wreck location is aerial photography. A well-defined site in shallow water often shows up quite clearly in an aerial photograph (Figure 3.23). Arnold (1981) illustrated a number of examples of aerial photography with specialized films which have provided information on shallow water sites. It has been suggested that sites could be located using satellite photographs (Landsat), but at present the resolution of the system is probably not sufficient to enable sites to be identified.

Figure 3.23 Aerial photography identification of wrecks. This photograph, with the enlarged insert, shows the *Carbet Castle*, a large iron wreck on the beach at Bunbury, Western Australia. The site is now completely covered up and the position of the site was determined from this early photograph.

V. ELECTRONIC TECHNIQUES

A. Magnetometer

1. Principles of Operation

The use of the magnetometer for locating archaeological shipwreck sites was developed by Professor E.T. Hall at the Research Laboratory for Archaeology, Oxford, England. In this pioneering work, he showed that a marine proton magnetometer could be used to locate shipwrecks (Hall, 1966). A number of marine archaeological magnetometer surveys have been conducted, notably off Padre Island, TX (Arnold, 1976, 1981; Arnold and Clausen, 1975), in the *Bell* project (Arnold, 1996a,b), and in the Canadian Great Lakes (Nelson, 1979, 1983). They are an excellent guide to the logistics of mounting large-scale magnetometer surveys. Particular case studies of interest include those by Cusnahan and Staniforth (1982), Green (1987a), and Green *et al*. (1984).

Although the instrument is ideally suited for locating iron ships, it can, in certain circumstances, be used for locating nonferrous shipwrecks. The marine magnetometer has been widely used for archaeological survey work and the principals and application are well understood. The proton precession absolute magnetic field intensity instrument is the most commonly used magnetometer for marine work, although differential proton magnetometers, fluxgate, and cesium vapor instruments have also been used. There are three main problems with using a proton magnetometer (which is generally towed behind a survey vessel) in the marine environment: (1) determining the height of the detector head above the seabed; (2) the limitation of the sensitivity of the system when operating in seawater; and (3) determining layback.

The magnetometer measures the intensity of the Earth's magnetic field at the sensor head. The presence of ferromagnetic material influences this field; the local effect increasing the intensity in some areas and decreasing it in others. Assuming that the Earth's magnetic field intensity is uniform over small geographic distances (compared to the site being searched for), and that an iron object behaves like a short bar magnet in this field, the object will create an anomaly. Figure 3.24 shows, in a simplified form, the cross section of a magnetized object in the plane of the magnetic meridian. Areas where the local field intensity is enhanced and diminished are shown together with a contour map showing an idealized intensity plot at a fixed distance above the object.

The intensity of the anomaly varies as the inverse cube of the distance, and an approximate formula for the intensity (the Hall equation) is as follows

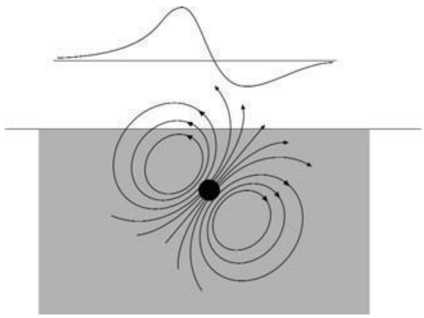


Figure 3.24 Cross section of magnetic anomaly. This illustration shows a buried magnetic dipole and the magnetic field intensity plot along a line passing above the object. In this case the object is in the Northern Hemisphere. Initially to the right the dipole opposes the local Earth's magnetic field creating a small negative. As one passes over the object the dipole adds to the local field producing a strong positive. Note the location of the object coincides with the approximate zero or steepest part of the curve, not the positive maxima.

$$\Delta M = 10\left(\frac{A}{B}\right)\left(\frac{w}{d^3}\right)$$

where:
ΔM = magnetic anomaly in nanotesla (nT)
w = weight of object in grams
$\left(\frac{A}{B}\right)$ = length to width ratio of the object
d = distance of object in millimeters

Because most marine proton magnetometers can detect about a 5-nT anomaly and the A/B ratio for a ship would be about 5, then:

$$D^3 = 10^4 W$$

where D is distance in meters and W is the weight in tonnes (t).

Thus a 10-t ship should be detectable at 45 m and a 10,000-t ship at 450 m. For smaller objects, a 10-kg cannon ball can be detected at 3 m and a 2-t cannon at 27 m. However, it must be remembered that the ability to detect the anomaly will depend on the background noise and the field gradient (Hall, 1966).

Interestingly, ceramic material has a thermoremnant magnetic component. Thus an amphora wreck would present a magnetic anomaly. Although during the firing process the individual ceramic objects are all magnetized uniformly, the strength of each object is diminished because the subsequent stowing onboard a ship is completely random, thus reducing, by cancellation, the magnetic effects of the individual items. The effect is very localized, but it can be utilized in a predisturbance survey to determine the extent of the buried wreck site (Green 2002; Green *et al.*, 1967). This is discussed in Chapter 5.

2. Search Considerations

Obviously with a towed magnetometer search some preliminary considerations are necessary. First, it is essential to have an estimate of the size of the object being searched for, so that the most effective deployment of the sensor head can be achieved. Knowing the size of the object, it is possible to calculate the detection range from the Hall equation. The detector head must then be streamed behind the search vessel at a depth that will give the best lateral coverage. Maintaining a height equal to the maximum detection range of the object being searched for is useless, as the lateral coverage or lane width being searched will be negligible. Experiments have shown (Green, 1969) that the optimum height above the seabed is half the detection range, which gives a width of coverage equal to 1.7 times the detection range. In other words, the increased difficulty and danger of towing the detector head just above the bottom adds little value to the detection range after half the detection range.

Because the velocity is the most critical variable in determining the depth of the sensor head, any variation in the velocity will make a considerable difference to the depth of the head. Therefore, it is essential that the survey is either carried out with the detector heavily weighted to the required depth (the weights being nonferrous and kept several meters away from the sensor), or that a method of depth determination be used. Most high-quality (and thus expensive) magnetometers have some form of depth sensor. However, this does not give a direct reading of the height above the seabed, which is, of course the critical issue for both safety and knowing the distance for the Hall equation. Ideally, an echo sounder transducer located near the head would give the head–seabed distance. A less complex and easier system to install is a fine (1–2 mm in diameter) plastic tube taped to the cable and open-ended at the bottom end. The top end is attached to an accurate pressure gauge which is calibrated in the depth of the seawater. A constant air flow valve is connected to a high-pressure air source to give a regular and minimum flow of air down the tube no matter what the depth. The depth is then given by measuring the pressure required to maintain the output of the constant flow valve. Alternatively, the strain gauge depth sensor is a more sophisticated solution which is available in some commercial versions. These systems give the depth of the head, not the head–seabed distance, so an echo sounder seabed depth measurement is required for the head–seabed distance to be calculated. In some respects this is a good system, because the echo sounder can warn the operators if there is a sudden change in depth of the seabed, which may cause the detector head to snag the bottom.

More recently, successful trials have been made using a side scan sonar and a magnetometer combination. When the magnetometer is located reasonably close to the side scan tow "fish," it gives information about the seabed and the distance of the detector head from the bottom. All these data then can be combined within the side scan computer data logger. At the Department of Maritime Archaeology at the Western Australian Maritime Museum we have integrated a side scan sonar with a magnetometer. The side scan system we use is a Marine Sonic Sea Scan PC system which, apart from logging the side scan data, allows data from the magnetometer to be recorded in a data file together with the GPS information. In this way it is possible to log the information on the magnetic field strength and, as the information is georeferenced, create magnetic contour plans. If the magnetometer tow fish is deployed a short distance behind the side scan, the side scan trace can be used to determine the height of the unit above the seabed. So that when a magnetic anomaly is encountered its mass can be estimated from the approximate Hall equation.

In the situation where a position fixing system is not available, it is possible to locate an anomaly by throwing a buoy overboard when the anomaly is first observed. The course is then reversed and another buoy thrown overboard when the anomaly is again observed, thus bracketing the target. This process can be repeated on a course at right angles to the first anomaly to help to define its position more accurately.

The only effective way to operate a magnetometer survey is to carry out the survey first and then investigate the anomalies. The temptation to examine each anomaly as it occurs should be avoided, as this is both time-consuming and very inefficient. Most magnetometers have a digital readout and, in some cases, have a paper trace or a data output through an RS232 interface. Whatever system is used, it is necessary to relate the magnetic intensity figures with the position being plotted. Where there is only a digital readout, the values should be recorded against time, for example, every 10 seconds; however most systems have a paper trace or chart recorder that gives a continuous intensity reading (Figure 3.25). Thus, it is only necessary to mark the point on the trace at which each fix is taken. In the situation where a GPS is used, if the position data and time can be logged on a data logger, then it is only necessary to record the time on the trace. Obviously, the ideal situation is where the magnetic intensity is recorded together with the position automatically. There are a number of integrated systems that allow that to happen.

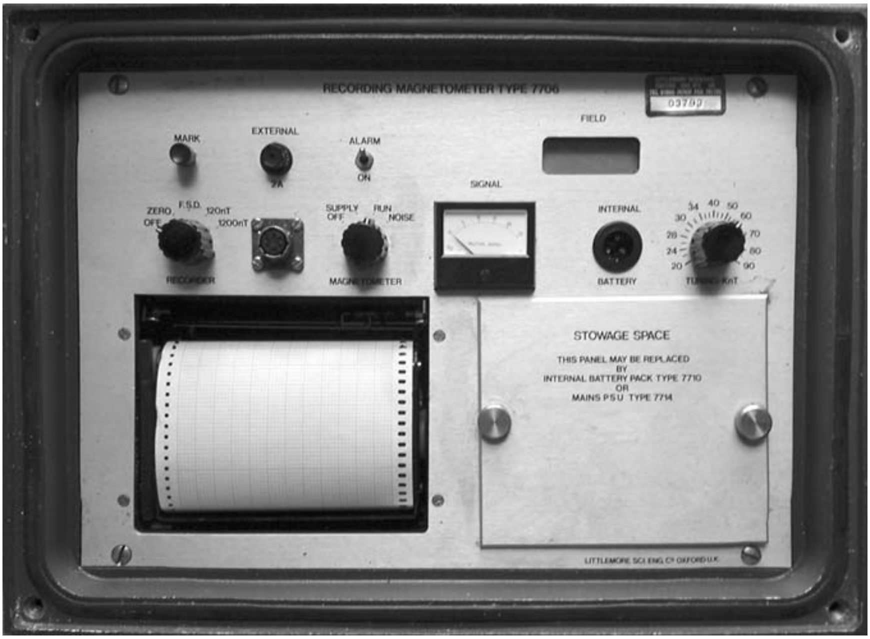


Figure 3.25 The control unit of an ELSEC Small Boats Magnetometer EL7706. Magnetometer controls left to right central row above chart recorder: recorder control, RS232 data output, magnetometer control, signal strength meter, external power supply, and magnetometer tuning control. LCD window above external battery gives digital readout of magnetic field strength.

After the initial phase of the survey, or when a major component of the survey has been completed, these data can be plotted (Figure 3.26). There are different ways this can be done: contour plots, dot density diagrams, and three-dimensional surface plots. These three plotting systems can be either hand-drawn or computer generated. In the case of the manual recording system, the readings from the traces can be related to the plotted position of the vessel, thus magnetic intensity is plotted according to position. It is best to plot the survey runs on the chart first and then transfer the magnetic intensity values to these runs, for example, in tens or hundreds of nanotesla. This may be quite difficult if there is not a large number of position fixes for each run. In such cases it may be necessary to plot the values for each position fix and then interpolate between fixes. If manual contour diagrams are going to be drawn it is possible, although quite difficult, to follow contours around the chart and draw them in. Some thought needs to go into this process, as it is much easier to plot the contours if a differential value

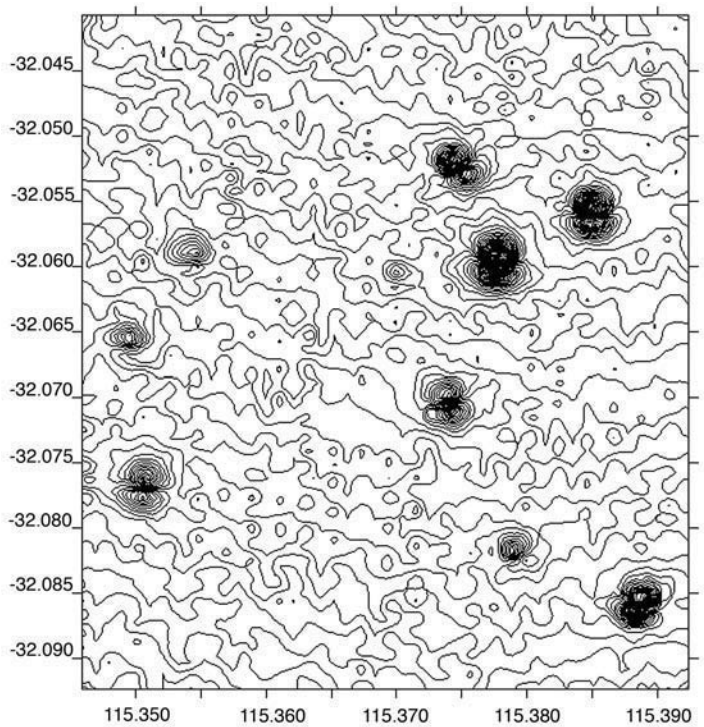


Figure 3.26 Contour magnetic map. This map was generated from an aerial magnetic survey of the Deepwater Graveyard off the Western Australian coast, an area off the port of Fremantle where ships were scuttled. Water depth ranges between 80 and 100 m.

is used. Therefore, by taking the approximate background reading and subtracting it from each reading one will obtain a differential reading where the numbers are much easier to plot. If the runs form a reasonable grid, then selecting a particular contour value (for example, starting with zero), one can compute the intersection of this value on each axis around the grid (see Figure 3.27). With an automated data logging system, the magnetic and position data are fed directly into a computer where it is stored for later processing. These data can subsequently be processed by contouring software to produce contour, shade, or three-dimensional plots.

Hopefully, the survey will be in a magnetically quiet area and anomalies will be small localized points affecting one or possibly two survey lanes. When plotting, it is necessary to take layback into account (the distance that the detector head is behind the boat where the position fix is taken or,

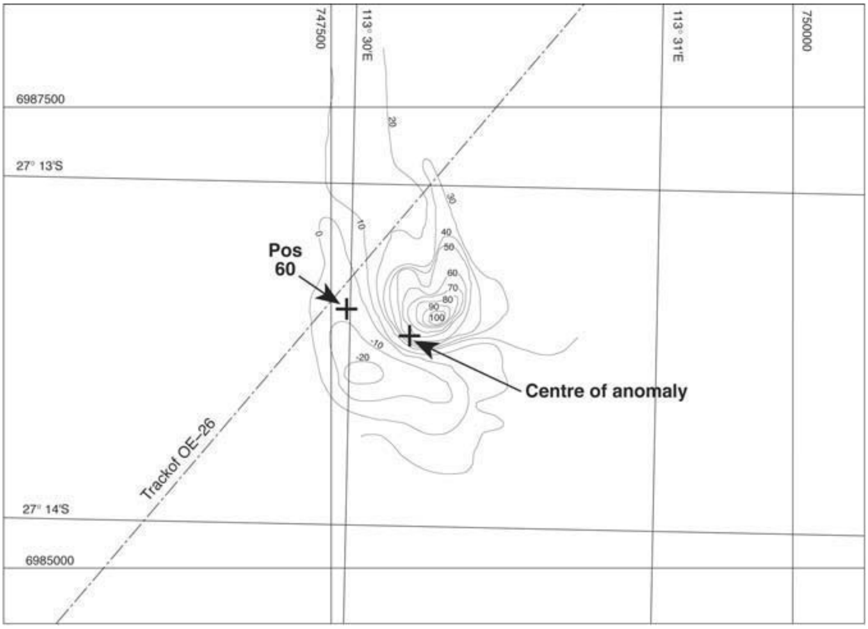


Figure 3.27 Example of a magnetic survey conducted from a vessel over a geomagnetic anomaly, thought at first to be a World War II wreck site.

in the case of the GPS, from where the antenna is located, Figure 3.28). Thus, if one steams up one lane and down the next lane past the same anomaly, and layback is not taken into account, then the targets will appear separated by twice the cable length. Access to a computer and a chart plotter will speed the processing of large surveys and, in many cases, the layback can be fed into the data logger during the survey.

3. Magnetometer Sensitivity

The sensitivity of a magnetometer depends on a number of variables including the background noise experienced when operating a magnetometer in seawater. In general, the explanation of this noise is complex, the usual noise level for a proton magnetometer is about 5 nT. The source of noise in the seawater environment can be divided between small, random variations in the magnetic field intensity. These variations are caused by physical effects which are largely microphony in the cable and general instrumental noise. Other physical effects include the physical movement

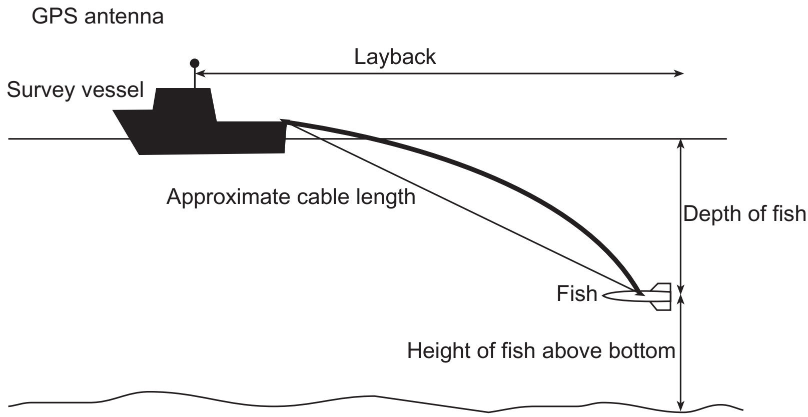


Figure 3.28 A schematic showing the principle of layback. Cable equations are complex, but an estimation of the horizontal distance from the detector head behind the boat is important when conducting accurate surveys.

of the detector head caused by turbulence and movement of towing cable. Such effects are likely to cause the detector to experience variations in magnetic field strength, thus causing noise. In addition, the inductive effect of the polarizing field of the proton magnetometer system is likely to be affected by being surrounded by a conductor (seawater). Other sources of noise encountered in general operation is electromagnetic noise originating from electrical discharge such as engines, lightning, electrical sparks, radio transmission, and sunspot activity. These usually result in large random spikes of noise.

4. Aerial Magnetometer

If the detector head can be removed from the seawater medium, both the noise-related effects of towing and the noise effects of the medium can be eliminated. Thus in shallow water it is often a preferable option to run the system out of the water with the advantage of the improved signal–to-noise ratio. The other option, in air, is to use a cesium vapor magnetometer which usually has a resolution of about 0.001 nT, although in reality this is probably about 0.05 nT due to a variety of other noise-induced problems.

Thus, in certain circumstances, there can be a real benefit to operating in air. Because the cesium magnetometer allows a much higher sampling rate, the survey can proceed at a much faster rate and can even be deployed on an aircraft. This immediately has implications relating to cost-effectiveness of a survey. Although the cesium magnetometer is inherently expensive, the possibility of using it on an aircraft has considerable significance. An aircraft can fly in most weather conditions and can cover very large areas very quickly. An aerial magnetic survey of the Deepwater Graveyard off Rottnest in Western Australia (see Figure 3.26 was recently conducted. The survey covered an area of 33 km^2 and was completed in just over three hours.

In early 2001 Prospero Productions, a local Western Australian film production company, approached the Department of Maritime Archaeology with the proposal to make a series of documentaries entitled the Shipwreck Detectives. One of the projects that they funded was the search for and location of ships that had been scuttled in the shipwreck graveyard off Fremantle. This project was originally initiated by McCarthy, and his research indicated that, since about 1910, vessels that were no longer useful were taken out to a site about 20 nautical miles west of Fremantle and scuttled in depths between 60 and 100 m of water. Later, after the WW II, military equipment, submarines, Lend-Least material, and commercial aircraft were also known to have been dumped there.

The first phase of this project was to gather all the archival information available, together with the information that McCarthy had collected over the years related to fishing snags. This information was placed on the first level of a GIS of the area. A local geophysical surveying company, UTS Geophysics, was contracted to survey two areas: he Deepwater Graveyard (24 km^2) and the HMAS *Derwent* site (8 km^2); the latter being a frigate sunk in 200 m of water as part of an Australian navy exercise in 1994. The survey took approximately 3.5 hours, and covered 338 linear km and this information can be shown on a GIS (Figure 3.29).

Deepwater Graveyard	HMAS *Derwent*
Coordinate system AMG84	Coordinate system AMG84
Grid zone: 50	Grid zone: 50
343285.000 6453607.000	328758.000 6451525.000
347696.000 6453607.000	331057.000 6451525.000
347696.000 6448129.000	331057.000 6455260.000
343285.000 6448129.000	328758.000 6455260.000

The results of the survey were extremely interesting. In the Deepwater Graveyard at least nine large magnetic anomalies were located (see Figure 3.26 above).

In the case of the *Derwent* site the aerial magnetometer (flown by UTS in August 2001) recorded a 14.787-nT anomaly over the *Derwent* area. The *Derwent* was a Type 12 frigate of 2100 t and 112.8 m long by 12.5 m breadth. It was built in Williamstown, Victoria, in the late 1950s and did not have the

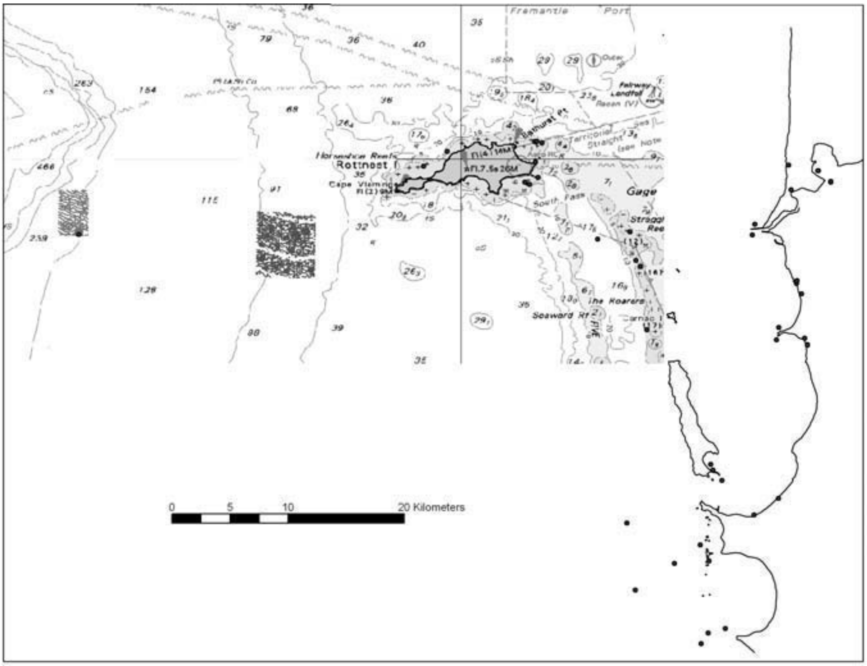


Figure 3.29 A GIS of the Deepwater Graveyard showing the magnetic contour diagram shown in Figure 3.27 georeferenced on a chart of the area together with other data.

aluminum superstructure of the later Type 12 vessels built in the early 1970s such as the HMAS *Swan* and HMAS *Torrens* (Geoff Hewett, personal communication). So the tonnage represents a totally iron hull with 1% aluminum, whereas the later Type 12 had about 20% aluminum in the superstructure.

Using the Hall equation (Hall, 1966)

$$\Delta M = \frac{A}{B} 10^4 \frac{W}{D^3}$$

where

ΔM = nT
W = t
D = m
$\left(\frac{A}{B}\right)$ = length/breadth ratio

For HMAS *Derwent*

$$\Delta M = \frac{9.02 \times 10^4 \times 2.1 \times 10^3}{(225)^3}$$

$W = 2100\,\text{t}$
$D = 225\,\text{m}$
$\left(\frac{A}{B}\right) = 112.8/12.5 = 9.02.$
So $\Delta M = 16.6\,\text{nT}$ calculated.

This largely confirms the application of the Hall equation, in particular, the application of the $\frac{A}{B}$ ratio.

There can be little doubt that the application of an aerial magnetometer is the most effective application for shallow water surveys for large–to-medium vessels containing iron. This is because the system has increased sensitivity over any in-water magnetometer and, more particularly, because it can cover areas faster and more reliably than the marine magnetometer. The in-water system has the advantage that it can be deployed closer to the seabed. But with the size of the anticipated medium-to-large anomalies, the advantage gained in decreasing target-to-sensor distance is offset by low speed of operation, operational unreliability due to the effects of weather conditions, and thus increased costs.

The *Derwent* experiment clearly shows that a vessel of 2100 t can be detected at 250 m (50 m flying height) giving a 15-nT anomaly. This also has considerable implications for the rate of coverage. Figure 3.30 shows a plot of a 10,000-t object which shows the size of the predicted anomaly at different offset distances from the center of the anomaly for different depths of water. This indicates that beyond approximately 1000 m of water the anomaly is almost undetectable, even with a highly sensitive instrument.

However, there are also some considerations which affect the detection distance, in particular, the background noise. Variations in the observed magnetic field of the Earth can be attributed to the presence of a body that is capable of being magnetized. This measured variation can be quantified by two factors: the amplitude of the response and the half-width of the positive peak.

The magnitude of these variations can be considered a function of two factors: the spatial geometry, which includes the size, orientation, and depth of the causative body; and the magnetic susceptibility of the body which is simply a measure of the body's ability to be magnetized.

The efficiency of the magnetometer system in detecting such sites is limited by the following parameters:

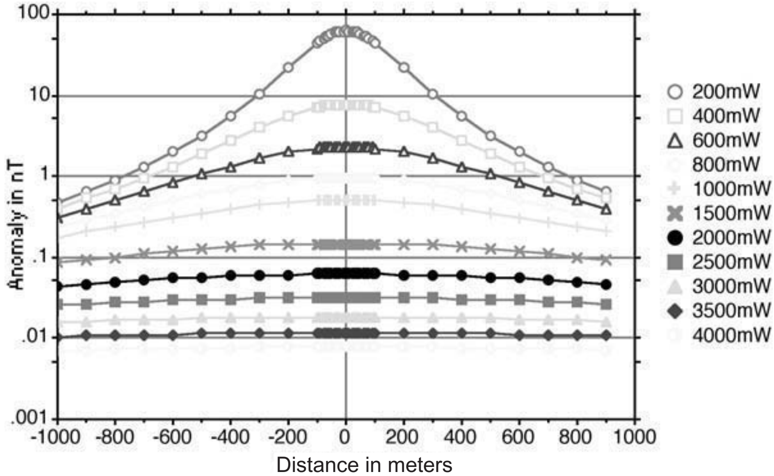


Figure 3.30 Plot of the theoretical field intensity (logarithmic scale) against different ranges from the center of the anomaly for different depths of water in meters (mW).

1. The detection range and half-width response
2. The background signal-to-noise ratios
3. The relative density of geomagnetic, magnetic, and other anomalies

Clearly, if one is searching areas well within the theoretical detection range, the main problem will be differentiating between anomalies of the same or similar size to that predicted for the target. In any given depth it will be possible to discount larger and smaller anomalies to the prediction, but some upper and lower theoretical limits will need to be applied. Where one is close to the theoretical detection range, the noise issues will become significant.

The results of the UTS survey of the *Derwent* and Deepwater Graveyard sites (see Figure 3.26 above) show a noticeable gradient across both search areas due to the natural variation in the Earth's magnetic field. In addition, a series of regular magnetic field intensity fluctuations can be observed, and these are attributed to the effect of the swell. "Swell noise" is caused by the movement of a conductor body (the ocean saltwater) through the Earth's magnetic field which produces eddy currents (Faraday's law). The magnetic component of the eddy currents thus increases or decreases the magnetic field intensity. It is not clear if this effect can be compensated for; if it could, then there would be a considerable gain in detection range.

B. Other Towed Detector Systems

There are a number of interesting methods that could possibly be used to locate wreck sites. In many cases these systems have been suggested, but never tried in practice. For example, it is possible that a form of towed metal detector could be used for wreck site location. However, these systems depend on the 10^{-6} law rather than the 10^{-3} law of the magnetometer. In simple terms, if one doubles the distance from an object then the signal is reduced by 1/8 using a magnetometer, whereas it is reduced by a 1/64 in a metal detector. As a result of this short range, such systems have limited use. Others have suggested using a sensitive, differential conductivity meter to locate sites. To date neither of these systems is available either commercially or in a development stage. Many systems, while sounding theoretically attractive, either do not work, or do not perform as well as advertised or claimed. Therefore any new or unproven system should be treated with a great deal of caution until the claimed performance to detect sites can be clearly demonstrated.

VI. ACOUSTIC SYSTEMS

A. Echo Sounder

The paper trace or the color screen echo sounder is one of the simplest acoustic wreck location systems. With this system a wreck, standing above the seabed, can usually clearly be seen on an echo sounder trace (Figure 3.31). Such a system of wreck location is limited, because the narrow beam width of most modern shallow water echo sounders results in a very narrow search path. The echo sounder trace can be used quite effectively to precisely pinpoint a wreck site once its general location has been determined. This is particularly important when plotting a site with a GPS. Two variations of the simple echo sounder are described next.

B. Scanning Sonar

The scanning sonar is a system where the sonar transducer rotates, like a radar antenna, and the reflected signal is used to produce a sonar plan of the seabed. The beam is directed approximately horizontally and a time variable gain is used in the electronic system to amplify the signals reflected from a distance. The farther away the target, the weaker the signal and

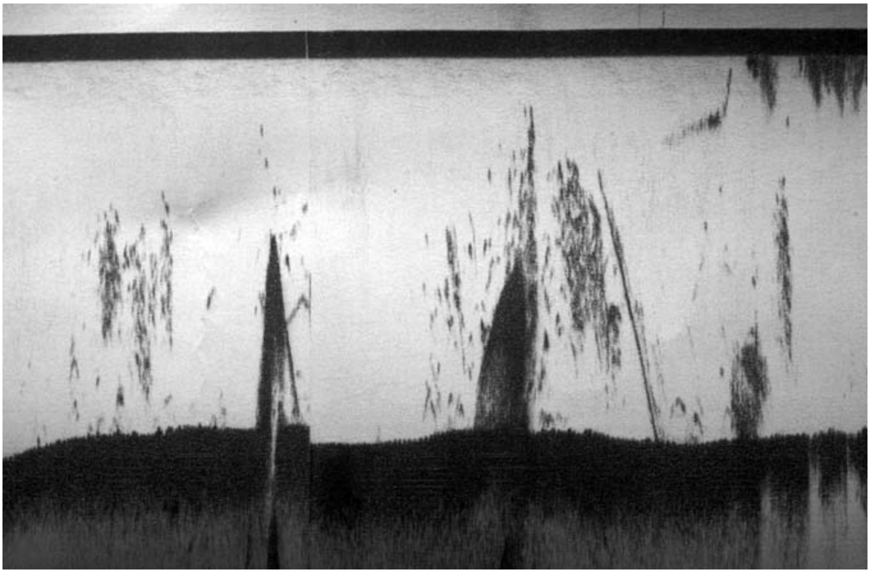


Figure 3.31 Echo sounder trace of wreck. The trace shows a large number of fish in the water column above the site, a common finding on wreck sites. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

therefore the greater the gain required. Using this system, a target can be located by distance and bearing, but care has to be taken to ensure that the speed of the vessel and the rate of rotation of the sonar beam are such that targets are not missed within one revolution. These factors can produce an area of uncertainty, which usually lies directly under the track of the vessel. The surveyor will have to exercise caution to ensure there are no holes in the survey. A variant of this system is the sector sonar which usually operates in a forward direction with a sector beam.

C. Multibeam Sonar

A recently developed system for surveying the seabed is the multibeam sonar. This system is widely used in hydrographic survey work and although excellent for logging the depth of large areas of seabed, its underwater archaeological applications are still uncertain. Multibeam sonar systems provide fan-shaped coverage of the seafloor similar to side scan sonar, but the output data are in the form of depths rather than images. Instead of continuously recording the strength of the return echo, the multibeam system measures and records the time for the acoustic signal to travel from the transmitter (transducer) to the seabed (or object) and back to the receiver. It then calculates the depth at seabed by calculating the angle from the point of return of the signal Multibeam sonar systems are generally attached to a vessel rather than being towed like a side scan, although very advanced models are used commercially (Figure 3.32). Therefore, the coverage area on the seafloor is dependent on the depth of the water, typically two to four times the water depth. Recent advances with this system shows that it can locate large iron vesselsbut the operational range and its resolution are currently unclear. With a multibeam it is possible to generate a three dimensional image of the seabed which can be used in software to analyse seabed features and create depth contour plots or alternatively image wreck sites (Figure 3.33).

D. Side-scan Sonar

In the operation of the side scan sonar, the transducers are usually attached to either side of a fish which is towed behind the vessel on a long cable. The sonar beams then radiate on either side of the fish providing a two-way look (see Figure 3.34). Early side scan sonar had a single transponder attached to the side of the vessel and had a one-way look, but

Figure 3.32 A Fugro Seafloor Survey SYS 09 swath bathymetry side scan or multibeam sonar. This large-scale system produces accurate bathymetry by measuring the angle at which the seafloor reflections arrive at the stabilized and towed hydrophone array.

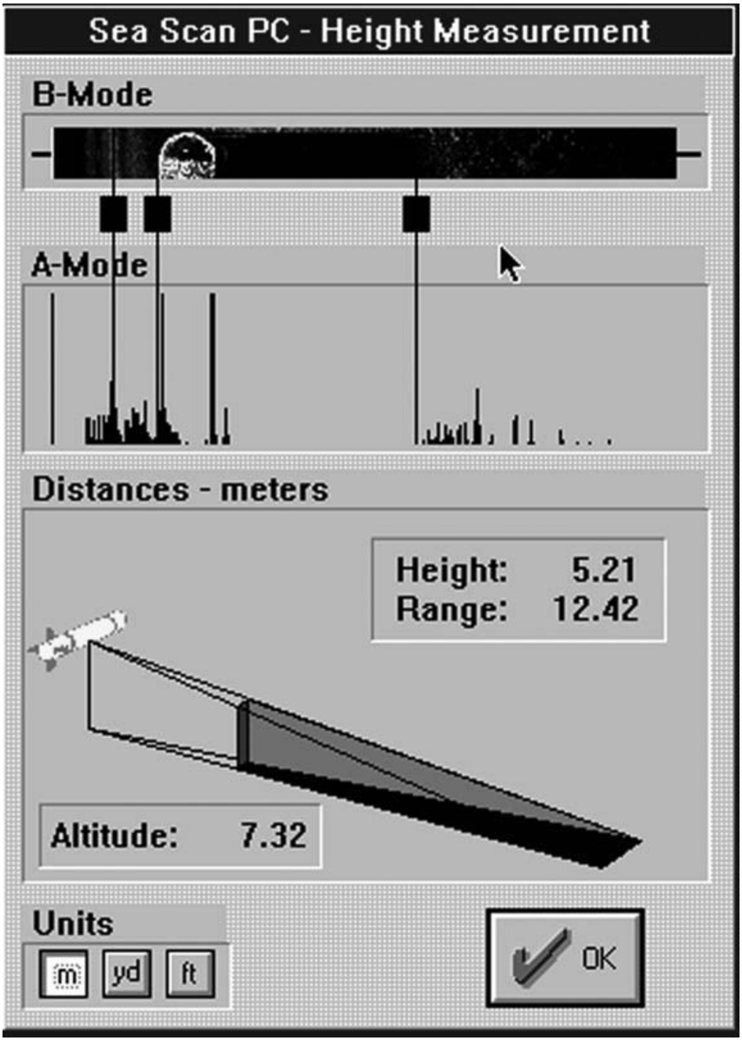
Figure 3.33 Multibeam image of a shipwreck in the Persian Gulf. Data collected by the RESON SeaBat Multibeam System. (Courtesy of RESON.)

these were less flexible in their use and the rolling of the vessel in anything except flat calm conditions usually made the system inoperable. The side scan transducer emits a fan-shaped pulse of sound which has a narrow beam width in the fore and aft direction and a wide beam width laterally. The fan-shaped beam lies in a plane at right angles to the track of the fish, and the center of the beam is directed slightly downward from the horizontal toward the maximum anticipated range. Nonlinear, time-variable amplification enhances the signals coming from distant objects and compensates for strong near-field signals. The unit records the intensity of the return of the time-variable signal. In the case of a towed fish, the trace displays three elements: the seabed; the water surface; and a shadow picture of the seabed (see Figure 3.34). Interpretation of the record is often quite complex, particularly because the output often shows the water surface and the seabed as single lines and the adjustment of gain to obtain the best bottom signal can be difficult.

In normal operation the side scan is best operated over a smooth sandy seabed. Usually the system is interfaced with a GPS, so that the image trace is created to scale. Thus in a search for the *Sapporo Maru* in Truk Lagoon,

Figure 3.34 Side scan sonar interface. This is the Marine Sonics side scan interface showing the standard display (a) with the size of object dialog box (showing length of wreck as 20.56 m) and magnetometer trace along the right-hand side of the screen. The height of a target display interface (b) and a close-up image of the barge (c) seen in (a). (Figures 3.34a and b are courtesy of Eric Danielsen, Inwood (International) Pty Ltd.)

the trace of suspected target could be compared with the known plans of the vessel and the site was identified without having to dive on it (see Figure 3.35). The overall length of the vessel measured on the sonar trace was one metre shorter than the known length and the superstructure features exactly matched. Where there are rocks, the signal from cultural remains—even quite large iron wrecks—can be obscured. In addition, different environments and different depths have unpredictable effects. Obviously the best possible conditions for operating side scan is flat calm. If there is any swell or wind-blown waves, the effect on the survey vessel can be transferred to the tow fish which moves with these effects and, as a result, disrupts the signal. Thus, at times, even very large sites can be missed due to these effects. Although it is important to maintain the depth of the fish at some reasonable distance from the seabed, in, for example, 100 m of water, it is usually not necessary to have the fish much more than 50 m down. In the case of the Sea Scan system, in a 300- or 500-m range provided the bottom is not undulating or rocky, an operation depth of about 30 m is quite



b

Figure 3.34 (*Continued*)

reasonable. Different sites present different situations, so that it is difficult to generalize.

The side scan sonar can be a highly sophisticated system with various models from the simple and cheap to the complex, sophisticated deep-water systems which are extremely expensive and weigh hundreds of kilograms. The early models displayed the sonar image on a paper recorder in which the scales were nonlinear. If the vessel sped up, because the paper rate

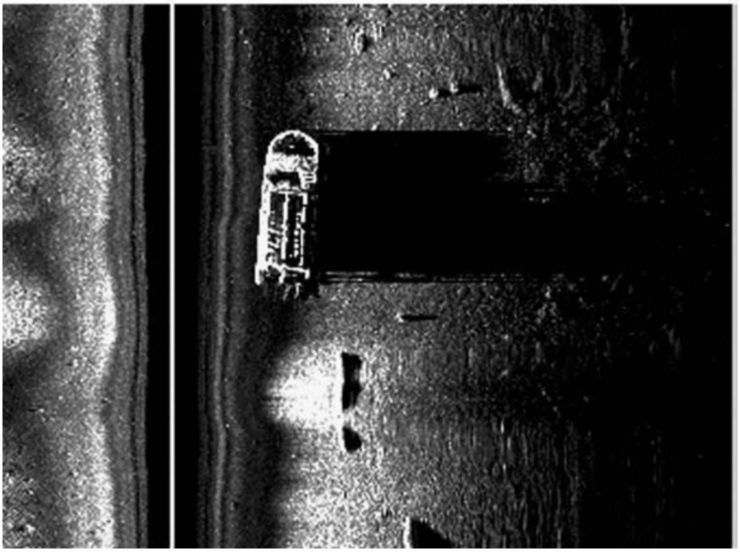


Figure 3.34 (*Continued*)

remained constant, the scale became smaller. In the horizontal direction, the scale varied with the distance from the transducer and the depth of water. The latest instruments, which have extremely sophisticated microprocessors, link the GPS data so that the output is displayed in proportional scale. Thus the traces are at a constant scale and can be joined together to form a mosaic (see the next section).

Additionally, if the tow fish has the capacity to record the depth from the fish to the bottom, then it is possible to rectify the horizontal distortion caused by the slope distance, and thus the horizontal scale can be made linear. The horizontal range (R) is calculated by simple trigonometry, because the horizontal distance on the display (D) is proportional to the slope distance or hypotenuse of a right-angled triangle formed by this distance and the height of the head above the seabed (H), thus

$$R^2 = D^2 - H^2$$

or

$$R = \sqrt{(D^2 - H^2)}$$

Similarly, the height of an object (h) above the seabed can be estimated by the length of the white shadow which represents the acoustic shadow. Using the same symbols as above, if the length of the acoustic shadow is

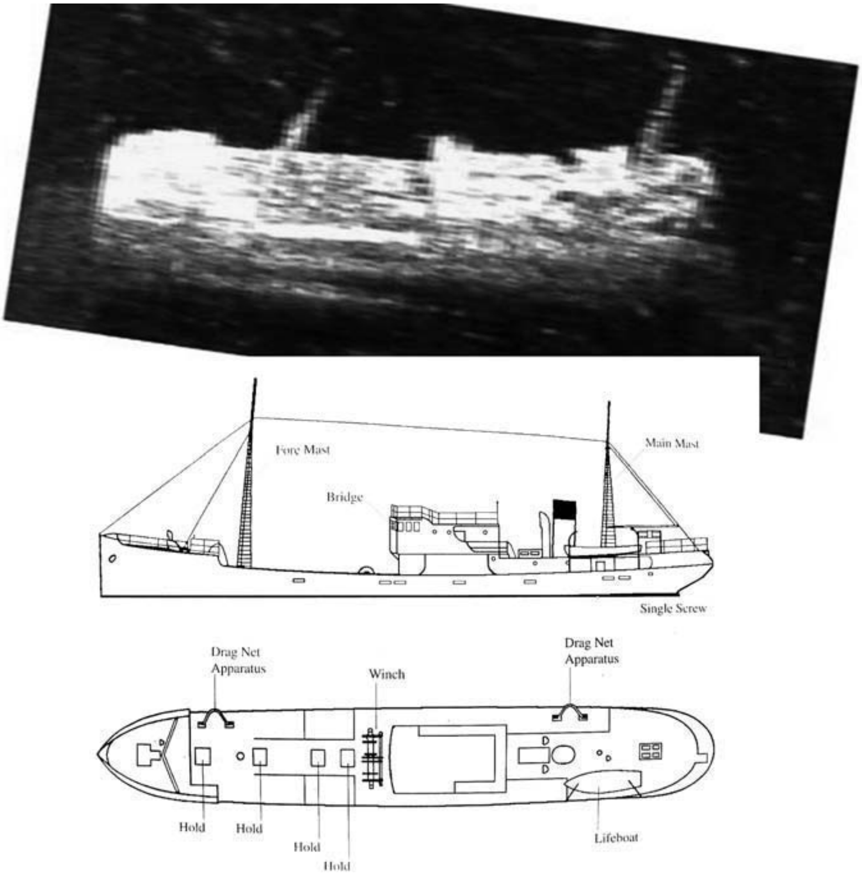


Figure 3.35 Side scan sonar trace *Sapporo Maru* at Chuuk Lagoon in the Federated States of Micronesia. This illustration shows the sonar trace set against the scaled plan of the ship. From the sonar record it was possible to positively identify the ship before diving on it.

(W) and the horizontal distance (D) is measured to the end of the white trace, then R can be calculated and the height is given by

$$h = \frac{HW}{\sqrt{(D^2 - H^2)}}$$

E. Sonar Mosaic

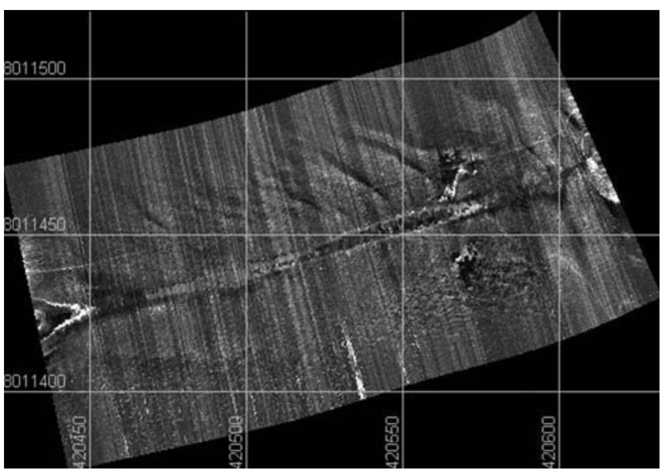
One of the most interesting developments with side scan sonar is the ability to georeference the sonar images. This means that because the side scan sonar is constantly monitoring position, the location of the source of the sonar image is known for each sonar "ping." Because the course is known, the azimuth or direction of each ping is known. As the range is also known, it is possible to approximately track the path of the sonar sweep. For each point on the graphic image of the seabed that is output from the side scan sonar, a precise location can be given. With complex software it is then possible to take the graphic image (usually a tiff or jpeg file) and georeference the image. Thus when the image is displayed it is shown in its correct orientation (see Figure 3.36a). One problem with side scan sonar images is that they usually display the water column and then the seabed. This means that precise georeferencing of the sonar image is not possible unless the geometry is taken into consideration. Thus, it is possible to obtain the precise location of an individual target using the Marine Sonic software as the GeoTIFF images are not totally accurate. One way around this is to use a post-processing software package that removes the water column and compensates for the acoustic pathway so that the GeoTIFF is a true representation of the seabed. There are a number of programs that do this of which Chesapeake Technology's SonarWeb is a good example (see Figure 3.36b).

Finally, these georeferenced images can be incorporated into a GIS to provide a sonar mosaic that can be then be overlayed on map and aerial photography (see Figure 3.37). The sonar mosaic is invaluable since one can examine wide expanses of seabed in gorrect geographical orientation (rather than one continuous trace without any real idea of relative orientation) and to ensure that the seabed is completly surveyed.

F. Sub-bottom Profiler

Sonar which penetrates below the seabed, in some instances, can reveal buried structures. More often, sub-bottom profiling sonar is used to examine geological and sedimentary formations, but at times the sub-bottom echo has indicated buried cultural objects (Frey, 1972). It is, however, questionable if this system has ever found a buried ship. During the *Amsterdam* survey (Marsden, 1974), a sub-bottom sonar survey indicated a high probability that there was a buried object at the site, but it is far from clear that this could have been determined if the site was not already known to have been there. Because the device was operated over a known site that had been previously buoyed, this was hardly a scientific test of the system. Although the trace certainly showed some unusual features in the area, these may have been geological. Likewise, with the *Mary Rose* sub-bottom survey, it is again doubtful that the acoustic return was actually responding

a



b

Figure 3.36 Side scan sonar target displayed as a GeoTIFF. Note the sonar trace in (a) is geographically coordinated by the processing software but does not allow for the removal of the water column (the dark center line). In this case positions on the GeoTIFF are not strictly correct (pseudo-georeferenced). In case (b) using SonarWeb, the processing has removed the water column thus allowing for slope correction. Any position on this GeoTIFF will be correctly georeferenced.

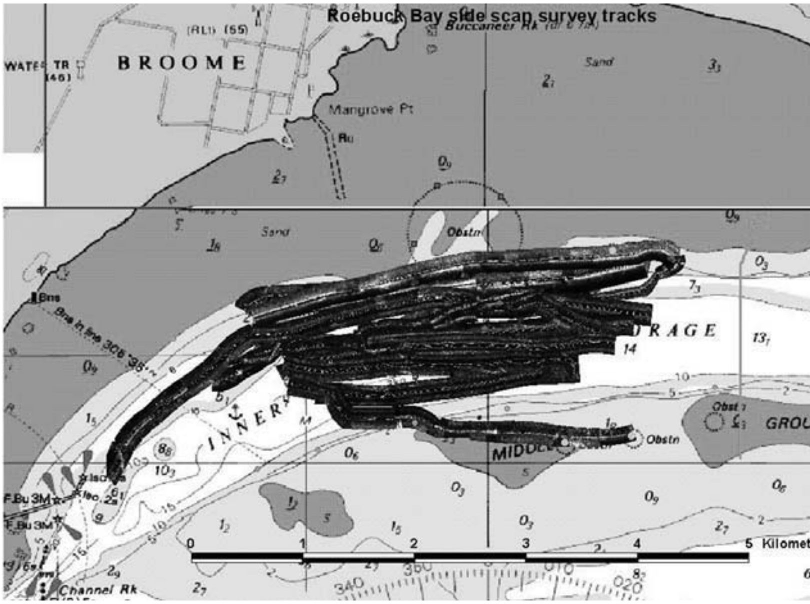


Figure 3.37 Side scan mosaic Roebuck Bay, Western Australia. The sonar mosaics have been created from converting sonar traces to GeoTIFFs and then placing them on the chart of the area.

to the buried shipwreck. The system clearly indicated the surface features of the mound and scour (McKee, 1973; Rule, 1982), but the W-feature, believed by McKee to be the ship, was later questioned by Rule. Other sites that claim to have evidence of sub-bottom features are the *Pandora* (Gesner, 1993i) and the survey at Takashima by Mozai where he was searching for the fleet lost during the Chinese invasions of Japan during the Yuan dynasty (Green, 1987b). As it is uncertain at present if a sonar signal will respond to buried wooden wreck material, the use of the sub-bottom profiler as an instrument for searching for wrecks must be questioned. It can only be recommended as a support for a survey or where the sonar target is likely to be extremely strong, such as in the case of an iron ship.

VII. OTHER METHODS

A. Local Knowledge

Finally, there is the age-old method of using local knowledge. There are a number of different groups of people who may have information about the location of shipwrecks and these include: the navy; sports divers; people involved in the fishing industry including line fishing, sponge diving, pearl diving, and bottom trawling; and professional divers. The navy keeps records of wrecks for defense purposes, because it is possible for a submarine to hide within the magnetic anomaly caused by a wreck or its acoustic "shadow." Naturally, this information is usually restricted, although naval Orion aircraft with sensitive magnetic location equipment have been used in searches in Australia for the *Pandora*, the *Koombana*, and HMAS *Sydney*. However, in most cases defense organizations are reluctant to provide detailed information of targets. Sports divers are a source of information about shipwrecks; but unless there is good cooperation between the archaeologists and the divers, this information is difficult to obtain (see Chapter 14). Possibly the most likely source of information about shipwrecks will come from people involved in the fishing industry. Small fish congregate around wrecks which provide food and shelter. Larger fish are predators on these fish and thus line fishing is profitable in the vicinity of a wreck (see Section V.A.4). In places where there are large areas of flat featureless seabed, line fishermen have somehow discovered wreck sites. In the Gulf of Thailand, near the islands of Ko Si Chang, three wreck sites are known in an area of about 25 square miles (Green and Harper, 1983, 1987; Green *et al.*, 1986, 1987). How these sites were first discovered is not known, but they exist up to six nautical miles from an almost featureless shoreline in depths of up to 35 m and, at most, cover an area of 60 × 30 m. This instance of local knowledge illustrates that fishermen can be exceedingly good navigators as the ability to relocate by eye such a tiny point at such an extreme distance is quite remarkable. It also implies that the fishing must have been carried out for a very long time and one must presume that the site was found by chance. It is possible that these sites were first discovered by the trawlers that operate in this area, however, the line fishermen deny this and this is confirmed by the trawler operators. Because trawlers drag their nets across the seabed for many hours, if shipwreck remains are recovered in the nets, the time that the net collected the material and thus the location cannot easily be determined. It is remotely possible that the site was recorded at the time of the shipwreck loss and the knowledge of the site has been maintained by word of mouth.

Similar situations exist elsewhere in the world and, through careful negotiation with the fishing community, it is often possible to obtain information about wreck site locations. In Turkey sponge divers are a very useful source of shipwreck information. In particular, Bass (1974) has used information from sponge divers to locate wreck sites and this work has been extremely rewarding.

A great deal of consideration should be exercised when working with fishermen to ensure their cooperation for yourself or others in the future. The presence of divers on the site will disturb the fish and if excavation is undertaken on the wreck site it will destroy the fish habitat and thus remove the fishermen's livelihood. Similarly, by reporting a site a fisherman may end up with loss of income, either from recovering material or from fishing. One simple solution, if excavation is undertaken, to ensure goodwill is to replace the wreck site at the end of the operation with some form of artificial reef, for example, made of car tires. Then the fish will still be there and the fishing community may then be willing to reveal other sites.

Chapter 4

Conventional Survey

I. OBJECTIVES OF PREDISTURBANCE SURVEY

This chapter deals with the methods and techniques of survey that can be used after a site has been located. Subsurface survey is discussed in Chapter 5, photographic methods will be discussed in Chapter 6, and the presentation of the results in Chapter 15. This chapter deals with the principles of preliminary or predisturbance survey and the standard methods for measuring and recording sites. This work may have a number of different purposes: as part of a cultural resource management plan; as a site survey for archaeological recording purposes; as a predisturbance survey prior to excavation, preceding some form of archaeological sampling; or as a predisturbance survey prior to an exploratory test excavation. The type of survey possible will depend on the site conditions. For example, if the site lies in an area where there are very rough or turbulent conditions or where there is poor visibility, then only a very simple survey may be possible. Conversely, if the site is in clear, shallow waters, a much more detailed survey could be considered. Apprised of the particular environmental conditions prevailing on the site, the archaeologist or the surveyor will have to decide what type of survey is required to provide the necessary information. In many cases the type of survey methods used will depend on the local conditions, and where there is good visibility, almost certainly, photographic methods may well be best.

A good recording system is required to ensure that measurements taken are reliable and well recorded. Transcription errors can occur both under water when the operator notes the reading and, subsequently, when the field data are recorded on land prior to processing. It is worth printing up recording sheets, once the survey system is established, to help the underwater recording. It is also worth considering voice communications, so that these data can be transferred directly to the surface and, in the ideal situation, processed on the spot. This ensures the readings are correct and helps to make a good fix. With programs such as Site Surveyor (see Section VI.D), it would not be difficult to set the system up so that the measurements were transferred directly to the surface computer operator. The operator then enters these data directly into the program and confirms the fix. This could greatly increase the efficiency of the system. In situations where it is difficult and time-consuming to return to the site and re-measure an object, or where an artifact cannot be removed until its coordinates have been confirmed, it will be necessary to make at least five or more independent measurements. This ensures that if one measurement is wrong there is enough redundancy to still obtain a result. By having voice communication only four measurements will normally be necessary, and if one measurement is wrong the program will identify the measurement so it can easily be re-checked.

A. Basic Survey

The objective of a basic, or first-order, survey is to record the site as it exists. This includes all the topographical information and any other useful data that can be collected quickly, efficiently, and at a relatively low level of accuracy. With this information subsequent, more detailed survey work can be planned. Therefore, the first priority of the basic survey is to determine the approximate extent of the perimeter of the site and to fill in other approximate details. With this information a strategy can be developed to record the more complex and detailed information that will become the main predisturbance plan. Information about dimensions, depths, and physical features together with the potential problems and difficulties of working on the site provide essential information for planning the subsequent survey work.

Although sites vary in extent and complexity, the principle of working systematically rarely fails. There are obviously a lot of different ways that this first-order survey information can be obtained. For example, one method would be to select a point somewhere on the site (even if this is not the center) and, working in a systematic manner, measure from that point to the extremity of the site in the four orthogonal directions. The cardinal points are the easiest to use, because one can use a wrist compass to determine direction and a tape measure fixed at a convenient origin to measure the distance. By swimming survey lines in N, S, E, and W directions, the extent of the site can be deduced quite simply. The results, plotted on a sketch map of the site, should give a fair idea of its approximate extent and dimensions. It may then be worthwhile to run the NE, SE, SW, and NW directions to fill in more information. There are, naturally, many other ways to determine the perimeter of the site depending on its nature. It will be important to make a careful assessment of how best to do this given the conditions. For example, it may be possible to swim around the perimeter of a site measuring distance and bearing, or to measure from one side of the site to the other directly. The system chosen will depend on the local conditions, but the objective is to establish the approximate area of the site. It should be remembered that the area initially investigated may not, in fact, be the main part of the site, and that there might be other areas of comparable significance some distance away.

Various alternative approaches to deal with this present themselves. One option is to carry out an extensive survey of the general area. Another option is to concentrate on the main area with limited exploration in the neighborhood. A person could concentrate on a local survey, while carrying out a limited survey over a wider area with a small team. Whatever happens, work should always proceed systematically. The priorities will depend on the circumstances. Logical and simple solutions are of the essence; one is not trying to produce a plan of the site, simply an overview with some basic dimensions.

It is very useful to establish a baseline across the center of the site, preferably along the long axis of the site (if there is one), as it can serve as a datum for further survey work and operate as an important orientation aid for the surveyors and others working on the site. It is best to use the baseline for rough or initial survey work as the points on it are not precise enough to serve as accurate survey stations. The ends of the baseline can act as permanent reference points and should be fixed and marked so that even if the site survey is abandoned, the baseline can be relocated. It will also be necessary, if the baseline is long, to pin it or attach it in some way to the bottom, thus preventing bowing and reducing the effects of currents.

It is advisable to use a tape measure or a marked line. A number of two-dimensional survey options exist to develop and refine this first-order survey. These are discussed next. The choice of method will be subject to the nature of the site and the preferences of the surveyor.

It is suggested that proper underwater writing slates are constructed with removable sheets that can be stored in a file (see Chapter 9). After each dive the record sheets with the date, diver, and time logged on it, together with the survey data, can be removed from the slate and stored in a ringed binder. All measurements should be made using the same conventions and with tape measures corresponding to these units. It is usually best to work in ISO units of millimeters, meters, and kilometers. Thus all site recordings should be in 000.000 units (i.e., meters and millimeters). For obvious reasons, the tape measures should be chosen with millimeter graduations. A survey book should also be kept so that all data can be recorded from the sheets as soon as possible after the measurements are taken, or, alternatively, these data stored on a computer. Again, documentation is of the essence in all underwater archaeological work. It is very easy to lose data simply because it is not properly documented. Although a diver's writing slate is a very useful tool, unless the data are regularly and systematically transferred to some other system, they will inevitably get lost. With the diving slate, these important data can be recorded on the removable sheets and the reverse side used for a scribble pad where nonessential communication between divers can be written down and later erased. The use of Mylar or some form of semimatte plastic drawing film is strongly recommended, particularly film that can be used in a photocopier or printer, where prepared or predrawn plans can be produced either for the project, individual dive, or project.

In many cases there will be only vague traces of the site visible on the seabed during a predisturbance survey, thus the initial survey may be relatively cursory. However, it may be possible to extend a survey below the surface of the seabed using a simple probe or more complex remote sensing techniques, thus obtaining additional information about the extent of the buried remains. These issues are discussed in the next section. In the case of a site that is highly complex but confined to a single area, photography will usually be the most effective method to record the site, provided there is good visibility. Again this is discussed in Chapter 6.

In other circumstances, where a site is comprised of a number of discrete areas of interest separated by considerable distances (i.e., separated by distances that are several diameters from the area of interest), it would be wasteful to produce a photomosaic or a detailed survey of large areas of nothing. Therefore, it is important to record the areas of interest in detail and relate these areas to each other. A good example of such a site would be an anchor graveyard. The areas between the anchors are of no particular interest, except perhaps for the broad topographical features. The anchors have to be recorded in detail and their orientation with each other determined. This type of site requires that a broad area survey be carried out to define the areas of interest, and additionally some point on each individual area of interest needs to be defined.

II. TWO-DIMENSIONAL SURVEYING TECHNIQUES

Because most site surveys are largely two-dimensional, the more complex techniques of three-dimensional surveys will be described separately, however, the principles are essentially the same. Most, but not all sites, have a small vertical elevation compared with the horizontal components. Therefore, in many cases where the vertical elevation is less than 5 to 10% of the horizontal elevation, ignoring the vertical components will have very little effect on the survey. For example, the difference between the "true" horizontal measurement of 10 m where the relative vertical height between the two points is 0.1 m is 9.95 m. If this was 100-m with a 1-m vertical height the distance would be 99.995 m, a mere 5 mm difference. If this is all that is involved, measuring vertical components could be irrelevant. Obviously, this needs to be treated with caution, and the survey system needs to take into account the fact that the vertical component is being ignored. It should also be remembered that all measurements will have errors, both due to mistakes in recording measurements and in the accuracy of the measurement itself.

A. Distance-Angle or Radial Survey

To use a single tape measure and measure the bearing or angle of the object to a fixed reference point is an example of a simple survey system. This technique works best in clear water where the point to be measured can be seen. If one cannot see the end of the tape, a bearing along the tape can be utilized, but one needs to ensure that the tape is not snagged on an obstruction.

This system can be worked with one or two operators. With one operator, the zero end of the tape is fixed to a central reference point. The operator then swims to the first point, making sure that the tape is kept well above the seabed ensuring that it does not snag the bottom. At the point to be measured, the distance and bearing to the reference point is recorded. If it is not possible to see all the tape because of poor visibility, then it will be necessary to swim along the tape to check for snags. With the two-operator system, the mobile operator takes the zero end of the tape and places it on the position to be measured. The other operator, who is at the reference point, records the angle and bearing on a pre-prepared list on the record sheet, while the mobile operator with a similar list makes notes of the features being recorded. This is easier to manage than the reference operator having the zero end of the tape and the mobile operator the tape reel and recording the distance, because it is almost inevitable that the two operators will, at some point, get out of sequence in their readings. It will then be difficult, if not impossible, to reconstruct these data. The two-operator system has the advantage that it is easier to keep the tape free from snags and it is faster.

When using this system, it is important to note the difference between a back or reciprocal bearing and a forward bearing. If a surveyor takes a tape with the zero attached to a datum point and swims in a northerly direction, then, turning around, sights back along the tape, this will give a back or reciprocal bearing or southerly reading. Alternatively, if the compass is used to sight in the direction of travel, then this is a true bearing (from the reference point to the object) and will be north. Thus great care is needed in recording what type of bearings are being used.

Underwater angle-measuring devices, by nature, are of simple construction. They unfortunately suffer from inherent accuracy limitations, particularly because it is not possible to incorporate an optical telescope into an underwater angle-measuring device to give the equivalent of the highly accurate terrestrial theodolite. Most underwater angle-measuring devices have accuracies of around ±0.5°. There is a limitation, though. For example, if one had an error of 1° in the measurement, then at 10 m from the measuring point the error in position will be 175 mm, and this error will increase in proportion to the distance from the measurement point.

The magnetic compass is one of the most simple underwater angle-measuring devices, but because it has an accuracy of about ±5°, it has only very limited application. Also, magnetic compasses are affected by iron objects, thus making it quite unsuitable for survey work on ships that have large amounts of iron on them. The compass is ideal for broad survey work such as defining the extent of the site or in the general preliminary survey work, but it is not useful for detailed work.

An alternative solution, if an angle-measuring device is required, is to enlarge a 360° protractor to a diameter of about 0.5 to 1 m, which can then, because of the enlarged scale, measure angles at greater accuracy (Figure 4.1). A simple way to do this is either to photograph a good quality plastic 360° protractor using lithographic film, or to place it on a sheet of photographic lithographic film and expose it to light to produce a contact negative. When developed, the negative can be used to print a large-size positive on resin-coated paper. The resultant print of the protractor can then be trimmed and mounted on circular plastic or a metal sheet, making an ideal underwater angle-measuring device. The protractor, mounted horizontally on a reference stake, can be used to take direct bearing measurements, but care is needed to ensure that the protractor does not rotate on the mounting and that the mounting is rigid. The tape measure can be attached to the center of the protractor with a short length of wire so that the wire can be

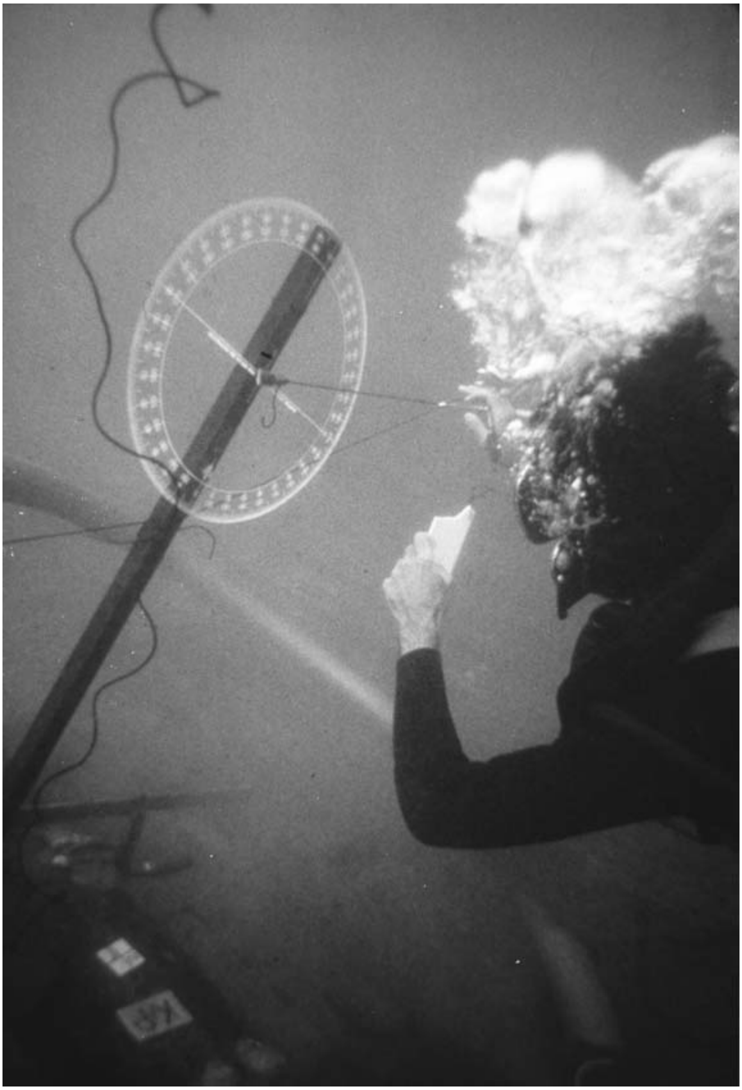


Figure 4.1 Distance-angle measuring system. Circular protractor mounted on the keelson of the *Santo Antonio de Tanna*, a Portuguese wreck in Mombasa, Kenya. The protractor and tape measure were used to plot the curvature of the hull.

used to take the readings on the protractor thus giving a greater degree of accuracy. The bearing is taken by noting the angle that the wire makes with the outside of the protractor.

Alternatively, an alidade, consisting of a simple ruler rotating about the center point of the protractor with sighting pins or a tube with cross wires at either end, can be used to sight independently in the direction of the tape. It is also possible to use a nonoptical, underwater theodolite, which is basically the same as the sighting tape alidade, except that it measures both vertical and horizontal angles. This will be discussed in Section III.

B. Right Angle Survey

An alternative and potentially more accurate option to a circular protractor is a rigid T-shaped angle-measuring instrument. The angle is determined by taking a reading on a tape mounted on the cross-part of the T. Because the distance from the origin (at the bottom of the cross) is fixed, the offset along the T gives the tangent of the angle (Figure 4.2). This instrument can give a greater accuracy than the protractor, because it is easier to construct on a large scale. It also has the advantage that it can be constructed very quickly and simply in the field. Other systems include the hydrolite. See Lundin (1973) and Cederlund (1977) for a description of this system.

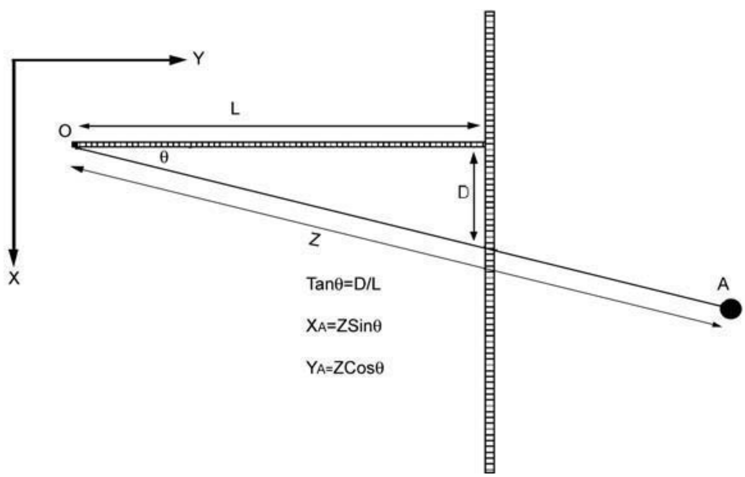


Figure 4.2 T-shaped angle-measuring device. This is more accurate than the protractor. In this case the angle is determined from the arctan ratio of D/L.

It should be noted that the distance-bearing system has a constant error function, i.e., the position error is a function of angle and distance and although it increases linearly with distance, the angle error is constant irrespective of the angle, unlike trilateration which depends on placement of the control and the strength of the fix. Thus the distance-bearing system can be a very attractive system, because there is no need to take into consideration factors relating to placement of survey points and accuracy or strength of fix. The survey point may be placed in the center of the site or off the site, depending on the situation. When working close to the survey point, if the sighting device stands above the seabed, care must be exercised to ensure that the slope angle of the tape measure to the horizontal is not greater than a few degrees; otherwise offset errors will occur.

C. Rectangular Measuring Systems Offset Survey

A simple form of a rectangular measuring system is the offset survey, where offset distances are measured from a baseline (Figure 4.3). The system requires some method of defining a right angle, usually a rigid right angle cross. This can easily be made out of square, mild steel tubing about

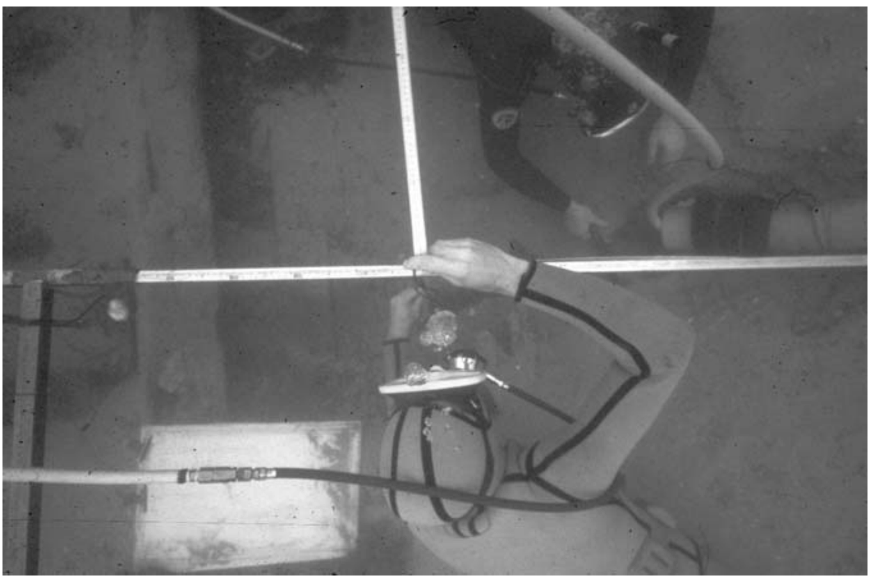


Figure 4.3 Offset recording. Diver is using a tape measure to measure the offset from the baseline running horizontally across the photograph. (Courtesy of Catherina Ingleman-Sundberg, Department of Maritime Archaeology, Western Australian Maritime Museum.)

2 m long with a sighting pin at each end of the cross. As with most of this type of work, good visibility is essential. The rigid square is placed on the baseline so that one of the arms of the cross is parallel to the baseline; the arms at right angles give the direction of the offset on either side of the line. In this simple form, it is a reasonably accurate and efficient system with good visibility. Alternative systems include a right-angled triangle and an optical square. In the first case this is a simple variant of the square; in the latter case, an optical square is a complex system which is, again, only useful where there is clear visibility. In general, the usefulness of such systems relies on two issues: first, the ability of the surveyor to project the line or sighting beyond the local range of visibility, and; second, the accuracy and ease of use of the visual system.

The construction of a hand-held instrument on the lines of a terrestrial optical square requires a mirror mounted at 45° to the axis of the direct sighting and two pins on a bar with a 45° mirror in between. By aligning the two pins along a baseline, the visual position at the right angle to a point at which the instrument is located can be sighted. In this situation, a second assistant can move a marker around until the operator has determined that the baseline and the marker are in coincidence, and thus at right angles. This type of system is also very useful for setting up a rectangular grid on a site.

D. Trilateration

Trilateration is, in theory, one of the simplest two-dimensional survey techniques, however at times it can be complicated (Figure 4.4). A single point can be uniquely determined relative to two fixed reference points if, first, the distance between the two reference points is known, and secondly, the distances from these two reference points to an unknown point can be measured (Figure 4.5). This represents the textbook situation where three sides of a triangle are known and, as a result, the triangle is uniquely defined.

In practice, two fixed semipermanent markers or survey points are set up on the site, possibly on the baseline. In some cases, several different survey points have to be selected because of the size of the site. These must be rigid and permanent reference points that can be easily identified with some sort of tag. On a sandy or muddy site, the points can be a series of stakes driven deeply into the seabed so that they are rigid. In rocky conditions, pitons or steel pins with a ring can be driven into the rock. The survey may be extended from one area to the next by selecting a new reference point and utilizing one point from the last survey with the new point.

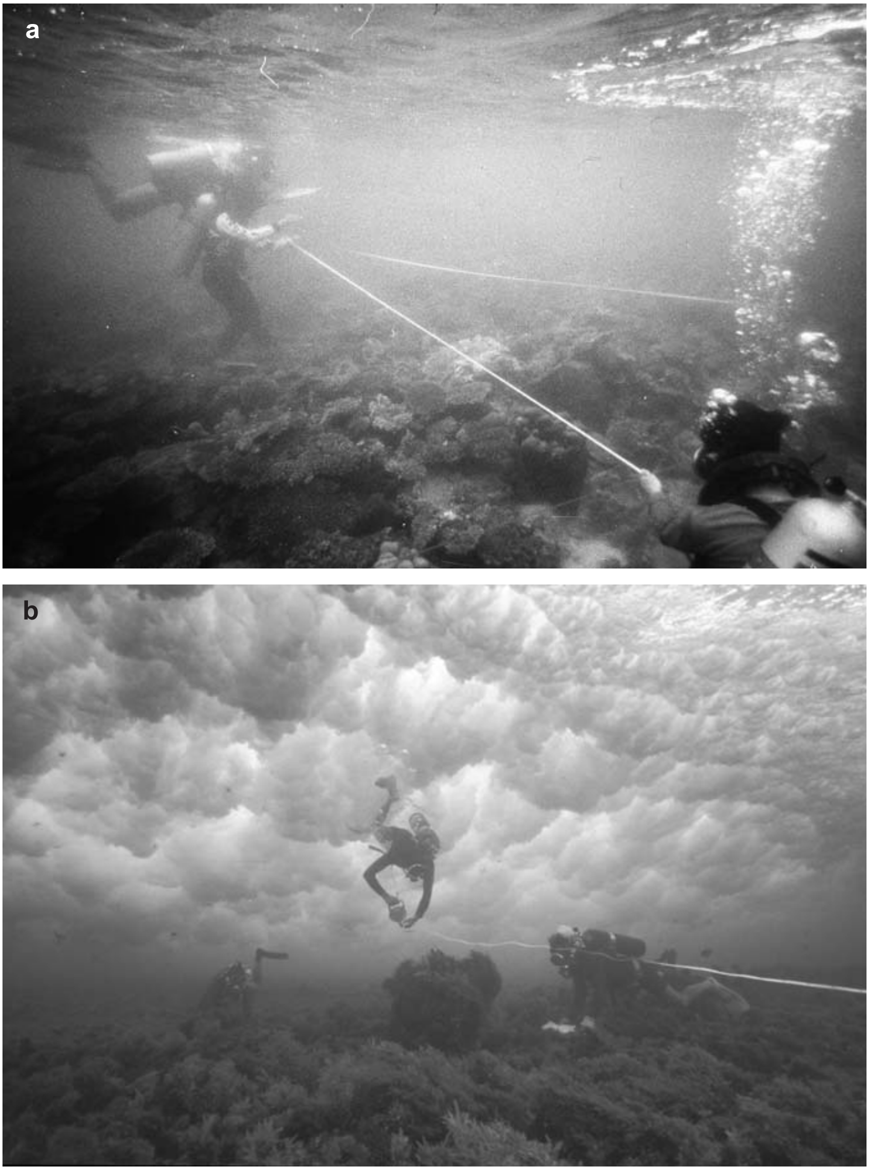


Figure 4.4 (a) Underwater trilateration on a shallow water wreck site in Thailand. (b) Attempting to measure in heavy surf conditions on the *Zeewijk* site in Western Australia. (Courtesy of Hugh Edwards.)

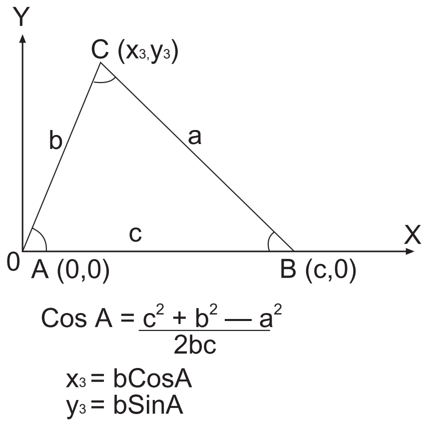


Figure 4.5 Diagram showing how to solve trilateration. Point C, with coordinates x_3, y_3, can be located if distances a, b, and c are known.

The zero end of the measuring tapes are looped over the stakes and a measurement should first be made of the distance between the two stakes. Points on the site can then be trilaterated by measuring the two distances from the stakes to the object concerned. Care is needed to ensure that the measurements are related to their respective stakes. The position can thus be uniquely defined, provided it is noted on which side of the baseline the object lies. It should be remembered that there are two solutions to a two-tape trilateration; one is the mirror image of the other on the opposite side of the baseline. It is worth considering setting up the trilateration reference points off the site so that the area of best fix is on one side of this line and contains the site. The accuracy will be poor in the area close to the baseline where the angle of intersection of the arcs are fine, and where a small error in measurement makes a large error in distance. The surveyor will need to consider what are the best conditions so that the arcs intersect almost at right angles (see Chapter 3, Section II.C).

Before plotting the results of a survey, the reference points must be accurately plotted on the survey sheet. It is of utmost importance to ensure that the location of all reference points has been surveyed as exactly as possible.

The easiest way to plot these data is by using drafting compasses. The compasses are set on the reference point from which the measurement was obtained, and an arc is described with a radius proportional to the measured distance. The compasses are then placed on the second reference point, again the radius is set proportional to the measurement and a second arc described. The intersection of the arcs gives the position (provided it is on the correct side of the baseline and not the mirror image). The main criticism of this method of plotting is that it produces a mass of unsightly arc intersections on the plan, and on large-scale plans the distances involved may be beyond the length of conventional beam compasses. A more efficient means is a programmable hand-held calculator or a small computer to convert the trilateration data to rectangular coordinates. The program requires that the X and Y coordinates of the two reference points be known. With this information, it is possible to link the survey with the grid or coordinate system of the whole site. If this is not required, the X and Y coordinates of the two points A and B (Figure 4.5) will be A = (0,0) and B = (c,0) with c being the measured distance between the two points. Take the complex case of A = Xa,Ya, B = Xb,Yb, and C is the point at which the X, Y coordinates are required (Xp,Yp).

Then if AC = b, BC = a, and AB = c.

Assuming first that A = (0,0) and B = (c,0) then:

$$\cos A = \left(\frac{c^2 + b^2 - a^2}{2bc}\right)$$

X_3 = b cosA and Y_3 = b sinA.

Now rotate and translate the coordinate system so that

B = Xb,Yb and A = Xa,Ya.

The angle of rotation β is given by

$$\mathrm{Tan}\beta = \left(\frac{X_b - X_a}{Y_b - Y_a}\right)$$

and coordinates of C are $Xc = X_3\cos\beta + Y_3\sin\beta$ and $Yc = Y_3\cos\beta - X_3\sin\beta$ (see Figure 4.6).

These equations can be set up quite simply in a programmable calculator or a computer such that the entry of X_3 and Y_3 will give the values Xc and Yc. This method of plotting is much faster and more reliable than the double arc system. These data can be presented on printout paper so that with suitable programming, one can obtain a listing of the measured distances and the coordinates. Alternatively, with a computer, these data can be imported into a plotting program and the results accurately scaled and plotted onto paper.

The two-tape system has some inherent problems that need to be considered. Because only two distances are measured, there can be only one solution (ignoring the trivial mirror image solution). In the case of one of the measurements being wrongly recorded or some inaccuracy in the mea-

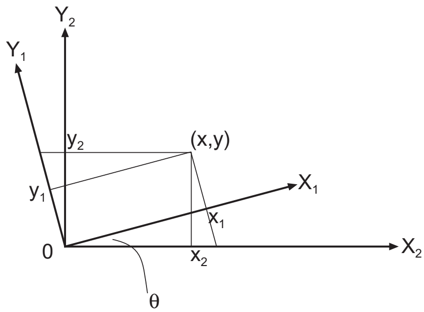


Figure 4.6 Coordinate rotation showing how a coordinate system X_2, Y_2 is rotated to coordinate system X_1, Y_1.

surement, although the calculated position will be incorrect, the surveyor will have no obvious indication of this other than that the plotted position may seem rather unusual. In order to overcome this, three reference points and three tapes are often used. Thus if there is an error, when the arcs are drawn it will show up because the three arcs will not intersect. This is known, because of its shape, as a cocked hat. The larger the cocked hat, the larger the error. This system has a great advantage over the two-tape system because it tells the surveyor when there is an error. It does not, however, indicate which measurement is at fault, so all that can be done is to discard the measurement or treat it with caution. The three-tape technique is more difficult to use under water with the added confusion of yet another tape, but it is worth considering on shallow water sites where there is more time available. As will be discussed in the next section, three-tape trilateration is unsuitable for recording the third dimension, if this is small in relation to the distances measured. Three-tape trilateration can only be used if one of the reference points is elevated in the Z-axis, or if the component of Z is comparable with the other two axes. In other words, it cannot be used to measure small height differences.

III. THREE-DIMENSIONAL SURVEY TECHNIQUES

A. General

On some sites, where there is an extensive vertical component in the topography, some form of three-dimensional measurement is required. This occurs because the object being surveyed is required in three dimensions, or that the site is irregular and the measurements need to be reduced to a common datum plane. There are various ways of surveying in three dimensions. One simple way is to measure the vertical component in combination with a horizontal survey, and reduce all the slope measurements to a common datum plane by applying Pythagoras' theorem to the right-angled triangle formed by the slope distance and the height. Other approaches use three-dimensional spatial geometric measurements to calculate the coordinates.

Trilateration can be used to survey in three dimensions under water, however, it requires at least three reference points, usually two ground points and one elevated point, and can be extremely complex. Therefore, it is worth considering if the simpler approach of a two-dimension survey is justified. The accuracy of the vertical component is related to the elevation of the vertical reference point. Whereas ground reference points are typically 2–5 m apart, a vertical reference point is unlikely, except in special circumstances, to be greater than 1–2 m above the ground level. This is because it is difficult to construct a stable reference much higher than this. As a result, the level of accuracy in the vertical plane will usually be considerably lower than that in the horizontal plane.

Although the degree of vertical accuracy may be acceptable, it should be noted that, because the coordinates are interrelated, this can also affect the horizontal accuracy. For example, take a simple, poor fix situation where the intersection lies about 1° from the straight line joining the two survey stations. If the distances are 1000 units, then the fix will be offset by about 17 units. If the measured distances are 1001 units, then the distance will be offset 48 units. Compare this with a situation where the angle of intersection is about 20° and is thus a strong fix. In this case an increase from 1000–1001 makes a difference of 342–345 offset (Figure 4.7).

Obviously, when working within a three-dimensional structure like substantial ship remains, there will be considerable vertical structural components. These will provide opportunities to establish rigid survey points so this will not be a problem. In this situation, the only problems may be in selecting appropriate points that will allow uninterrupted access, with the tapes, to the interior of the structure.

B. Three-Dimensional Rectangular Coordinate Survey

An extremely simple and effective technique for surveying a site in three dimensions was used on the excavation of the *James Matthews* (Baker and Henderson, 1979; Henderson, 1976, 1977b; Figure 4.8). A rigid three-

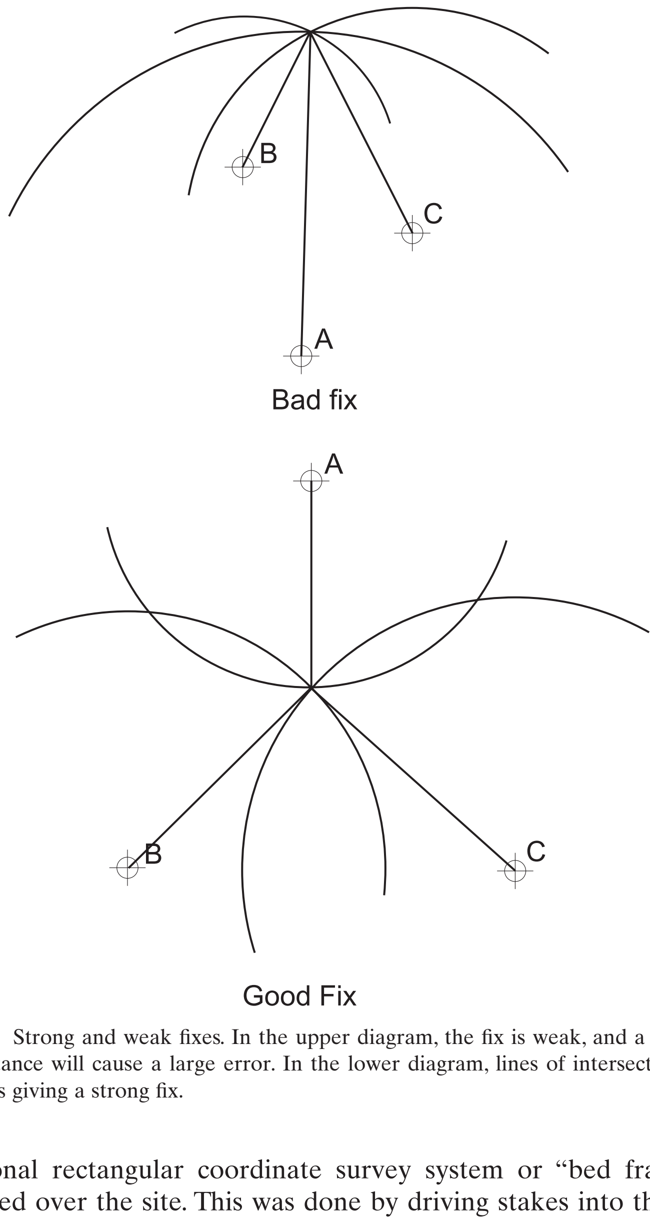


Figure 4.7 Strong and weak fixes. In the upper diagram, the fix is weak, and a small variation in distance will cause a large error. In the lower diagram, lines of intersection cross at right angles giving a strong fix.

dimensional rectangular coordinate survey system or "bed frame" was established over the site. This was done by driving stakes into the ground at 1-m intervals along the baseline. Between a pair of these stakes, a bar was set up and leveled with a spirit level. A pair of bars was then mounted extending horizontally and at right angles to the baseline 6 m across the site to a second pair of stakes. Using a carpenter's level the framework was

Figure 4.8 Recording system used on the *James Matthews* wreck site, often known as a "bed frame". Measurements were taken from the leveled frame in X, Y, and Z directions to give the coordinates of a point.

accurately leveled so that it formed a horizontal datum 6 × 1 m. On this frame, resembling a bed frame, a sliding H-shape was placed so that the vertical arms of the H could move along the 6-m bars, and the cross of the H ran between the 6-m bars across the site. From this bar, a plumb-bob was dropped to particular points on the site that were to be measured. The vertical distance from the reference plane to the point to be measured gave the vertical or Z coordinate; the distance across the H-bar gave the second, longitudinal or X coordinate (to this had to be added the position of the bar from the start of the survey, because, as the excavation proceeded, the bars were moved along the site and leveled). The distance from the baseline to the H-bar gave the lateral, or Y coordinate. Thus, as the bed frames could be extended and leveled across the site, it was possible to effectively create an artificial reference plane across the whole of the site. Tape measures were attached to the arms of the H and to the bed frame so that the X and Y coordinates could be easily read.

A sketch plan was made of each 6 × 1 m grid frame and the positions of points of interest noted on the plan and numbered. These numbers were then listed, and the recorder made the three-dimensional measurements of the several hundred coordinates in the frame level (Figure 4.9). The drawback with this technique is that it is extremely time-consuming and only suitable for calm, shallow water sites. It is, however, a highly effective method of accurately recording a site and it can be complemented with photographic recording. This is helpful for adding additional details.

C. Angular Measurement

The distance-bearing system of measurement can easily be modified for three-dimensional work in clear water. An underwater theodolite is not a particularly difficult instrument to construct. It is based on the land theodolite with simplified optics (Figure 4.10). This system, mounted on a solid tripod, consists of three parts. The first part is a table or platen that can be leveled with three adjustable leveling screws. Two small bubble levels are mounted on the platen, one between two of the leveling screws, the other at right angles to this (in the same way as an ordinary terrestrial optical theodolite). Leveling proceeds first by removing the tilt between the two screws that have the bubble level between them. Then the other component of tilt is removed by adjusting the third screw. Provided the first pair of screws are adjusted by an equal and opposite number of turns, the leveling will proceed quickly and a final round of fine adjustments removes the remaining tilt. Thus, the platen is level.

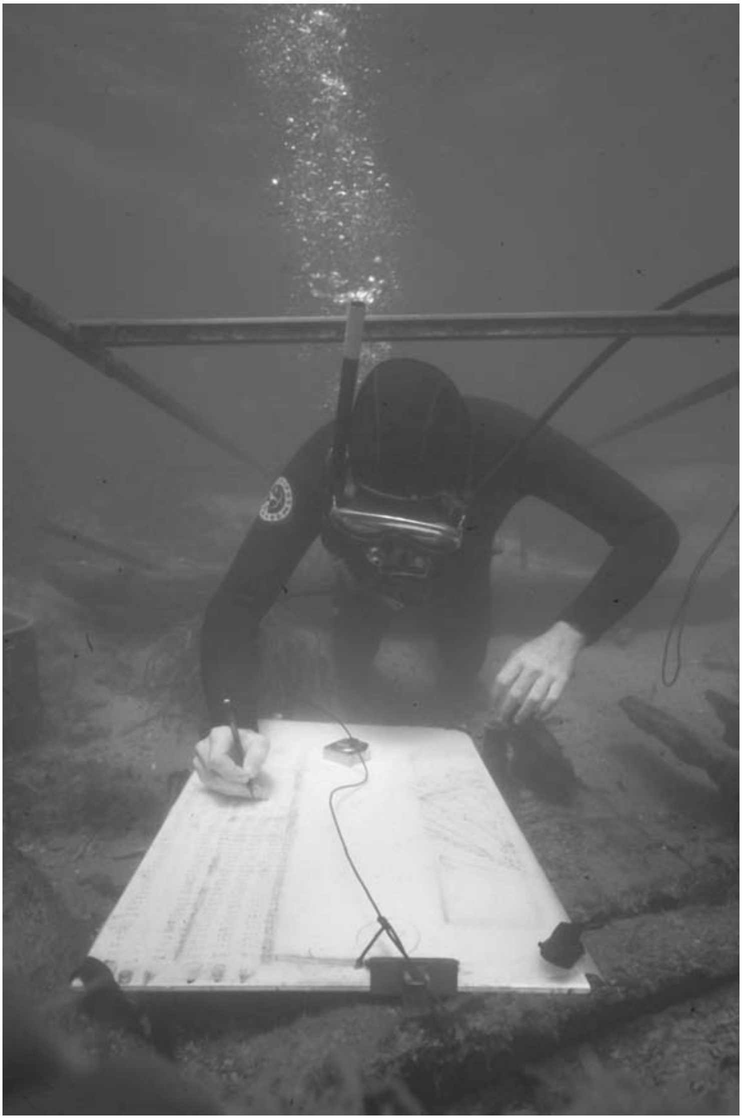


Figure 4.9 Diver entering measurements on the record sheet on the *James Matthews* survey. Survey sheets were prepared before each operation to assist in recording. (Courtesy of Catherina Ingleman-Sundberg, Department of Maritime Archaeology, Western Australian Maritime Museum.)

In the center of the platen is a pivot on which a circular protractor turns. This is the second part, the horizontal circle onto which a holder is mounted. Onto this is mounted the third part, which consists of a sighting tube with cross wires at each end attached to a vertical protractor. The center of the axis of the sighting tube and vertical protractor are arranged to lie vertically above the center of axis of the horizontal circle. After leveling the platen, the operator sights the object under investigation through the sighting tube, aligning the cross wires exactly on the object, and the horizontal and vertical angles are then read. The bearings taken from the horizontal circle may be made relative to a fixed point by taking a bearing from a reference point, thus any subsequent survey from this measuring station can be correlated to this fixed point.

The tripod or stand carrying the theodolite has to be heavy and solid so that it will not be easily dislodged. The theodolite should be carefully calibrated, in air, to ensure that there are no systematic errors in the readings of the protractors; in particular, the sighting tube should always be viewed from the same end of the tube. The leveling of the tube should also be checked to ensure that the tube is horizontal. With the vertical marker on zero, an object is viewed in coincidence with the cross wires in one direction through the tube. The sighting device is then rotated through 180° in the horizontal plane and the object should still appear in coincidence with the cross wires. The underwater theodolite is a simple and effective instrument for predisturbance and site surveying work, but it is only effective in clear, calm water. Its accuracy is limited because the angle measurements do not benefit from the sophistication of the land-based instruments.

The instrument can be used in a number of different ways to determine three-dimensional coordinates. One option is to set up the theodolite in a particular position. The distance and horizontal and vertical bearings are measured to objects on the site, and these measurements can then be used to calculate the horizontal and vertical components of the coordinates of the objects on the site relative to an arbitrary grid. To properly define the grid, it will be necessary to select a datum point and define its three-dimensional coordinates. In this way, the height of the theodolite above the ground need not be known. Should the theodolite be moved, it is simply necessary to coordinate, at the next station, a few common objects so that the new survey can be matched to the old.

Alternatively, the theodolite can be used as a level. In this case an underwater surveying staff is used. The theodolite is set with the tube horizontal and the operator indicates to the staff operator where the coincidence or level occurs. Horizontal distances can then be taken from the staff to the theodolite.

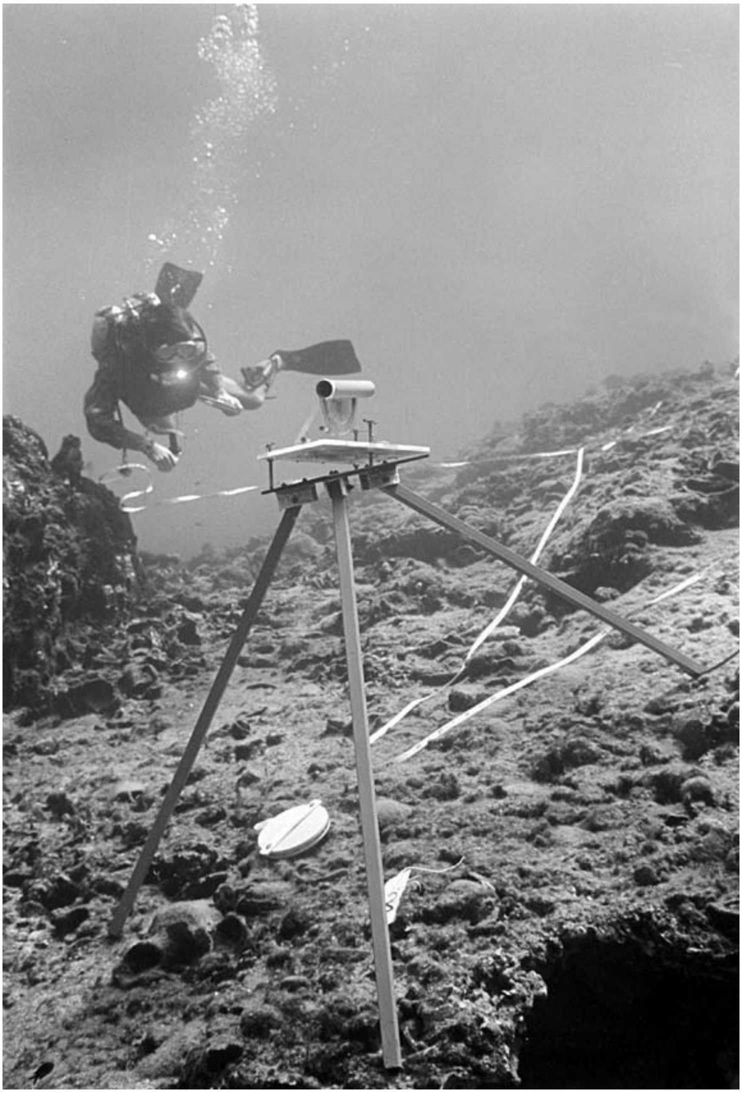


Figure 4.10 Underwater theodolite used at Cape Andreas, Cyprus. Only useful in clear water, it works on the same principle as a terrestrial theodolite. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

D. Three-Dimensional Least-Squares Adjustment

A three-dimensional least-squares adjustment program is another solution to the problem of surveying a three-dimensional structure and is discussed in Section VI.

E. Three-Dimensional Trilateration

Three-dimensional trilateration consists of measuring from a number of control points to the point of interest by using tape measures. The system has been widely used on projects such as the *Mary Rose* and by the Institute of Nautical Archaeology projects in Turkey. In most cases at least three control points must be used in order to obtain three-dimensional information, and in general four or more control points are used to determine the accuracy of the fix and to assist in the identification of "rouge" measurements. Obviously, for good three-dimensional trilateration the geometry of the control points needs to be carefully considered. Vertical control points need to be reasonably high in order to ensure that vertical accuracy is at least as good as horizontal accuracy (see Figure 4.11). This is discussed in more detail in Section VI.

IV. PROFILING

In certain situations, profiles can be particularly useful and may contribute vertical or three-dimensional information to a horizontal survey. There are a number of different situations where profile information can be of use; particularly in the case of recording a flattened hull structure, where the curvature of the hull is of interest. There are various simple systems of recording profiles: the offset bar, the distance-angle method, and the mechanical profiling device. Alternatively, leveling methods can be used to measure profiles (see Section IV.D).

A. The Offset Bar

The offset bar is placed across the site at right angles to the axis and pinned to the site so that it cannot move. Its orientation in the horizontal plane is thus random. Provided there is a fixed linear feature such as a baseline, the longitudinal position of the bar can be determined, and it can be set at right angles to this baseline (Figure 4.12a). The orientation of the bar to the horizontal plane can be measured with a spirit level or plumb bob, so that the relationship of the bar to the horizontal plane is known (Figure 4.12b). Measurements of the perpendicular distance from the bar to the feature on the site can be made with a ruler that must be set at right angles to the bar. Either the ruler can be made to slide in a slot, which is mounted on the bar and in turn can move on the bar or, alternatively, a square, which can slide along the bar and can be used in conjunction with a ruler to measure the distance (Figure 4.12c). Because the orientation of the bar at the various stations are known, the coordinates can be reduced mathematically to a common datum (see Green and Harper, 1983).

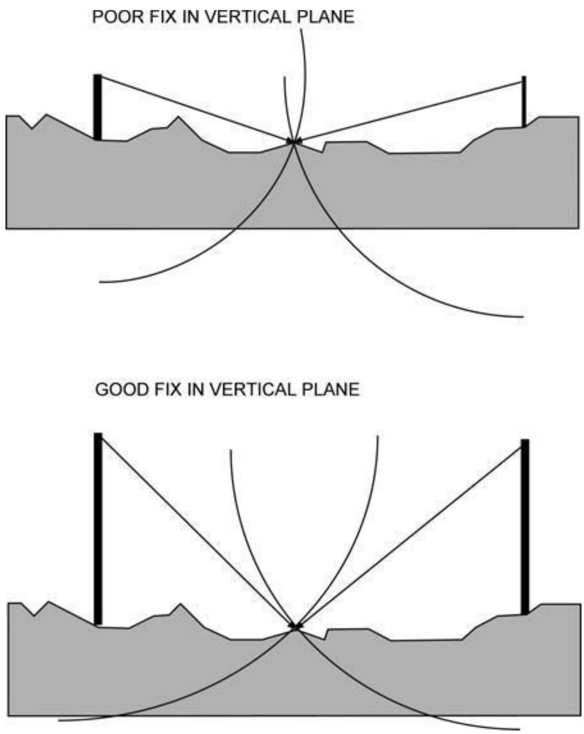


Figure 4.11 Vertical control problems. Note that where there is little vertical elevation the fix is bad. With elevated control points the fix is improved, but constructing elevated control is often difficult. See Figure 6.13 where artificial control has been used.

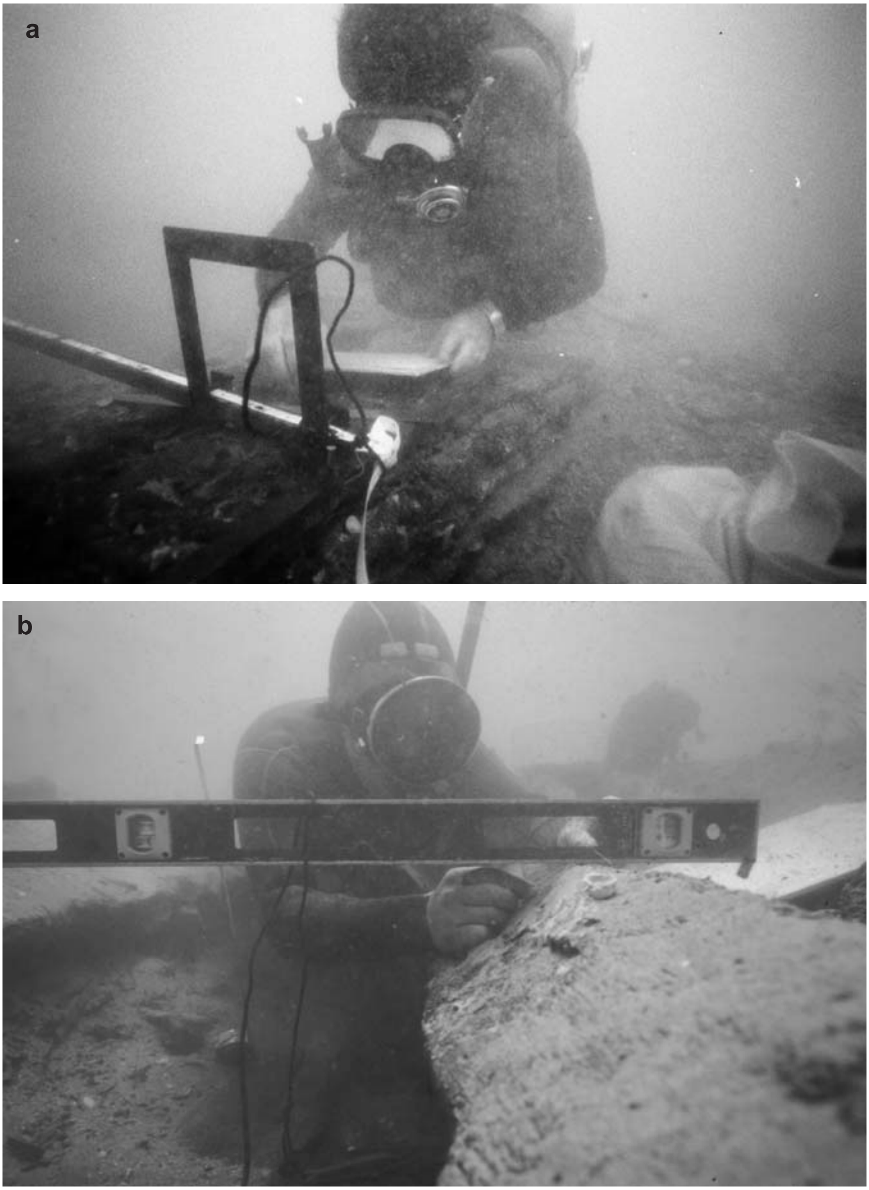


Figure 4.12 Three simple profiling devices. (a) A horizontal bar with a right-angle frame used to measure profiles, the angle of the bar is horizontal and measured separately. (b) A carpenter's level used to measure from horizontal.

Figure 4.12 (*Continued*) (c) A modified carpenter's level with bubble levels in two planes used to take vertical and horizontal measurements. (Figures 4.12a and c are courtesy of Brian Richards and Figure 4.12b is courtesy of Patrick Baker, both of the Department of Maritime Archaeology, Western Australian Maritime Museum.)

B. The Distance-Angle Method

The other similarly simple method of recording a profile is to use a distance-angle system with a circular protractor and a tape (see Figure 4.1). In this case, the protractor is set in the plane of the profile, and the distance and angle are measured to selected points on the profile. A simple example of this system is illustrated in Piercy (1981).

C. Mechanical Profiling Device

Another simple profiling system, described by Leonard and Scheifele (1972), utilizes a series of parallel rods mounted in a frame that can be adjusted to touch the profile to be recorded. The frame is set up on the site, at the point at which the profile is required, and the rods are adjusted to contour the profile. The rods are then clamped and the orientation of the frame holding the rods measured. The system is then brought to the surface and the profile recorded by measuring the extent that the rods project. Although the system is simple to use, the time and effort required to make the frame together with the mechanism for clamping the rods mitigates against its usefulness, especially as there are other simple techniques that are more flexible and easier to implement.

D. Leveling

1. Hydrostatic Leveling Devices

Hydrostatic leveling devices can be used in situations where three-dimensional measurements are required. The device measures the height or Z coordinate and is, therefore, useful for recording profiles and where relative heights are required.

The most common hydrostatic leveling device is the bubble tube, which is usually a long, clear plastic tube into which air is introduced. Because the air–water interfaces at either end of the tube will be in the same horizontal plane, this effect can be utilized to measure levels. It can be a difficult method to use, as the tube is long and unwieldy. There are two ways of using a bubble tube, either in the dynamic or static mode. In both cases, one end of the tube is attached to a reference datum point. In the dynamic system, air is introduced into the top of the tube under a small positive pressure (Figure 4.13). The mobile end is then adjusted in height so that air just begins to bubble out of the datum end of the tube. At this point a vertical

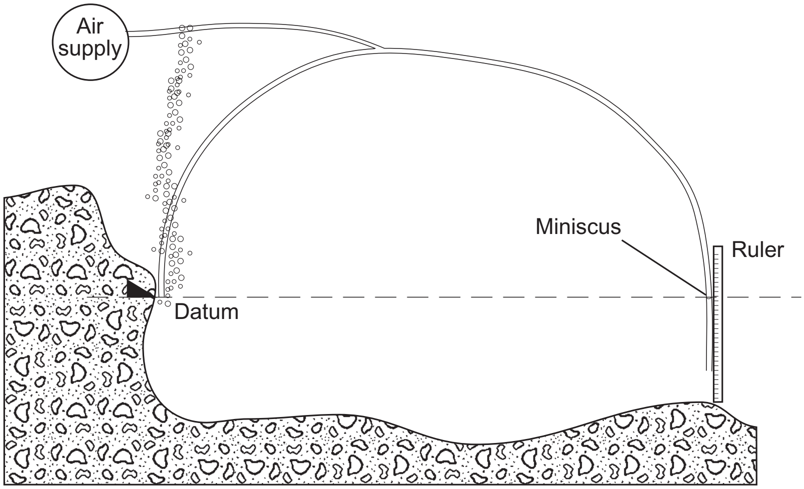


Figure 4.13 Active bubble tube has air slowly bubbling through the tube. The point at which the bubbles stop coming out of one end and start coming out of the other end means the ends of the tube are level.

measurement is taken from the air–water meniscus at the other end of the tube. This point lies in a plane with the reference point where the air is bubbling out. Great care has to be taken to ensure that the hydrodynamic effects of pathways taken by the air do not produce anomalous effects. It has been noted that, if air is introduced at the top of the loop, there is a tendency, when air starts to come out of one end of the tube, for it to continue to exit from this end. This happens even when the other end is significantly higher, whereas, according to theory, the air should be coming out at the higher end.

In the preferred static technique (Figure 4.14), a fixed volume of air is introduced into a clear plastic tube about 10 mm in diameter. The reference end of the tube is attached to a stake and the working end of the tube is placed alongside it. Enough air should be introduced into the tube so that there is a reasonable length of water filling the tubing at either end. Thus should the tube be inadvertently moved above or below the datum, air will not be spilled from the tube and upset its calibration. Alternatively, a large reservoir can be mounted at the static end of the tube to ensure that there is no overflow of air from the tube. Once the air is fixed in the tube and the static end is fixed, the meniscus at the mobile end of the tube will always remain at the same level provided the tube is not raised too high (or too low) so that there is air loss. If the tube is not distorted, the mobile end of

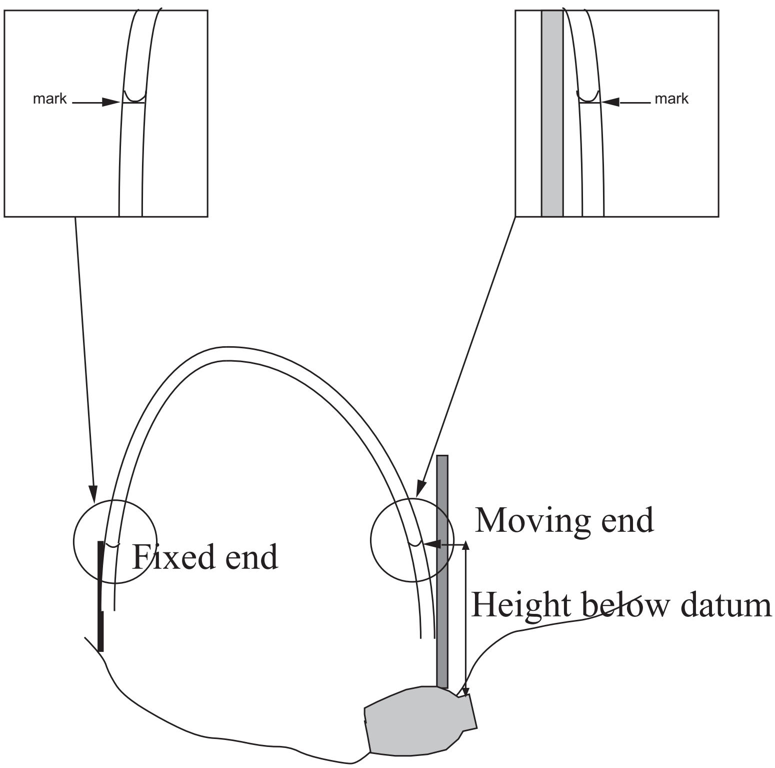


Figure 4.14 Static bubble tube has a fixed volume of air in tube, and one end (the fixed end) is brought to a fixed datum point and the meniscus point marked on the working end. The measuring end can then be used to measure from meniscus to object.

the tube can be moved around the site and heights can be measured from meniscus to objects. These heights should correspond to the height of the reference mark. At this point, the mark lies in the same horizontal plane as the original calibration. Vertical measurements can then be made from the reference mark up or down to the point of interest.

An interesting, pressure-based system which was proposed a number of years ago by Colin Martin consists of an air reservoir with a fine capillary tube (Figure 4.15). A volume of air is introduced into the reservoir and an adjustable marker is set to locate the position of the meniscus at a particular reference point on the site. The instrument can then be moved over the site and, provided the meniscus remains at the datum mark on the capillary tube, the mark will lie in the same horizontal plane as the reference

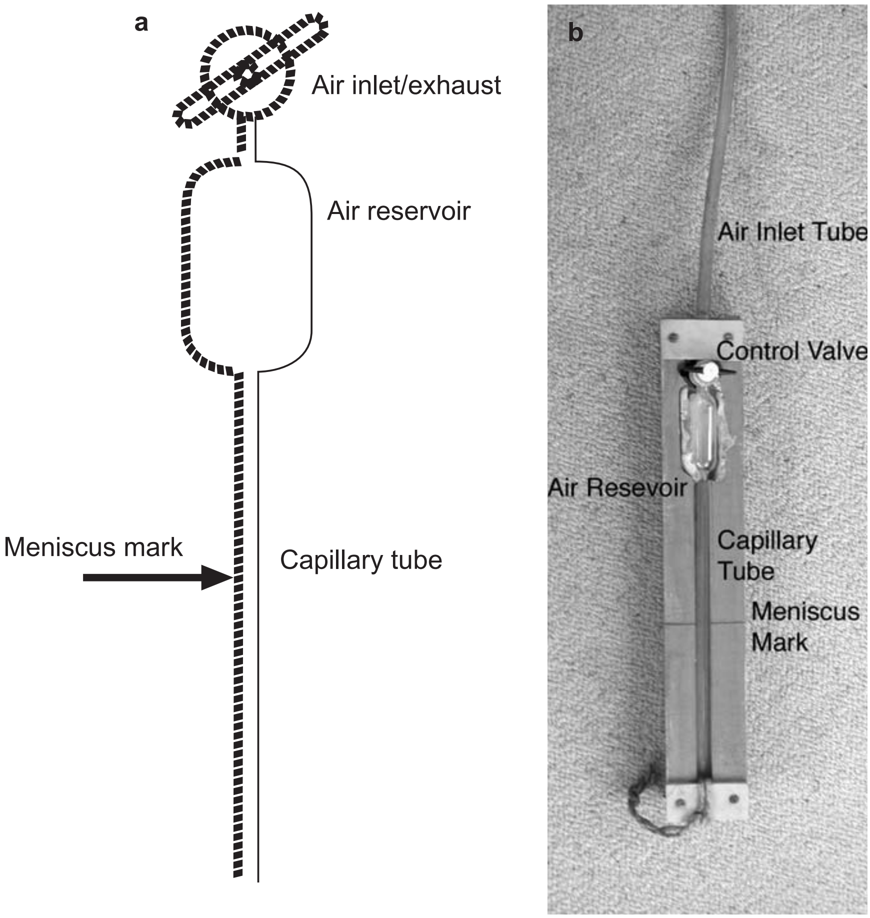


Figure 4.15 The Martin depth-measuring device. A schematic diagram of this device is shown in (a) and a working version in (b). The device has a reservoir of air and a capillary tube. It is filled with air at depth so that the meniscus sits in the capillary tube. The device can be moved around at the same level to measure distances to objects.

point. From this mark, depth measurements can be made to points on the site. Obviously, great care is required not to raise the instrument too far above the datum plane in which case air will bubble out of the tube and the calibration will be lost. The instrument provides a constant datum plane from which measurements down to the site can be made. If the capillary tube is narrow and the reservoir large, then small variations in the height of the instrument produce large movements of the meniscus in the tube. If there is an appreciable tide, it is possible that the instrument will lose calibration and a recalibration at a datum point will be required to ensure that the measurements are related. Choppy sea conditions may also cause problems, because in shallow water the meniscus will oscillate and an average will be needed to define the value of interest.

2. Carpenter's Level

A carpenter's level can be used to obtain vertical measurements, either by measuring directly down from the end of the level to the point of interest or by using the level to set a reference bar horizontal so that measurements can be taken from the bar. A development of the former method was made in Thailand by Geoff Glazier and the author, and this has proved to be particularly useful in low-visibility conditions (Atkinson *et al.*, 1989). A simple form of the system consists of a carpenter's level and a ruler. Starting from a fixed point, the level is adjusted so that the bubble indicates that it is horizontal. A ruler is then used to measure the rise or fall at the other end of the level. The position is marked on the site and the level reset on this mark. Using this system, a number of rises or falls can be recorded across a profile for fixed distances equal to the length of the level.

A modification to this system consists of two bubble levels mounted at right angles in a Perspex block. Two adjustable steel rulers can be moved in and out at right angles to each other through the block in directions parallel to the levels. The instrument can be used in three ways. In the first way, the horizontal is set at a fixed distance (e.g., 1 m), and then the rise or fall is determined across a profile, regardless of the features (see Figure 4.12c). In the second method, the horizontal and the vertical distances are measured from one feature to another, thus giving precise details on the structure. In the third system, only the vertical component is recorded, so that an effective leveling process is carried out around a site from feature to feature until finally ending up at the start again.

This method is extremely efficient, although it requires meticulous record keeping. In particular, great care is required to note what a rise is and what a fall is. A simple way of working is as follows. If the long arm of the starting point extends away from the start, in other words, the vertical ruler rises from the origin and the horizontal arm extends out to the next point, then this is noted as an outward reading or, in surveying terms, a "fore" reading. In the opposite case, where the horizontal ruler starts at the origin and extends out to where the vertical ruler drops to the next point, then that reading is an inward or "back" reading (see Figure 4.16). If one proceeds around a traverse, finishing at the starting point, then the fore readings should equal the back readings, i.e., the rises should equal the falls.

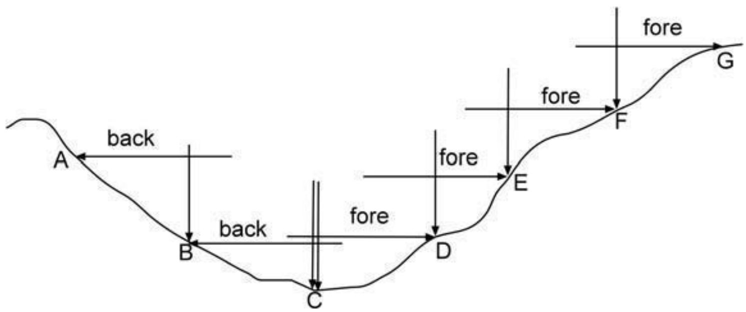


Figure 4.16 Back and fore readings. This shows the process from point A to point G with fore and back readings using the modified builders level shown in Figure 4.12(c).

It is possible, using statistical methods, to close the traverse and readers are referred to the standard works on surveying (Hydrographer of the Navy, 1965, 1982).

3. Depth Gauge

Absolute pressure measurement is a useful method for obtaining vertical height, particularly because electronic gauges are available which will measure depth to about 0.1 m. At depth, the effect of surface waves or swell produces minimal fluctuation of pressure signals. Additionally, there are systems that allow the downloading of depth information where necessary. An alternative method consists of using a pressure gauge to measure the differential pressure between a reference point and the point to be measured. A standard aneroid differential pressure gauge or two electronic pressure transducers can be used; the tube from one end of the gauge is attached to a reference point, and the relative pressure readings are taken at the gauge. Issues to do with pressure–depth readings are discussed in Section VI.

V. COMPUTER-BASED METHODS

A. General Considerations

Calculating the position of a point—the fundamental objective of survey—is not the only consideration in producing survey results. It is also important to know the precision of the location of the point. All measurements have random errors and the size of these errors can vary. If the measurements used to position a point have small random errors, or are precise, then the position error for the point will be small. If one makes redundant measurements as a check on position, because of the random errors in the measurements, there will almost certainly never be a single point position. Instead there will be lots of possible positions that can be calculated using different selections of the measurements in the set. Therefore, it will usually not be possible to calculate the true position for the point, and it will be necessary to determine the most probable position. In general, the most probable value for the true measurement is the average or mean value. If each measurement in turn is compared with the average value, the difference is called the residual. To compute the position of a point using a large number of measurements, the use of the mathematical calculation known as least-squares gives the most probable position. (Where the sum of the squares of the residuals is the smallest, the sum of the residuals for each measurement, will be smaller than that for any other position.) The least-squares calculation produces a single solution regardless of how many measurements have been made, the type of measurements, or how they were collected. This technique also provides information on how well the measurements fit together and can be used to help find mistakes.

By using this type of program, a number of possibilities exist for the archaeologist who wishes to conduct survey work under water. In one application, the interobject distances are measured to develop site plans. In the more common application, a control network is set up around the site and this is used to survey objects. The interobject technique first requires only distances between points to be known, so it is not necessary to introduce survey reference points. It is therefore a very useful method for surveying control points or a series of site tags that are used for other types of survey, particularly when establishing photographic control. It does not require every distance to be known, but the more distances that are measured the better the results will be.

There are a number of important advantages to using this approach. First, because survey reference points are unnecessary, the need for elaborate survey stakes and the time required to put them in place is avoided. In the other application, the objective, like the way the computer program Web was used on the *Mary Rose* project, is to establish basic control points and then measure the objects. The control network must be rigid and fixed in a location that allows access to all possible locations of objects. This is the more common situation, particularly when dealing with a large complex site, where measuring interobject distances would be unfeasible.

B. Least-Squares Adjustment Technique

The least-squares adjustment program is a mathematical method of calculating the best fit of a series of data measurements. If, for example, every unique distance between four points is measured, giving a total of six measurements, there will inevitably be some error in each of these measurements depending on the accuracy of the measuring system. If the measurements are used to plot the position of the points on a plan in a conventional manner with a compass, there will be a resulting uncertainty in the position of each of the plotted points. The least-squares adjustment program calculates the best fit from this given data using rigorous statistical techniques. It also provides a statistical estimation of the errors involved in the measurements. Through a series of mathematical iterations, the distances are systematically varied by small amounts in order to seek a unique best fit that requires the least amount of adjustment to the measurements. It is obviously not necessary to have a complete understanding of the mathematical theory or the program, but this method offers a very interesting solution to the problem of surveying sites under water.

The concept of least-squares adjustment has been known and understood for a number of years. With the advent of small and powerful computers, programs have been developed that can be used to make these calculations. It is generally recognized that Cross (1981) popularized the least-squares concept and was influential in the development of the Web, Site Surveyor, and most acoustic position fixing system programs. The Department of Maritime Archaeology at the Western Australian Maritime Museum developed an early least-squares adjustment program in 1987 by Duncan (see Atkinson *et al.*, 1988). The initial program was written by Duncan as part of the underwater, acoustic, position-fixing project (HPASS described later). It was obvious that the program had ap-plications in underwater surveying and the results were published in Atkinson *et al.* (1989) together with the source code. At the same time Rule (1989) was developing the Web program and this, in turn, was superseded by the more sophisticated program, Site Surveyor (see Section VII.D).

There are two basic approaches to using computer adjustment programs. One is where a series of points on a site are systematically surveyed, the points being the points of interest on the site and not artificial reference points. This type of survey is commonly a predisturbance survey or the survey of control points. The other option is to use predetermined control points and to use these control points to conduct an ongoing survey, typically during an extensive excavation. The latter example requires a preliminary and careful survey of the control points which act as the basis for the survey.

Before measurement can begin, each point or feature to be surveyed must be tagged with a unique code or number and, if one operator is doing the survey, the tag must be robust enough to hold the end of the tape measure firmly in place (a strong nail or hook is ideal). A pre-prepared writing slate should list, in a logical manner, all of the combinations of measurements required to complete the survey. The distances are then measured under water. If two operators work together, then it is necessary for one to check that the tape is not snagged and possibly hold the writing slate when it is not being used. However, very little time is saved using two operators, particularly in clear water when the operator can see that the tape is straight. On return to the surface, these data are entered in the computer. In practicing this technique, it has been demonstrated that if both the recording slate and the computer entry layout are based on the triangular format (Figure 4.17), then there is less chance for data error and the results are more understandable. Obviously, where communications are available there is the option to record the measurements at the surface and check for reliable fixes.

It may be seen, therefore, that this system has a number of extremely useful features in comparison with other surveying techniques. Any system that provides a rigorous statistical treatment of errors has immediate advantages over standard trilateration and the other relatively primitive underwater surveying methods. A practical field trial of the system in Thailand (Atkinson *et al.*, 1989) is worth mentioning. Major features of an excavated hull structure (in 27 m of water) were marked with numbered tags. A total of 15 stations covered an area of 14 × 3 m. All the ranges of the matrix were recorded. The measurements were initially taken by ten divers, but the numbers were later limited to four as inconsistencies among observers became apparent. This problem was compounded by having a number of tapes in use, some of which had both metric and imperial units, adding reading problems caused by the effect of depth. High residual values from the output of these data indicated which ranges were suspect and needed to be re-measured. Re-measurement was continued until shortage of time

	A	B	C	D	E
A		27.05	16.55	12.37	15.95
B			7.36	19.76	11.32
C				9.85	22.13
D					14.31
E					

Figure 4.17 Triangular format for direct distance measurements. Using a template like this, it is easy to ensure that all necessary measurements are taken.

restrained further surveying. Large standard deviations were then assigned to those few remaining unreliable measurements. As the measurements were refined and estimates of the coordinates became more accurate, the resulting standard deviations for the coordinates and the residual values became uniformly small. In one particular case, a small but consistently larger than average standard deviation was noted for measurements to one particular point. On subsequent inspection of the point, it was discovered that the tag was attached to a plank that was slightly loose and as a result was causing unreliable measurements (for further details, see Atkinson *et al.*, 1989).

C. The Direct Survey Method System

One of the first maritime archaeological applications of computer-based surveying techniques was developed in Norway during the *Lossen* wreck by the Norsk Sjøfartsmuseum in 1967 (Andersen, 1969). In this system three distance measurements were made from three reference points and a simple calculation of resection was made. This was done graphically and also using a Fortran program. Christensen (1969) noted that the system had the potential to save time while at the same time providing high accuracy. Because the site was in a rocky gully, it was possible to utilize elevated datum points making it possible to obtain three-dimensional coordinates.

A similar system, which he refers to as the direct survey method (DSM), was developed independently by Nick Rule during the *Mary Rose* excavation (Rule, 1989). The basis of the formulation is to solve the three equations of the three spheres representing three distance measurements from the respective reference points. The equations have two solutions with one being the mirror image of the other. Additional distance measurements were added to the computation and the results averaged to give an estimate of error. This system was used in the survey work on the *Mary Rose* project. It is estimated that 450 diver days were taken up surveying 100 datum points including the underwater work of sighting, leveling, and surveying these data, together with the land-based work of recording, computing, and plotting the results. It is calculated that it took about 4.6 minutes to make one measurement. A total of 740 measurements were recorded from the site of which about 560 were useful measurements. Rule estimates that the DSM system takes about one quarter of the time taken to plot data using a ruler and compass (Rule, 1989). The author is extremely grateful to Nick Rule for the information provided as part of an extensive report on the DSM surveying technique to be published as part of the *Mary Rose* report (Rule, 1982). It appears, however, that a large proportion of the measurements made on the *Mary Rose* remain unprocessed and the final report has yet to be published. The DSM program was later rewritten as Web for Windows (a somewhat confusing term nowadays as Rule's coining of the word "web" pretty much predated the term now widely understood to be the Web as in the World Wide Web).

D. Site Surveyor

1. Introduction

After the initial development of Web, there were not any major updates of the program until the mid-1990s and a huge number of copies exist (probably pirated versions). A more sophisticated program called Site Surveyor was developed in the late 1990s by Peter Holt of 3H Consulting Ltd (Holt, 2003). Much of the following section is based on the Site Surveyor instruction manual and the author is grateful to Peter Holt for allowing its reproduction here. This program, which is dongle protected, is based on far more rigorous algorithms than Web and has a much more sophisticated interface.

2. Control Points

One of the rules of this survey philosophy is that the network of control points should be separated from the network of artifact points. The control network is a network of fixed survey control points placed in and around the site that are not used to directly position artifacts or structure. The site should be covered by the simplest network positioned using high-quality measurements. It is important to note that these control points must remain even if the site was excavated and recovered. The relative positions of the framework of control points are first determined in order to serve as a base for the detail survey. One major advantage of separating the roles of the control points is that the process of positioning the artifacts becomes easier. The control points and the artifact points are sometimes referred to as datum points in some marine archaeological literature, usually when no distinction is made between the two types of points.

A number of basic principles apply to the survey when using Site Surveyor. A circular or elliptical network of control points should surround the whole site and at least four distance or baseline measurements should be made to each point. The maximum distance between control points should be no more than 15 m, measurements between control points should form a set of braced quadrilaterals and, where possible, the same measurements should be repeated a number of times. Depth measurements should be made at every control point. In addition, angle and offset measurements are not to be used in the adjustment. Angle measurements are not included due to their inherent inaccuracy under water. Offset measurements are used in Site Surveyor to position artifacts but are not used to compute the position of the control network.

Three types of control points can be used in a survey: primary control points, secondary points, and detail points. Primary control points are established in the planning phase and are the main reference points for the survey. These are the most important points and must remain after excavation and should not be placed on artifacts or the structure of the site, but should be fixed to the seabed. Secondary points may be added later to help extend the site or to solve a line-of-sight problem. These points can be left in place after excavation but may be removed, and they can be placed on the structure as long as enough measurements have been made to the secondary point from surrounding primary points so that the secondary point's position can be reconstructed. Detail points may be added so that the fine detail of the site or structure can be recorded, such as a hull profile. These points are likely to be removed during excavation and are usually placed on the structure rather than on the seabed, as they are usually used to fill in gaps in the coverage of the primary and secondary points.

Artifacts can be used as secondary and detail points but should not be used for the primary control network. The artifacts used as control points should not be able to move and the actual point on the artifact used as the "point" should be obvious.

The optimum network shapes that should be used are circles and ellipses: Circular shapes are useful but generally an elliptical network is required. The ratio between the length and width of the ellipse (major to minor axes) should ideally be less than 2:1. Where the site is large, intermediate points can be placed within the site so that long baselines are not used. On some sites these points can be permanent and fixed to the seabed, however, this may not always be possible. Secondary points fixed to structure or big artifacts can be used to jump the gap between the two sides of the site. Very pointed network shapes should be avoided as the position error will be large for the points away from the main body of the network.

3. Accuracy

A position error is the known accuracy of a position. Position errors are most usually shown as an ellipse drawn around each point. The ellipse indicates the probable position of the point, and the point should lie within the area of the ellipse. The smaller the ellipse the more accurate or precise is the position computed for the point. Ideally position error ellipse shapes should be almost circular. This shows that there is equal knowledge of the accuracy of the point in all directions. A long, thin ellipse shows that the position of the point is poor in one direction, the direction in which the ellipse is biggest. Error ellipse dimensions are expressed as two values: the semi-major and semi-minor axes. The semi-major axis is half the largest distance across the ellipse, the semi-minor axis is half the smallest distance across the ellipse, and these values are equal for a circle. The measurement errors shown by the error ellipses increase for the points farther away from the control points.

The measurements to each point always possess a measurement error, and this error states how accurately the measurement was made with the tool used. The overall effect of the built-in measurement error in our distance measurements is to give each point a position error, or an uncertainty in the point's actual position. To this error we can add problems caused by the shape or geometry of the network. Where points being positioned are farthest from the control points, the angle between the two baseline measurements is small. The angle between the two baseline measurements can be used as a measure, and this angle is sometimes known as the "angle of cut." Where the angle of cut is too small or too large the position error ellipses will be long and thin, therefore, the position errors for the points will be large. Ideally the angle of cut should be no smaller than 45° and no larger than 135° for a good network shape. It is important to note that this effect is not obvious unless position errors are computed for the points. If only the residuals for the distance measurements are used as a quality figure the increase in position error would not be noticed; the residuals are zero for all four points yet the actual position error gets worse as you go away from the control network.

4. Position Reference Points

Because of the way the adjustment works, three primary control points must be selected as reference points for the whole survey. The control network would be free to move in all directions if it were not fixed by these three reference points. The position of a point is given in three dimensions: the X direction is usually shown across a typical site chart, the Y direction is drawn up and down the chart, and the Z direction is not shown as it lies perpendicular to the page. The first reference point is fixed in all three dimensions (XYZ) and is not allowed to move at all during the adjustment. The second reference point is fixed in either the X or Y and the Z direction. During the adjustment it can only move toward or away from the first reference point. The third reference point is only fixed in the Z-dimension so it can move horizontally but not vertically. For our survey design it is essential that a depth measurement be made for every point on the site. The flat shape of most survey networks means that it can be difficult to determine the depth of a point from measurements alone. Fortunately, dive computers provide a readily available method of measuring depth to a reasonable accuracy.

In general, the site will have some form of obvious symmetry so that the location of the position reference points and thus the coordinate system can be easily established. In other cases the coordinate system will have to be set arbitrarily. In both cases the choice of the coordinate system and the position reference points are worth considering. It is useful to have a system where all of the coordinates in the survey will be positive. Thus the origin can be set well off the site with the site lying in the upper right quadrant of the rectangular coordinate system. Additionally, care needs to be exercised when dealing with the Z component. It is important to be sure that the depths are set with the correct sign (down, positive; up, negative).

5. Depth Reference Points

The depth reference point is used as the overall reference when making depth measurements. As seen earlier, the control network can be placed anywhere on a local grid in the same way the depth of the site can be placed at any chosen level. If the equipment is available the depth of the site can be referenced to some other point such as the lowest astronomical tide (LAT), although usually an arbitrary depth is selected. The absolute depth of the site may not be important, however, all of the other points must be positioned in depth relative to one point on the site—the depth reference. The choice of which control point is used is arbitrary, but the first reference point would be a good choice.

6. Specifying Overall Accuracy

The overall accuracy required for the survey should be specified by the archaeological director during the planning phase. The accuracy specified should be realistic and achievable. It is important not to overspecify the accuracy required. The accuracy specified should depend on the accuracy of the tools being used, the time available, the size of the site, and what accuracy is really needed.

Three values have to be specified: the root-mean-square (RMS) or average of the residuals, the maximum position error, and the maximum allowed depth error. Other more advanced figures can also be quoted such as unit variance and reliability values. For a typical underwater survey of a small site, an RMS of residuals of less than 50 mm is easily achievable along with a maximum position and depth error of less than 150 mm. A well-surveyed site will have an RMS of residuals at approximately 20 mm and a position error of approximately 100 mm. For large sites or for quickly completed surveys the errors can get quite large. This is only a problem if these large errors are ignored and the survey is quoted as being more accurate than it really is, or worse still, not computed at all.

The scale of the required drawing used to be a significant issue that could be used to determine the required positioning accuracy. As it is now commonplace to produce the drawings in a computer-assisted design (CAD) program, this is less important as the site plan can easily be produced to any scale. The limiting factor on accuracy is now the accuracy of the tools used to position objects on the site.

7. Line of Sight Problems

In a number of cases the survey will be done around a structure, so there is no clear line of sight from one side of the site to the other. In this case the primary control points should be set around the outside of the site and secondarily, linking points should be set up on the highest points of the structure. If a part of the structure containing a secondary point is moved or recovered, then the secondary point needs to be re-established from the remaining primary points around it. Placing the control points high up around the site has two advantages: first it can be easier to make measurements across the site and secondly it adds extra depth information. The adjustment needs this depth information to be able to compute positions in three dimensions on what can be a flat site.

8. Installing Control Points

Once a theoretical control network has been designed, it will have to be set up on the site. It is at this point where the problems associated with surveying under water start to affect the quality of the survey. The tape survey is dependent on the diver's ability to install control points in the right place and to measure the distances between the points with sufficient accuracy.

The first step is to install the control points, which are usually a series of construction tasks involving hammering pitons into rocks or poles into the seabed. Therefore, it is important to ensure that the points are in the right place and that they are secure and absolutely rigid. It is also important to clearly mark each control point so it can be found and uniquely identified, especially in low-visibility conditions. The point should have a label attached on it or nearby along with a bright marker. Short lengths of bright orange tape work well as they are obvious and float up from the seabed.

Once the control points are in place the measurements between the points can be made.

9. Collecting the Measurements

To get the best results when collecting measurements, the recorders need to be trained in making measurements under water. Common mistakes can be avoided if one is aware of the problems beforehand. Typical problems include:

1. Control points that cannot be easily found; clearly mark the control points with bright markers and big labels
2. Measurements made from the wrong point; uniquely and clearly identify all points
3. Recording forms are unreadable; use standard forms and teach the operators to use them correctly
4. Numbering formats on the forms vary; standardize in meters to three decimal places (000.000) or millimeters (000000)
5. Values read wrongly from tape measure; teach the operators to read the tapes correctly on land then try under water
6. Wrong part of control point used is used for measurement; demonstrate how and where to measure using the same type of control point
7. Offset was not recorded; where an offset is expected add a field on the recording form
8. Snagged tape measures; ensure the operators swim the length of the tape if both ends cannot be seen at the same time

It may be necessary to refer back to the recording sheets during processing to help decide whether a measurement should be rejected. A number of factors affect the quality of the measurements: working in low visibility, currents, and deep water. These all tend to produce more frequent mistakes or blunders. So the visibility, current, and any other potential problems should be recorded on the form together with the measurements.

10. Depth Measurements

Care has to be taken when measuring depth because of the effects of tide. To counter these effects it will be necessary to select one control point on the site to use as a depth reference. When a depth measurement is made at any other point, a measurement of the depth at the reference point should be made so that corrections for changes in tide height can be calculated. It is possible that the change in tide could be tracked using a depth-recording instrument, so that at the time that the reading was made the depth correction for tide can be calculated. The recording forms should include a sequence of depth measurements and times along with the depth of the depth reference point at the start and end of the sequence of measurements. The difference in depth at the start (StartDepth) and end (EndDepth) of the sequence shows how much the tide changed while the measurements were being made (TotalDepth). The difference in time between the start (StartTime) and end (EndTime) of the sequence shows how long it took to make the measurements (TotalTime).

At any time during the sequence of measurements it will be possible to calculate how much the depth changed up to that time (MeasureTime) by using proportions. If the raw measurement was made three quarters of the way along the sequence then the change in tide at that time will be three quarters of the total change.

The total tide height is the difference between the assumed depth of the depth reference (DepthRefDepth) and its depth measured at the start of the sequence (StartDepth) plus the change in tide calculated previously. This is the correction to be applied to the raw depth measurement. The raw measurement and the correction should both be entered on the depth measurement dialog.

11. Adjusting

The next step is to adjust the positions of the points using the measurements. The adjustment is an iterative process requiring a number of repeated calculations before it comes up with an answer. Once the adjustment has stopped and an answer is calculated, it is then possible to interpret the results and to work out what to do next.

12. Interpretation

Interpreting the results of an adjustment is the most difficult part of the survey. If the results are good and the network fits together well, then no interpretation is required and the next stage can be carried out. It is more likely that some problems will have occurred so that the network does not fit and thus some additional work is needed to find the causes of these problems and to correct them. It is important to work to the accuracy specified and no better. It is possible to go on fine-tuning the results to get a better result but, in reality, this stage is complete when the answer is good enough.

The RMS residuals (the square root of the mean of the residuals squared) is a quality figure showing how well the measurements fit together.

The smaller the residual RMS the better the network fits together. The average absolute residual can also be used but the RMS is preferred as it is more sensitive to single large residuals remaining in the network. Unfortunately, the residuals on their own are not a good measure of the fit of the network as they do not include any information about the shape of the network. A poorly designed network can have very small residuals for its measurements but still give large computed position errors for the points. The geometric error is a value showing the overall horizontal position error for the network or how well all of the points have been positioned. Again, the smaller the number the more accurate the survey. The depth error is an equivalent value for the depth axis of the point positions. These figures need to be used alongside the RMS of the residuals when stating the quality and precision of the network. If both the geometric error and the RMS residuals are smaller than the required specification, then this part of the survey process is completed. In most cases there will be blunders or omissions in the measurements and some additional work is required.

13. Identifying Suspect Measurements

If your RMS residuals and unit variance is large it will be necessary to find the measurements causing the problems and fix whatever is wrong. The figures are a summary of all of the residuals for all of the measurements in the project, so if the RMS is too big then one or more of the residuals is too big.

In the chart window acceptable measurements are shown in green, measurements that are too long are shown in blue, and measurements that are too short are shown in red. The thicker the measurement the larger its residual; the thickest have the largest error.

On the observation list window the measurements are shown along with their residuals and their w-test values. Measurements that are too long have positive residuals, those that are too short have negative residuals. In the observation list window you can sort the measurements by column by clicking on the appropriate column label.

14. Rejecting Measurements

The next step is to identify suspect measurements or blunders with large residuals. The w-test value is a kind of residual and can also be used to identify blunders. Select the most obvious blunder, usually the one with the largest w-test value, and then set it to be ignored. Readjust the network and see if the answer improves. All residuals will be small and the chart will only show green measurements. Do not delete any measurements at this stage.

If after rejecting one measurement the situation does not improve, look for any other obviously wrong measurements and reject them one by one, readjusting in between. Do not reject so many measurements that less than four are available on each point. If enough measurements are rejected then almost any network can be made to fit.

For baseline measurements the blunders tend to be longer than the "true" values, because snagging or bowing always makes these measurements longer. If a short blunder occurs because of a misread tape, then the value tends to be considerably shorter and is obviously wrong. Check dive logs to see if any measurements are likely to be blunders and check if they are candidates for rejection. If they are suspect but you still want to use them, then increase the estimated error for the measurement and the adjustment will rely on them less.

Start with a small group of points and measurements and get them right. Ignore any other measurements until later. When the small set is correct start adding more points and their measurements. Once a small set is assumed to be right you can temporarily fix their positions before including more points and measurements. If some of the included measurements are wrong, then they will be easier to identify. It is *essential* that the positions of these points are freed once the whole network is to be adjusted.

Where multiple measurements have been made be wary of rejecting all of the measurements except one just to make the network fit. As multiple measurements have been made the most likely value should be the average of all of the measurements.

15. Insufficient Measurements

When rejecting measurements you must ensure that too many measurements are not rejected. To position any point we need three measurements; additional measurements are used as checks to ensure that the position is correct. As a minimum there should be three baseline measurements plus one depth measurement for each point.

If it becomes necessary to reject more measurements than this, repeat measurements should be made. To allow readmission of rejected measurements you should not delete measurements but ignore them. Once a network has been positioned successfully then some measurements could be deleted, however; it is better to leave them in the project in case the survey is to be reprocessed again later.

16. Limitations

A least-squares adjustment does not give the true solution, only the most likely solution on average. It is not possible to get the true solution as there are always errors in any measurements made. Using a better measuring instrument will not get the true solution, only a better one. The least-squares method will tend to spread the effects of any blunder around the network. This is why it can be so difficult to identify the measurements that are blunders. The position error computed for the points is controlled by error estimates in the measurements. You are unlikely to be able to position a point to 20 mm when the error in your tape measurements is 100 mm. The adjustment needs the best measurements it can get to be able to compute the best results. The position error computed for each point is affected by the choice of position reference point. This is a side effect of constraining the network. Care in selection of which points to use as reference points and a good network shape will help minimize these effects.

17. Layers

Site Surveyor has the ability to create layers so that different sets of survey work can be placed in different layers. This has the advantage that the complete survey can be held in one file, so that, for example, each day's survey work can be placed in a separate layer, the common control points maintained in another layer, and by switching the layers on and off adjustments can be made without having to needlessly readjust data that have already been fixed.

18. General Conclusions

Site Surveyor is undoubtedly the best underwater archaeological surveying program on the market. It has been widely used in various situations and is referred to here on the *Pandora* survey, Tektash, and its use with the HPASS system (see next section).

VI. ACOUSTIC SURVEYING SYSTEMS

The use and development of the High Precision Acoustic Surveying System (HPASS) has been described previously by Green and Duncan (1999) and Green and Souter (2002). HPASS is discussed here as it illustrates the potential for acoustic systems for underwater archaeological work, particularly where the site has poor visibility. Where a site has good visibility, for example, more than 10 m, photogrammetric techniques would generally be used. Other acoustic systems include the PLSM Aqua Metre and MIT's EXACT, which exist for general diver tracking (ecological surveys, search and rescue, etc.). The offshore oil industry has systems such as the Sonardyne Pharos system with accuracies around 20 mm, although this system generally requires surface control. The following description is given of the use of the HPASS system on the Museum of Tropical Queensland 1999 *Pandora* expedition and on a project undertaken by the Rijksdienst voor het Oudheidkundig Bodemonderzoek (ROB) and The Netherlands Institute of Ship Archaeology (NISA) on the remains of a Roman bridge at Maastricht, The Netherlands.

The *Pandora* has been the responsibility of the Queensland Museum since 1983 and has been the subject of ten archaeological excavations (Gesner, 1993a,b; Gesner, 2000; Ward *et al.*, 1998). Peter Gesner, the *Pandora* project director, invited the author, as part of Australian National Centre of Excellence in Maritime Archaeology, to assist in surveying the site using the newly developed HPASS system. The HMS *Pandora* was wrecked in 1791 while attempting a passage through the remote northern part of the Great Barrier Reef (latitude 11° 22.669S; longitude 143° 58.579E) carrying 10 prisoners from HMS *Bounty* to England for trial for their part in the "*Bounty* mutiny." The site lies at a depth of about 31 m and the area is subject to unpredictable currents and, during the time of the expedition, a tidal range of 1.5 m. The 1999 expedition lasted from January 31 to February 28 and the HPASS system was used on a daily basis to survey the site. Data were processed in the field and used to record features on the site, excavation targets, and grid markers. At the end of the expedition a lengthy postexpedition data processing program took place, during which the manipulation of these data was refined and the software processing programs were modified or changed. This provided a series of progressively more refined and more reliable results. This part of the report describes the site surveying process as well as the developments in the programming made in conjunction with Alec Duncan from the Centre for Marine Science and Technology (CMST) at Curtin University of Technology and with Peter Holt of 2H Surveying; and, finally, the results of the survey work with comments on the accuracy of the system.

In May 2000, Thijs Maarleveld and Arent Vos of NISA requested the CMST's HPASS system to be used on a project consisting of a third century ad Roman bridge site in Maastricht, The Netherlands. This presented an opportunity to use the system on a site with poor visibility for which acoustic survey systems are ideally suited. The second part of this report describes work carried out by Souter who conducted all of the HPASS survey work in The Netherlands.

A. The *Pandora*

The *Pandora* wreck site covers an area approximately 50 × 30 m on a slightly sloping seabed. The site had a previously established grid system covering the whole area with the grid lines defined with 1.5-m survey poles. The first objective of the HPASS survey was to plot the existing grid to determine the position and accuracy of the coordinate system. The HPASS system was then used to plot some of the major features on the site. As the HPASS system had only just completed field evaluation trials in shallow water, it was uncertain what the performance and operating range of the system would be at a depth of 30 m. The maximum designed survey range of the system was 50 m, so, given that this was at the limit of the range for this site, it was decided to divide the survey into two parts to ensure reliable coverage.

The stern area was surveyed first and then the bow section. This arrangement also allowed the six transponders to be deployed well outside the operating area of the excavation. Thus they would not interfere with the excavation nor be disturbed by hoses and lines. The six transponders were first placed around the perimeter of the site in their tripods (Figure 4.18). Survey work started on February 6 continuing on February 7, 10, and 11. On February 13 two of the transponders in the stern section (T4 and T6) were moved to new positions in the bow area (T7 and T8) and the survey continued on February 13, 14, 16–18, 21, 22, and 24. Each dive lasted 40 minutes and on one day (February 10) the system was used on two separate dives. During the expedition a total of 217 measurements were made in a total diving time of 520 minutes. Given the delays at the start and end of each dive and the setting up time, the system, on this site, was capable of making about one measurement per minute.

1. Post-Processing

At the end of each day these data were downloaded from the diver-unit (Figure 4.19) into a computer on the expedition vessel in a directory designed to contain all these data for that day. HPASSConvert, the program developed by Alec Duncan at CMST, was then used to process the raw data from the diver unit by converting time delays between sending the signal to a transponder and receiving a reply and calculating temperature and pressure. These data were then output in a format that could be read by Nick Rule's Web program.

HPASSConvert, in its first version, allowed the operator to manually enter the average temperature for the whole dive and the measured salinity. This provided the essential parameters for the program to calculate the

Figure 4.18 HPASS transponders. Operator is removing protective cover from transponder. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

velocity of sound in water. With the velocity of sound, together with various fixed parameters, the program then calculated the distances from the diver unit to each transponder. It also calculated the depth obtained from a pressure transducer located on the diver-unit probe and the temperature obtained from a temperature sensor on the diver unit. The resulting text file contained the following information for each fix: time, temperature (in

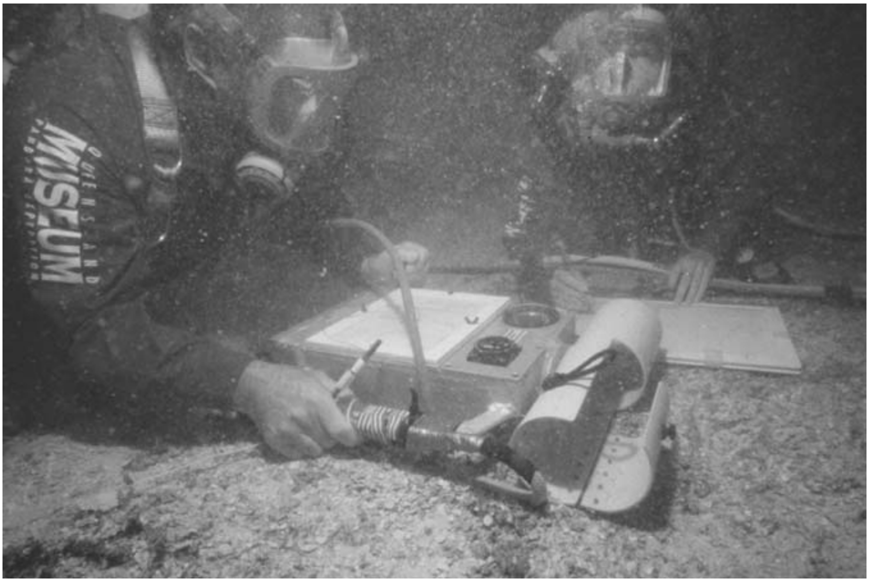


Figure 4.19 HPASS diver unit. Operator on left is holding the mobile recording transponder. (Courtesy of Gary Cranitch, Queensland Museum.)

°C), depth (in meters), and the six transponder-to-diver-unit distances (in meters). Associated with each of these measurements (excluding time) was the standard deviation of the measurement and the number of measurements used to obtain the final value (the unit usually made 20 measurements to each transponder and the program rejected readings that lay outside a predetermined range). In studying the resulting data, it was found that there were a number of interesting factors that affected the results.

2. Temperature Considerations

The *Pandora* site lies on the edge of the continental shelf in a region where there are numerous reef and lagoon areas. With the tidal range, the water is noticeably variable in the current strength and temperature, suggesting that water from the warm lagoon areas and the colder deep ocean was ebbing and flowing in an unpredictable manner through the site. Readings showed a remarkable variation in temperature, varying between 24.3 and 28.8°C over the period of the expedition and by up to 0.6°C over the course of a dive (Figure 4.20). These variations suggested that using the

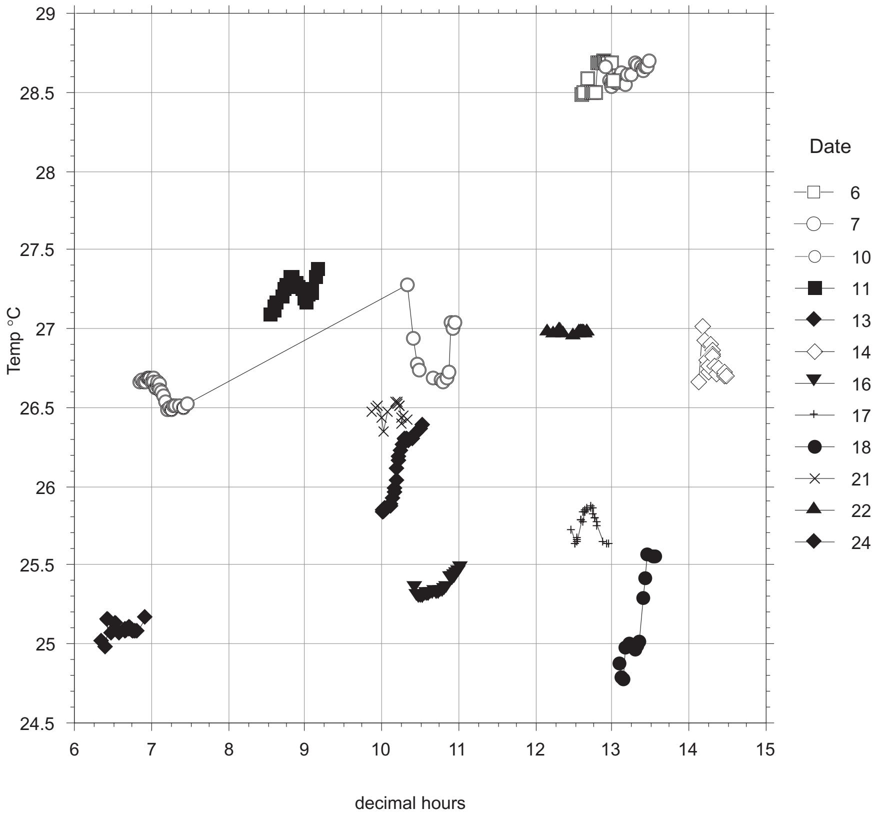


Figure 4.20 Temperature variation over a number of days noted on the *Pandora* site.

average temperature for the whole period of the dive was likely to result in significant errors in the distance calculations. As a result, the software was modified to use the temperature recorded at the time of each reading so that the velocity was corrected for temperature at each individual reading.

3. Pressure Considerations

It was known that the *Pandora* site was subjected to a considerable tidal range. Initially it was thought that the tidal variation would be insignificant during the course of a dive, particularly as the HPASS calculated relative depths. However, during the analysis of these data, it became apparent that the tide influenced the measurements. As the tide was not monitored during the expedition, the tidal predictions for the *Pandora* site were obtained (Figure 4.21) and used to determine the approximate depth correction over the period of each dive.

A series of tests were then run on these data to determine the variation in the depth measurements on individual transponders on different days and at different times. Figure 4.22 shows the transponder depth readings determined on different days without tidal correction.

Figure 4.23 shows the results of applying corrections obtained from the tidal data to the transponder depths. It is interesting to note that this

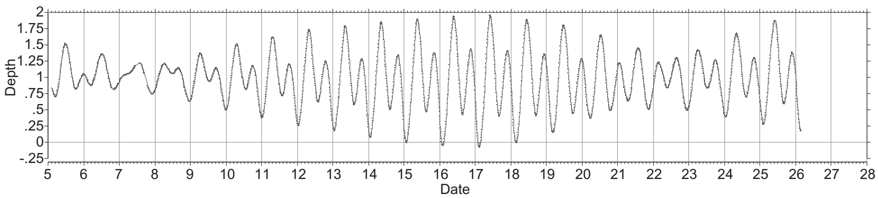


Figure 4.21 Tidal predictions for period of operation on the *Pandora* site.

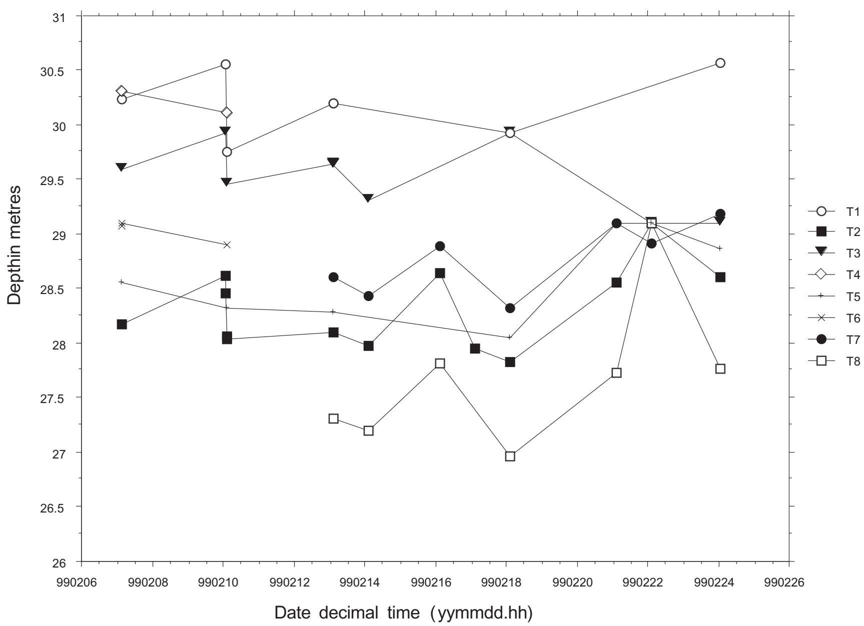


Figure 4.22 Uncorrected depth measurements on the *Pandora* site.

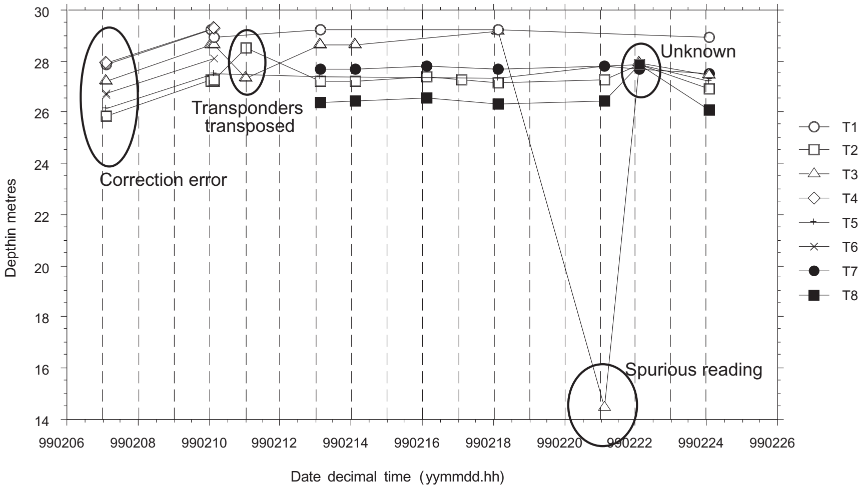


Figure 4.23 Corrected depth measurements on the *Pandora* site.

analysis revealed a number of anomalies in these data that were useful in identifying the sources of errors. For example, note that the depths on February 7 are all systematically too small, indicating a possible error in the use of the tidal predictions. On February 11 it is almost certain that the operator has mistaken T2 and T3, on February 21 at T3 there is a spurious depth reading, and on February 22 there is an obvious anomaly in all but possibly one of the depth readings. These data were rerun using the new tidal corrections applied to all measurements. This resulted in a noticeable improvement in the depth and position residuals.

4. The Adjustment Program

Having developed the HPASSConvert program to a state where it was able to deal with the problems of the processing data from the diver unit, the analysis of the data using the adjustment program was then assessed. At the time of the 1999 *Pandora* expedition, the expedition team was evaluating a program called Site Surveyor, a more advanced version of the Rule Web program. Up to that time HPASS had used Web, but we were aware of its limitations, particularly in handling large data sets. Previously, HPASS-Convert provided output in Web format, and these data were then adjusted using Web and the final results were presented in a text report or graphic DXF format. Peter Holt of 3H Consulting Ltd was approached seeking his assistance with the development of HPASSConvert so that it could be used to import data directly into Site Surveyor. Together with Alec Duncan from CMST, HPASSConvert was programmed so that it exported data in a csv (comma delimited) format enabling these data to be directly imported into Site Surveyor. In addition, the HPASSConvert was modified to take advantage of the layers option in Site Surveyor, which allowed each day's survey data to be placed in a unique layer containing the intertransponder distances in a control layer and the distance to fixes in the fix layer. It was then possible to add that day's intertransponder distances to the previous intertransponder data and then recalculate by simply turning on all the control layers. This progressive adjustment of the intertransponder distances provided more refined and accurate results while indicating if the transponders had been disturbed since the previous measurement and adjustment. Once the intertransponder distances had been adjusted, the position of the transponders was locked so that they took no further part in the point location adjustment, instead simply acting as fixed points. The layer option then allowed all but one set of measurements or fixes to be adjusted. This reduced the processing time while keeping all the measurements in a fixed data set. The process is shown in the flowchart in Figure 4.24.

The flowchart shows the process of adjusting the new intertransponder distances, then locking the transponder positions, and then adjusting these data for the day. This turned out to be an extremely useful process, enabling the manipulation of data on a day-by-day basis.

5. General Results

The final results of the *Pandora* survey were exported from Site Surveyor as a DXF file and imported into ArcView GIS for final graphic presentation (Figure 4.25). A total of 178 points were recorded by 758 measurements using the HPASS system. The final RMS residual error was 35 mm, which is impressive given that the system was operating over measured distances of up to 45 m.

On the overall site plan (Figure 4.25), the system showed a small but significant error in the alignment of the grid system. There were problems with recording features in excavation trenches, as the probe tended to be in an acoustic shadow at the bottom of a hole. The system was modified with a 1-m extension pole that could be attached to the probe and then carefully leveled with a bubble level thus giving a more reliable fix.

It is difficult to represent the overall accuracy of the system in a form that can be easily visualized, particularly on a site where the precise size of the objects is not known and where the positions of objects are not clearly defined. Two examples are illustrated here to attempt to demonstrate the system's accuracy. On the stern section of the site, while surveying the grid

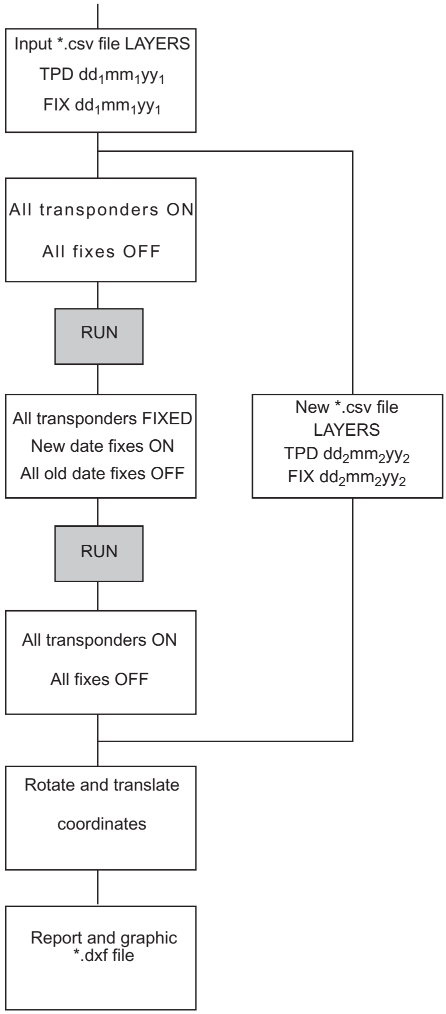


Figure 4.24 Flowchart of HPASS operation.

poles, an abandoned 2-m grid frame was found lying on the seabed in passing, and without great attention to accuracy, HPASS was placed on each of the four corners of the grid. The resulting data have been plotted (see Figure 4.26) to demonstrate the short-range accuracy of the system.

The statistics give an interesting overview of the system. Site Surveyor provides data on the statistics of the system, particularly these data relating to measurement residuals. Using Site Surveyor, the measurements were

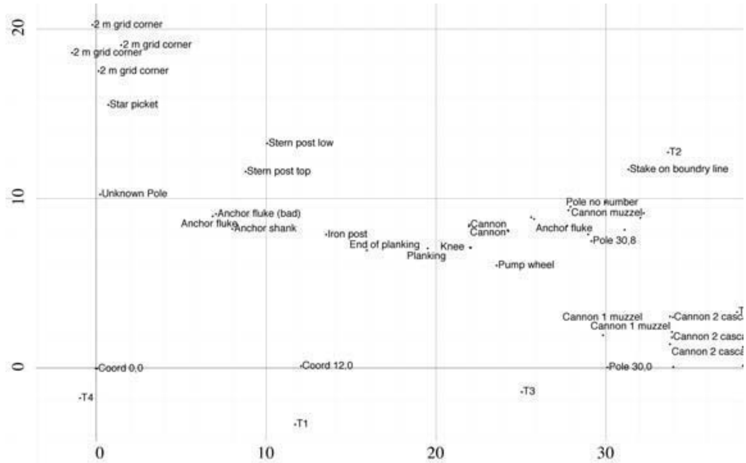


Figure 4.25 GIS of *Pandora* site.

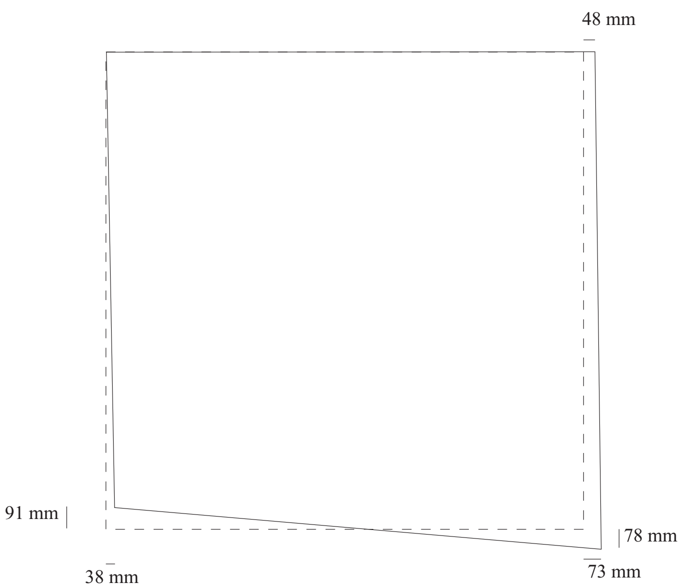


Figure 4.26 Example of HPASS measurement of a 2-m grid square on the *Pandora* site.

processed and measurements with large residuals were rejected, usually any measurement with a residual greater than 100 mm. This allowed a successive manual refinement of the measurements. As a test all the measurements relating to control points were gathered together and an adjustment run on them to determine the best fit for these data. The statistics were as follows:

RMS residuals:	0.034 m
Avg. residual:	0.026 m
Redundancy:	186
Points used:	8
Points ignored:	0
Observations used:	210
Observations ignored:	91

The results show that in the 210 measurements used the average residual was 26 mm. Given that almost half of the measurements were over 30 m this is a very impressive result. We can be certain that the system far exceeds the accuracy of conventional tape-measuring systems, and the only limitation appears to be the problem of acoustic shadowing when the system is deployed in depressions and anomalies that were tide dependent.

Data processing was complex because of the evolving understanding of the problems of the relatively untried system. If the system was to be used again on this site, some form of depth monitoring would be advisable. A simple depth logging system would be an ideal solution where the monitor could be attached to the reference transponder and would record the depth during the duration of the operation of the HPASS system. At the end of the operation the unit can be recovered and the depth and time data downloaded. A correction can be applied to the depths recorded by the HPASS to compensate for the effect of the tide.

B. Roman Bridge at Maastricht

In May 2000, in collaboration with the city of Maastricht, the Rijkswaterstaat, and ROB/NISA, a diving survey was carried out by the archaeological diving team of NISA on the remains of a Roman bridge in the river Maas just south of the St. Servaas bridge. This was a continuation of a survey initiated in 1999 which covered an area of about 400 m^2 revealing three different structures which have tentatively been associated with three phases of the bridge's construction. After utilizing the Sonic High Accuracy Ranging and Positioning System. (SHARPS) system in the 1999 campaign, NISA requested the use of HPASS.

The remains of the bridge were discovered in 1915 as a result of extremely low water levels in the river Maas. The then city archivist, W. Goosen, published the statement that these were the remains of a bridge from the late Roman period. In 1963, ROB was informed of a site known as "de fundering" (the foundation [piles]) which was a navigational hazard for shipping. The highest point was situated 2.4 m below the present water level of the Maas. It was planned to dredge the channel, but the stones were an obstacle that had to be removed. The site was dated to the late third to fourth century Ad by the engraved stones removed as part of this process. These stones had previously been used in an architectural context and then reused as foundation material and possibly as bridge piles. The rest of the remains consisted of heavy oak piles with iron pile shoes, arranged in regular networks, rammed into the riverbed. The project planned to accurately locate and map the remains of the bridge.

1. System Deployment

The Maas riverbed consists of fine mud that quickly silts up the water when disturbed. Even the slightest contact with the riverbed results in loss of visibility. Visibility ranged from 0–80 cm. Water temperature varied from 15–19°C with depths between 3–6 m. The topography was generally uniform, with the major Z-variations occurring to the east of the site, in the main shipping channel. A rope grid 14 (NS) × 28 (EW) m was placed on the site to aid in orientation. Each of the squares was 2 × 4 m and was numbered from A1 (SW) to G7 (NE).

The primary aim of the survey was to re-measure the bridge section surveyed in the 1999 campaign. It was then intended to survey an area similar in size, to the northeast, mapping a series of large stones noted during the expedition. Traditional tape trilateration was carried out in an area immediately north of the 1999 site, providing a comparison of techniques.

Transponders were initially located on the riverbed encompassing the area of the 1999 survey. A survey of the transponder positions was undertaken first to test the geometry of the network. The initial results from the transponder positions survey yielded high error residuals. It was thought that this problem was the result of surface reflection due to the shallow water depth. It was suggested that changing the height of the probe on a fix-by-fix basis would help if this became a major issue (A. Duncan, personal communication). Thus the transponders were lowered to a depth of approximately 3.5 m to compensate for surface reflection. The survey of the 1999 area was completed with reliable results and many residuals as low as 30 mm.

With the completion of the survey of the 1999 area, three transponders, T3, T4, and T5, were moved to incorporate the new stone area discovered northeast of the 1999 grid, approximately 12–15 m from T2. In the Site Surveyor project these were renamed: T3 = T7; T4 = T8; and T5 = T9. Because the survey needed to be extended, three transponders were kept in their original position and the other three moved to encompass the new area. The newly positioned transponders were leveled between 3.5 and 4 m, slightly deeper than the initial survey as this site was in the shipping channel. Two tapes approximately 25 m in length extended in a NS orientation delineating the new stone area. The ends of each of these tapes were buoyed and the transponders placed at these positions.

Deployment of the HPASS in this area was relatively expeditious with up to 60 points or 400 measurements acquired in a dive. Initial post-processing results showed that HPASS could not only determine the relative positions of the stones, but could also plot the four corners of individual blocks. These macrosurvey capabilities were made possible due to the relatively small intertransponder distances and good geometry between the targets and transponders.

The HPASS data were processed using Site Surveyor 2.1.2. One of the ultimate aims of this survey is to integrate acoustic data with geodetic information with constructional detail then projected into it (T. J. Maarleveld, personal communication). These results, used in conjunction with terrestrial surveyed positions of the bridge remains, will eventually be used to illustrate where the bridge crossed the river. Exporting a DXF file to ArcView GIS and then to Freehand so that it could be combined with the manual measurements created the final graphic presentation.

2. Processing in the Field

On site it was found more practical to process each day's data as a single project. The results showed the relative positions of the targets more clearly without the confusion of several layers of points. The operators were also able to identify potential problems in the survey and to re-measure if necessary. Observing the residuals for individual distances and rejecting measurements with high residuals manipulated data. Measurements with high residuals were probably the result of multiple pathways interference. Results indicated that the main errors were multipaths, because the residuals were mainly positive. This means that the acoustic signal, instead of traveling on the straight line path between the transducer and the diver unit (the shortest path), travels along a path where it is reflected from the water surface one or more times. Such paths would be longer than the direct path resulting in a positive and relatively large residual. Thus all measurements with residuals over 100 mm were ignored.

One interesting issue was that most of the depth readings also had a slight negative residual. This may be due to the program assumption that the pressure sensor depth is calibrated for seawater, and although the HPASS program corrects for salinity in the sound velocity, it does not correct for density in the depth. As the Maas is largely a freshwater river, this may be the explanation for the negative residual.

The deployment of HPASS in The Netherlands and on *Pandora* further proved the system's capabilities in poor visibility. In its present form, HPASS presents an interesting alternative solution to conventional underwater surveying techniques. The system has a number of advantages: it is fast; it is accurate; it can be operated in low visibility and relatively deep sites; the speed of operation, once the transponders have been deployed, is at least as fast as a three-tape trilateration system; it gives an accurate and more reliable z-coordinate than the three-tape system; there is a considerable saving on post-dive processing; and there is reliable assessment of errors.

VII. COMPARISON OF TECHNIQUES

In Chapter 6 photogrammetric surveying techniques will be discussed. There are some interesting comparisons of the efficiency, relative merits, and accuracy to be made between standard tape trilateration, acoustic measuring systems, and photogrammetric techniques (Green and Gainsford, 2003).

Reports of recent underwater surveys using standard tape trilateration, photogrammetric techniques using PhotoModeler (Green *et al.*, 2002; Holt, 2003), and an acoustic system, HPASS (Green and Souter, 2002), raised questions about the efficiency, relative merits and accuracy of the various methods. In 2002, the Department of Maritime Archaeology at the Western Australian Maritime Museum, in conjunction with James Cook and Flinders Universities, conducted a practicum as part of a postgraduate diploma course. This course was designed to teach students the practical aspects of maritime archaeology and one of the student projects was to examine these survey issues. The assignment required the use of Site Surveyor in trilateration (on land and under water), PhotoModeler (on land and under water), and HPASS. The results of this work prompted the decision to carry out further studies and collate the results. One system not evaluated at that time was trilateration using control points. After the course was over, the system was further evaluated in an underwater environment (Green and Gainsford, 2003).

The trials were based on a rigid, 2 m^2 photo tower (Figures 4.27 and 4.28) which was used as a calibrated testbed for the project so that intercomparisons of land-based and underwater measurements could be made. Eighteen targets were set on the tower, eight (1–8) on the base, four (9–14) at about 0.6 m above base, two (15 and 16) at 1.1 m above base, and another two (17 and 18) at 2.2 m. The students were divided into two teams to carry out measurements in the different environments with the different systems.

1. Definitions

It is important to understand the terminology used in survey because, unless one is quite clear what is being said, a great deal of confusion can occur. There are a number of basic terms that need to be defined. The following are based largely on Kaye and Laby, (1966).

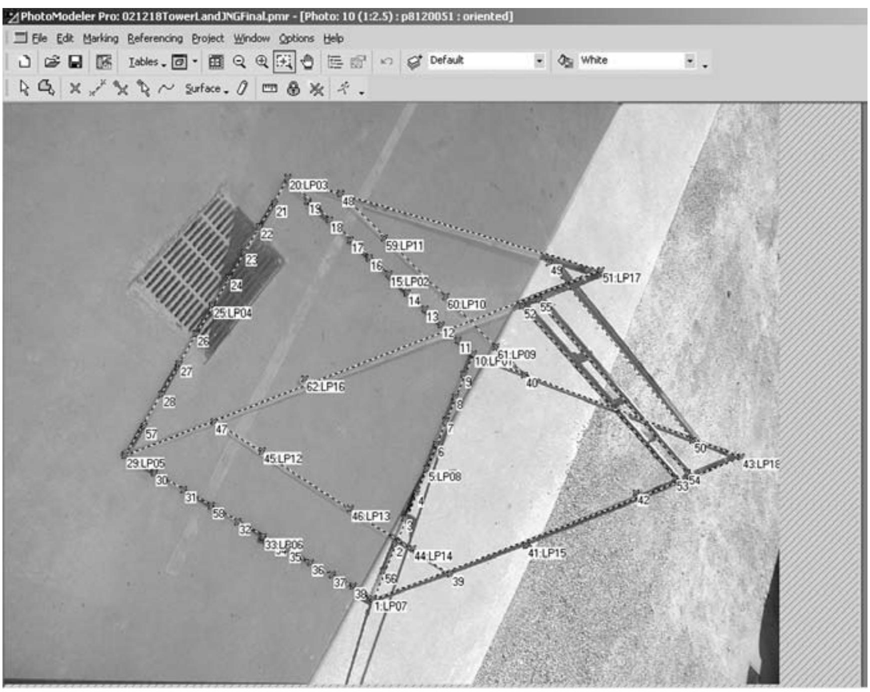


Figure 4.27 Photo tower on land shown in the mark-up mode of PhotoModeler interface.

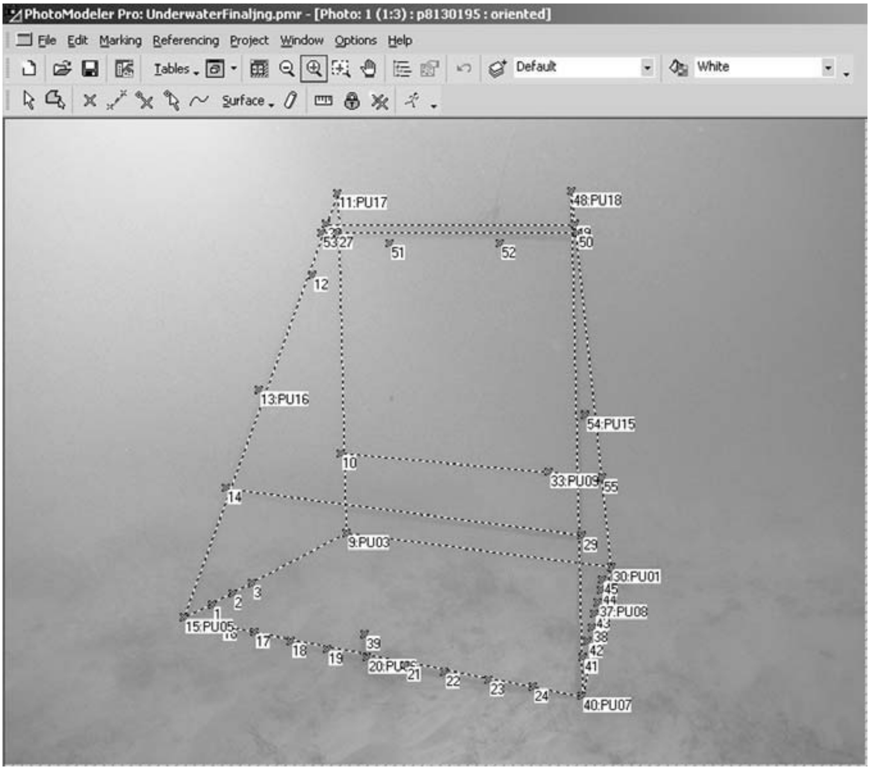


Figure 4.28 Photo tower under water, showing the mark-up mode of PhotoModeler interface.

Accuracy—In simple terms accuracy refers to the closeness of measurements to the true value. Imagine if a fixed distance is measured 100 times and the frequency histogram is plotted, then a binomial distribution (sometimes referred to as a Gaussian distribution) as shown in Figure 4.29 would be expected. If the curve was skewed, then problems with the recording probably due to a systematic error would be expected. We can now assess the accuracy of a measurement through the standard deviation, which includes 68% of the measurements lying less than one standard deviation from the mean (two standard deviations states that the measurement has a 95.5% probability).

Binomial distribution—A binomial distribution is a frequency distribution of the possible number of successful outcomes in a given number of trials in each of which there is the same probability of success.

Precision—In simple terms precision is the closeness of duplicate measurements to each other. The precision of measurements is affected by random errors (usually poor reading of tape). Other errors include gross errors caused by transcription errors and systematic errors that are caused by a stretched tape or an offset at the zero end of the tape. The random errors are usually considered to affect the precision where the gross and systematic errors affect the accuracy.

Repeatability—Repeatability and reproducibility are subdivisions of precision; the first relates to measurements made by same operator and same equipment, the second the same measurements by different operators. Generally they refer to how capable a system is of producing the same result when the measurements are repeated.

Normal distribution—A normal or Gaussian distribution is a commonly employed theoretical frequency distribution (Figure 4.29). Two standard measurements of a frequency distribution are the mean ($\bar{x}$) and the variance (σ^2).

Mean—The average of the values.

Root-mean-square—This is the mean of the square root of squared values or, in other words, it is the mean of the values ignoring the sign.

Variance The variance (σ^2) is defined as:

$$\sigma^2 = \frac{1}{n}\sum(x - \bar{x}^2)$$

Where x is value, $\bar{x}$ is the mean, and n is the number of measurements.

Standard deviation—The standard deviation s is the square root of the variance, sometimes called the root-mean-square (RMS) value and is given by:

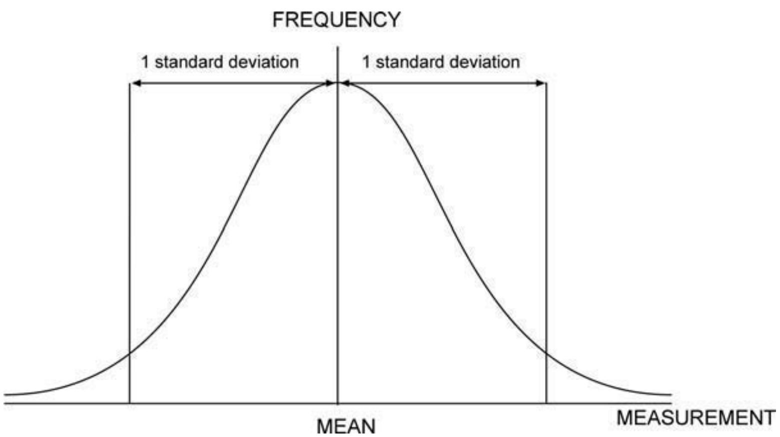


Figure 4.29 A typical normal or Gaussian distribution.

$$s = \sqrt{\frac{\sum (x - \bar{x}^2)}{n}}$$

2. Survey Rationale

The survey required a system that allowed measurements to be made on land and under water and that the results could be easily compared. The photo tower was selected for the project because it was rigid, easily collapsed for transportation, and had calibrated targets on the surface of the framework. As different systems would be used both on land and under water, it was also necessary that the system could be transported from the terrestrial to the marine environment without undue difficulty. Because the targets on the photo tower were suitable for measurement using the different systems, it was then relatively easy to compare these data. The tower was also appropriate because it had considerable vertical elevation so that an assessment could be made of both the horizontal and vertical measurements and the relating accuracy. Bathers Bay was selected for the underwater work as it was close to the Department of Maritime Archaeology (about 500 m), reasonably sheltered, and with a hard sandy bottom that gave good visibility while divers were working on the survey.

In the tape-measuring system (trilateration), there are two basic methods of conducting a survey: either by measuring the interpoint distances or by using control points and making measurements from the control points to points of interest. In the interpoint measuring system, where the measurements are made without control points, there is the problem that, as the number of points increases, the number of measurements rapidly become unmanageable (Table I illustrates the problem). Duncan in Atkinson *et al.* (1988) suggested that in these types of calculation (least-squares) it is more useful to measure the absolute minimum necessary to define the station coordinates. If only the minimum number of distances have been measured, the procedure will still be able to calculate the coordinates. The minimum number of distances required to define the coordinates of k stations is 2k—three for a two-dimensional fix. However, for a three-dimensional fix Holt (personal communication)suggested that it is 3k, ignoring redundancy. Thus it is possible to reduce the number of measurements considerably. In the second system control points are used. This system is commonly used in archaeological survey work, particularly excavations, where there are usually a very large number of points of interest that become uncovered and therefore need to be surveyed. Because the control points remain in place during the survey and generally are rigid points outside the excavation, each position is located by a series of measurements equal to the

Table I

The relationship between the number of points and the number of measurements required if every inter point distances to be measured.

No points	Number of measurements
4	3 + 2 + 1 = 6
5	4 + 3 + 2 + 1 = 10
6	5 + 4 + 3 + 2 + 1 = 15
7	6 + 5 + 4 + 3 + 2 + 1 = 21
8	7 + 6 + 5 + 4 + 3 + 2 + 1 = 28
9	8 + 7 + 6 + 5 + 4 + 3 + 2 + 1 = 36
10	9 + 8 + 7 + 6 + 5 + 4 + 3 + 2 + 1 = 45
11	10 + 9 + 8 + 7 + 6 + 5 + 4 + 3 + 2 + 1 = 55
12	11 + 10 + 9 + 8 + 7 + 6 + 5 + 4 + 3 + 2 + 1 = 66
13	12 + 11 + 10 + 9 + 8 + 7 + 6 + 5 + 4 + 3 + 2 + 1 = 78
—	etc.
100	4950
101	5050

number of control points, therefore involving far fewer measurements than the interpoint system. The main issue with this type of survey is the question of how many control points should be used. Obviously, to obtain a three-dimensional coordinate the very minimum number is three (there are also issues relating to vertical accuracy which will be discussed later). With three measurements, one cannot estimate error or reliability. If one makes four measurements it is possible to estimate the accuracy of the point or fix and determine if one measurement is incorrect. Five measurements increases the reliability of the fix and the error estimation. So there is usually a compromise between the number of measurements to any one point (three is inadequate; four is just adequate, but usually requires the fix to be re-measured; five is good but is starting to become a major "production," etc.).

One of the major considerations in any surveying technique is the estimation of errors (see Holt, 2003). There are a number of different types of errors that occur in survey work, but for standard tape-measurement systems the errors are relatively simple. They include:

1. Errors due to misreading the tape; these can range from very large (gross errors) to very small. The gross errors are usually caused either by a transcription error or a serious error in the tape caused by snagging. Readings with these sorts of errors can be simply disregarded.

2. Random errors usually caused by differing tension on the tape, currents, lack of precision in measurement, etc.
3. Systematic errors usually caused by a stretched tape.

Thus, one can generalize and say that when a measurement is clearly wrong (a gross error) there will be a large residual and this reading can be ignored. Where the residual is small, it is likely that that the error is either random or a transcription error. It is generally not possible to tell the difference between these two causes and, therefore, it is not possible to compensate for them. The result is, therefore, a poor fix.

In the case of the photogrammetric method, errors are more difficult to assess. The two main errors are the camera lens calibration and the point positioning accuracy. It was generally found that there were larger residuals in measurements that were close to the edge of the photographic image. This suggested that the calibration is less rigorous at the extremities of the image and that in some cases it was difficult to observe targets from particular views, thus reducing the accuracy of the fix.

With the HPASS the question of accuracy have been discussed in Section VI above and by Green and Souter (2002). It was again found that the depth measurements created problems that required the application of a tidal correction.

The comparison of accuracy is always a complex issue, particularly where there are two different measuring systems. The procedure adopted was to indicate in the distance-measuring system what the average residuals were for the measurements and in the optical system what the average tightness was for the points (points are computed by intersection of light rays and due to measurement errors these rays do not necessarily intersect, thus the tightness is a measure of the largest distance). In addition, because there were various methods used and it is felt that the land-based tape measurement will give the best results, it has been assumed that these measurements were the most accurate. Therefore the computed X, Y, and Z coordinates of the various methods have been compared with the land-based results to give an idea of the relative accuracy.

3. Site Surveyor on Land

The tower was set up in the car park of the Maritime Museum (see Figure 4.27). Two teams then measured the intertarget distances using a predrawn measuring matrix or pro forma. This matrix was used both on land and under water and provided a system which ensured that all necessary measurements were recorded. A total of 162 measurements were made between the 18 targets, and this took a total time of 96 minutes. Starting at the first target measurements were made to all of the other points (17), then the second point was selected and measurements were again made to all remaining unmeasured points (16), and so on, until all measurements were completed.

These data were then transferred from the record matrix to an Excel spreadsheet and saved in a csv format so that these data could be imported directly into Site Surveyor. This method was slightly faster than using these data input interface in Site Surveyor where the interpoint measurements require the 18 points to be set up and then the 162 measurements entered in Site Surveyor graphically, which is time-consuming.

These data were processed in Site Surveyor with the base of the tower acting as the coordinate system. Point 1 was the origin, point 3 was the X-axis, and point 7 the Y-axis. By fixing these three points it was possible to nominate the coordinate system. Thus point 3 was given X equal to the distance from 1 to 2, Y = 0, and Z = 0. Point 7 was given Y equal to the distance from 1 to 7, X = 0, and Z = 0. The program was then run and the residuals examined. It was noted that one measurement (3 to –7 = 3.826) had a residual of 0.995, almost certainly a misreading of 2.826. Ignoring this measurement and a second poor quality measurement, the adjustment gave an average residual (AR) of 0.004 m and RMS residual of 0.006 m. Transcribing and processing data took about 30 minutes.

4. Site Surveyor Under Water (Interpoint Survey)

The underwater survey was conducted in the same way as on land, with a pro forma recording sheet and the same tape measures. The tower was erected and then the survey was carried out taking 86 minutes (the shorter time probably reflects the fact that under water it was easier to measure to the high points on the tower than on land where a ladder was required).

The same processing procedure was used, however, the results produced more errors. All measurements with residuals greater or equal to 0.100 m were ignored (15 measurements), the largest outlier 3 to 4 = 3.00 had a residual of 1.998 m, obviously a misreading of the distance 1 m. The other errors were inexplicable and were due to either transcription or measurement errors. Presumably, the number of errors reflects the difficulty in recording under water compared with on land. The resulting adjustment gave AR = 0.006 m and RMS = 0.008 m. Transcribing and processing data took about 30 minutes.

5. Site Surveyor Under Water (Control Point Survey)

In this situation, five control points were established a few meters away from the base of the tower and the intercontrol point measurements were made prior to erecting the tower (thus avoiding tower interference with the tape measurements). The tower was then erected and measurements were made to each of the targets from the five different control points. This involved 15 intercontrol point measurements and 80 control point measurements (total of 95 measurements). The underwater recording took 58 minutes with about 15 minutes used to set up the control stakes. Transcribing and processing data took about 30 minutes. The resulting adjustment showed AR = 0.008 m and RMS = 0.018 m.

6. PhotoModeler Land

A standard, previously calibrated Olympus Camedia 4050 digital camera was used for the photography. The use of the PhotoModeler for land and underwater survey work has been described by Green *et al.* (2002). The only difficulty on land was the problem of achieving a high aspect view of the tower. Eight low oblique photographs were taken from ground level at 45° intervals around the tower. Using a tall step ladder a similar set of eight high oblique photographs was obtained. The whole recording operation took about 10 minutes. Photographs which gave good coverage of all the targets, were as far orthogonal as possible, and were both high and low oblique were then selected. Downloading data and processing took about 25 minutes. Results showed an average tightness (AT) of 0.009 m with a standard deviation (SD) of 0.005 m.

7. PhotoModeler Under Water

The same digital camera was mounted in an underwater housing with a water-corrected lens which had previously been calibrated (this system has been described by Green *et al.*, 2002). Essentially the same set of photographs that was taken under water (see Figure 4.28) was taken on land, but with the inclusion of a vertical view of the tower from above (not possible to easily obtain on land). The whole recording operation took about 10 minutes. The only difficulty experienced under water was the problem with weed gathering around the base of the tower and obscuring the targets. Downloading data and processing took about 25 minutes. It was noted that target points close to the edge of the frame of the photograph tended to give large residuals. This is thought to be due to the calibration system. Results showed AT = 0.020 m and SD = 0.014 m.

8. HPASS

The application of HPASS has been described in Section VI above and by Green and Souter (2002). In these tests, the transponders were set up on their tripods around the tower and the diver unit was placed on the target points. The operation, including positioning the tripods, placing the transponders in the tripods, erecting the photo tower, taking intertransponder distances, and taking measurements took 95 minutes of which 20 minutes was involved in the survey itself. Downloading and processing data took 20 minutes. The resulting adjustment resulted in AR = 0.016 m and RMS = 0.032 m.

A. Results

These data were processed either with Site Surveyor or PhotoModeler software. It was decided to process these data so that each system had exactly the same coordinate system. In that way it would be possible to compare the accuracy of the systems.

Table II–VII shows the values of the coordinates of the targets for the six different methods of recording. The 18 targets are given X, Y, and Z coordinates where point 1 = (0,0,0) the origin (a corner of the base of grid frame), point 3 the X-axis, and point 7 the Y-axis. It was noted that there was a large systematic error in depth using HPASS.

Tables II through VII show intercomparison of coordinates from the different systems.

Table II

Comparison of techniques with hand measurement on land.

Type od Survey	Measurement	X	Y	Z
UW Tape	Mean	–0.008	–0.006	0.025
	SDEV	0.015	0.009	0.015
	Overall SD	0.020		
Control Point UW	Mean	0.018	0.010	0.031
	SDEV	0.040	0.015	0.047
	Overall SD	0.037		
HPASS	Mean	–0.004	–0.028	0.028
	SDEV	0.027	0.023	0.076
	Overall SD	0.053		
PhotoModeler on Land	Mean	0.006	0.000	0.001
	SDEV	0.019	0.009	0.011
	Overall SD	0.014		
PhotoModeler UW	Mean	0.014	0.015	0.000
	SDEV	0.019	0.015	0.017
	Overall SD	0.018		

The quality of the measurements in Table II; first the arithmetic mean for the X, Y, and Z coordinates, the standard deviations errors for the X, Y, and Z coordinates, and the standard deviation of all the measurements.

B. CONCLUSIONS

The results of this investigation are very interesting, although it must be remembered that the investigation was based on a small site with a large vertical component. It is clear that the following conclusions will not necessarily apply to very large or a very small sites. Additionally, the visibility and sea conditions were good, visibility was about 10 m, and the water was calm and a temperate 20°C, thus making the recording easy and reliable. Therefore, in this situation the general conclusions for underwater work are that PhotoModeler is at least as accurate as underwater hand measurement, but considerably faster, thus saving in time and making the recording much more efficient (an aspect, previously noted by Green *et al.*, 2002), which is particularly relevant for deep-water sites where time is at a premium (see Table III for the comparison of efficiency). In this situation the underwater hand measurements (interpoint) took 86 minutes, compared with PhotoModeler where the underwater image capture took 10 minutes. Obviously PhotoModeler only works in good visibility and at relatively short ranges (in Turkey, where the water was extremely clear, PhotoModeler was used to survey distances around 20–40 m, (Green *et al.*, 2002), however, it must

Table III
Accuracy and Performance Time for the Different Systems.

Survey type	Approximate accuracy (mm)	Time to survey (minutes)	Set up survey (minutes)	Processing (minutes)	Total (minutes)
Interpoint hand measurement land	0	96	0	30	126
Interpoint hand measurement under water	20	86	0	30	116
Control point hand measurement under water	37	100	10	30	118
HPASS	53	20	30	20	70
PhotoModeler land	14	10	0	25	35
PhotoModeler under water	18	10	0	25	35

be remembered that PhotoModeler requires discrete targets or points that can be clearly identified in a variety of photographs. Thus, objects that are smooth and featureless or "fuzzy" do not work well with this system and the photo tower experiment hides this problem. This is discussed in Green *et al.* (2002). HPASS performed remarkably well, with an SD = 68% of underwater interpoint hand measurements but with a recording time of 20 minutes. However, this must be offset with the time to set up the control transponders (about 30 minutes). Obviously this situation would improve as the number of points increased because, like the hand-measured control points, the system becomes more efficient with a large number of mea-

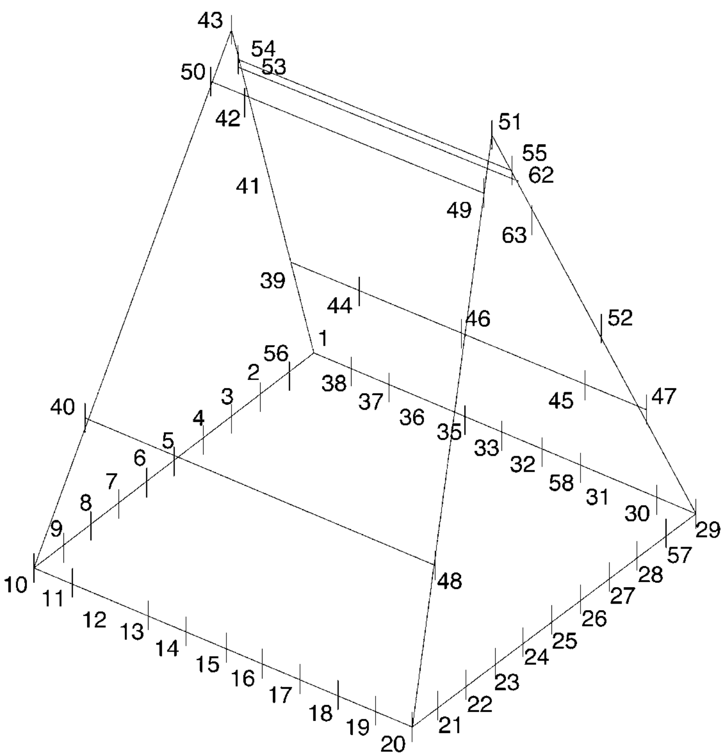


Figure 4.30 A perspective view of the photo tower obtained by exporting from PhotoModeler to the three-dimensional graphics package Rhino. This image is a "screen grab" and thus low quality, although this image can be utilized at high resolution. Note the dimensions are to scale.

surement points. This is contrary to the interpoint system which becomes less efficient as the number of points increases (as described previously). Additionally, HPASS will work in poor or almost zero visibility and. Table II summarizes the conclusions, but processing was common to all systems with differences in time. This information has also been included.

Finally, one important addition to processing data in this manner is the ability to extract the information in a three-dimensional graphical format. Thus a DXF format allows these data to be imported into a wide range of two- and three-dimensional packages such as AutoCAD and Rhino. Figure 4.30 shows a DXF export in Rhino viewed from the perspective viewpoint.

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Chapter 5

Subsurface Survey

I. CLOSE-PLOT MAGNETOMETER SURVEY

A close-plot magnetometer predisturbance survey was first tried on the Kyrenia shipwreck in Cyprus (Green *et al.*, 1967) in an attempt to obtain information about the material buried on the site. A grid was set up over the site and the magnetometer detector head was placed at regular intervals on the grid to measure the local field strength. By plotting the field intensity, the extent of the magnetic anomalies on the site could be determined. The diver who placed the magnetometer detector head was equipped with aluminum aqualung cylinders and the ferrous component of his equipment was kept to a minimum so that it did not affect the measurements (Figure 5.1).

Tests were made to determine how close the operator could work to the detector before it was influenced by the equipment; the tests showed that the diver needed to be at least 10 m away from the detector head to avoid having any effect. The operator was also equipped with voice communications which enabled the surface operators to advise when a reading had been made, and the diver to advise when the detector was in place.

Initially the detector was set on the seabed in order to take the readings. Later it was found that it was better to have the head about 0.5 m above the seabed to filter out small, surface ferrous material. Readings were made at 2-m intervals over an area of 28×10 m. A further series of readings was taken at 0, 1, 2, 3, 5, and 10 m above the bottom, so that an estimate of the mass causing the anomaly could be made using the formula discussed in Chapter 3 Section V.A. The results were plotted as a magnetic field inten-

Figure 5.1 Operator using nonferrous diving equipment to conduct a close-plot magnetometer survey on the Kyrenia wreck site. See Figure 5.2. (Courtesy of Kyrenia Wreck Excavation.)

sity contour diagram. This showed two sharp magnetic anomalies, which were thought to be due partially to the amphora cargo and partially to possible buried ferrous material (Figure 5.2). This same method has been used on the Cape Andreas tile wreck (Green, 1971, 1973), the *Amsterdam* survey (Marsden, 1974; Figure 5.3), and at Padre Island, TX where a computer-drawn close-plot magnetometer survey was carried out (Arnold, 1981).

There are many tricks of the trade in working magnetometer surveys. In anticipating a close-plot survey, one should seriously consider obtaining advice about making the survey and the interpretation of these data. It is essential that proper reference points are set up to ensure that the diurnal variation can be monitored properly and that, if the survey proceeds over a number of days, each day's survey can be linked to previous work.

II. METAL DETECTOR SURVEY

At the time of the Kyrenia survey, it was proposed that a metal detector survey should be conducted over the same area as the magnetometer survey

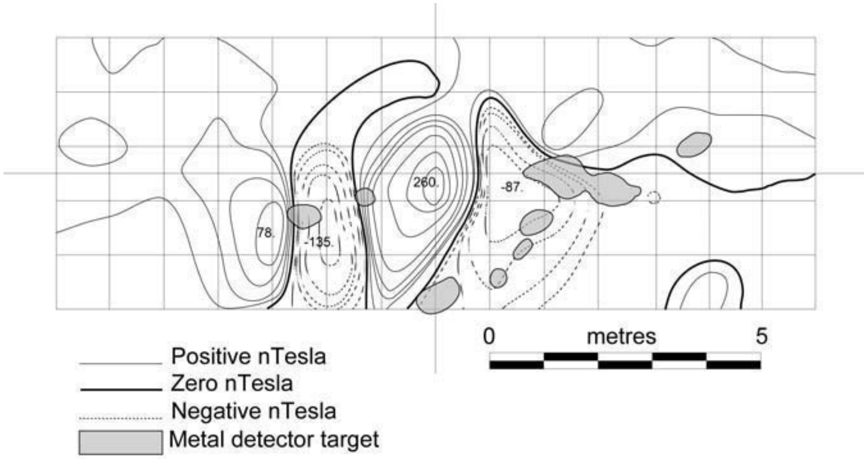


Figure 5.2 Magnetic close-plot survey in Kyrenia showing the metal detector survey superimposed on the contour plan. Shaded areas indicate metal detector targets. Z1 and Z4 correspond to magnetic anomalies whereas other metal detector targets do not correspond to magnetic targets. This indicates nonferrous targets. Subsequent excavation showed these targets were lead sheathing.

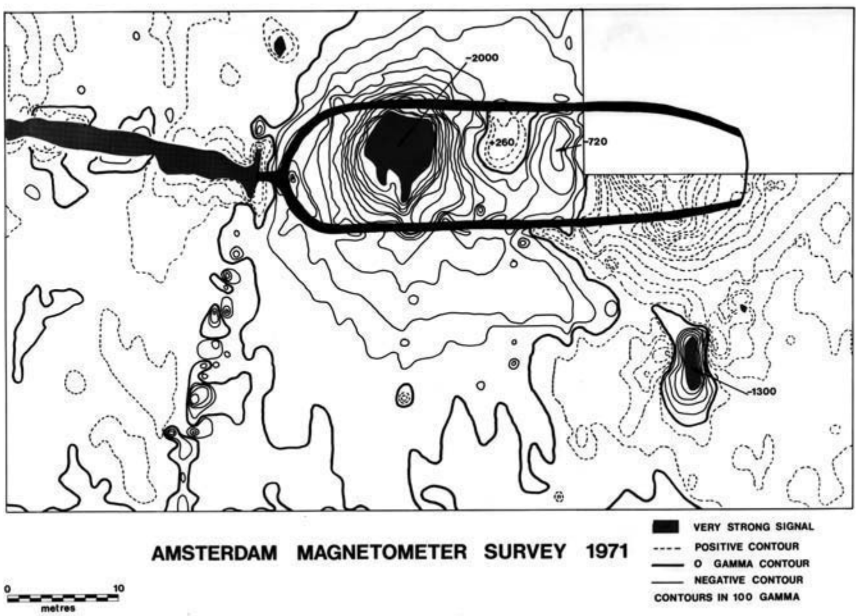


Figure 5.3 Magnetic close-plot survey *Amsterdam* wreck site, Hastings, UK. This detailed magnetic survey shows a number of interesting anomalies. The very strong linear feature running from upper left to the bow of the vessel was an iron water pipe. The large isolated anomaly, lower right, is a very large iron object, possibly a cannon or anchor. The faint linear feature running from the bow of the vessel to the lower left is possibly a mast. The large iron concentration in the center of the vessel is likely to be an iron shot locker.

on the grounds that the metal detector (a pulsed induction machine; Foster, 1970) could locate both ferrous and nonferrous material. Thus it would be possible to differentiate ferrous material found on the magnetometer survey from the ferrous and nonferrous targets found on the metal detector survey. The results of the survey clearly showed metal targets occurring on the metal detector that did not occur on the magnetometer survey. These items later proved to be the lead sheathing of hull. Other targets which appeared in both surveys proved to be large iron concretions (see Figure 5.1, note metal detector targets Z5–Z10 are nonferrous targets, whereas Z1 and Z4 are ferrous). A similar approach was made with the *Amsterdam* survey (Figure 5.2), which also turned up large nonferrous targets (Marsden, 1974).

A close-plot metal detector survey was used on the *Santa Maria de la Rosa*, where the metal detector was used to locate small, buried metal objects, but did not reveal the expected iron and bronze guns on the site (Green and Martin, 1970).

In the *Amsterdam* survey, the instrument reading was recorded and used in a dot density diagram to indicate targets. In the other two surveys, the instrument was used to delineate the areas where strong signals were recorded. These were plotted on the plan.

III. PROBE SURVEY

Probes have been widely used to determine the extent of a buried site. At Kyrenia, Cyprus (Green *et al.*, 1967), a simple iron-rod probe was used to determine where material was buried (Figure 5.4a). The site was probed at the intersections of the grids, and if there was no contact, the position was re-probed in the neighborhood of the grid intersection. If there was a contact, and usually the operator was able to distinguish if it was ceramic, wood, stone, etc., this was recorded. If there was no contact, this was also recorded. By working systematically, it was possible to clearly delineate the area of the wreck site. Later, at Cape Andreas, a contour probe survey was made to determine the extent of the buried cargo (Green, 1971). In this case, the depth of contact was measured and recorded, so that a contour plot of the site could be made (Figure 5.4b). One of the problems of using a probe under water is that it is often difficult to force into the ground, particularly when the bottom is clay. An effective way of resolving this is to pump air or water down a tubular probe enabling the probe to penetrate quite easily to great depths. The tube can be an ordinary, small-bore, steel water pipe and the air or water pressure does not need to be very high to have the required effect.

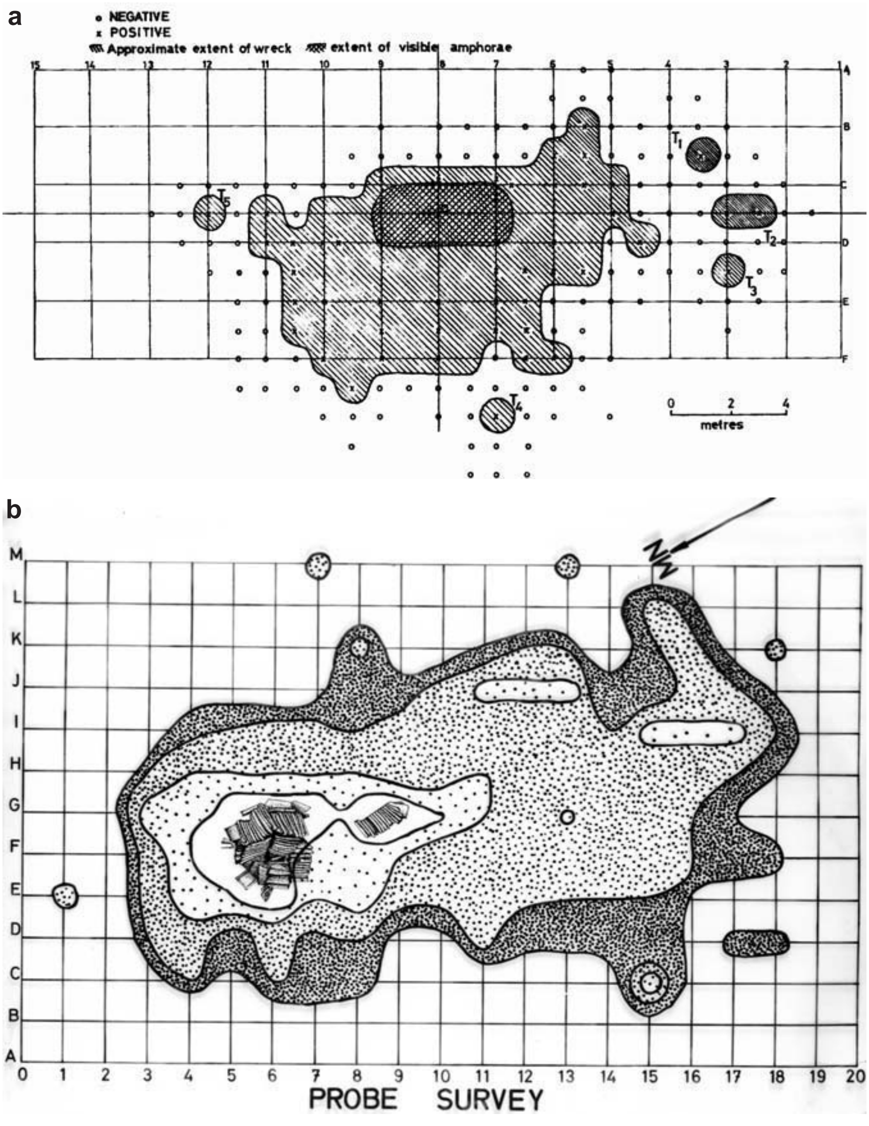


Figure 5.4 Probe survey: (a) Kyrenia and (b) Cape Andreas. The simpler Kyrenia survey indicates the extent of the site, whereas the more thorough Cape Andreas survey indicates the depth of burial.

When working in muddy or sandy situations on a wreck site where the archaeological remains are likely to be deeply buried, some form of probe survey can be advantageous. Provided the probe is used sensibly, the extent of the buried site can be determined, and this can be very important in planning an excavation. The visible site may only be 10% of that buried, for example, which will have major implications on the planning of the excavation. Additionally, with careful probing it may be possible to determine the location of the bottom of the hull of a site, thus giving an idea of the depth of material on the site. Used sensibly, probing is unlikely to damage anything except the most fragile material and potential harm can be kept to the absolute minimum by not probing too violently.

IV. GROUND-PENETRATING RADAR

Ground-penetrating radar (GPR) is generally applied on land for detecting subsurface anomalies. This system uses pulses of ultra-high frequency radio waves (microwaves) that are projected into the ground through an antenna. The transmitted energy is reflected from various objects depending on their conductivity and received by the antenna. Recently an ultra-wideband (UWB) GPR has been developed. This is basically an advanced form of GPR that operates by producing billions of short-duration, low-powered radio frequency pulses. The GPR consists mainly of a PC for storing and viewing the present measurement and a dipole antenna unit with send and receive antenna. The system sends short pulses in the range of nanoseconds and uses a synthetic sampling on receive. In a post-processing step it is possible to view any slice in the three-dimensional data volume. As the signal analysis is done in a near sensor fashion, it includes the physical properties of electromagnetic waves, especially polarization effects and resonance effects.

GPR has been used in a wide range of archaeological situations, however, because the high-frequency radiation cannot penetrate seawater, it is not applicable under water or where material lies inundated in a seawater environment.

Chapter 6

Photogrammetric Techniques

I. SITE RECORDING

Photography can be used to record the relationships between artifacts on the site and help in the production of site plans, thus complementing conventional survey work. In other cases photography can be used for photogrammetric purposes to obtain measurements and as the primary method for producing site plans. Photogrammetric techniques include multiviewpoint photogrammetry, where data from multiviewpoint photographs are manipulated to obtain three-dimensional information; and stereophotogrammetry, where three-dimensional information is obtained by observing the site stereoscopically.

There are a number of different types of recording photographs:

1. Photographs of small-scale details showing groups of artifacts or sections of structure
2. Survey photographs showing the topographical relationships between groups of artifacts
3. Photomosaics which are used to show large areas that cannot normally be covered in a single photograph
4. Photogrammetry which enables accurate measurements to be made from the photographs
5. Stereophotogrammetry in which accurate measurements are made from stereophotographic pairs

II. SMALL-SITE SURVEY

The ordinary, graduated measuring rod placed against an object gives a ready reference to overall length. It has the additional advantage of being portable, but its major drawback is that it is one-dimensional. The one-dimensional scale works reasonably well with an object like a cannon, or in the case of an object which is two-dimensional, and the camera is orientated at right-angles to the plane of the object. However, as soon as a perspective view occurs, problems arise because the scale is only correct in a plane at right angles to the optical axis of the camera passing through the scale. It is more useful, therefore, to use a two-dimensional scale like a square grid frame or a cross rod, even though these are more awkward to handle under water (Figure 6.1, note in this case it is a three dimensional grid frame). The square grid placed over or on an object can be used to orientate the camera so it is perpendicular to the frame. The grid can also be used to estimate the correct flying height or camera-to-subject distance by working out beforehand what the relative size of the grid square should be in relationship to the frame of the viewfinder. The camera–grid frame distance can then be adjusted until the grid frame is approximately the correct

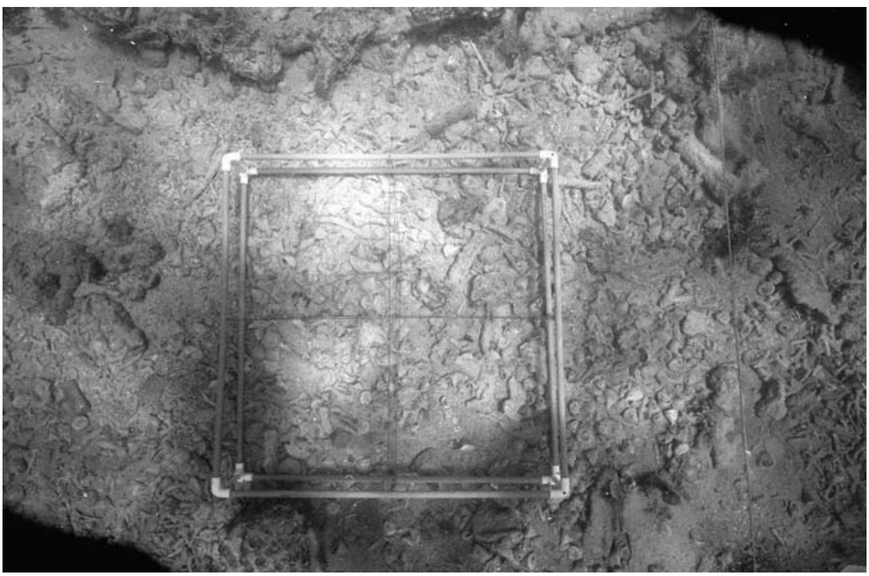


Figure 6.1 Cross-hairs grid frame used to ensure vertical photograph. The photographer attempts to align the cross-hairs on the grid frame thus ensuring the camera is vertically above the frame.

size in the viewfinder. If necessary, the viewfinder can be opened up and a clear film inserted with the correct size grid square drawn on it. The grid can then be viewed through the viewfinder and the flying height adjusted to match the predrawn grid on the film.

In most cases it will be preferable to take a vertical photograph of the grid, because this will greatly simplify the processing of the information. Where the view is not exactly at right angles to the grid frame, the photograph will have to be rectified or a perspective grid drawn on the photograph. These techniques will be discussed later, but it should be remembered that the grid frame must lie in the plane of the object for the scale to be correct.

A. Site Surveying Using Grid Frames

The use of a two- or three-dimensional grid frame to produce artificial control as an application for underwater work was a technique suggested and described by Williams (1969). This technique was initially for land archaeology but was later modified for underwater work (Williams, 1972). Two of the most common two-dimensional grid frame shapes are a cross and a square. The former has various defects including a lack of rigidity, but is easy to carry disassembled and assembled under water. The grid square, on the other hand, is rigid, but it is relatively difficult to carry and to assemble or disassemble.

The grid frame, when photographed on flat terrain, can be used to construct a perspective grid on the photograph. It is important to ensure that the plane of the grid lies in the plane of the terrain, otherwise the scale will be incorrect.

This use of the underwater perspective photograph and grid frame is limited. The technique was developed for the land situation where it is very difficult in normal circumstances to take high vertical photographs of a site without using a cherry picker, balloon, photo tower, aircraft, or other form of flying machine. Under water, the diver's three-dimensional independence usually makes it feasible to obtain almost any viewpoint. The only physical limitations may be where the water is too shallow to allow an adequate camera-to-subject distance to include the whole view, or where the underwater visibility is restricted. This technique has largely been superseded by PhotoModeler and other computer-based programs. But where a more simple solution is required, it may well be advisable to make a photomosaic. It is usually preferable in the underwater situation to take a vertical photograph rather than an oblique one. The perspective technique is therefore mostly applicable in a situation where a vertical photograph has inadvertently been taken from an oblique viewpoint. Usually the underwater camera operator, with skill and practice, can take a reasonably true vertical photograph of a grid frame. However, unless special precautions are taken, it is unlikely to be exactly vertical, although it will normally be within 10°. To convert this to a true vertical, a perspective grid may be constructed and the details transferred to a true plan (as described previously), or the print can be rectified in an enlarger to correct the perspective distortion (see the following). Again, the conversion of photographs to a digital format opens up enormous possibilities in the area of modification and scaling of images. Photoshop is one of the most widely used computer programs that is both sophisticated and flexible enough to do this.

Baker (1984) has used an interesting technique to obtain a vertical photograph of a three-dimensional grid square. In this method, thin lines were attached between opposing midpoints of the upper and lower sides of the squares of the grid frames. Because the crosses on each square are symmetrical, if the photographer lines up the cross-hairs then the camera position will be vertical to the grid frame (see Figure 6.1). However, with good manipulation of the camera this may well be an unnecessary complication. At the same time it is more relevant to level the grid frame to some meaningful plane on the site rather than be concerned that one is simply trying to obtain a good vertical photograph of a randomly orientated grid frame.

III. PHOTOMOSAICS

This section deals with noncomputer application of photomosaic work. In Section III.H issues relating to the application of computers to photomosaics will be discussed. However the fundamental principals of the photomosaic apply in both computer- and noncomputer-based applications.

Visibility under water is scarcely comparable to that on land due to the effects of suspended matter (sediments and plankton) in the water and of scintillation caused by variations in the refractive index of the water. As a result, underwater photographs rarely have the clarity and sharpness found in photographs taken in air. If this is the norm, there are other factors which heighten the complexities of obtaining a clear underwater picture. If, for example, an overall vertical photograph of a 30-m long wreck site is taken using the Nikonos 15 mm lens (In reality, underwater this is a 20 mm lens), a camera-to-subject distance of more than 16 m is required. Apart from the problem this presents on a shallow water site, the resultant photograph would be, at best, a vague and indistinct outline of the site unless there was exceptional clarity. This unsatisfactory result would mainly be due to the visibility effects, but there is also a physical limit to the resolution of the

35-mm format photographic film. Using a standard 35-mm black and white film, for example, PAN F, and calling the narrowest resolvable line on the negative d, then the smallest object resolvable on the seabed (D) is given by the formula:

$$D = \left(\frac{d \times H}{20} \right)$$

(for the 15 (20) mm lens at height = H).

If $d = 0.01$ mm and $H = 16000$ mm, the smallest resolvable object is 8 mm, and this will be the absolute limit of resolution of the system.

On a large underwater site where the visibility is poor or the water is shallow, an overall view of the site may not be possible. A simple solution to this problem is to take a series of overlapping photographs that can be joined together to form a photomosaic (Figure 6.2). However, it must be recognized that a photomosaic is always going to be a compromise. The slightest variation in vertical topography or camera tilt will inevitably lead to perspective distortions that will make it impossible to exactly match photographs. Where there is a minuscule tilt, it may be possible to match one pair of photographs exactly, but there is little hope of matching successive pairs and attempting to do so is futile. Better results are gained by accepting a poor initial match in order to allow for more integrated subsequent matching. Provided the relief is not excessive, it is possible to produce a highly acceptable photomontage or mosaic of the site. This is a good simple method for getting reasonably accurate site plans.

Figure 6.2 An example of a photomosaic showing the Pattaya wreck site in Thailand.

A. Control

In order to produce a properly scaled photomosaic, each photograph requires some form of two-dimensional control. The choices are threefold: grid lines can be set up, a two-dimensional grid frame can be positioned in each photograph, or a network of control points can be used. There are merits and drawbacks in all the systems and the choice will depend on a number of complex factors.

B. Grid Line Control

The grid line system consists of a series of parallel lines graduated in fixed intervals set up across the site. The lines are generally colored rope (to reduce halation) black taped at regular intervals. The control can be implemented by driving a series of stakes into the seabed at either end of the site, set at a fixed, predetermined distance from one another, parallel, and at right angles to the baseline. This operation requires careful surveying to set up the right angle; various methods for doing this are discussed in Chapter 4, Section II.B.

Another factor to consider is the type of rope used in grid line control. Rope, and particularly synthetic rope, stretches when put under tension; over 20 or 30 m it is possible to stretch a rope 1 to 2 m without difficulty, i.e., by 10%. Ski rope, plaited rope, or woven synthetic line are ideal as they have a low stretch; are colored, which is useful for anti-halation; and come in convenient diameters. This type of rope still has some stretch in it, so care must be taken not to overtighten the line. Another alternative is wire, but there are some problems with this. It is generally too fine to be resolved in a photograph so special targets are required; and more significantly, it can be dangerous in rough conditions as it can easily injure divers.

Before setting up the grid, it is important to calculate the appropriate lane separation. In order to establish proper control, each photograph needs at least two, or preferably three lines with at least two graduations on each line. The required flying height can then be calculated once the orientation of the camera format to the baseline has been determined. Assuming that the long (36 mm) side of the frame is at right angles to the axis of the site, then (from Figure 6.3), if D is the line separation and d is the length of the graduations, then the height H is given either by:

$$H = \left(\frac{20 \times D}{36}\right) \quad \text{or} \quad H = \left(\frac{20 \times d}{24}\right)$$

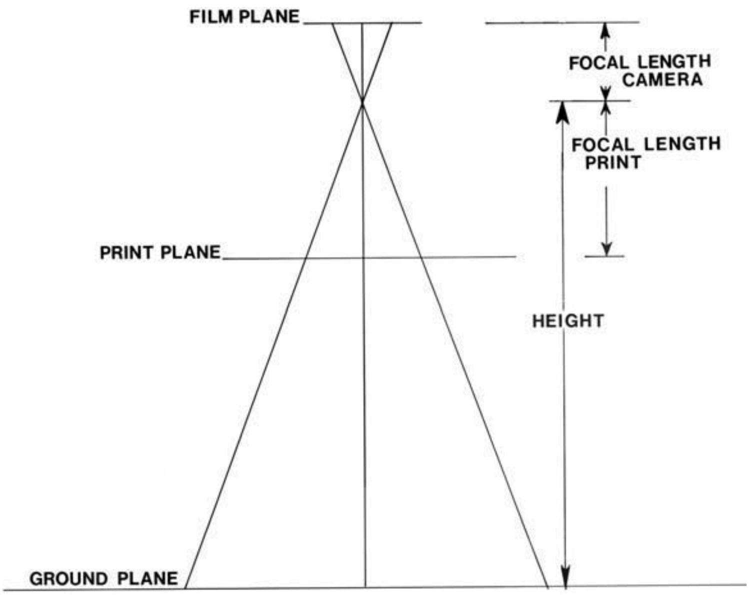


Figure 6.3 Schematic showing the main distances involved in photography. The image shows the relative position of the negative, the center of the camera lens, the plane of the print, and the plane of the object. Knowing the focal length of the camera lens allows the calculation of angles and sizes of objects in any of the planes.

whichever is the larger. Usually, there is a tendency to work at the flying height which gives the best resolution for operating at the time. Above this height, the required detail will start to become obscure; whereas lower heights will not substantially increase the archaeological information, but will require a lot more photographs. The sequence should be to determine the optimum flying height first, and then calculate the line separation and the length of the graduations. Naturally line separation and graduations are best selected in integral values of meters or millimeters. For example, for a flying height that gives a frame width of 2.1 m, a 2-m line separation may seem appropriate. However, should there be a slight disorientation of the camera, it is likely that one of the lines may not appear in the view. It would be preferable to have a 1-m separation and to include three lines in each view, in which case there is the added advantage that the center line can act as a guideline for the photographer. Using this type of control a free swimming photomosaic coverage will take approximately 10% of the time that the same coverage would take using a photographic tower.

Once the flying height has been determined, the exposure distance or air base between successive exposures can be calculated. Because adjacent pairs of photomosaic photographs can be used in a stereoscope, it is useful (although not essential) to work with 50% overlap which will allow the images to be viewed stereoscopically. This means that every part of a photographic run will always appear in at least two adjacent photographs; or, in two adjacent photographs, the right-hand half of the view appearing in the left-hand photograph also appears in the left-hand side of the right-hand photograph. If the flying height is H, then the short format coverage (24 mm) will enclose a ground distance of $1.2H$. For a 50% overlap, the separation of each exposure is $0.6H$. Again, for convenience and to ensure proper coverage it is necessary to work to the next smaller integer, and it may be necessary to adjust the flying height taking care not to compromise the framing (see Baker and Green, 1976).

For example, using the long axis at right angles to the baseline, in order to include three lines in each frame, and with a line separation of 1 m, the flying height must be at least 1.7 m and the forward ground coverage will be 2.04 m. If exposures are taken at 1-m intervals, there will be a 50% overlap, but the slightest tilt will create problems. In this case, it would be preferable to increase the flying height to 2 m, for example, which would give a format of 3.6×2.4 m, which provides plenty of leeway for errors.

C. Grid Frame Control

An alternative approach to the photomosaic lines is to use a square graduated frame. Giving due consideration to flying height as discussed previously, the height is adjusted to give the appropriate framing in the view. At the same time the grid frame is observed in the viewfinder and used to assist in leveling the camera (the Baker technique discussed earlier is particularly useful here). This system is most efficient with two operators, one to do the photography and the other to turn the grid frame over. Otherwise, it is extremely time-consuming for the camera operator to repeatedly swim down to turn the grid frame over. Once again, close attention needs to be paid to overlap and camera format orientation to ensure adequate coverage. The work of turning the grid frame over can be made easier by rotating the frame on one of its edges from one side to the other. The progress of the mosaic has to be carefully monitored to ensure that the run does not start to deviate from a straight line. It may be worthwhile setting up a temporary baseline that can be used to align the grid frame. As it is possible to estimate distances up to at least three grid squares from the line, the line will not need to be reset at the end of each run.

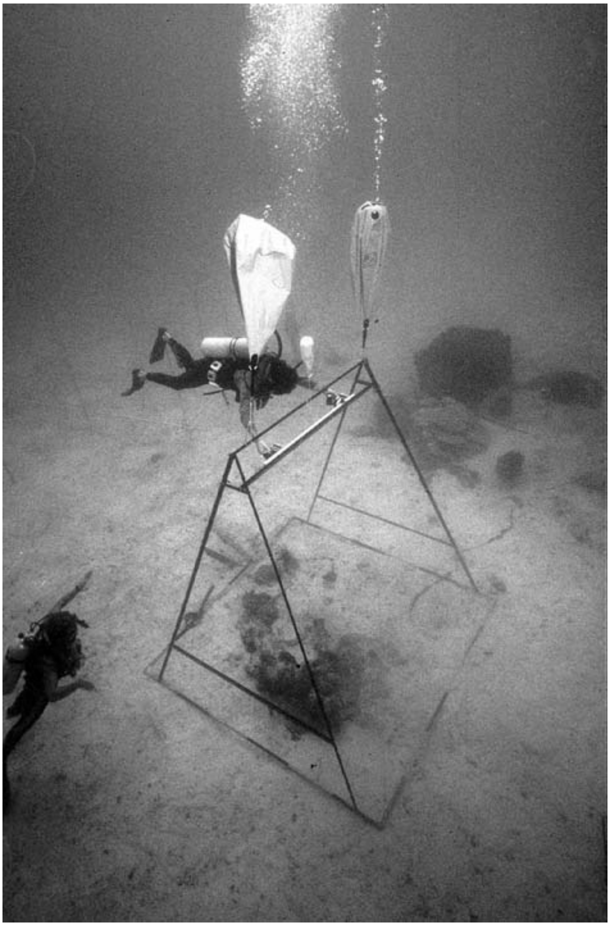
It is important that the camera be leveled relative to the grid frame, because tilt creates distortions that cause difficulties in matching adjacent prints. There are a variety of methods available to help orientate the camera vertical, one of which is using the grid frame as discussed earlier. An alternative is to mount a small bubble level on the camera bar to help in leveling to horizontal, but this can be an additional complication because the photographer will already be trying to adjust the longitudinal and lateral position and the height and the camera format orientation, all of which require considerable concentration through the viewfinder. Because it is distracting to have to glance away from the viewfinder in order to observe the small bubble level, a solution is to mount the bubble level so that it appears in the corner of the the viewfinder's field of view, utilizing the great depth of field of the level.

A most practical approach to this form of survey control is to mount the camera on a photographic tower (Figure 6.4). There are considerable advantages to using a photo tower. First, it reduces darkroom time. Next, the orientation of the camera is set vertical to the grid frame and the distance is always the same. Thus, once the enlarger is set up, all photographs can be run off without further adjustment. The tower can either be mechanically leveled or set up each time in a random orientation. This advantage is offset by the inconvenience of maneuvering the tower under water. This technique will be discussed in detail in Section VI. Another alternative, where the practicalities of a large cumbersome four-legged tower may be difficult, is to use a bipod frame or stand (Figure 6.5).

D. Network Control

Atkinson *et al.* (1989) recently developed a system for producing accurate photomosaics as a result of the least-squares adjustment program which was designed by Atkinson *et al.* (1988) for site survey work (discussed in Chapter 4, Section VI.C). This system was first tried during a survey of the extensive hull structure of the Ko Si Chang 2 wreck site in the Gulf of Thailand in 1987. It involved making a photomosaic of the site and taking a number of measurements with a tape measure between selected survey points on the site. These points were then used in a least-squares adjustment program to calculate the coordinates (see Atkinson *et al.*, 1988). The output of the program provides calculated X and Y coordinates for each station together with residuals for each measurement.

However, there are now a number of more sophisticated and more user-friendly programs available, and although the basic principals are the same, the least-squares program is obsolete. Once the coordinates have been located they can then be used to scale the photomosaic of the site. As the tags used in the tape survey can be identified on the photomosaic, it is therefore possible to determine the scaling factor. Usually it is found that the scale of a photomosaic is marginally smaller than that indicated by the



a

Figure 6.4 (a) Photo tower used with a stereo system to record the *Pandora* wreck site.

b

Figure 6.4 (*Continued*) (b) Photo tower used in a swimming pool to calibrate the camera lenses. (Figures 6.4a and b are courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

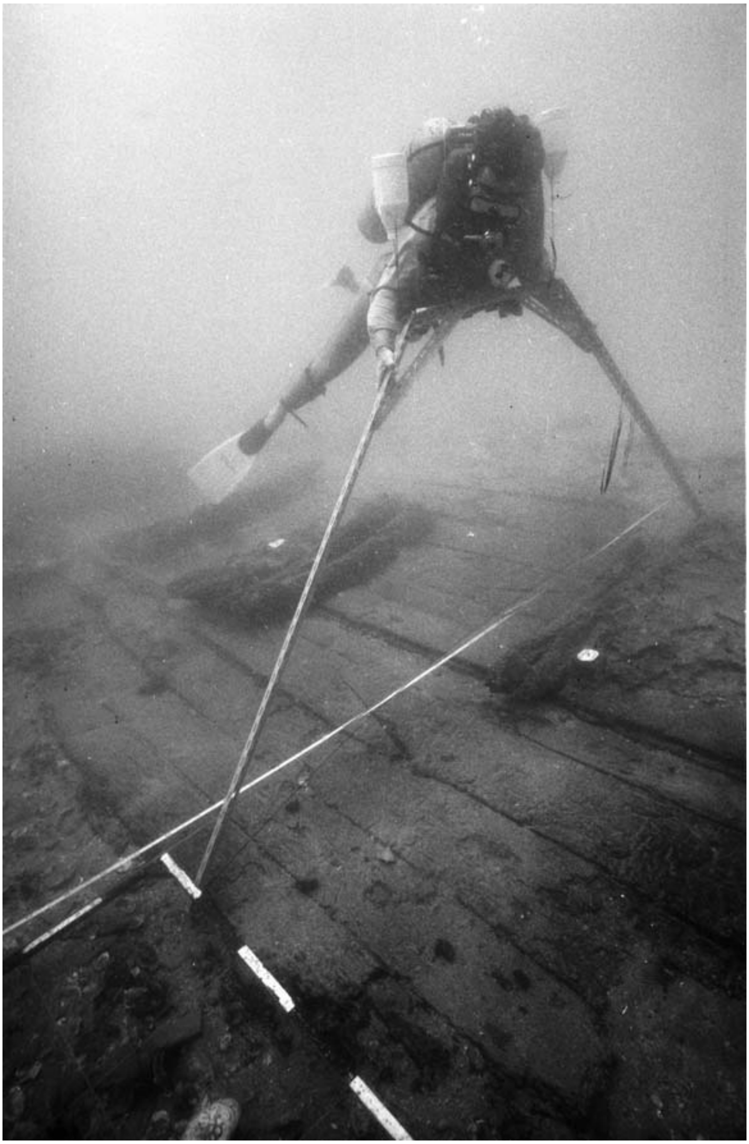


Figure 6.5 Bipod tower used on a wreck site in Thailand. This bipod system is easy to use and less cumbersome than a tower. (Courtesy of Brian Richards, Department of Maritime Archaeology, Western Australian Maritime Museum.)

survey, because the control scale is usually slightly above the seabed. To scale the site plan, it is necessary either to increase the scale of the photomosaic or to reduce the scale of the plan of the coordinates by the determined scaling factor. The less time-consuming option is to reduce the plan, rather than to reprint the photomosaic. Again, computer graphics make much of this discussion redundant unless one is using photographic prints.

In the Ko Si Chang 2 survey, the positions of the stations were first plotted using the calculated coordinates. Station 3 was used as the origin, with the X and Y axes drawn arbitrarily. The plan was then reduced to match the scale of the photomosaic. To determine the scale of the photomosaic, the distances from each station (tag) were measured from the photomosaic and divided by the distances measured on the coordinate plan to give the scaling factor.

The scaling factor of 1.05 was applied to the program coordinates and these adjusted station positions were plotted on an overlay. The transparent overlay was then placed over the photomosaic and rotated until a "best fit" position was found. The results indicated a very good correlation between the tag positions from the photomosaic and these same positions determined by the least-squares adjustment method. The results suggest that if a photomosaic is laid up using this method and the site has little vertical displacement, measurements taken from the photomosaic should have a standard deviation of about 2.5% over long distances.

E. Correcting for Tilt

It should be remembered that the objective of all surveying systems is to maximize efficiency both under water and on land. Therefore, it is important to consider the merits of making a free swimming photomosaic of a site. This is done taking into account the long period of time spent in the darkroom rectifying and adjusting the magnification of the prints to correct for the variations of tilt and flying height introduced in the field. How do the advantages of reduced diving time weigh against the extensive darkroom time needed with this approach? Would it be preferable to spend a longer time under water using a tower and reduce the time spent in the darkroom afterwards? The choice will depend on a variety of considerations: How much time can be afforded for the work? Is time in the field at a premium? Is there a field darkroom?

If a photo tower is used to produce a photomosaic, unless the tower is leveled each photograph will inevitably have some different component of tilt. Although the scale across the grid frame of the tower will be correct, the scale on the seabed may be different. This may cause problems in matching adjacent photographs of a photomosaic.

F. Rectification

The photogrammetric process of rectification is an operation requiring a complex photo rectifier. This large and expensive machine is well beyond the budget or accessibility of most excavators. However, provided high accuracy is not required, rectification can be done quite simply under an ordinary enlarger. The process requires tilting the photographic paper so that the distortions created in the photograph are compensated. This can be a time-consuming exercise, particularly as the various photographs will be at different orientations. To facilitate the rectification process, it is useful to construct a simple, adjustable, photographic printing table. This consists of a normal printing table mounted on a frame that can be rotated about its center and tilted in an axis which passes through the axis of rotation. The table should have facilities to measure the angles of rotation and tilt and a method of clamping the table in the required orientation (Figure 6.6).

The adjustment of the table to give a rectified print can be done either on a trial-and-error basis or by calculation. In the former case, a correctly scaled square grid is drawn up and placed on the adjustable printer board. The board is then adjusted until the distorted grid projected from the enlarger coincides with the correctly drawn grid on the printer board. Alternatively, complex mathematical equations can be used to obtain the rectification parameters. A generalized view of a grid square showing the effects of perspective caused by camera tilt is shown in Figure 6.7. In reality, the photographic darkroom is rapidly becoming obsolete and rectification can now be done far more efficiently using a computer (see Section H below).

G. Laying Up a Photomosaic

At the outset, before mounting a photomosaic, the photographs must all be printed at the same scale and arranged in order. It is advisable to print the photographs at a lower contrast than normal as this helps to prevent the joins showing up and improves the quality when the mosaic is re-photographed and printed.

There are two ways of tackling photomosaics: the controlled method or the so-called uncontrolled approach. In the former method, the optical center of each photograph is first determined. The principal point from the adjacent photograph is then transferred onto the photograph (while viewed stereoscopically). A line is drawn through the principal point of the photograph and the transferred principal point. This is the flight line (Figure 6.8). The print is cropped, feather-edged (see later), and fixed on the mounting board. The adjacent print with a similar flight line is then trimmed and

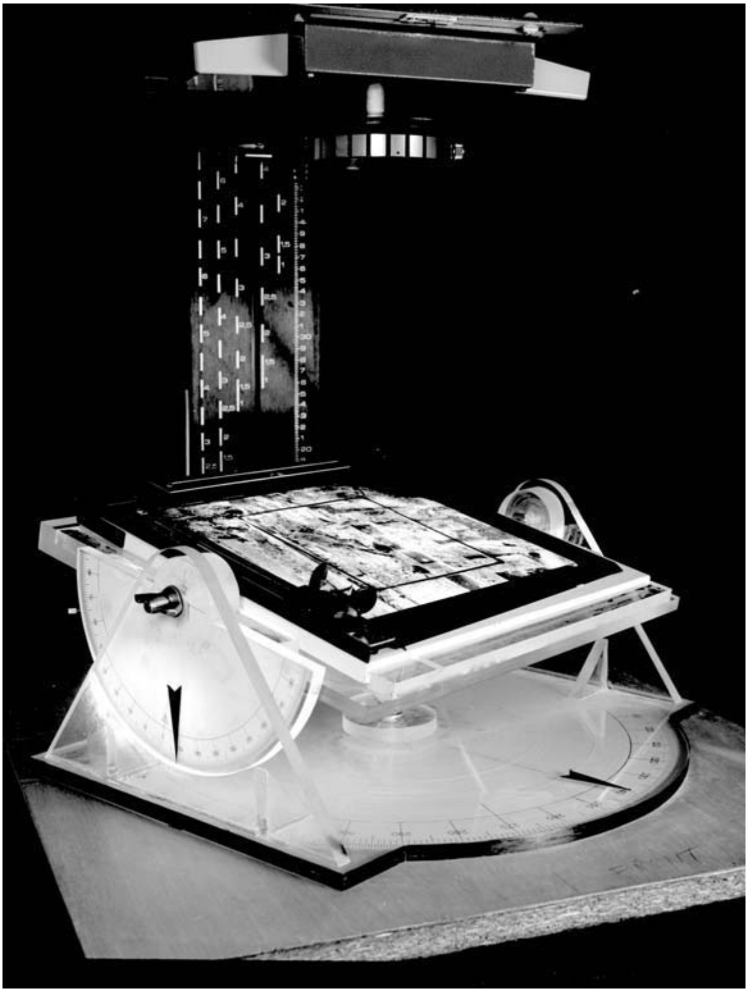


Figure 6.6 Rectification table used to rectify photographs under an enlarger. Most darkroom techniques have now been replaced with digital imagery, particularly the rectification of tilt can be managed more quickly and efficiently with programs like Photoshop rather than the cumbersome and time-consuming darkroom methods.

feather-edged so that half of the overlap is discarded. This is then placed on the mounted print so that the flight lines correspond and adjusted until the two prints match at the join. This process is continued in all four directions from the central print. This system is extremely effective provided the rules are adhered to exactly. It is, however, time-consuming and, as a result, tends to be abandoned in favor of the ad hoc uncontrolled system.

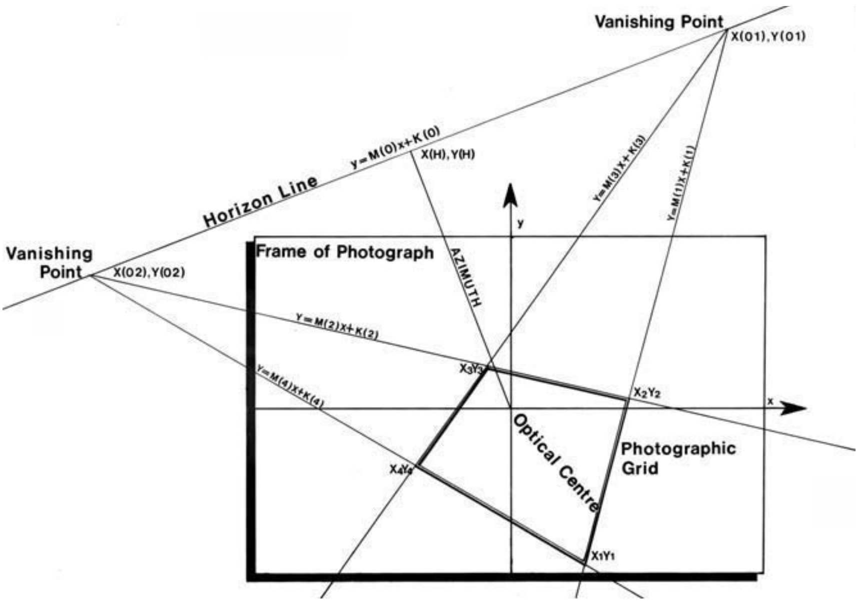


Figure 6.7 The general factors involving tilt in a perspective view of a square grid frame.

This starts with one print being laid down and then successive prints in the run, with half the overlap cropped out, are matched to it. Adjacent runs are mounted in the same way and the runs matched together. There are always problems doing it in this way, as often the adjacent strips of photographs will not match exactly.

It is advisable to use a stiff card or board for mounting the photomosaic (Bristol board is recommended) and a thin PVA glue for paste up, particularly when using resin-coated (RC) paper, because it allows the prints to slide on the board. The most effective means of cropping prints for photomosaics is by feather-edging. To do this, the surface of the photographic layer of the print is lightly scored with a sharp scalpel. This should be done carefully so as not to cut too far into the paper layer. The print is then turned over, folded along the score mark, and torn in a diagonal motion while holding the side of the print to be retained with a finger. This creates a very thin, clean-cut edge to the photograph, which gradually thickens up to the full paper thickness at 10 to 20 mm from the edge. When stuck down, it produces a smooth flat surface without unsightly, thick-cut edges that cause shadows and crinkles. A small piece of stiff plastic can be used to smooth down the prints and to remove bubbles from under the print. Excess PVA glue can then be wiped from the surface of the mosaic with a sponge. A

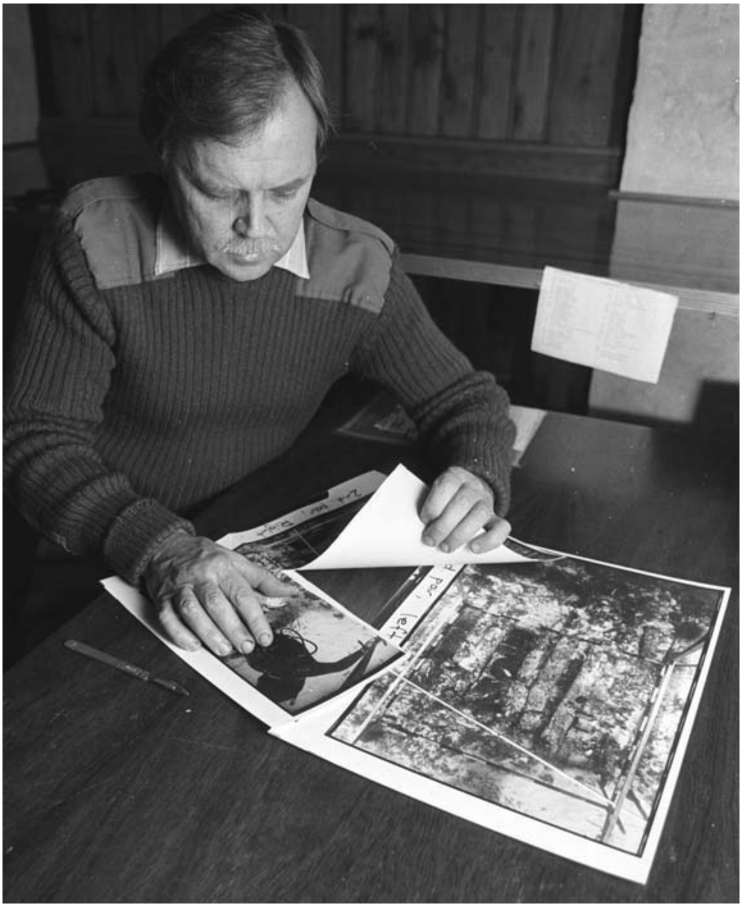


Figure 6.8 Laying up a photomosaic. (Courtesy of Brian Richards, Department of Maritime Archaeology, Western Australian Maritime Museum.)

number of texts (Moffitt, 1967; Wolf, 1974) describe this process in more detail and should be consulted if good quality mosaics are required.

An alternative method of sticking down the photographs, which obviates the need for feather-edging, is to use nonreflecting transparent sticky tape. By using tape the results can be unstuck and rearranged. This is an important advantage over the PVA glue method, which is fixed once the paste has dried. This method is also faster and less messy, but the presence of the tape makes it difficult to examine a photomosaic directly, and it is best to re-photograph the mosaic with a large format camera. The resulting print is usually much better than the original, because the effects of the unsightly tape are removed and the details are at a much better contrast.

H. Computer-Based Applications of Photomosaic

In nearly all situations it will be possible to convert conventional photographs into digital images by scanning either the print or the negative, or to take digital images directly with a digital camera. Whichever system is used the images will consist of a series of files, probably JPEG images, which will need to be combined to form a mosaic. There are obviously a number of ways that this can be done and it is probably best done in Photoshop, although there are other programs that can do the same thing.

As the mosaic is going to be a two-dimensional image, a worksheet or pasteboard is required set up at an appropriate scale. Thus for a site 100 m^2 the site would want to be about 500 mm^2 square so that the scale would be 1:200. Some thought will have gone into the number of images taken of the site and the overlap. The images will be scanned at reasonably high resolution or available at 2–5 mega pixel per digital camera image. It will probably be best to convert these images to gray scale and to adjust the levels to give good contrast. The control points will have an X and Y co-ordinate, so that their positions can be placed on the pasteboard as, for example, small crosses with a well-saturated color (for instance, bright red) in their correct locations. The first image is then pasted onto the pasteboard and scaled so that it is at approximately the correct scale. The image, which will lie in a layer above the control points, can then be made semitransparent and the control points then identified. The image is physically moved so that one set of the control points coincides. The image can then be "free transformed" around this point, rotating, scaling, and skewing the image so that as many of the points as possible coincide. This image is turned off and the next image is imported. The process is repeated until all the images are fitted. It is then necessary to crop each of the images so that the overlap between two adjacent images will be evenly distributed. Inevitably, because of distortion effects there will be areas of mismatch for which the operator will have to exercise judgment on how best to deal with the problem. Finally, the project can be flattened (merging all the layers into one) thus reducing the file size. However, this should only be done when the whole process is complete as the flattening merges all the layers and it will no longer be possible to move them around. Recently Martin and Martin (2002) have published a paper describing a similar method for using Photoshop to create photomosaics.

An alternative technique is to use a GIS system (such as ArcView) and register the images against a ground control using the georeferencing tool of Arc Map 8 (or using a ground control point file using a photoregistration program such as Mapping and Beyond's Smartimage). This is a more sophisticated option with the ability to conduct limited "rubber sheeting" (distorting the image to fit the control points). Obviously, the speed of operation and the complexity of the system will dictate the best solution. However, the digital solution is far more preferable than the printing, feather-edging, and gluing of large numbers of photographs.

IV. STEREOPHOTOGRAPHY

Much of the practical application of stereophotogrammetry has changed in the last ten years. Once photogrammetric laboratories contained large, if not huge, stereoplotters like the Wild B8 and A10. These behemoths weighed at least a ton and have now largely become redundant. Indeed to my knowledge, some have actually been used as boat moorings.

Through a series of progressions these analog instruments have largely been replaced with software programs that can be run on desktop and high-end computers. Where once mechanical movements provided the necessary adjustments, this is now done with software. As a result a machine that cost a huge amount of money now, relatively speaking, costs very little. Also, the software programs are easy to use and can also be used in the field. So, photogrammetry, which was once for an archaeologist an almost impossible objective, unless one had dedicated personnel with expertise, can now be conducted by anyone with a good camera, a computer, and some training. The stereo principles still apply, but today software has removed most of the complexities. In some cases the discussion of earlier methods has relevance to the more current techniques.

In the past, using a pair of cameras on a stereobar with precisely defined optics, it was possible to apply the parallax equations under water to obtain three-dimensional coordinates. A number of different approaches were used to apply underwater stereophotogrammetry. In the 1960s and 1970s at Yassi Ada, Turkey, a series of photogrammetric surveys of shipwrecks was carried out using stereophotography. In some cases, single and, in other cases, pairs of SLR cameras in underwater housings were used to make three-dimensional plans of the sites (Karius *et al.*, 1965; Rosencrantz, 1975). Later, Hohle (1971) used Nikonos cameras with a 28-mm lens in conjunction with a Stereotope to produce topographic plans of the Kyrenia shipwreck. These covered an area of 6×12 m with a mean square error of ±10 mm in the vertical.

These early, simple underwater photogrammetric techniques generally consisted of a photo tower with a pair of cameras mounted on a sterobar. The cameras were optically aligned so that their optical axes were parallel. The stereobar was mounted on the tower so that it was symmetrical and level relative to the square grid at the base of the tower. One of the most common methods was to set the tower on the site in an unleveled orientation (Figure 6.9b). It was anticipated that this system would be used when time was at a premium. A series of overlapping stereo pairs were then taken

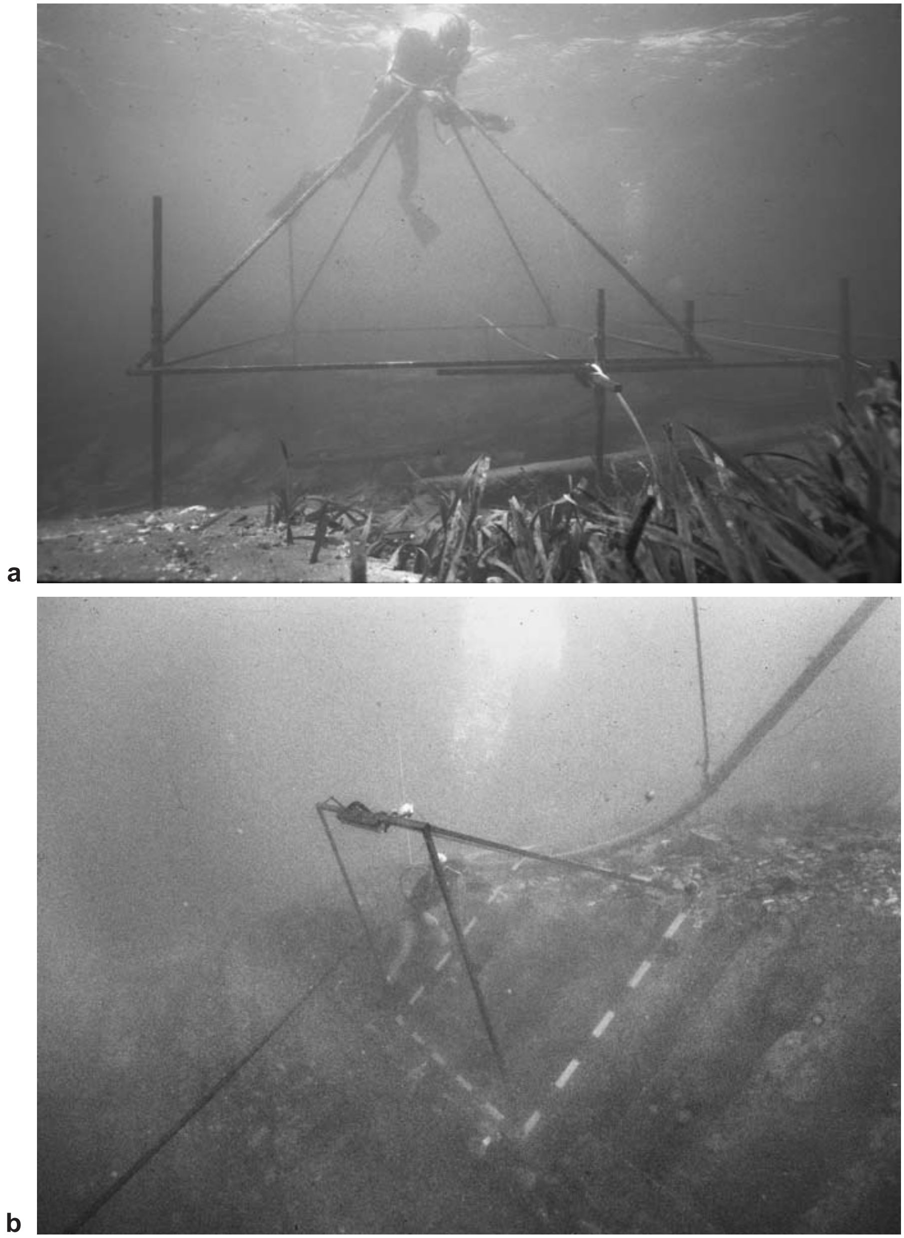


Figure 6.9 Photo tower (a)in a leveled situation on the *James Matthews* wreck site and (b) in an unlevelled situation on the *Santo Antonio de Tanna*, Mombasa, Kenya. (Figure 6.9a is courtesy of Catherina Ingleman-Sundberg, Department of Maritime Archaeology, Western Australian Maritime Museum. Figure 6.9b is courtesy of Mombasa Wreck Excavation.)

over the whole site and processed to produce a series of topographic plans. Each topographic plan was then reduced to a common datum plane by selecting several common points in a pair of plans and applying a reduction formula. In the other common approach, the tower was leveled manually so that the plan from each stereo pair was automatically produced in a common datum plane. Although the relative heights between different tower positions may be different, their correction to a common datum was relatively simple.

Another simple method that was used to produce leveled stereo pairs involved a bipod made of a pair of metal tubing legs with a short horizontal connecting bar at the top, forming an inverted V-shape with a truncated apex (Figure 6.5). The height of the bar above the ground was set at 1.5 m and the horizontal bar was 750 mm long. Attached to the horizontal bar was a carpenter's level with a pair of bubble levels, which allowed the bar to be leveled in the horizontal plane. Two Nikonos cameras with 15-mm water-corrected lenses were mounted on the level at exactly 500 mm separation. The cameras were accurately aligned so that their optical axes were parallel and at right angles to the level. Some form of scale is required, but since the cameras will always be horizontal when the photographs are taken, it is only necessary to have a one-dimensional scale. Because the legs of the bipod were rather flimsy, a string or wire between the bottoms of the legs could be used to set the leg separation at a fixed distance. It should also be noted that a small photo tower can be useful in low light levels, both to ensure constant subject to camera distance, but also to eliminate camera shake and enable ling time exposure shots (Figure 6.10).

During the photography some buoyancy needs to be added to the tower to make it slightly negatively buoyant and thus easy to control. The tower is set above the exposure station with the two legs at right angles to the center line. The level is then adjusted and clamped so that it is horizontal or level in the sideways direction (parallel to the cameras and at right angles to the center line). The operator then slowly rotates the tower in the forward or backward direction, using the bottom of the two legs as a fulcrum, until the bubble level in the forward direction indicates that it is level. The sideways level should be checked to see if it has moved out of alignment. If it is still level the exposures are taken. This system is very simple to use and ensures that the cameras are always in the same plane when the photographs are taken. It has considerable advantages when analyzing the coverage in a stereoscope and avoids the lengthy leveling procedures required with a standard four-legged tower.

With modern stereophotogrammetric techniques, there are a number of ways of calibrating cameras and determining the accuracy of the system, see the following sections. The promise of simple underwater stereo- and

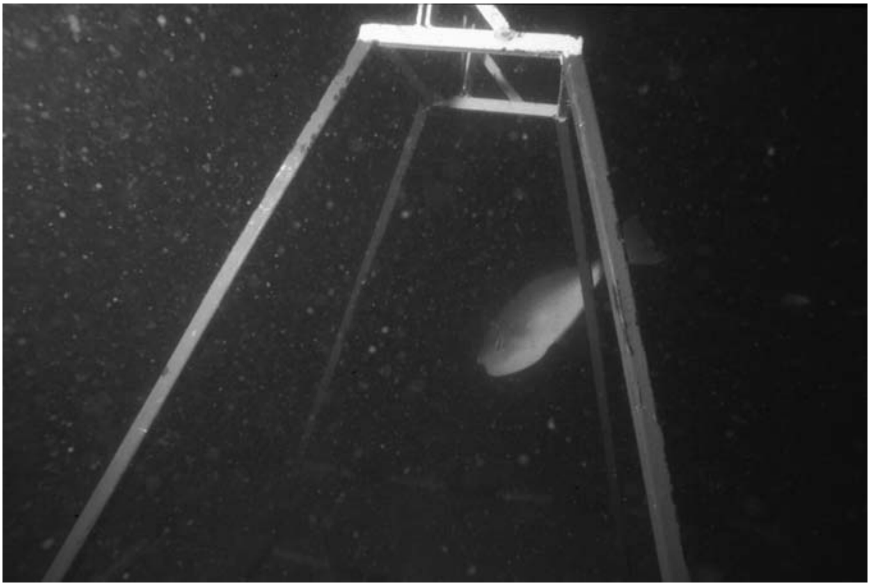


Figure 6.10 Small tripod used to steady camera in low-light conditions. (Courtesy of Brian Richards, Department of Maritime Archaeology, Western Australian Maritime Museum.)

nonstereophotogrammetry is currently available for archaeologists or archaeological surveyors who are prepared to learn some simple techniques. In this situation, routine archaeological surveying work can be conducted in the field by people who are directly involved in the work, rather than by technical experts remote and unconnected with the project, as was previously the case.

A. Optical Alignment

At times it is extremely useful to be able to align cameras on a stereo-bar so that their optical axes are parallel. One simple and effective method to do this utilizes mirrors and optics. The cameras are mounted on the stereo-bar with the normal lenses either replaced with mirrors set flat against the lens mount or with the plane port 35-mm lens (the glass acting as a plane mirror). The camera separation is accurately measured. A second bar is constructed with round targets set at exactly the same separation as the cameras. This target bar is set on a tripod several meters away from the camera bar. The targets have small viewing holes drilled in their centers so that one can look through the targets and observe the mirrors on the cameras. The first operation is to set both bars level and parallel. Leveling can be done with a spirit level. The bars are set parallel using a plane mirror placed flat on the face of one bar (i.e., the camera bar) exactly in the center and a pin placed exactly in the center of the other target bar. An observer with the pin in front of the eye looks in the mirror on the other bar for the reflection of the pin. A second operator adjusts the angle of the camera bar with the mirror until the reflection of the pin in the mirror coincides with the pin in the other operator's view. At this point, the camera bar with the mirror is at right-angles to the center of the other bar. The mirror and pin are interchanged, and the process is repeated to make the target bar parallel.

Now that the target bar and the camera bar are parallel, it is necessary to adjust the cameras so that their optical axes are parallel and at right angles to the camera bar. From this point onward, great care must be exercised to avoid disturbing the bars and thus upsetting this alignment. The observer now looks through one target at the corresponding camera mirror. The other person adjusts the camera until the reflection of the observer's target appears central in the mirror. This will usually require a rotation in the horizontal and vertical planes. When the coincidence occurs, the camera is locked in position. The process is repeated for the second camera, and then the first camera is rechecked for alignment. It is worth casting epoxy resin blocks around the bases of the cameras so that they can be semipermanently fixed in place.

V. PHOTOTRIANGULATION

A. PhotoModeler

PhotoModeler, a computer program produced by Eos Systems, is one of the best examples of a phototriangulation program. The program uses a calibrated camera to measure the ray paths from the principle point of the camera, through the photographic image, to various points on the site and from this calculates the coordinates of points in the view. There are other similar programs, which the reader is encouraged to investigate, however, the basic system is largely the same and, as the author has had the greatest experience with this program, PhotoModeler will be used as the example for this section. With multiple views of the same points, providing the geometry of the camera and lens is known, it is possible to calculate angles and from the various camera locations the complete geometry can be resolved. The target points need to be well defined and some form of control is required to provide scale for these data. PhotoModeler has been used elsewhere for maritime archaeological work (Franke, 1999), although little has been published on its application to underwater archaeological sites.

The program was thoroughly investigated on the Institute for Nautical Archaeology (INA) Tektash expedition in Turkey from 1999–2001 (Bass, The Tektash site was discovered in 1996. It was thought, when it was first discovered, that there were about 250–300 amphorae on the site that needed to be mapped and recorded. Because the site was deep it was decided to try and replace conventional multitape trilateration with a reliable photogrammetric surveying technique so that the three-dimensional coordinates of each amphora could be recorded. This information would then be transferred to a three-dimensional program so that the site could be viewed in three-dimensional space. This was particularly important, as the site lay about 100 m from the shore, directly below the cliffs (Figure 6.11), on a steeply sloping seabed. It was hoped that this approach would help interpret the obviously complex wrecking process. In the third and final season, photogrammetric surveying was further developed to deal with small finds and to contour the complex and steeply sloping seabed on and around the site.

At Tektash, Tufan Turanli of the INA developed a novel solution to the complex problem of recording the exact location of the amphorae in three-dimensional space (Green *et al.* 2002). Amphorae are difficult to survey in any situation because they are regular, smooth, and only have three distinguishing features (foot and two handles) that can be identified for measurements, but these diagnostic points are difficult to pinpoint. Turanli therefore

Figure 6.11 Tektash field base operations. Wreck site located 50 m off the diving platform at right of photograph. (Courtesy of Jeremy Green, Department of Maritime Archaeology, Western Australian Maritime Museum and the Institute of Nautical Archaeology, Bodrum, Turkey.)

decided to create artificial points. As each amphora was uncovered, a survey target, or mapping label, was placed over the mouth of the amphora. This target was a disk of white plastic sheeting with three targets (black spots forming a triangle, together with an identification number; Figure 6.12). These dots were machine printed and spaced exactly 10 cm apart and thus could be used as further control points. Survey target disks were made for each of the two different types of amphora that constituted the bulk of the ship's cargo. The apex of the triangle was set to point toward one of the handles, generally the highest point or the one that could be clearly seen. If the three points could be located in precise three-dimensional space, then the orientation of the amphora is known. It was necessary to ensure that the label was attached centrally on the mouth rim and that the rim was smooth and free of concretion. This system presented an accurate set of reference points on the amphora, which unlike the natural features of the foot and handles used previously for surveying, gave more accurate results.

PhotoModeler is ideally suited for mapping this type of precise amphora target that is then used to link the photographs. Providing good viewpoints are selected, accurate results can be obtained. In addition, around the site were known control points that were being used for the multitape trilater-

Figure 6.12 Amphora tags used in PhotoModeler survey. (Courtesy of Jeremy Green, Department of Maritime Archaeology, Western Australian Maritime Museum and the Institute of Nautical Archaeology, Bodrum, Turkey.)

ation survey work (carried out while the photogrammetric technique was being evaluated). For PhotoModeler each of the control points was set up with a photographic target (a white plastic funnel painted black and white, the apex of the funnel set to the control point; Figure 6.13). These could be seen from any point on the site and were utilized by the PhotoModeler program to provide control and scale.

In the third season, the system was further developed to record small finds. In this case small targets were constructed (Figure 6.14) which excavators could place against objects, or, if a fragile or otherwise at-risk artifact required removal, to mark the location where the object was found. These small targets at a distance were difficult to see together with the control points and resulted in poor fixes. To improve the accuracy, a secondary, 1-m control grid was placed around the target. A set of close-up photographs was first made of the target and grid in order to get a reliable model. Then a more distant set of photographs was taken of the grid and the control points with the grid providing the link between the target and the control points (Figure 6.15). Two types of grids were tested: one was a

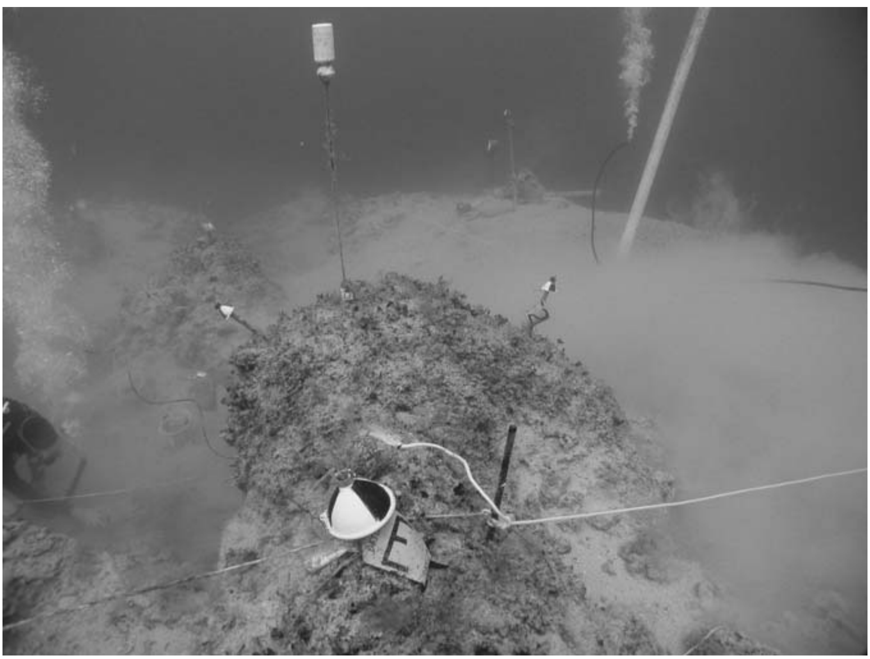


Figure 6.13 Control points mounted on top of tape measure survey points using plastic funnels. (Courtesy of Jeremy Green, Department of Maritime Archaeology, Western Australian Maritime Museum and the Institute of Nautical Archaeology, Bodrum, Turkey.)

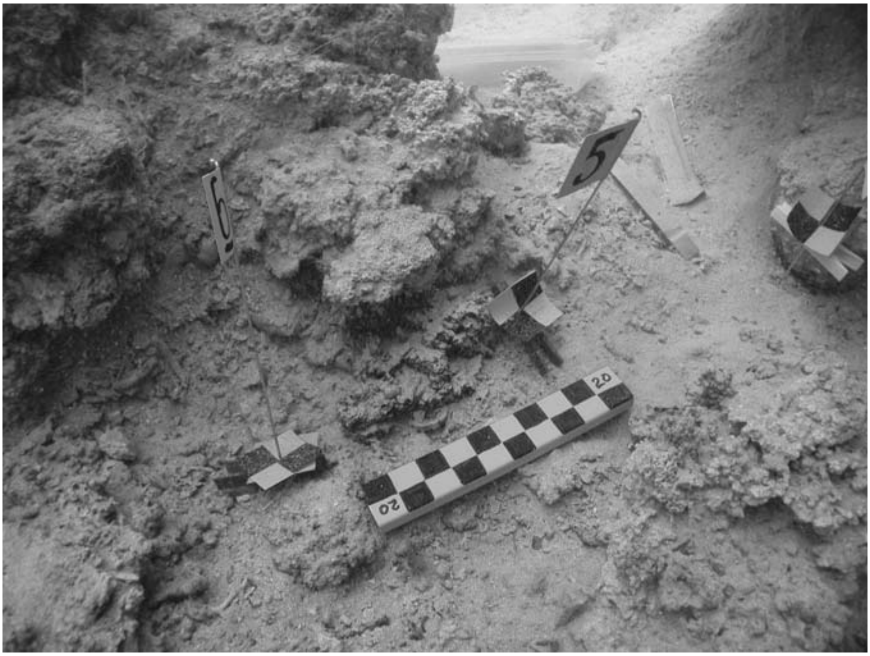


Figure 6.14 Small finds target markers shown with a 20-cm scale. Targets were used to mark small fragile objects that were removed from the site. (Courtesy of Jeremy Green, Department of Maritime Archaeology, Western Australian Maritime Museum and of the Institute of Nautical Archaeology, Bodrum, Turkey.)

light-weight, 1-m square grid made of plastic water pipe with 100-mm graduations marked on the piping; the second was a rigid, 1-m square grid made from steel square-tubing, graduated with 200-mm graduations.

This control grid system was also useful where objects were located on holes or under rock shelves. The grid again acted as a secondary control system so that the photographer could concentrate on first obtaining views of the grid and the object and then the grid and the primary control system. Obviously there were situations were PhotoModeler could not work, for example, when an amphora was orientated with its mouth facing downward. In this situation the camera could not see the whole mapping label and photographing one or two of the spot points together with the toe or attempting tape measurements were tried.

1. Cameras

In the 1999 and 2000 seasons, the Nikonos system was used. In 2001 a digital camera in a custom-built underwater housing was used. The two systems make an interesting contrast in the ease of operation and the

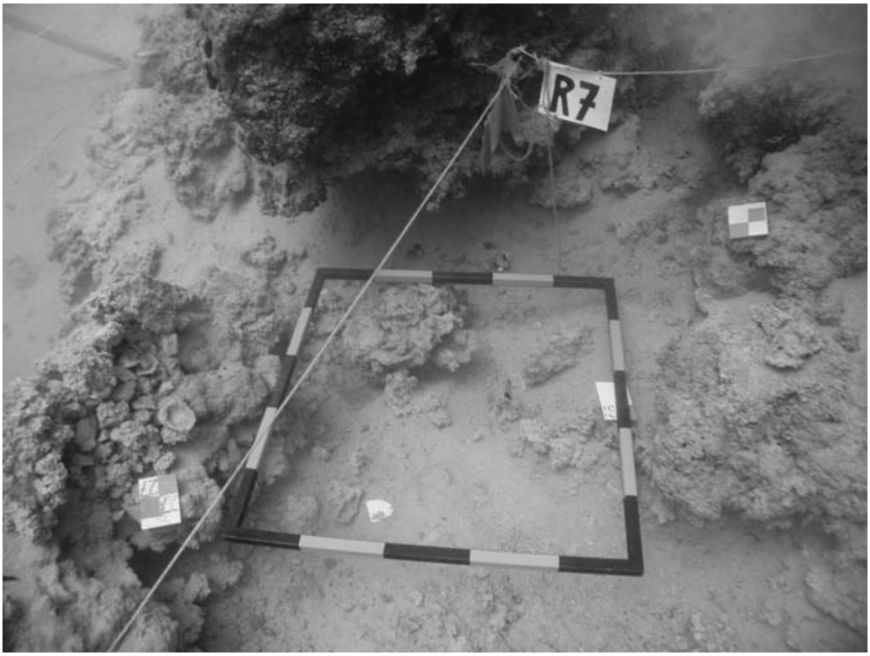


Figure 6.15 Grid frame used to link close-up survey with wider site control points. (Courtesy of Jeremy Green, Department of Maritime Archaeology, Western Australian Maritime Museum and the Institute of Nautical Archaeology, Bodrum, Turkey.)

relative advantages. During the first two seasons conventional Nikonos cameras with 15-mm lenses were used for all photographic work. One system was a fully calibrated camera with a reseau plate and predetermined fiducial points. In the other system the camera and lens system were calibrated on site using the PhotoModeler camera calibration program. Although the Nikonos camera system has excellent optics, it has the drawback that the processing is lengthy and time-consuming. Generally, at the end of a photographic dive, the film would be extracted from the camera and processed. At best, the film was dry by the evening of the day of photography. It then had to be cut up and scanned prior to being used by the PhotoModeler program. As a result, position data were not generally available until at least 24 hours after the photographs were taken. This had a considerable bearing on the planning and logistics of the excavation, because objects could not be raised until it was certain that they had been properly recorded. This was considered to be a serious shortcoming of the system.

The multitape trilateration which was the fallback system, on the other hand, was time-consuming in the diving operations, but once these data were recorded, they could be quickly processed and the object then safely removed, at best about one hour after that data reached the surface. Thus often hand measurements were used in preference to photogrammetry.

In the third season, an underwater digital camera was used. This was a 3.3 mega pixel Olympus Camedia 3000 digital camera mounted in a custom-made Wills camera housing with a wide-angle lens and corrected dome port (Figure 6.16). The camera system was calibrated prior to the expedition and used for all recording work (4.71 mm focal length on a 6.26 × 4.69 mm format, equating to a 27-mm lens in the 35-mm film format). This system proved to be an ideal solution. At the end of each dive the case was opened, the Smart Media card extracted from the camera, and these data were downloaded directly into the computer (taking about a minute). The images were thus immediately available for processing by PhotoModeler and results were generally available within less than 30 minutes after the camera arrived at the surface (depending on the complexity of the model). The quality of the image was as good, if not better, than the Nikonos system; the only drawback was the rather long focal length. The rechargeable batteries lasted 4 hours, more than enough for the two dives each day, and the

Figure 6.16 UW digital camera. This system is an Olympus Camedia 3000 camera mounted in a custom-built Wills camera housing.

64 MB Smart Media card could hold 84 high-resolution pictures which in JPEG format were between 650 and 750 KB in size equating to 3.16 MB in TIFF format. The camera was capable of working in low light levels provided it was held steady; it seemed to be more red-sensitive than normal color film; and it contained autofocus and autoexposure, so essentially it was point and shoot. What was being photographed could be seen in the LCD screen at the back of the camera, so it was relatively easy to frame the shots.

VI. STEREOPHOTOGRAMMETRY

The other photogrammetric program used at Tektash was the Georeality VirtualMapper, a stereophotogrammetric program that can be used to plot three-dimensional features or terrain on sites. Like PhotoModeler, VirtualMapper is one of a variety of programs that essentially do the same thing, and this will be discussed here in detail. VirtualMapper requires two overlapping photographs to be taken (a stereo pair) that are then processed to produce an epipolar file that is then viewed by an operator or operators in stereo on a computer monitor using stereo glasses. The glasses are connected to the computer and the program rapidly alternates a left- and right-hand image on the monitor. The glasses have polarizing optics that sequentially turn the left- and right-hand optic of the glasses on and off. The program alternates this rapidly so that the left-hand eye sees the left-hand image (on the monitor) and the right-hand eye sees the right-hand image. This results in the operator being able to observe a stereo view. The program provides a cursor that can be moved around the site and appears, "floating,", three-dimensionally in the view. By keyboard control, the cursor can be made to rise and fall in the view so that it is possible to "place" the cursor on any point or surface in the field of view. The cursor location is recorded in three dimensions with the program providing X, Y, and Z coordinates of its location. It can be used to obtain the coordinates of any point in the view or to track features using a polygon line tool.

At Tektash, there was a need for a contour plan of the site that would provide the background for the location of the artifacts in three-dimensional space. Both conventional tape trilateration and PhotoModeler were unsuitable for this work, the former being too time-consuming, and the latter requiring a large number of targets to provide spot heights. An experiment was made using PhotoModeler and white bathroom tiles as targets, however, even with about 50 tiles there was insufficient information to provide any sense of the complex nature of the site. The advantage of VirtualMapper and, by extension, any stereo system, is that it is not necessary to have precise targets to be able to plot objects. Thus it is reasonably easy to follow features such as ship structures or to plot contours.

A series of overlapping stereophotographs was taken of the site by swimming at about 10m above the site and taking photographs. In 2001, the images were loaded into the computer as TIFF files, compressed, and then sent via the Internet using FTP to Georeality in Australia for processing the epipolar files. Because the only phone access at Tektash was cellular, this necessitated leaving the site and returning to the INA headquarters in Bodrum, where these data were transferred using a conventional phone line. Georeality kindly processed these data in 24 hours, enabling the epipolar files to be processed using VirtualMapper the following day in Turkey and contour plans obtained the day after. The site was contoured in 200-mm intervals and the resulting image exported in DXF format and imported directly into the Rhino site plan (Figure 6.17).

Currently, Georeality has produced a new program, Virtual Image Corrector (VIC), which allows the stereophotographs to be processed so that epipolar files can be produced in the field. This obviously makes the system much more useful than before. Similar programs have the same facility, for example, VirtuoZo is a software suite that accepts scanned stereophotog-

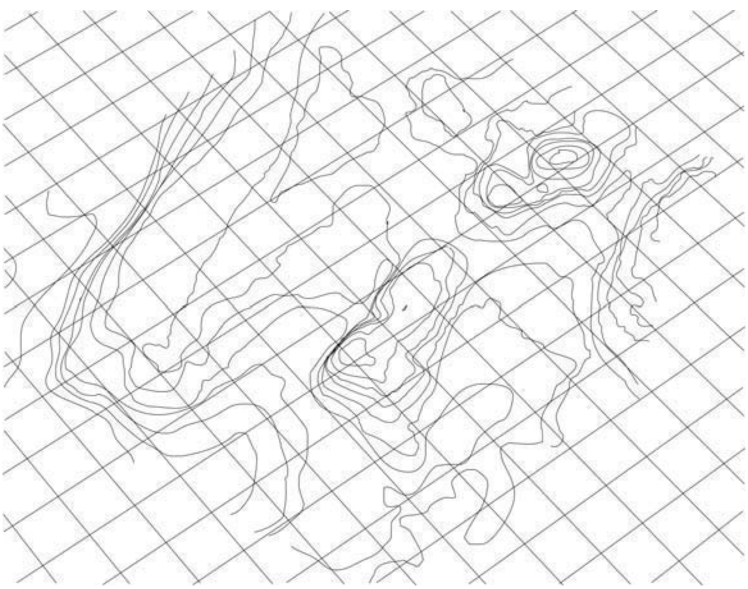


Figure 6.17 A contour plan of the Tektash site made from stereophotographs and then imported into Rhino to produce a three-dimensional plan.

raphy or stereo SPOT imagery as input and produces ortho-rectified imagery, digital terrain models, and contour maps as output. Dynamic 3-D stereo visualization is also possible. Users can view the results of every stage of the photogrammetric process, including raw images, epipolar images in stereo, ortho images, and contours. Mono and stereo perspective views are possible. The software allows interactive editing of matching (x-parallax) results, however, the program is extremely expensive (U.S. $50,000). There are many other systems, that do the same at varying prices. The reader is referred to the listing of commercial terrain visualization software at http://www.tec.army.mil/TD/tvd/survey/survey_toc.html.

A. Results

As mentioned earlier, early phases of survey work used multitape trilateration and the measurements were initially processed using the Rule Web program, later the 3H Consulting Ltd Site Surveyor 2 was used because it was more powerful and more flexible.

Control points—the points from which tape measurements were taken—were a complex issue. The points were mainly 10-mm steel rods driven into the rock with a nail attached to the rod to which the end of the tape measure was attached. Additionally, several towers were constructed to provide access to low lying areas on the site. However, these towers were likely to be accidentally caught by airlift hoses or lines and subjected to unusual stresses resulting in occasional position change. The location of the control points therefore needed to be continuously monitored; obviously, if the control point moved slightly, then all the subsequent measurements from that point would reflect this indicating that the point needed to be recalibrated.

Three control points defined the axis of the coordinate system on the site: zero (coordinate 0, 0, 0) and X (3.575, 0, 0.3) and A (0.899, –3.952, –0.061) downward was negative. There were a total of 22 control points on the site and these were surveyed using 225 individual measurements (including a depth measurement at each point). These data were then processed using Site Surveyor. Nine measurements were then rejected because their residuals were too high, and these data were then reprocessed. The resulting data gave an average residual of 6 mm with a root-mean-square (RMS) residual of 9 mm.

Once the control points had been surveyed and fixed, excavators then used these points to measure to the objects. Usually, measurements were taken from at least four control pointsand were recorded by the diver and brought to the surface. Matthews then processed these data and the measurements checked to ensure they made a good fix. Sometimes the person taking the readings was sent down on their next dive to take more readings or to recheck measurements. If the readings produced a poor fix, the program would indicate which of the four measurements was wrong, or alternatively if the orientation of the selected control points was producing a poor fix. Typically the RMS residual for individual objects was about 13 mm (distance measurements typically ranging from 1–10 m).

Using PhotoModeler, the procedure was quite different. Once excavators had uncovered an amphora, they were issued a mapping label with a designated number and type. After ensuring that the rim was clean and free from concretion, the mapping label was carefully attached to the mouth of the amphora, apex toward the handle. A photographic dive would then be scheduled with a list of amphora to be recorded. The photographer had to ensure that all the mapping labels were viewed from at least four (preferably six) different positions. This was at times difficult to do, because the amphorae were often lying horizontally with their mouths pointing in random directions, occasionally pointing downward. Thus in a particular view some amphorae would be in view while others were pointing away from the camera obscuring the mapping label.

Similarly, high vertical photographs would often not show the mapping labels of amphorae that were horizontal. Generally the photographer took a large number of photographs around the site with the hope that coverage would allow all the labels to be mapped. As a rule of thumb, eight low level (15°) views at 45° azimuth intervals, eight high level (60°), and one vertical would generally ensure adequate coverage. Photogrammetric targets (a circle divided into quadrants of black and white) were also tried to compare with the three round dots (the latter worked well in the PhotoModeler sub-pixel mode when they could be clearly viewed). These would have allowed more precise positioning of the point marker cursor in PhotoModeler, while not detracting from their visibility. The advantage of PhotoModeler was that once the amphorae were photographed, large numbers of mapping labels could be processed. So in one photographic dive it would theoretically be possible to plot over 100 amphorae, a task that would take several days using conventional tape measurements. In reality, large numbers of amphorae were not uncovered at one time, but progressively. So that during any one photographic dive one was usually re-recording amphora that had been covered on previous days.

The biggest problem in using PhotoModeler for this type of work is housekeeping. It is essential to establish a strategy for handling the images, the PhotoModeler files, and the output data. Potentially, there will be hundreds of points each related to a particular object and cross related to Photo-Modeler files and images. If a strategy is not developed the whole process can rapidly get out of hand. A directory structure was established using two separate folders, one for the images and the other for the PhotoModeler files. By keeping the images separate, they were easy to duplicate and to ensure they were not modified (resaving modified JPEG files results in loss of quality as it is a "lossy" compression). Images were kept in folders and named according to the date and time of dive (for example: 010718AM, 010718PM, 010719AM, etc.). With the digital camera the individual files are date and chronologically named. The PhotoModeler folders were managed in the same way. The targets were named in PhotoModeler with the amphora number (or target number) together with target descriptor, L (left), R (right), C (center) for the mapping labels, and T (toe, for the toe of an amphora).

Another problem with Photomodeler (discussed earlier) was when trying to measure very small single artifacts, items otherwise hidden from the camera, and upside down amphora with only the small toe visible for mapping. In the first two seasons these situations were dealt with by taking direct measurements, whereas in the third season with the development of the control grid, PhotoModeler was used.

B. Accuracy

Estimating the accuracy of any underwater surveying technique is notoriously difficult. Comparison between the conventional surveying technique and the PhotoModeler system proved interesting (see also discussion in Chapter 4, Section VI.C). The control points were surveyed using tape measures on a number of occasions resulting in a large number of measurements. Site Surveyor was then used to process these data, which then provided statistical information on the accuracy of the survey (See Table I). These results represent the best possible accuracy achievable on the site using conventional tape measurements. Given the nature of the control points (some robust others more fragile), it is likely that the points themselves have an uncertainty in their position which may affect the accuracy. As described previously this gave an average residual of 6 mm with an RMS residual of 9 mm. This was not the accuracy of the survey of the amphora, because the control point calculation was the result of hundreds of measurements. It is likely that the manual measurement of an amphora consisted of four or five individual measurements for each point and was probably an order of magnitude larger.

PhotoModeler was also used to survey the control points and the results are shown in Table II. By fixing the three coordinate defining points (zero, X, and A) in PhotoModeler the program provided the true coordinates of

Table I

Statistical data from conventional tape measurement of control points.

RMS Residuals	0.009 m
Avg. Residual	0.006 m
Redundancy	189
Points Used	19
Points Ignored	0
Observations Used	246
Observations Ignored	12
Observations Rejected	0
Depth Ref. Point	zero

Points:

Name	X	Y	Z
A	0.900	–3.947	1.072
A1	0.867	–3.809	0.978
B	1.232	4.847	–1.995
C	4.989	–2.075	0.979
C1	6.271	–0.955	–0.888
D	4.336	–4.296	1.648
D1	8.546	–5.256	0.972
E	0.329	2.020	–0.760
E1	0.617	0.297	–0.137
E2	–0.905	0.429	–0.122
F1	2.041	2.666	–1.216
G1	6.281	–7.688	0.300
J1	1.102	–8.996	2.503
K1	–0.945	–11.083	2.123
M1	–6.274	0.844	–0.039
N1	–4.234	4.908	–2.012
P1	–3.514	–5.949	0.582
Q	3.173	–7.398	1.738
X	3.575	0.000	–0.300
X1	3.364	0.105	–0.653
zero	0.000	0.000	0.000

the other points. It can be seen that the accuracy of PhotoModeler is generally better than the manual tape measurements from Site Surveyor.

Two sets of PhotoModeler tests were made using the grid frames mentioned earlier. As the frames were of known dimensions and graduated, the coordinates of the graduations were recorded and then compared. It can be seen that the lightweight frame had a reasonable linear accuracy, but the rectangularity and “levelness” of the grid were poor indicating that the grid

Table II

Statistical information from PhotoModeler measurement of rigid frame.

Id	Name	X (m)	Y (m)	Z (m)	Tightness (m)	Tightness (%)	X Precision	Y Precision	Z Precision	Largest Residual (pixels)
3	“0.0,1.0,0”	0	1	0	0.010116	1.011632	0.011254	0.00416	0.008894	5.361904
4	“0.2,1.0,0”	0.20407	0.998069	0.00035	0.007635	0.76355	0.010812	0.004476	0.008717	2.843521
5	“0.4,1.0,0”	0.40401	0.997047	–0.000727	0.007473	0.747297	0.010512	0.004745	0.0086	2.356565
6	“0.6,1.0,0”	0.606571	0.993912	–0.000785	0.008254	0.825426	0.010333	0.00497	0.008524	3.126201
7	“0.8,1.0,0”	0.805504	0.993629	–0.003214	0.005301	0.530095	0.010309	0.005152	0.008507	1.88321
8	“1.0,1.0,0”	1.001491	0.994393	–0.008325	0.00734	0.733993	0.010437	0.005301	0.008552	3.738406
9	“1.0,0.8,0”	1.002261	0.798973	–0.008841	0.006791	0.679149	0.010276	0.005205	0.008602	2.522222
10	“1.0,0.6,0”	1.001379	0.597387	–0.008861	0.007363	0.736334	0.010287	0.00525	0.008859	3.825791
11	“1.0,0.4,0”	1.000602	0.398978	–0.007686	0.006063	0.606318	0.010339	0.005238	0.008988	4.196657
12	“1.0,0.2,0”	0.998773	0.197168	–0.004617	0.002671	0.267063	0.010468	0.005231	0.009064	7.704376
13	“1.0,0.0,0”	0.998056	0.000058	0	0.006014	0.601372	0.010726	0.005335	0.009315	20.729929
14	“0.8,0.0,0”	0.804132	–0.002453	0.002943	0.003957	0.395743	0.010519	0.005524	0.009377	8.888967
15	“0.6,0.0,0”	0.600898	–0.001985	0.002843	0.007022	0.702174	0.010432	0.005676	0.009497	3.682489
16	“0.4,0.0,0”	0.39935	–0.003561	0.001513	0.007217	0.721733	0.010487	0.005764	0.009669	4.38471
17	“0.2,0.0,0”	0.195965	–0.002548	0.001892	0.003918	0.391774	0.010666	0.005768	0.009874	3.733617
18	“0.0,0.0,0”	0	0	0	0.007144	0.714362	0.01096	0.005699	0.010125	4.649686
19	“0.0,0.2,0”	–0.001692	0.195733	0.001795	0.003897	0.389651	0.010831	0.00532	0.009803	2.519157
20	“0.0,0.4,0”	–0.0019	0.396688	0.003344	0.006704	0.670418	0.010784	0.004963	0.009504	2.229375
21	“0.0,0.6,0”	–0.002616	0.597843	0.001074	0.007622	0.762247	0.010843	0.00465	0.009261	3.212612
22	“0.0,0.8,0”	–0.001813	0.801378	–0.000017	0.007863	0.786317	0.010999	0.004377	0.009054	4.607657

was distorted. Because the grid was lightweight it had a lot of flexibility and it distorted easily. The rigid grid, however, had much higher accuracy all round. Figure 6.18 shows the extent of the reliability of the system. The average difference in the X, Y, and Z coordinates between the true position and the PhotoModeler position is $\Delta x = 2.3\,\text{mm}$, $\Delta y = 2.6\,\text{mm}$, and $\Delta z = 2.9\,\text{mm}$. This means that the individual accuracy for any single point, using PhotoModeler, is exceptionally high.

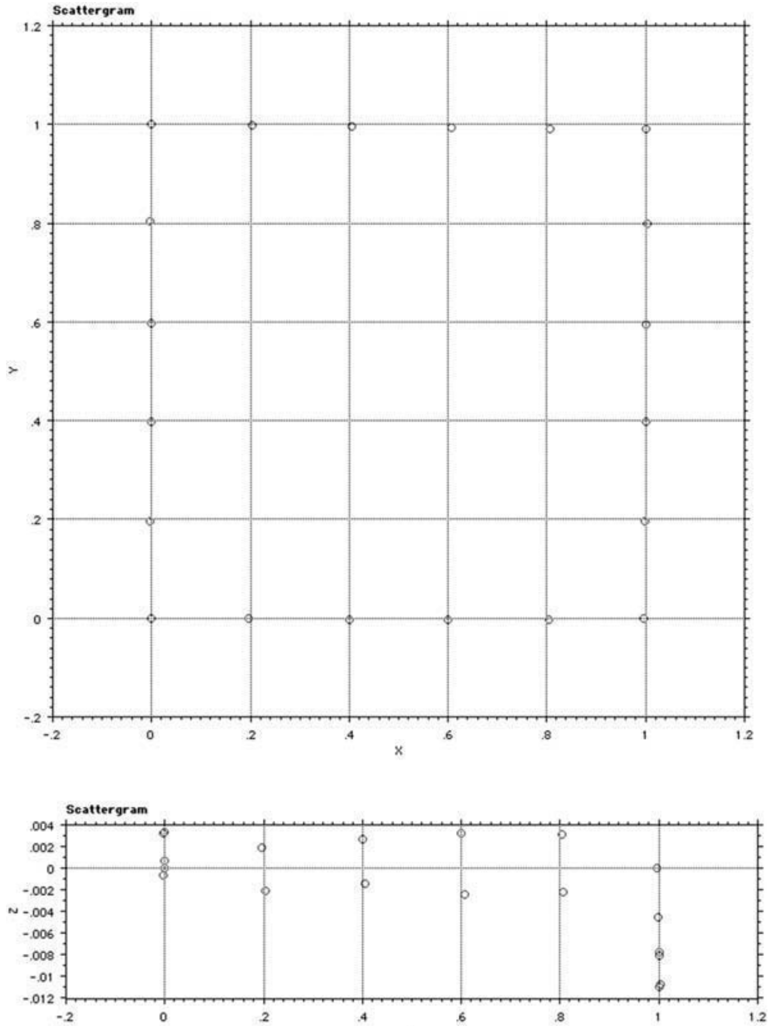


Figure 6.18 Plot of the 1-m grid frame showing the reliability of the measurements.

C. Rhino

The three-dimensional package, Rhinoceros, a NURBS 3D modelling program, was used to plot all artefacts on the site and Matthews carried out this work. Rhino is a very sophisticated, yet easy to use, program, and a complete three-dimensional site plan was produced with this system.

The program has the usual four-window format: plan, front, side and perspective views (although other views can be chosen, i.e. bottom). A wire-frame model of each type of amphora (and various other objects) was generated, usually from a photograph of the object itself. To keep the file size small, a generic example of each artefact type was made. The outline of the object is produced and then rotated around the vertical axis to produce a solid wire-frame object and then scaled. The handles are generated separately and added or "attached" to the main body of the amphora. Additionally, the three target points on the mapping labels are then added. Other artefacts were generated in a similar way, although only the amphorae had the mapping label arrangement. For the small objects, they were either placed in their approximate position, or two or three selected points were measured on the object and used to locate its position.

Once an amphora were surveyed using PhotoModeler, a set of three X, Y and Z coordinates for the "top", "left" and "right" targets on the mapping label were obtained. The amphora wire-frame was then placed on the Rhino plan (in a random position). An extremely useful function in Rhino is the "Orient" key which will move and orient any two or three points chosen on an object with the target X, Y and Z points. Using this feature, the whole object was moved so that the three points on the wire-frame were placed exactly on the three coordinates calculated by PhotoModeler, (note there is only one unique solution to this and there is no chance of creating a "mirror-image" position for the amphora). Figure 6.19 shows a section of the site with the amphora as wire frames (above) and then rendered (below). The enormous benefit of this process is that the image is a true three dimensional model that can be combined with the three dimensional image of the seabed obtained from Virtual Mapper (above) and then rendered (Figure 9.20). The archaeologist can then view the image from any direction giving a unique three dimensional impression of the site. This system of displaying excavated sites is an exciting new development with many implications for interpretation and analysis.

As the model developed, the wire-frame objects could be rendered so that they appeared solid Figure 6.19. It was then possible to view the site in perspective, rotate it, and view it at any particular angle. This was an extremely useful way of analysing the composition of the site and how it had been formed and provided far more detailed information then the conventional archaeological site plan.

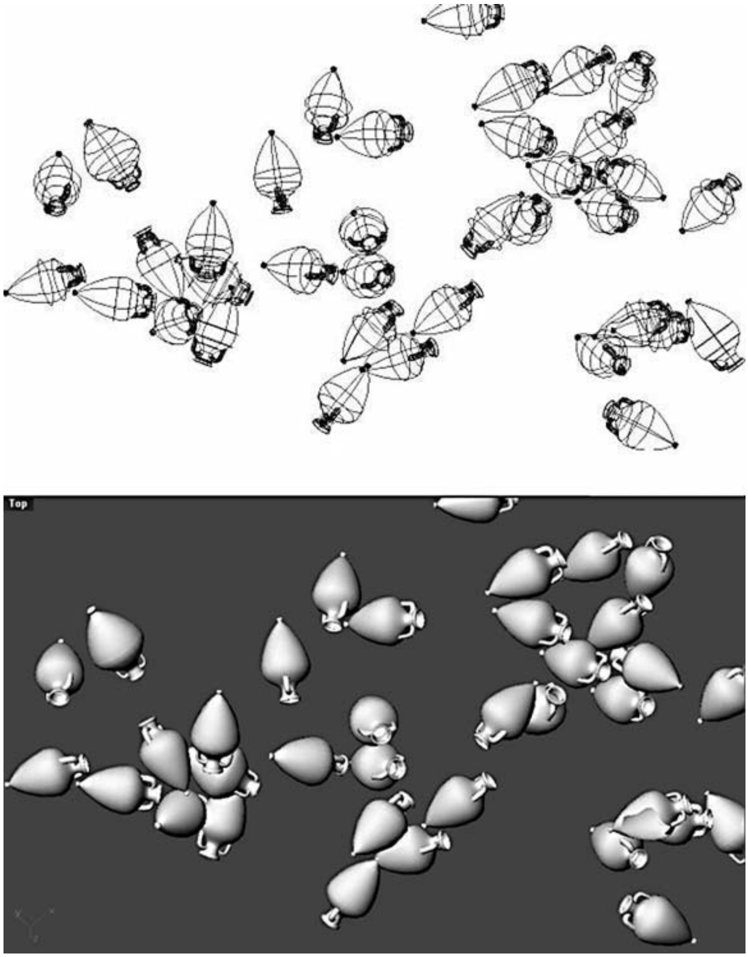


Figure 6.19 A three-dimensional plan of the Tektash site created in the Rhino 3-D graphics package. (Courtesy of Xila Matthews and the Institute of Nautical Archaeology, Bodrum, Turkey.)

VII. LOW-VISIBILITY WORK

There are situations where it may be necessary to work in low visibility, where it is not possible to see more than about 1 m. In these conditions, it is worth reconsidering the necessity to work on the site in the first place. Is it possible to wait until the conditions improve? Or for the time, effort, and hazards of working in these conditions, could time be spent more profitably elsewhere? If the decision is made to work in poor visibility, safety is of prime importance, particularly where the site is in deep water. Owing to the

Figure 6.20 An oblique three-dimensional plan of the Tektash site created in the Rhino 3-D graphics package. (Courtesy of Xila Matthews and the Institute of Nautical Archaeology, Bodrum, Turkey.)

lack of visibility under water, it is strongly recommended that every task to be performed under water should first be practiced on land (this is a good idea irrespective of the visibility). Consider, for example, a typical situation of setting up a right angle for a site grid 10×10 m. Each task in the process can be rehearsed on land in order to anticipate problems which will be exceedingly difficult to resolve in poor visibility under water. Diver A takes the stakes and the hammer, diver B the tape measure. The point of the corner of the grid needs to be preselected and a guideline to the spot laid beforehand. Diver A hammers in the stake and A and B then go 3 m to set up the start of the 3-4-5 triangle. How do you determine which direction to go? Should a prearranged line be laid or a compass course be used? Would it be better to have a string 3-4-5 triangle rather than a tape? Which is easier? If all these operations can be tried out so that the divers are familiar with exactly what they have to do, where they have to go, and what is likely to go wrong in rehearsal, there is a chance that the operation may be a success. In general it is difficult for divers to communicate under water, but it is worth noting that it is possible to talk under water through a regulator, provided you speak slowly and clearly. It should be remembered that Murphy's law operates with extra efficiency in low visibility, i.e., anything that can go wrong will go wrong and probably in a big way. Certainly underwater communications systems would be of immense benefit here, both for efficiency and safety.

Chapter 7

Site Plans and Geographical Information Systems

I. INTRODUCTION

Plans, particularly site plans, are an essential part of the archaeological record and come in many different formats and qualities. It should always be remembered that it is easy to produce a high-quality plan based on a low-quality survey, so it is important to indicate on the plan the level of the accuracy of the survey. The situation when the first edition of this handbook was written is quite different from today. The availability of graphic packages and computer programs which assist in the surveying of sites has radically altered the potential for producing high-quality plans. Indeed, currently it is quite easy to produce three-dimensional plans of sites and it is anticipated that the development of the geographical information systems will make the ability to integrate survey, remote sensing, predisturbance, and excavation work commonplace, with enormous potential to link text-based data with the graphic three-dimensional reality.

With all site plans, it is essential to draw up the information at the time the data are being collected. If one vital measurement is missing, this can be identified on the spot and rectified. If this is discovered later after leaving the site, the measurement will be impossible or very difficult to recover. Thus, at the very least a basic or rough plan should be produced at the time the survey work is undertaken.

The production of plans also requires careful thought. A plan of a whole site on a very large scale will be an essential part of the archaeological process, however, such plans can be 1 or 2 m in size and are quite unsuitable for publishing in an archaeological report. With some planning it may be possible to utilize the large-scale plan in the publication in a reduced form. For example, if line thicknesses are small in the original, they can disappear in reduction, thus requiring the plan to be redrawn. To some extent, the use of computer-based plans can resolve this problem, provided the archaeologist is comfortable working on a computer rather than a hard copy.

II. RASTER GRAPHIC PACKAGES

Raster graphics are images made up of a matrix of individual cells, and generally are created by scanning an image, or originate from a digital camera, or other similar device. Raster graphic programs allow for the manipulation of the raster images, which are images that are made up of an array of cells or pixels with each cell having various forms of information. Thus, the image can be a bitmap, where each pixel is either black or white; grayscale, where the pixel can have 256 shades of gray; or a variety of color options. If a raster image is enlarged, the pixels get larger, resulting in what is usually called pixilation (Figure 7.1). It is important when creating raster images to consider what the final scale is going to be and to ensure that the object is recorded at a resolution suitable for final production. Thus, for most high-quality publications it is necessary to scan an object so that the final image, when placed in the document, has a resolution of about 300 dpi

Figure 7.1 Pixilation, showing the effect of greatly enlarging a digital image.

(dots per inch) or 118 dpcm (dots per centimeter). For example, if the image is going to be placed in an A4 document in landscape format with a width on the page of 175 mm and the original is 35 mm wide, it will be necessary to scan the original at a higher resolution than the final. In this case, the calculation for the scanning resolution is simply:

$$\frac{175 \times 300}{35} = 1500 \text{ dpi.}$$

In other words, if one doubles the image size, the resolution will be reduced by a half provided the file size is constant. It is not possible simply to scan the original at 300 dpi and improve the quality by enlarging it. If, on the other hand, the image was scanned at a much higher resolution than required, there would be no problem reducing it to the required resolution, because unnecessary information is being discarded. The opposite situation is where you are trying to create information by increasing the resolution is not really there. In reality this is not a complex issue; if you print a document at a resolution higher than the capability of the printing system, then you will have a very large file, but the quality will be exactly the same as the quality if you printed the image at the resolution of the printer. If you print an image with a resolution lower than the printer resolution, then the results will be poor.

Some packages allow the addition of text and some pseudovector graphics, however, in the final production, the image is converted to raster, so it is still essential to consider resolution. Other issues relate to the file format. There are a number of basic formats. The most common are: TIFF, JPEG, GIF, BMP, EPS, PICT. Each format has a different use and significance. Tagged-image file format (TIFF) is used to exchange files between applications and computer platforms. TIFF is a flexible bitmap image format supported by virtually all paint, image-editing, and page-layout applications. Also, virtually all desktop scanners can produce TIFF images. Joint photographic experts group (JPEG) format is commonly used to display photographs and other continuous-tone images in hypertext markup language (HTML) documents over the World Wide Web and other online services. JPEG format supports CMYK, RGB, and grayscale color modes. Unlike GIF format, JPEG retains all color information in an RGB image but compresses file size by selectively discarding data. A JPEG image is automatically decompressed when opened. A higher level of compression results in lower image quality, and a lower level of compression results in better image quality. In most cases, the maximum quality option produces a result indistinguishable from the original. Graphics interchange format (GIF) is the file format commonly used to display indexed-color graphics and images in HTML documents over the World Wide Web and other online services. GIF is a compressed format designed to minimize file size and electronic transfer time. BMP is a standard Windows image format on DOS and Windows-compatible computers. BMP format supports RGB, indexed color, grayscale, and bitmap color modes. Encapsulated PostScript (EPS) language file format can contain both vector and bitmap graphics and is supported by virtually all graphic, illustration, and page-layout programs. EPS format is used to transfer PostScript-language artwork between applications. When you open an EPS file containing vector graphics, Photoshop rasterizes the image, converting the vector graphics to pixels. PICT format is widely used among Mac OS graphics and page-layout applications as an intermediary file format for transferring images between applications.

III. VECTOR GRAPHIC PACKAGES

A. Two-Dimensional Packages

There are a number of two-dimensional packages, the best known are Adobe Illustrator™, MacroMedia FreeHand™, and AutoCAD™ and its variants. These programs enable computer-aided drawing of a whole range of archaeological projects, from site plans to artifact drawings. There are great advantages to working electronically. The ability to work in a non-pen-and-ink environment is an obvious advantage, particularly as it is possible to produce hard copy at any scale, using A0 plotters through to A4 printers and e-mail these plans across the world in a blink of an eye. Because vector graphics are created by a series of equations which define lines, text, and fill, the files are small, for example, the plan shown in Figure 11.11b (below) is a scan with a file size is a 64 KB file whereas the relatively low resolution scan of the plan (Figure 11.11a) is 236 KB. In addition, scaling of a vector image has no effect on pixilation, because the lines are equations and can be infinitely scaleable. Figure 7.2 shows the effect of enlarging a letter created in raster and vector graphics. Often, vector graphic packages are used to trace over hand-drawn plans. For example, a drawing of a site plan can be scanned and imported into the vector graphics package in a background layer. This image can then be locked and the standard drawing tools used to trace around the drawing. Proper text and symbols can be inserted, and when the job is finished the underlying drawing can be deleted.

B. Three-Dimensional Packages

The three-dimensional package, Rhinoceros (Rhino), a NURBS three-dimensional modeling program, is typical of a range of similar packages that

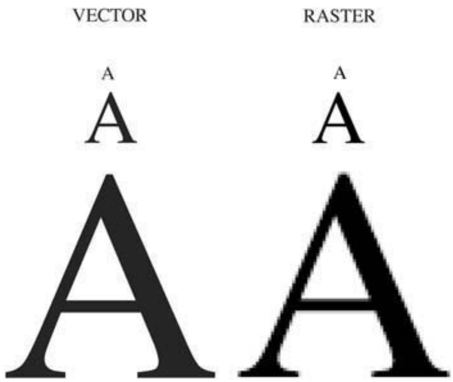


Figure 7.2 Enlargement of vector and raster graphics. Image on left shows vector graphics image of letter A at three different enlargement sizes. On the right is shown the same images in raster format. The vector image can be enlarged indefinitely without loosing line quality.

allow three-dimensional visualization of a site (VectorWorks, Extensis, etc.). This system was used by the Institute of Nautical Archaeology at Tektash during the 1999–2001 seasons to plot all artifacts on the site. Rhino is a very sophisticated, yet easy to use, program, and a complete three-dimensional site plan was produced with this system.

The Rhino program has the usual three-dimensional modeling, four-window format including plan, front, side, and perspective views (although other views can be chosen, i.e., bottom). A wire-frame model of each object was generated, usually from a photograph of the object itself. To keep the file size small, a generic example of each artifact type was made. Figure 7.3 shows the process of generating a wire frame of an amphora. The outline of the object is produced and then rotated around the vertical axis to produce a solid wire-frame object and then scaled. The handles are generated separately and added or "attached" to the main body of the amphora. Additionally, the three target points on the mapping labels are then added. Other artifacts were generated in a similar way, although only the amphorae had the mapping label arrangement. The small objects were either placed in their approximate position, or two or three selected points were measured on the object and used to locate its position.

Once an amphora was surveyed using PhotoModeler, a set of three X, Y, and Z coordinates for the top, left, and right targets on the mapping label were obtained. The amphora wire frame was then placed on the Rhino plan (in a random position). An extremely useful function in Rhino is the "orient" key, which moves and orients any two or three points chosen on an object with the target X, Y, and Z points. Using this feature, the whole

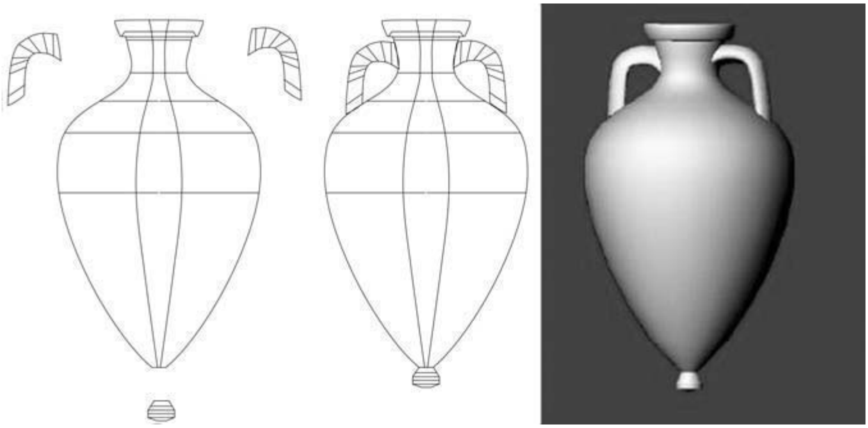


Figure 7.3 Rhino wire-frame image of amphora showing how model is built up and various components added. On right the wire frame is rendered.

object was moved so that the three points on the wire frame were placed exactly on the three coordinates calculated by PhotoModeler (Figure 7.3; note there is only one unique solution to this and there is no chance of creating a mirror-image position for the amphora).

As the model developed, the wire-frame objects could be rendered so that they appeared solid (Figure 7.3 right). It was then possible to view the site in perspective, rotate it, and view it at any particular angle. This was an extremely useful way of analyzing the composition of the site and how it had been formed, and it provided far more detailed information then the conventional archaeological site plan.

IV. GEOGRAPHICAL INFORMATION SYSTEMS

The geographical information systems (GIS) have growing application in archaeological work. Essentially, they allow the display of numerical, text-based, and graphical information in a visual environment. As usual a variety of software packages are available, all doing much the same type of process. There are several GIS programs, ArcView, ArcProject, and TNTMips. ArcView GIS has been used by this author and will be the subject of the following generalized discussion.

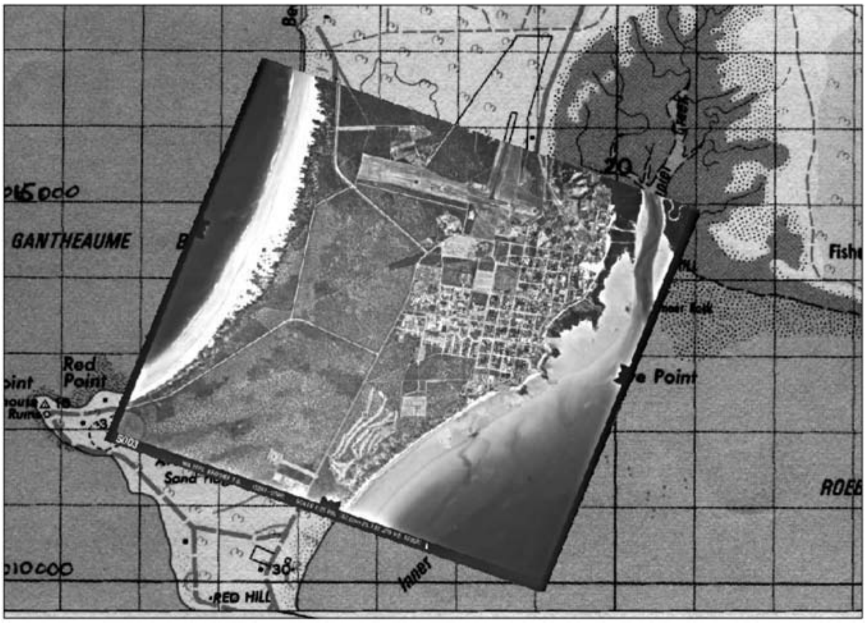


Figure 7.4 Georeferenced historical map. In this example an aerial photograph of Broome, Western Australia, is linked to a topographical map by georeferencing.

The GIS has the ability to import and manipulate graphical data in true geographical space. For example, if one had an aerial photograph of an area, we could assume as a first approximation that if this image was imported onto a GIS working plane, then by scaling and rotating the image it will be possible to show the image so that each pixel corresponds to a geographical point (a latitude and longitude or easting and northing). This, of course, has immense implications. Not only can different geographical images be placed layer by layer (topographical maps, charts, plans, etc.), but so can other geographical information such as sonar traces, magnetometer plans, excavation site plans, artifacts, etc.

The other type of information that a GIS can manipulate is numerical data that is related to a location, for example, the magnetic field intensity of a track of a survey vessel. Here there would be three fields in the data-set: X coordinate, Y coordinate, and field intensity. More complex data could include a shipwreck database where there is the location of the ship and then all the known information about the vessel in a number of different fields.

Using this graphical representation of alphanumeric data, groupings and patterns are shown that could never be seen otherwise. A good example of this was when the Western Australian shipwreck database was first put into a GIS. The database had been managed for a number of years as a simple, flat-file database. A great deal of effort had gone into the editing and quality control of these data. The moment the shipwreck positions were placed on a map of Western Australia, two sites showed up as completely wrong with one being in the middle of the Gibson Desert. It was obvious that there had been a transposition of the second and third digit in the longitude, but that was not something seen by looking at just the data.

The GIS for planning, urban development, management, etc., has much more sophisticated potential because of the wealth of data. For example, in the United States house numbers on streets have been geocoded so that it is possible to exactly locate the position of a street address. Demographic and geographic information is available about suburbs, counties, and states that can help to plan things as far apart as emergency response to flooding to planning the best location of a new McDonalds.

For the maritime archaeologist, there are three main areas where a GIS can be used: in survey, excavation, and site distribution. Although it is acknowledged that there are other things it is routinely used for now. In the following discussion, it will be assumed that the techniques of creating a GIS are understood and readers are referred to manuals and guides for the use of GIS in archaeology.

A. Survey

The most useful aspect of a GIS for survey is the ability to superimpose all sorts of two-dimensional images in a georeferenced form. Thus aerial photographs, charts, and topographical maps can be arranged in layers. Then historical maps and charts can be placed in the layer and georeferenced using the GIS programto complex georeferencing where the graphic image is stretched in a complex fashion in different directions so that selected points on the image align with geographical positions on the GIS. Most georeferencing is simple scaling and rotating. In more complex situations there may be some skewing, and in the most complex situation the transformation is nonlinear. In this case one could take a historical map and georeference it to a modern map. From this one would be able to determine the changes in coastline by comparing the historical map with the modern map.

Additionally, as indicated above, survey data can be included so, for example, the traces of a towed search can be traced on a chart showing what areas the survey has covered and what has been missed (see Figure 3.19 showing the towed search for the Portuguese ship *Correio da Azia* and Figure 7.5 showing the search area in Galle Harbour, Sri Lanka). This sort

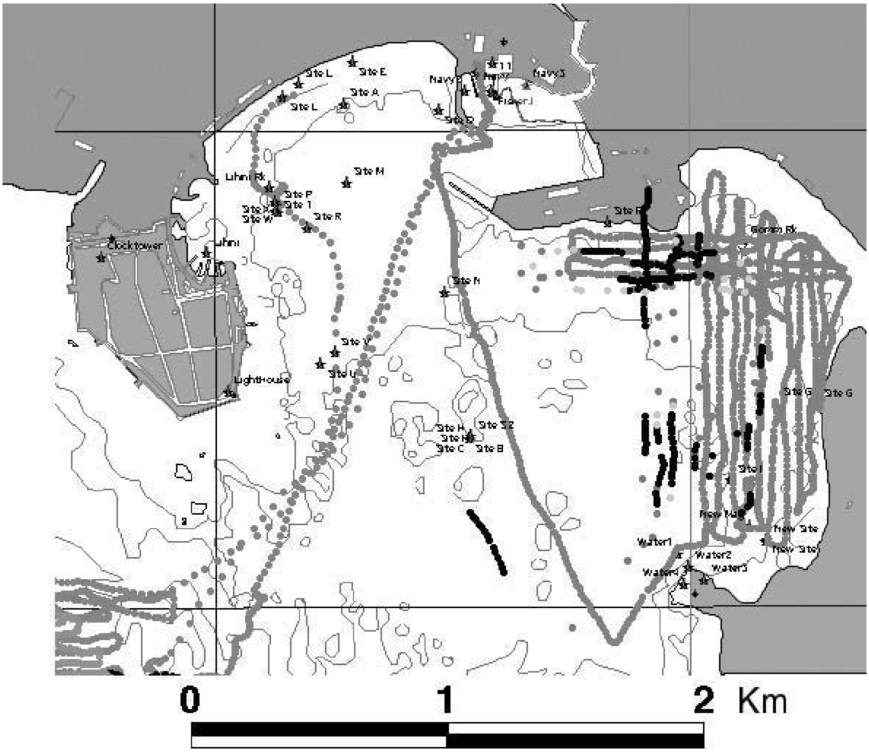


Figure 7.5 Plot of a search pattern in Galle Harbour, Sri Lanka, on a GIS.

of data, which is just the track of the search vessel, can be complimented with real data such as depth, seismic, or magnetic field intensity. In all cases the geographic location, which is usually just an X and Y coordinate, has an additional data component, the value of which has a geographical coordinate. From this sort of data simple and sophisticated georeferenced plots of data can be produced. For example, a simple survey across a geomagnetic anomaly can produce a contour plot (see Figure 3.28), and an intensive and systematic survey can produce complex magnetic data (see Figure 3.27).

In the case of side scan sonar, and data that are more complex than just a particular value related to a particular geographical point, there are more complex solutions. As indicated in Chapter 3, it is possible to create side scan sonar images as graphic images. Because the geometry of the sonar image is known and the geographical position of the beginning and end of the image is also known, the geographical coordinate of each pixel is then

Figure 7.6 Side scan sonar GeoTIFFs overlaying a georeferenced aerial photograph of Bathers Bay, Fremantle.

known. Through software it is possible, therefore, to produce a GeoTIFF image and these images can be placed in layers on the GIS. Figure 7.6 shows a series of side scan sonar GeoTIFFs placed on a GIS with an aerial photograph (also georeferenced).

B. Excavation

If an archaeologist has a site plan and knows the geographical coordinates of two features on the plan, it is possible to georeference the plan and place it on a GIS. Ideally, the opposite corners are ideal for georeferencing. This is quite simple and straightforward. However, if we are dealing with a raster image—a simple scan of a site plan there is not a lot that can be done after georeferencing. It is, however, possible to import a vector image; ideally a computer-aided drawing which will have both graphic and data information. When these are imported into the GIS they appear in different layers. One layer may contain the physical features of the site, the second may contain images of the artifacts, and the third may contain information about the objects. So it is possible to create a site plan where each object is connected to an artifact database making it possible to view all of the objects belonging to a particular category on a site.

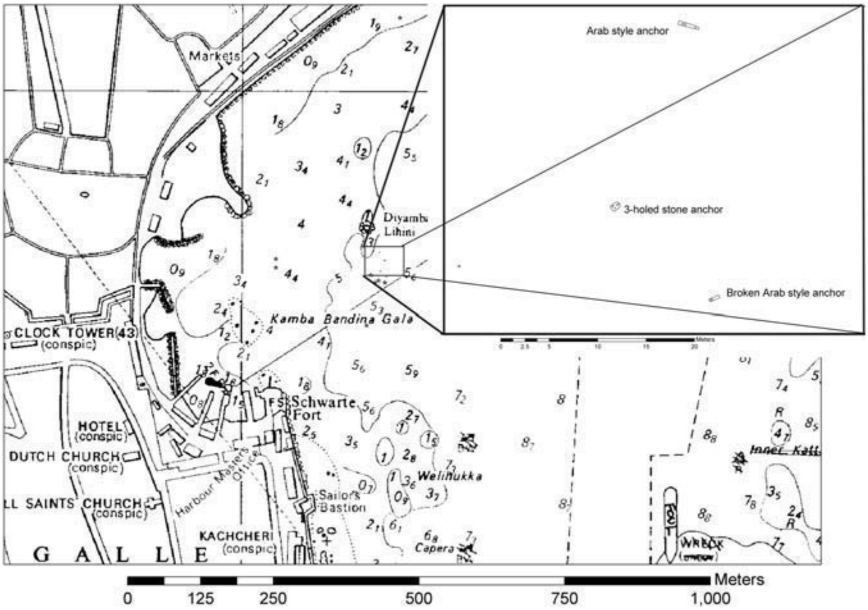


Figure 7.7 A GIS of Galle harbour showing an enlargement of an archaeological site, one of several layers of information relating archaeological information in the harbour. The insert (top right) is an enlargement of an area where three stone anchors were found. These anchors were drawn to scale and surveyed so that there geographical orientation was known and was then imported into the GIS with the known coordinates georeferenced. compare this with Figure 7.5 where the layer shown details the survey work.

C. Site Distribution

Provided a database has geographical information (i.e., the latitude and longitude of the entry), then the entries can be placed on a GIS. Thus a shipwreck database can be created quite simply and information relating to each shipwreck is associated with the location (see Figure 7.8). The GIS can also be structured so that when one zooms into a position, gradually increasing the scale, the site can be seen and proceeding deeper into the site it is possible to see the individual artifacts. In theory the database could be structured starting on a map of the world and ending up examining an artifact on a site.

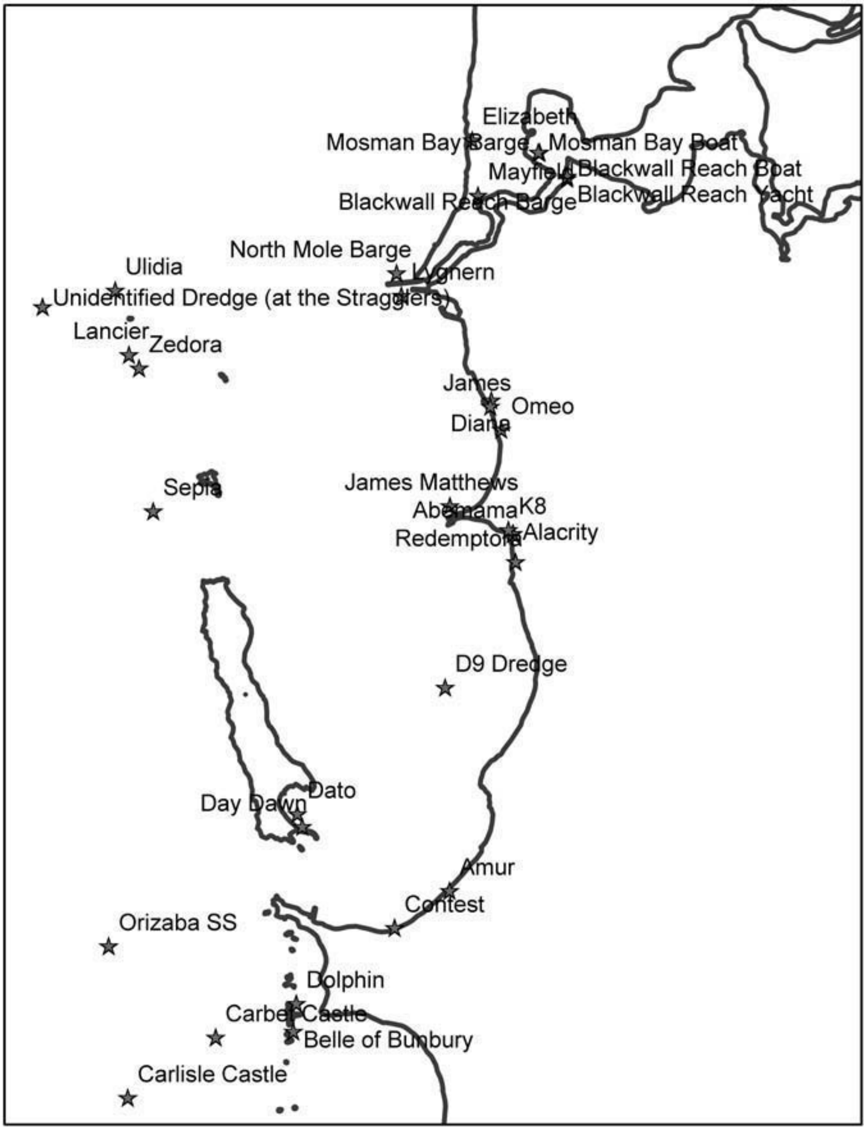


Figure 7.8 An enlargement of a GIS of Western Australian shipwrecks, showing sites in the metropolitan area. Each site is linked to a database providing information on each particular site. This is an important tool in the management of historic shipwrecks.

Chapter 8

Field Photography

I. GENERAL CONSIDERATIONS

Photography plays an essential part in underwater archaeology as it is an extremely practical method of recording information. This chapter deals with the role of photography in the field and includes aspects of terrestrial and underwater photography, particularly general underwater photographic recording and recording aspects of the surface operation of the expedition or field work. Additionally, the use of video cameras and remote operating vehicles is discussed. Technical site recording photography and photogrammetry is dealt with in Chapter 6 and artifact photography is dealt with in Chapter 12.

There are a number of different types of photography which the archaeologist has to consider when planning field work. The amount of work generated on an archaeological site can be enormous and can create serious logistic problems, particularly if the team is small or the site is deep. Because underwater photography is usually the most important part of the photographic work and requires considerable skill, it is generally advisable to choose a person who is an experienced underwater photographer and who would be totally dedicated to underwater photography. This person can then be involved in other aspects of expedition photography, although others may be available to take on the terrestrial photography, including the artifact photography and general darkroom work.

When considering the selection and role of an expedition photographer it is essential to understand that the nature of the work requires the photographer to be physically divorced from the archaeology. Observing an experienced photographer working on an excavation, it is noticeable that they rarely do any work other than photography. No matter how important or interesting the operation, it is not possible to put the camera down and become part of the work without losing the ability to photograph. This point is often misunderstood by the less experienced expedition members who tend to think that expedition photographers are less involved in the archaeology. By the same token, it is often important that the archaeologist is intimately involved in the recording of objects, artifacts, and details that only the archaeologist will understand or be aware of. Therefore there is a subtle balance that needs to be understood between the photographer and the archaeologist. Given that the techniques are now more easily understood and that there is a need for both types of recording, the archaeologist or project director should have no real difficulty in differentiating the roles and objectives of these two operations. Essentially, the archaeologist has to make sure that the photographic recording is done in a way which ensures that archaeologically important information is recorded so that it is useful and relevant to the archaeologist.

The best field situation is to assign at least one person to handle all the technical aspects of expedition photography. It is also important to ensure that a number of staff members, particularly those who do excavation, are experienced or trained in underwater photography so that they can record aspects of the work as the excavation progresses. This allows the more experienced, professional photographer to concentrate on the more difficult or demanding requirements of the photography.

II. CAMERA EQUIPMENT

A. Digital Cameras

The current range of digital cameras is making rapid in-roads into areas of work normally reserved for the conventional camera. The advantages of the digital camera are that images can instantly be made available for viewing via a computer, there is no lengthy and time-consuming developing, and processing and images can be quickly and easily manipulated using computer graphic software. The main limitations, up until recently, have been that the image size has been small, giving low resolution which meant that the images were only useful in certain circumstances. With the introduction of the 4, 5, and higher mega pixel cameras, the resultant image is very close to conventional 35-mm photography. Images can be enlarged to an A3 format of magazine quality and still retain sharpness with only slight pixilation. The technology (in 2003) is rapidly advancing with even larger image sizes. Naturally these cameras are not (currently) underwater cameras, so a commercial housing has to be bought for it (or a custom housing built) to accommodate the camera. Recent experience with an Olympus Camedia 3000, with a custom-built housing, has demonstrated that this camera system, for archaeological work, now outweighs the Nikonos in ease of use, flexibility, and range of application. The small LCD monitor on the back of the camera can be used to frame pictures and is virtually an automatic one-control system. This digital camera system was used in 2001 at the Institute of Nautical Archaeology Tektash excavation in Turkey to carry out underwater survey work using photogrammetric software including PhotoModeler and stereophotogrammetry (see Chapter 6).

B. The Nikonos System

Indisputably, the Nikonos camera is one of the most effective underwater cameras for archaeological work. The alternatives to the Nikonos range from the 120 format camera such as the Rollei Marine and Hasselblad, to the 35-mm single-lens reflex (SLR) camera. All of these are land cameras enclosed in custom-made watertight cases. The biggest problems under water with the 120 format are the limited depth of field and the restriction in the 12 frames available (although some cameras have 24 and 70 exposure backs). Generally, the system of placing a land camera in a watertight box has drawbacks. First, to load the camera it is usually necessary to remove it from the watertight case, and this involves disengaging a number of linkages and connectors. Often the person doing this is wet, so care has to be taken not to drip water into the case or camera. Secondly, the lens system on such cameras, although of good quality, is often impaired by the use of a plane port on the watertight case; this introduces a number of distortion effects. These effects can be remedied by using a specially designed domed port. Thirdly, the camera cases are usually bulky and relatively vulnerable; these shortcomings can create problems on a wreck site. Also, it is often thought that the advantage of using a camera housing is that one can utilize an existing SLR camera, however, this can be a false economy. The housing is usually very expensive, especially when fitted with a correcting port. It can end up costing more than the complete Nikonos system with the expensive 15-mm lens (over US$1000). Additionally, the SLR camera will then be locked in a housing made unavailable for other terrestrial work. The main advantage of using an SLR camera in a case is the ability to frame photographs accurately and to deal with very close-up, or macro photography where precise focusing is essential.

These problems are all resolved with the Nikonos system, but unfortunately the system is expensive, especially if the 15-mm water-corrected lens is used. Nevertheless, the benefits of the system, in my opinion, far outweigh the cost.

The Nikonos system has undergone a number of changes over the years, starting out as the Calypso, then followed by the Nikonos I (Calypso-Nikkor), Nikonos II, Nikonos III, Nikonos IVA, and finally, the latest Nikonos V. Apart from the Nikonos IVA and V, which are battery dependent with automatic exposure, all the cameras are essentially the same with minor improvements and modifications and can still be obtained second-hand. The instrument is basically a nonreflex, watertight camera, with all controls and openings having very effective watertight seals. The lens system is bayonet-mounted, enabling a number of different lenses to be fitted. The camera body has a focal plane shutter and a small, nonreflex viewfinder. The shutter speed control ranges from a 500th to a 30th of a second and time delay.

It is generally considered that the Nikonos II is a more robust camera than the Nikonos III. The Nikonos IVA incorporated major changes in the design. There were a number of improved features including an automatic shutter control system. All the original lenses could still be used, except for the 15-mm water-corrected lens. It seems that the Nikonos IVA exhibited a number of problems and, as a result, Nikon released the Nikonos V. This included further improvements like a redesigned rear door and a different meter readout with LEDs giving the shutter speed, and comprehensive exposure control system including manual and automatic control of shutter and flash. The present indications are that, although technically superior to the III, the later Nikonoses are prone to flooding and when this happens it requires expert attention. On the other hand, if the Nikonos II or III flood, they can be washed in fresh water, carefully dried out, and reused. In my opinion, although the automatic exposure system of the Nikonos V has great advantages, the possibility, in field conditions, of flooding with permanent catastrophic results is a major shortcoming. If the Nikonos II or III flood, with a simple treatment the camera can be back in operation within 24 hours.

The Nikonos range of lenses includes two basic types: those which are terrestrial plane port lenses; and those designed purely for underwater work with specially designed, water-corrected optics. Nikon offered three types of lens: a 35-, 28-, and 80-mm long focus lens. The 35-mm lens is of excellent quality and, with this alone, the Nikonos is an extremely attractive proposition for above water, sports, marine, and hostile environment work. If the glass port is exposed to water, dust, or mud, it can simply be wiped off. Under water, the lenses are less useful because of distortion problems.

In the mid-1960s, Nikon released the revolutionary 28-mm water-corrected lens. For the first time, there was an off-the-shelf, custom-designed, water-corrected lens. The improved quality of the photographs was immediately obvious. It should be noted that Nikon rated the focal length of their underwater lenses in air (even though they cannot be used in air), so that the effective focal length of the 28-mm lens in water is 36 mm. In the early 1970s, Nikon brought out the 15-mm lens (20 mm in water) and, until recently, this was the single most effective lens available for maritime archaeological work. The lens is virtually distortion-free; certainly, there is almost no spherical distortion at all, and recent measurements indicate that, for all practical purposes, it can be considered a stereometric lens. It represents an impressive technological feat enabling photogrammetric measurements to be made using this system. The short focal length reduces the camera-to-subject distance, thus reducing attenuation of the subject in bad visibility. In clear water, close-ups look as if they have been taken in air. The lens was redesigned for the Nikonos IVA and V cameras and in its present form will fit any Nikonos camera except the RS model.

The 15-mm lens comes with a large, clip-on viewfinder which is easy to operate under water, though some care is necessary to take account of parallax when working close up. The lens has an excellent depth of field, and it is a tribute to Nikon that they did not take a short-cut and make the lens fixed focus. At high light levels using f 16, the depth of field is from infinity to 0.25 m so that in such conditions, one can virtually use it as a fixed focus lens. At f 2.8 the depth of field is still good, infinity to 1.5 m, 1.0–0.6 m, or 0.32–0.27 m close up. Figure 8.1 shows some of the range of the Nikonos system. Nikon also added a 20-mm (27 mm in water) lens to the range.

Additionally, a new, non-Nikon, and consequently much cheaper lens, has been brought out by Sea and Sea. The initial reports are that the lens is of high quality, and that it may prove to be a useful alternative to the 15-mm Nikon lens.

III. MISCELLANEOUS EQUIPMENT

A. Exposure Meters

Another accessory for underwater photographic work is an exposure meter. Light levels under water are quite difficult to judge, particularly as our eyes accommodate to different light levels. An accurate exposure meter is very useful when working in natural light with the nonautomatic cameras like the Nikonos I and III. A battery-powered cadmium sulfide cell exposure meter is a good reliable choice.

Figure 8.1 The standard Nikonos underwater camera range. (Courtesy of Brian Richards, Department of Maritime Archaeology, Western Australian Maritime Museum.)

B. Flash and Artificial Light

Various forms of supplementary lighting are available for underwater work. There are two basic types: electronic flash (or strobe) and incandescent lights. In most cases, the flash is more effective as it can produce a very strong light with far less bulk than the strobe lights. Its main disadvantage lies in the fact that one cannot see what the effect will be until the film is processed. More experimentation is possible with lights. In some cases the latest electronic flash has a small light that can be used so that the photographer has some idea of the effects of the flash (shadows and coverage) before it is used. Additionally, the latest Nikonos cameras have flash attachments that have automatic through-lens control of the flash, which greatly simplifies the system. It should always be remembered that the capacity to reason is diminished when one's head is under water. The deeper the dive the less rational one becomes. So anything that reduces the need to think under water is helpful (see Section V.A). In addition experiments have been made using flash in turbid water to improve the quality of the image. In turbid water the main problem with flash is backscatter, where the flash illuminates small particles in the water between the camera and the subject. When the flash is reasonably close to the camera this can cause real problems. By mounting the flash on a long arm and positioning it well above the camera and subject, the backscatter problems can be reduced. If the flash is far enough above the scene, the flash acts as a wide diffuse light source and can dramatically improve the image. However, this is a complex process and trial and error will be required to obtain the optimum configuration.

C. Film

Correct exposure and adequate depth of field are the basic requirements of general underwater photography. It is worth considering the relationship between shutter speed, depth of field, and film speed. Under water, a good shutter speed is about 125th of a second. Things do not move very quickly under water, so there is no real need to increase the speed above this. Below this speed, one has to be careful to avoid camera shake. For more detailed aspects of this type of problem, readers are referred to standard texts on underwater photography (Mertens, 1970).

There are various speed ratings for various color and black and white films. In general, the faster the ISO (ASA) rating, the better the results, but at the expense of graininess. In normal situations of clear water and bright sunlight, medium-rated film of ISO 100–200 is normally used. With lower light levels, faster film will be required. Normally ISO 400 is the conventional limit for black and white film; beyond this, the film can be uprated or "pushed" to a higher ISO rating and then overdeveloped. Some special black and white films such as Ilford XP1 and Kodak T-Max have ISO ratings up to 3200 and can be pushed beyond this value, so that it is possible to take photographs in extremely low light levels. Kodak T-Max is particularly useful as it can be processed with conventional black and white processing. In most cases, color film is used for photographs that will be used for lecture and article illustration, and due to the increasing blueness of the color photograph with depth, artificial light is often needed to balance the color. For most recording purposes, black and white photographs are cheap and easy to produce in the field, and artificial light is only needed at very low light levels. With a little experience and by making some simple experiments, it is usually quite easy to determine the best film–developer combination. Provided that the light levels are monitored with an exposure meter, it is then quite straightforward to produce well-balanced and consistent results.

There are also some photographic films that are thinner than normal and thus allow more than the normal 36 exposures on a standard 35-mm film cassette. Ilford Autowind, with an ISO 400 film available in 72-exposure cassettes, has now been replaced by Ilford Type R550 Surveillance Film, available in 30-m rolls. Using this type of film can be advantageous when photographing a photomosaic, because it is possible to take twice as many photographs without having to reload the camera. Special developing tanks are required to take the longer film, otherwise the processing is conventional.

Finally, the introduction of digital cameras is rapidly changing most of this technology and one wonders if black and white film will be available in a few years time. Clearly, the same principles apply to digital cameras and the relationship between speed and aperture still exists, although it is purely for the photographer. The automatic exposure systems can be set or programmed to be biased toward speed (the usual situation under water) or aperture. The ability of the digital camera to deal with extremely low light levels is phenomenal, and provided one can mount or clamp the camera in a fixed position some surprisingly good results can be obtained.

D. Miscellaneous

Finally, a diver has to resolve the problem of how to carry all the bits and pieces that have to be taken under water. At times, a diver can look a bit like a Christmas tree. It is worth considering mounting the camera and exposure meter on a bar. The bar holds the camera and the exposure meter and provides a handle so that everything becomes an integral unit, all controls can be checked at a glance, and system can be picked up or put down as one. Interestingly, it does not make the unloading of film any more difficult with the Nikonos system because the camera base is bolted to the bar, but the body can still be removed from the top.

In most field situations where conventional photographic information will be required, the construction of a field darkroom will be essential. This may be just a simple tent which is light-proofed with black plastic, a blacked-out room, or a place used only at night. The basic necessities will be a small, portable field enlarger and some simple darkroom fittings including: safe light, developing trays, timer, contact printer, framer, or measuring jugs. All of which can be made to fit into a small suitcase for easy transportation. The advantages of having on-the-spot results are immense. Prints can be made within a few minutes and used directly in discussion on aspects of survey or excavation and the results are available for producing plans and surveys as the work proceeds. In addition, the photographic film can be processed to ensure that the proper coverage is being made and that the cameras are functioning properly. Even if a darkroom is not available, the processing can be done using daylight loading tanks (Agfa Rondinax), which are also economical on chemicals. Again digital photography is largely replacing these requirements and all one needs is a laptop computer. In some cases it is not even essential to have a printer.

a

b

Figure 8.2 Stereo camera bar on an underwater photo tower (a) and in a terrestrial situation (b) inside the *Wasa* at the Wasamuseet in Stockholm. Note in A the underwater cameras are mounted on small hand-held camera bars that are then attached to the stereo bars. (Figure 8.2a is courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

E. SCALES

Most record photographs will require some form of scale in the view. The obvious choice is a scale with black and white graduations of some appropriate size. There are, however, problems with black and white graduations because they often cause halation in the black and white negative. It is worth briefly considering this problem because it gives an insight into some of the technical difficulties of underwater photography.

Halation is the result of local overexposure causing the light to irradiate from the light areas into the darker surroundings of the photographic emulsion, giving the effect, on the print, of a halo around a white object. It is usually caused by the film backing and is most obvious in black and white film. It occurs to some extent with color film, but not at all with digital photography. In many cases, halation is simply aesthetically unpleasant; however, with scales it causes the graduations between black and white to be unequal in length. Usually, under water at low light levels there is no natural pure white, only a range of mid-grays to black can be observed. In order to get the correct exposure, a reflected light exposure meter is used. This results in the photograph being overexposed, but produces the full tonal range in gray. If the black and white scale was not in the picture, the results would be perfectly acceptable. If, however, small areas of pure white exist, which do not contribute to the integrative effect of the exposure meter, the white areas will be grossly overexposed relative to the gray, thus creating the halation. This effect can be overcome by selecting a suitable tone for the light part of the scale. Light gray is best, although a colored paint can also be used. The objective is to tone down the white, thus reducing the contrast between the light and dark graduations. It should also be noted that with digital cameras halation is not a problem.

IV. GENERAL FIELD PHOTOGRAPHY

General field photography covers all aspects of the non-underwater expedition work. It includes coverage of the preparation on the surface for the underwater work; it also involves recording the field conservation and any work related to the artifacts of a general nontechnical nature. The technical problems related to artifact photography are dealt with separately in Chapter 12. Essentially, general field photography covers the type of photographs that may be required to illustrate a talk or report on the field work or that can be used for reference purposes at a later date.

A great deal of care has to be exercised in these situations to ensure that the photographic recording does not get out of control. Large numbers of photographs can be taken of the running of the expedition, but they often lack purpose or meaning. An alternative is to request that the expedition be allowed to obtain copies of any personal photographs taken by team members during the field operations. This way, the best coverage can be selected from a wide range of material.

It is important that the archaeologist or project director decide well in advance what aspects of surface photography need to be covered. Usually, artifacts are photographed in the field entailing a major photographic field commitment. It will be necessary to decide what other aspects of the surface field work need to be covered by photography and how this will fit in with the other photographic work. It may be that a series of photographs will be required for slide show presentations, together with general black and white photographs for press releases. All these considerations should be thoroughly discussed in the planning stage with the photographers so that they are fully aware of any requirements. Specialists within the project may also have specific photographic needs.

There is one point of warning regarding photographic material. It is essential that the project director ensures that everyone is aware of the conditions of photography on an expedition. For example, does anyone have the right to take photographs for their own purposes and publish them at will, or is personal photography embargoed? It can be a potentially difficult situation if the conditions are not made clear. It is perhaps unnecessary to ban photography altogether, but it is not unreasonable for the expedition to expect to be able to obtain particularly important or interesting photographs from team members. Where there are major sponsors who have an interest in the images, the conditions of publication need to be clearly outlined. This may be best done by having a written agreement signed by all expedition members so that there can be absolutely no misunderstandings. It is obvious that there are many different ways of handling this situation, but it is important to ensure that everyone understands the rules.

V. GENERAL UNDERWATER PHOTOGRAPHY

A good underwater photograph can make a far greater impact than any amount of words, particularly as the underwater world is not familiar to everyone (Figure 8.3). It is necessary, at this point, to differentiate between a general photograph used to illustrate the site for the layman, and the specialized recording photograph used for making the site plans (see later). In the former case, the composition needs to show a particular aspect of the work that is to be illustrated. For illustrative pictures of artifacts or people working, it is essential to get close to the subject. A wide-angle lens is ideal for this type of work because it allows an enormous depth of field, enabling a close-up photograph of a small artifact to be taken with the diver completely in focus in the background. It is extremely good for composition and, at the same time, achieves a clear, crisp image of the object. Again, the photographer needs to always be in front of the subject as there is a

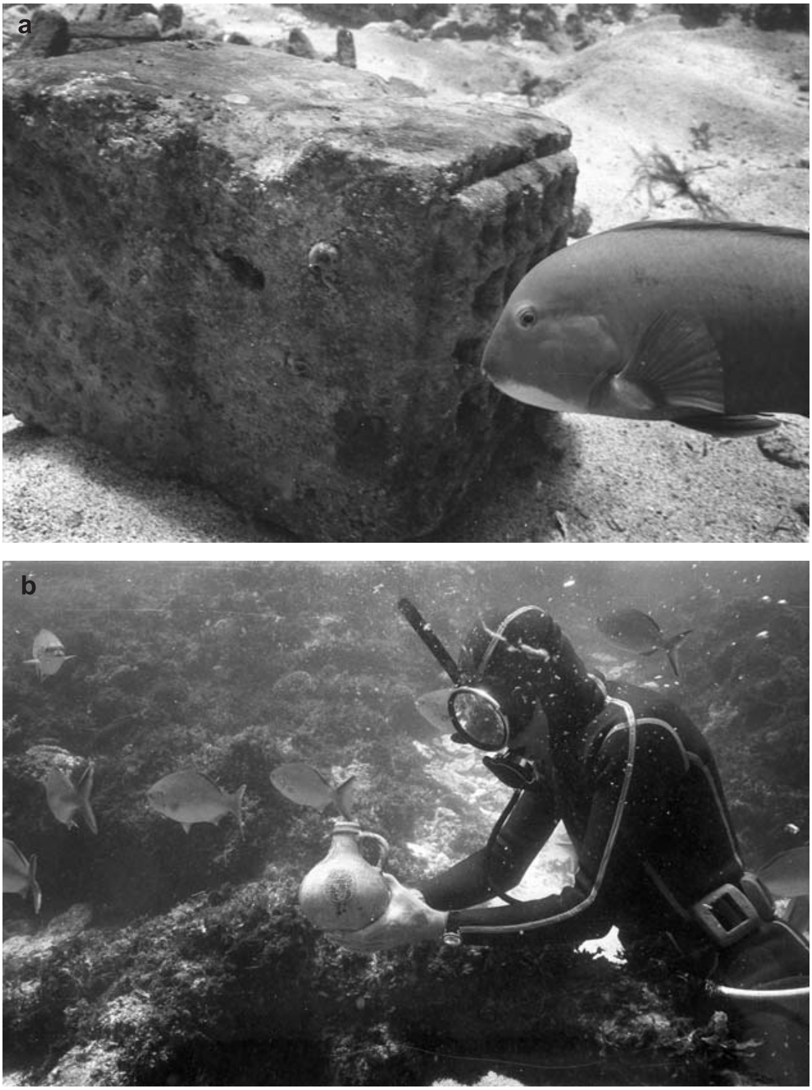


Figure 8.3 Good underwater pictures are invaluable for illustration.

tendency to have rear views of divers rather than full frontals if one is not conscious of the problem.

Before embarking under water, it is necessary to work out the type of photographs required and ensure that the people who will be working under water understand what is wanted. It is important that other diving members be made aware of the main principles of underwater photography as they may be co-opted at times into the photograph to act as a scale or to hold an artifact. For example, there is a need to understand composition and that an object should be held close to the face when being photographed; otherwise, there will be two opposing centers of interest, the face and the object, on either side of the frame. It is useful to experiment with different configurations (on land) of a model and the object using a wide-angle lens. In this way, it is possible to work out standard arrangements: object in front of face or at one side or the other. Inevitably, one will find that the most pleasing composition will be with an object held a few centimeters from the face. It is necessary to be cautious when using the very wide angle lenses because of the effects of perspective distortions. It is also worth remembering, that when photographing work under water, it is not particularly interesting to see divers with their heads down and their backsides up. It is more engaging to have them doing something while facing the camera. Each dive will have a general photographic objective which will be fairly obvious in terms of what is happening within the work pattern of the day. If, for example, the job for the dive of the day is surveying a single object, then the photographer will have to try and cover the whole operation from beginning to end. If a repetitive job is the order of the day, then it will be necessary to try and cover the work at various points in the operation.

On sites where visibility is reduced, it may be necessary to arrange special photographic dives. It is particularly difficult to photograph in these conditions because other divers inevitably stir up sediment as they work. The slightest movement of a fin on a site where there is fine silt, coupled with no current, can destroy a whole photographic session. It is therefore advisable to arrange photographic dives to coincide with the period when the water is the clearest, or to ensure that if others are to work during a photographic dive they are experienced and are aware of the problems. It may also be that there are certain times over a number of days when the water can become very clear like during a high-water spring tide. It is important to plan extensive coverage during these periods because the improved water clarity will provide better quality photography and help in the interpretation.

Many archaeologists face a moral dilemma in considering "staged" photographs of artifacts under water. The purists hold that a photograph must illustrate the true world and that to fake a shot is misleading. Provided that there is no danger to the artifact (and in many cases there is none), it is often more efficient to take a group of objects back down onto the site in controlled conditions where a better coverage can be made than at the time of discovery. Taking into consideration the conservation problems, a time may be selected when the water clarity is good, work can be stopped so that the sediments are not disturbed, and divers can be posed to re-enact the discovery. It is impractical to have a photographer on all dives to cover every possible eventuality. An alternative is to halt the operations and get the photographer down to cover the situation when a "find" is made, but in many cases this is difficult. By selecting the time and place to take a general photograph, a number of objects can be covered in one operation. However, such photographs, can have a staged look and care is required to make them look as natural as possible. If the results then provide a photograph that enables the archaeologist to illustrate the type of work being carried out, or to promote the project through sponsorship or fundraising, then, provided the artifact does not suffer, the process is more than justified.

A. Low Light Levels

Poor underwater visibility can be caused by two separate effects: the water clarity, which can range from clear to pea soup; and the light levels, which can range from brightly lit to dark. With turbid water and high light levels (at the surface) it is like swimming in brightly lit soup. The deeper the water the more the turbidity filters out the light, thus reducing its level until it is totally dark. On the other hand, the water may be clear and the light level low, and one is similarly in the dark at depth. However, in the latter case, the introduction of supplementary lighting can make a considerable improvement in the photographic image, particularly with color photography, and a flash or lamps can be used without much difficulty to illuminate the subject. Naturally, the composition needs to be considered, because it is impossible to illuminate level subjects that are in the foreground and subjects that are in the background at the same intensity. Either one can get flat-on to the subject by swimming over the seabed and illuminating and photographing downward, or choose to illuminate the subject in the foreground, leaving the background dark.

At low light levels in turbid water conditions, the problem is much more difficult and it is debatable if supplementary lighting is worth the trouble. If the lighting is placed too close to the lens, the suspended matter in the water is illuminated, causing strong backscatter. To avoid this, the lens-lighting separation has to be as great as possible. Archaeological site record photographs are often vertical and these are difficult to take with the flash or lights far enough away from the camera lens to prevent backscatter, but, at the same time, not creating uneven light levels across the subject. Because it is usually more practical to work with a flash, it is usually not possible to check if the arrangement is working until one sees the results. Some flash units now have a tungsten lamp that can be used to illuminate the subject so that the photographer can get some idea of what the effect of the flash will be. Thus the system has to be tested a number of times before it is certain that it is working and, should the conditions change, the arrangement will have to be reconsidered and tried again. It is essential with all flash work to conduct pretesting of the system to ensure the system will provide proper coverage.

There are other problems that occur when working at low light levels. For example, a curious "pooling" effect occurs in these conditions with the 15-mm lens (Figure 8.4). It appears in the photographs as if there is a central bright spot surrounded by a dark area. This is probably caused by the long light paths that occur with wide-angle lenses at the edge of the frame and the relatively shorter paths close to the optic axis. There may be increased attenuation along these paths, because there is about a 50% increase for the path passing through the edge of the frame, in comparison with the path length of an axial path, to the object at the same distance from the lens.

In very low light conditions, time exposures can be utilized, provided that the camera can be held steady during the exposure. Unfortunately, the nonautomatic Nikonos cameras do not have measured shutter speeds below a 30th of a second, so exposures have to be timed manually. With the Nikonos IV and V, the automatic system allows for electronically controlled time exposures through the internal exposure meter (with the Nikonos V timing automatically goes up to 15 seconds).

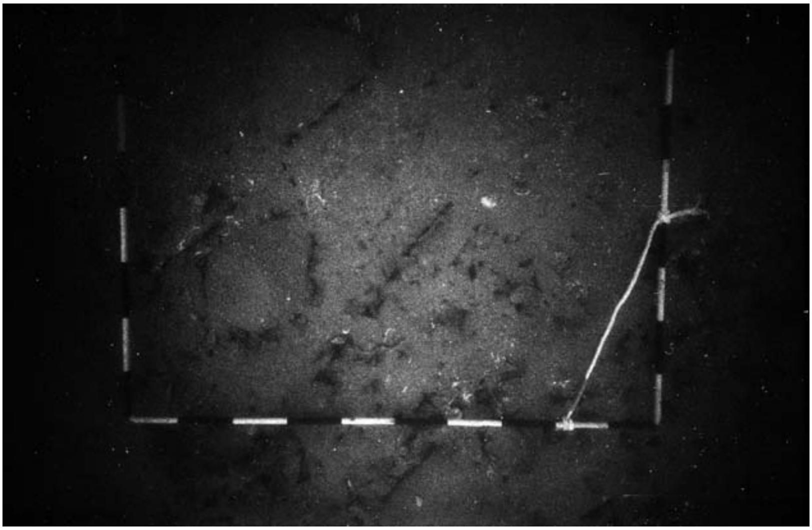


Figure 8.4 Photograph showing the effect of "pooling," where with low light levels and a very wide angle lens, there is a light center and a darker surround. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

One effective solution to the backscatter problem is to create an artificial sun with a flash unit. By using a very powerful flash unit mounted on a pole several meters above the camera, the flash acts as a diffuse light source. This technique has proven to be very effective and for any flash work, other than close up (300–500 mm), it has proven to be the only viable method although exposure tests are essential. Certainly, the flash unit should never be used close to the camera in turbid water.

As a general rule, provided the light meter registers and one can see about a meter or so, it is probably better not to use supplementary lighting. The quality in these conditions may not be particularly impressive, but consistent results can usually be obtained. If one wants any color at all in a photograph, irrespective of turbidity, then the use of a flash or lights is essential.

If there is only one camera available, it may be preferable to use color film rather than black and white, because color film can be copied in black and white and the results are reasonably effective, although having rather high contrast. Ideally it is better to use two cameras and to get color and black and white coverage. Usually, the kind of photographs that one wants to take in color are different from those in black and white, so two cameras are an advantage, although one often ends up with the perfect photograph on the wrong type of film. Color photographs are mainly used to illustrate talks and for glossy format publications, whereas black and white photographs are usually used in reports and for recording purposes. This should be considered carefully in planning any underwater photographic coverage.

Once again, the digital camera has real advantages in low light conditions and in turbid water. Certainly both digital still cameras and video cameras can actually see more than the human eye in turbid conditions. As a rule of thumb, the camera seems to be able to resolve objects at almost twice the distance that the human eye can see, with obvious advantages.

VI. TECHNICAL FIELD PHOTOGRAPHY

Photography plays another important role in maritime archaeology, i.e., as a means of surveying a site, recording the technical progress of an excavation, and recording artifacts *in situ*. The restrictions on the time a person can spend under water make the camera an excellent tool for simple site documentation. A maritime archaeologist does not have the easy access to the dig that a land archaeologist has, to be able to return at any point during the excavation, and make additional recordings in a reasonably relaxed environment. Methods of recording under water have been developed to get the maximum information under constraining conditions in the fastest and most efficient manner. Photographic recording, which allows measurements to be taken and provides information about the site, is therefore a useful method of maximizing resources. However, the archaeologist must have a clear idea of what needs to be recorded and why, and must also be conversant with the techniques to be used and their limitations; at the same time the person taking the photographs must have a thorough understanding of what is needed by the archaeologist. The photographer can then implement any number of techniques to help in the production of prints and plans of the site; but unless the right photographs are taken in such a way that plans and measurements can be created from them, the process will be wasted. For this reason a great deal of thought needs to go into the planning of this type of recording work. It is easy to assume that photography is a panacea and all that is necessary to record the site is to take lots of photographs. It is important to carefully document the work, otherwise the result will be a great number of irrelevant photographs, and a lot of wasted time and effort trying to interpret them. Carefully prepared and placed scales, accurate positioning of the camera, and planning will help to produce a photograph that can then be used as an aid in plan-making.

There are a number of different types of technical photography: a general view, usually a low oblique, to show the site; a vertical to provide a simple plan of an area; a close-up of detail on the site; a photomosaic for an overall site plan; a stereophotograph for viewing the site in three dimensions; and a photogrammetric coverage to obtain accurate three-dimensional site measurements. These different techniques can be used, depending on the requirements and needs of the work.

In the early stage of producing a predisturbance site survey, a photomosaic can be used to provide a detailed, medium-accuracy site plan. It is almost impossible to hand measure all the small details of a site that are not required at a high level of accuracy. The mosaic will contain most of the information and can be used in conjunction with a conventional tape survey (see Mosaics). The intelligent use of a combination of conventional and photographic techniques is ideal for this type of survey. Photography is also useful as a method of recording the progress of an excavation. A series of photographs of a grid square under excavation provides a record of the location of objects and their relative orientation and stratigraphy. In the case where detailed and accurate information is required, for example, of a hull structure, photography can be used to provide supplementary information should a mistake have occurred in recording or measurement. Unless there is a photograph, it can be almost impossible to resolve these types of problems. It is worth spending time and effort to get good photographic coverage, and photogrammetric and stereophotographs are particularly helpful.

VII. VIDEO CAMERAS

Underwater video cameras are widely used on archaeological wreck sites. On the archaeological excavations of the *Mary Rose*, the video was described as "probably the most important single piece of equipment loaned to the [*Mary Rose*] Trust during the excavation" (Rule, 1982). During the excavation it was used as a briefing tool for new divers and as a method of recording the ship's structure (see also Cederlund, 1981).

There is obviously a great advantage in using a video camera to monitor the progress of an excavation, particularly where the site is deep and it is impossible for the archaeologist to inspect the site at will. Additionally, the video system can be used to provide important educational and training programs. At present the normal resolution of the best commercially available systems (mini-DVD format with three-chip set) is not nearly as good as conventional black and white film resolution nor the high-end digital cameras. With the advent of the digital camera, it is unlikely that the video system will be used for photogrammetric recording.

When the video camera is used as a method of recording a site, a great deal of thought needs to go into the process. Just as it is easy to take huge numbers of meaningless or poorly documented still photographs, it is also possible to accumulate hours of meaningless video footage. It is essential that planning goes into video recording and a decision should be made as to the need for video footage. Where the video camera is an observation point for the surface operators, it is probably not necessary to keep a record of what is happening. Where site recording is taking place, it is probably better to use still recording rather than video. However, where complex operations are occurring it is possible that video recording will be useful. This is a decision that needs to be made depending on the circumstances. The most important aspect of video recording, and possibly the most difficult with which to achieve good results, is the use of the video camera to produce instructional, educational, or semi-commercial videos. In this case, some understanding of film techniques is essential.

Chapter 9

Excavation

I. GENERAL CONSIDERATIONS

This chapter deals with the techniques of excavation. The question of the surveying techniques that can be used to survey a site during an excavation is discussed in Chapter 4, the recording of the excavation work is discussed in Chapter 10, and the excavation and the archaeological interpretation of an excavation is dealt with in Chapter 13. It is difficult to generalize about excavation. Each excavator will have a different approach to a site, and no two sites are ever alike. It is therefore impossible to give more than the broad outlines of methods and techniques of excavation. Because an archaeological site contains unique records of the past which the process of excavation will dismantle, it is essential to understand that excavation can only be justified in certain circumstances. The excavator must have a clear understanding of reasons for undertaking the excavation, of the techniques and methods that will be used, and the effects these techniques and methods will have on the archaeological record. Adequate storage, conservation, and work facilities, together with trained archaeological staff to handle the material, are absolutely essential before excavation can be considered.

Archaeologists undertaking an excavation must not only be experienced in excavation work but must also be used to directing the excavation. It is, for example, possible to be a good archaeologist and yet not be able to direct an excavation; this can result in poor archaeology. However, the converse is not true; one cannot be a good director of people and, without any archaeological skills, direct an archaeological excavation. This may have been true 20 or 30 years ago when there were no archaeologists who were able to work under water and no proper understanding of excavation techniques. The subject was then in a learning phase. Today, the ordinary techniques of archaeological excavation under water are well understood, and research and development is tending toward highly sophisticated methods and strategies of excavation and recording. It is essential that archaeologists who excavate sites are thoroughly conversant with these techniques and methods, and this can only be achieved through experience.

Excavation is the process of uncovering a site by removing spoil or intrusive material, observing and identifying the archaeological material, and then recording and recovering it. The most difficult aspect of excavation is identifying what is archaeological material and interpreting its significance; this is again where experience is essential. In the past, many maritime archaeological excavations have suffered from inadequate excavation techniques. This was partially due to the fact that maritime archaeology was in a developmental phase and it is easy to criticize the mistakes of the past. The mistakes formed part of a learning process which now makes it inexcusable for the same mistakes to be made. Cousteau (1954) described the early days on the Grand Congloué site (one of the early excavations of a site using the aqualung, to remind us of how long ago this was). The article was entitled "Fish Men Discover 2,200-year-old Greek Ship." In the following he describes the use of the air lift:

> Sometimes we got astride it and felt it vibrate like a spirited horse's neck as we turned on the compressed air. And like a browsing horse, the mouth went forward into the pasture munching shells, sand, shards and things too big for it to eat such as heavy hunks of wine jars. When an amphora neck jammed in the pipe mouth, another diver with a hammer pulverized the obstacle.

This practice would be deplored today, but at the time, when archaeology under water was only a vague possibility, many mistakes were made. Today, after the experience of countless exemplary excavations, it is no longer acceptable to use this type of approach.

Although high standards of excavation are expected on all maritime archaeological projects, it must be remembered that excavation alone is not archaeology, but part of a process whereby information is obtained which allows archaeological interpretation. Excavation is therefore carried out in a systematic manner across the site in both the horizontal and vertical directions. All the artifacts and their associations are recorded along with their three-dimensional coordinate location. Subsequently, the archaeologist has the responsibility, which is no less demanding, of interpreting this information and then publishing it. It is therefore important to emphasize that minimum archaeological standards include publication. An excavation that is not published means that the information is lost and this is bad archaeology, probably worse than excavating with inadequate techniques.

Throughout the process of planning an excavation, it is necessary to evaluate what is to be done and what the implications will be as the excavation proceeds. There must be good predisturbance information on which to base this planning process, so the predisturbance work is critical for subsequent planning as the predisturbance survey will not tell you what *is* going to happen as the excavation proceeds. However, it should provide one with an insight as to what *might* happen. The extent of the sight will be known and probably the depth of overburden and some indication of the potential depth of the archaeological material. The physical constraints of the sight will be known so that estimates of how efficiently one will be likely to proceed will also be known. The nature of the archaeological material, its likely fragility, material, and size should be at least anticipated. Armed with this information and the knowledge of the operational conditions on the site and the final destination of the material, some serious planning can be started. This will include a variety of contingency plans for various possible scenarios. It is almost impossible to predict the totally unexpected. It should, however, with good planning, be possible to anticipate most likely problems.

II. EXCAVATION TECHNIQUES

There are two simple approaches to excavation: one is to excavate over large areas of the site, layer by layer; the other is to work the site in small sections (either grid squares or trenches), layer by layer, repeating section by section across the site. The former approach is usually taken where the site lies in relatively calm conditions, there is a large staff available, and there are no time constraints. The latter method tends to be utilized where conditions are difficult, there is a limited number of staff, or where budget constraints restrict the length of excavation. In the latter case, excavation can be rapidly terminated without danger to the site.

In planning excavation work it is important to refer to the predisturbance survey. The information from this survey will play an important part in the planning of the excavation. The survey will provide information on the area of the site, the depth of the overburden, and the extent of the archaeological material and its nature. Some form of exploratory excavation may be needed to complement the predisturbance survey. For example, it may be necessary to determine the exact periphery of the site prior to the main part of the excavation. This process may simply be to excavate the overburden at the periphery until the archaeological layer is exposed. Alternatively, it may be necessary to excavate a test pit in order to determine the depth of the archaeological material. A great deal of caution is necessary when carrying out this form of exploratory work; however, provided the work is done carefully, it will provide essential information in planning the excavation strategy. Until the extent of the site is fully understood, it will be impossible to plan how long the work will take or the necessary storage and conservation facilities that will be required. There will be a great deal of difference between the excavation of a site which has an average archaeological depth of 0.5 m and that of a site which has an archaeological layer 4 m thick.

The use of grid frames to assist with excavation needs to be carefully considered. There are a number of advantages and disadvantages attached to using grid frames. On extensive sites with a large staff, grid frames are often used to help define excavation areas and to orientate staff who may be unfamiliar with the site (Figure 9.1). Novice archaeological divers inevitably require some form of coordination and, at times, the grid frame may be the best solution. Otherwise, when left to their own devices, it is not uncommon to find inexperienced staff excavating totally unsystematically in some far off area.

With the grid frame system, one is confined. Grid frames can also be useful supports for the excavators while they are working over a site that has a large quantity of extremely fragile material exposed and, as previously mentioned, are particularly helpful when working with novice divers. Proper buoyancy control and coordination of the excavation using more

Figure 9.1 Excavating using a grid frame, Ko Kradat wreck site, Thailand.

experienced staff may be a better approach to the situation. On many sites it is a requirement that fins are removed because they tend to stir up the sediment, thus reducing the visibility.

The use of grid frames also introduces a danger of damaging fragile objects. There are varying types of grid frames ranging from rigid frames that are set up and fixed to the seabed (scaffolding-type situation), to semi-flexible frames (made of plastic tubing), to string grid frames attached to small stakes. Completely rigid grid frames have been used on many occasions (for example Bass and van Doorninck (1982) at Yassi Ada in Turkey, Henderson (1977ii) on the *James Matthews* and Gesner (2000) on the *Pandora* site (Figure 9.2)) where they were used as the basis for a measuring system. Semi rigid grid frames made of PVC water piping were used in Kyrenia by Katzev (1970) (Figure 9.3) and by Piercy (1977, 1978, 1979, 1981) on the *Santo Antonio de Tanna* in Mombasa Kenya and in this situation they are used to control excavation work and are not used for measuring. Recently, Bass (2002) used string grid lines to delineate the excavation areas on the Tektas Brunu site as they are less cumbersome and more flexible to use (Figure 9.4).

The choice will depend on the circumstances and if the archaeologist wishes to use the grid frames for survey work. In general, grid frames are not used for reference purposes in survey work, because it requires that they are firmly attached to the seabed. Unless the frames are really firmly

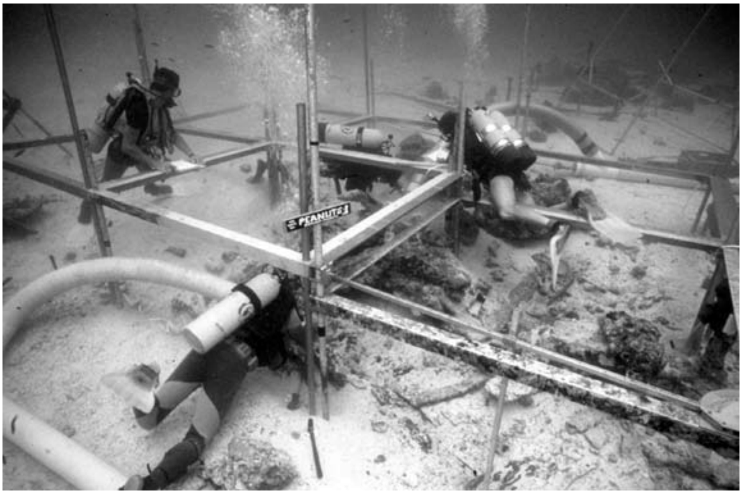


Figure 9.2 Rigid grid frames used on the *Pandora* wreck excavation as a basis for survey and photogrammetric work. (Courtesy of Brian Richards, Department of Maritime Archaeology, Western Australian Maritime Museum.)

Figure 9.3 Large complex grid frames made of plastic water piping in use on the Kyrenia wreck. (Courtesy of Kyrenia Wreck Excavation.)

Figure 9.4 String grid lines used at Tektas Brunu, Turkey, to delineate excavation areas. (Courtesy of Jeremy Green, Department of Maritime Archaeology, Western Australian Maritime Museum and the Institute of Nautical Archaeology, Bodrum, Turkey.)

attached to the seabed they will inevitably move if bumped by divers or equipment. Ideally, grid frames would be dispensed with altogether. The problem is they get in the way of the excavation, particularly when one has to work around the framework in order to get excavation equipment into a grid frame. If the excavation is deep, the grid frames will cause the edges of the excavation to slope down toward the center of the grid, because it is often impossible to get excavation equipment into the edges of the frame. As a result there will be slumping at the sides of the grid and a site can often look like a series of holes centered on each grid square. In such situations the use of grid squares cannot really be justified. If it is necessary to use a grid, it should be made as large as possible, ideally at least $4\,m^2$.

In many cases the grid frame plays some role in recording, however, it is usually not possible to use the grid frame for accurate recording. Such a system requires a rigid grid frame firmly attached to the seabed. Henderson (1975) used a rigid structure with great success to record and excavate the *James Matthews* wreck site, however, this approach is generally difficult to implement and to maintain. It is more likely that the grid will be used for approximate location and that important artifacts and structures will be recorded using a more reliable control. Thus, loose finds and fragments can be approximately located within the grid square, which will have some relationship with the site grid. Possibly, some objects, which do not require precise location can be registered within a subdivision of the main grid, giving a more precise location. Thus the grid can be very useful for recording purposes and allows the distribution of loose finds to be easily and quickly recorded.

One alternative to the grid frame is the trench system (Figure 9.5). Instead of square frames, a series of parallel lines or bars can be laid across the site. The lines marking the edges of the trench can be scaled so that the relative position in the trench may be determined.

In some cases it is possible to backfill from one grid square to the previously excavated square, or from one trench to the previously excavated trench. This simplifies excavation techniques considerably, particularly where spoil is too large to be removed with suction devices. The heavy material or even light spoil can be removed quite simply to the adjacent square (Figure 9.6). Naturally, such a system can never show the whole site completely excavated. This can be a disadvantage where there is a structure that would be best displayed completely excavated. This may be partially resolved by making a section by section photomontage or photomosaic of the site.

An excavation without frames has a number of problems, partially because it is difficult to control the excavation. It has already been noted that there is a danger that excavation will progress in random directions

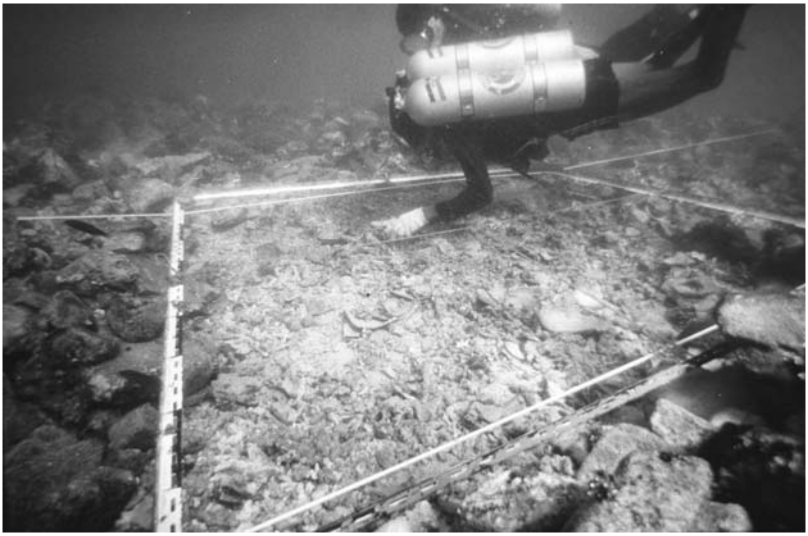


Figure 9.5 Excavating a trench and showing excavated square. Once the square is completed the grid is moved to the next position in the trench and the excavation continues.

Figure 9.6 Backfilling on Ko Kradat site showing the baskets used to recover ceramic shards. (Courtesy of Brian Richards, Department of Maritime Archaeology, Western Australian Maritime Museum.)

unless there is some form of control. However, if a start is made at one end of the site and excavation proceeds forward across the site, with experienced staff it is possible to excavate quickly and efficiently. A bar or tape can be used to help keep the excavation moving evenly across the site. The great advantage of this technique is that complex structures can be excavated in one piece.

When excavating in localized areas, a grid or defined trench is essential to confine the extent of the excavation. Excavation proceeds downward, layer by layer. The process is repeated grid by grid. However, it is often difficult to correlate grid square layers, as structures sometimes extend through several squares creating serious problems. On a site with little vertical component, the trench system works well.

One ingenious method of excavating a hole in order to make a test pit in loose sand or mud is to use an open-ended 200-L fuel drum as a caisson (Figure 9.7). By operating the airlift inside the drum, the interior base can be excavated away and, as this happens, the caisson drops lower and lower. The caisson keeps the sand from falling into the hole, thus enabling an easy excavation down to approximately 1 m. Using this system, it is also

Figure 9.7 Caisson excavation using a 200-L fuel drum open at both ends, Takashima, Japan.

possible to make careful records of the different layers excavated and record their depth by measuring how far the drum has penetrated into the seabed.

III. STRATIGRAPHY

It is not usually possible to excavate vertical cross sections under water, except when working in thick mud; therefore, stratigraphy can be difficult to record under water. In sand, silt, or gravel areas it is impossible to excavate in vertical sections, so excavation strategy will need to be carefully thought out if stratigraphy is to be recorded. The merits of working over a large area and excavating systematically downward have to be considered in relation to the difficulty of doing this evenly over the whole area. The problem with working in small grid squares (about $2\,m^2$), as discussed previously, is that the excavation ends up with a conical hole or pit, simply because the sand or silt will not hold any appreciable wall. Working along a front enables systematic recording and some degree of stratigraphy can be observed, although inevitably the working face will have slippage. The methods used will depend on the circumstances and the correct choice will only come with experience. Alternatively, careful excavation of layers is a possibility. With the judicious use of excavation tools, the excavator can remove layers over quite large areas, so for a start, the sterile overburden can be removed in one stage.

In many cases there is no stratigraphy, but rather a sterile overburden, followed by an archaeological layer, followed by a sterile layer. This is not always the case, and excavators must be cautious not to miss the subtle changes. Particularly, inside ship structures, it is possible to observe different stratigraphical layers trapped in compartments or on decks representing different phases of the wreck disintegration process. Additionally, when changes are observed, these are often difficult to record because of problems in establishing vertical datum points. This can be an extremely difficult problem and bubble tubes or depth-measuring devices will have to be used to make these measurements. These problems are discussed in Chapter 4.

It is additionally worth noting that under water, archaeological chronology can have a different significance than that for an archaeological site on land. In the excavation of a shipwreck, stratigraphy usually relates to a single event in time. Consequently, the stratigraphy may have little or no temporal significance, but it may have a particular spatial significance. Thus a shipwreck lying upright on the seabed will disintegrate in time. Any thing lying on top of another is determined by a spatial relationship rather than a temporal one. If the ship settled upright on the bottom, material would generally collapse downward and outward. If a ship sank heeled over on its port side, the guns (for example) on the starboard side would lie on top of the port guns after the wreck collapsed. By interpreting the events subsequent to the wreck, the excavator can thus determine more information about the ship. The unusual circumstance of a wreck, with the immediacy of the event, makes the spatial aspect of the site of much greater significance than the temporal aspect. This does not mean that one should ignore stratigraphy. The point is simply that the vertical component may be of no more significance than the horizontal component. As noted above, localized stratigraphy inside the structure of a shipwreck can have great significance.

Stratigraphy has played an essential part in the excavation of a number of shipwreck sites. In the IJsselmeer polder, sites can be dated using stratigraphical evidence. Because the vessels sank at a particular point in time archaeologists can identify the stratigraphy of the IJsselmeer and thus date the event (Reinders, 1982; Reinders *et al.*, 1978, 1984). Similar approaches have been made on the *Mary Rose* (Marsden, 2003) and the HMS *Pandora* (Gesner, 2000). Likewise, inundated land sites have an essential stratigraphical component. In the past, stratigraphy on underwater archaeological sites has often been ignored or not properly examined. It is essential in planning modern underwater archaeological excavation that the question of stratigraphy is taken into consideration. It is advisable to thoroughly understand the implications of stratigraphy on a wreck site as it will have quite a different significance to that of a land archaeological site.

Many other new and interesting underwater excavation techniques have been pioneered in the last few years. Some of these have been standard on land excavations for many years, but as the practice of maritime archaeology improves, so the technology moves with the times. On the *Amsterdam* project (Gawronski, 1986, 1987) the excavation work has developed into a multifaceted scientific study taking into account a wide variety of excavation strategies. Likewise, the examination of the mud in a late Saxon logboat found at Clapton shows the extent of the information that can be recovered using suitable excavation strategies (Marsden, 1989).

IV. COMMUNICATION

Communication between staff during an archaeological excavation is vital. Without good communication, excavations can become inefficient and artifacts and data can be lost. First, the excavation director must keep everyone informed of what is happening. This should be done on a day-to-day basis, either at a morning or evening meeting. It is the director's responsibility to ensure that the overall excavation strategy is being maintained and advise everyone when there is need for a change or where the excavation is working particularly well. This rapport with staff members is essential.

How this is handled will depend on the individual, but it is important for the excavation that everyone has a clear idea of what they are doing and why (see Chapter 2, Section V).

How to maintain continuity on a site is one excavation problem that is often difficult to resolve. If there are a number of different people excavating the same area then achieving continuity can be an exacting task, particularly if it is necessary to spend time on a decompression stop. There are several possibilities and these will depend on the type of site. In shallow water (<10 m), excavation can continue for considerable periods of time without interruption with cold or fatigue the limiting factors. Given that time will not be a limitation, excavators can always work in their own particular area, or a number of people can be assigned to a particular area. Continuity can be maintained by ensuring that at the changeover the next team is aware of what has happened in that area. On deeper sites, there will probably be a period on a decompression stop. During this time, there will be the impending problem of deciding whether to send the next team in straightaway or whether to wait so that they can be briefed. Because of the time constraints on deep-water sites, it will usually be necessary to send the next team in. Therefore, it is worth considering organizing the excavation so that successive teams work in alternate areas. Thus team A works in area 1; while they are decompressing on the stop, team B goes in and works area 2. When team A comes out of the water, they brief team C, which goes in and works in area 1 when team B is on the stop. Some variation of this type of system can be devised for any site, and it does ensure the continual awareness of what is happening in an area. Alternatively, diver-to-surface communication can be used (see next section).

A very useful method of communication was pioneered by Bass on a series of excavations in Turkey (Bass and Katzev, 1968). It consists of an underwater booth made out of a dome of clear Perspex or Plexiglas is anchored to the seabed and filled with air (Figure 9.8). This served as a refuge in case of emergency and as a place where the person working under water could communicate with a partner. In addition, a telephone was installed in the booth enabling the diver to communicate with the surface and obtain advice and exchange information.

Self-contained diver communications systems present a real advantage. Whereas once the encumbrance of a communication cable between the diver and the surface made the system unattractive, there are now a number of interesting alternatives. First, however, it will be essential to adopt a full face mask (or a "voice box") to enable clear voice recognition. Full face masks range from the simple to the complex (simple like the Aga and Scubapro to the complex Ultralight) and today these systems are more common in the field of underwater archaeology because of occupational

Figure 9.8 Telephone booth on the Tektash Brunu site, Turkey, at a depth of 40 m. (Courtesy of Jeremy Green, Department of Maritime Archaeology, Western Australian Maritime Museum and the Institute of Nautical Archaeology, Bodrum, Turkey.)

health and safety considerations. If the full face mask is used with scuba then through-water communications are possible (Buddy Phone, for example). This system works remarkably well, but allows only "simplex" voice transmission (i.e., either the diver is talking or topside is talking). If the system is surface supplied air (SSBA), then communications can be hard-wired in the umbilical and both the diver and the operator can talk at the same time. Being able to communicate with a partner or with the surface is a huge advantage, not only for improving the efficiency of the operation but also for training and safety. With this sort of arrangement it is possible to avoid some of the logistical problems that would occur when operating successive diving teams as previously described. The main disadvantage of the system is that it is generally expensive.

V. MACHINERY

A. Work Platforms

All sorts of different working platforms can be used, depending on the nature of the work and on factors such as on the type of site, budget, size

Figure 9.9 A variety of work platforms showing differing degrees of complexity and sophistication. (a) An inflatable Zodiac, Cape Andreas, Cyprus; (b) Department of Maritime Archaeology's work boat *Henrietta*; *Batavia* wreck site, Abrolhos Islands.

c

d

Figure 9.9 (*Continued*) (c) A small dingy used to run hookah equipment, V*ergule Draeck* wreck site, Western Australia; (d) Kyrenia shipwreck excavation barge, Cyprus.

e

f

Figure 9.9 (*Continued*) (e) *SantoAntonio de Tanna* shipwreck excavation barge, Mombasa, Kenya; (f) Local fishing boat used as an excavation vessel, Ko Kradat, Thailand.

g

h

Figure 9.9 (*Continued*) (g) Work boat on Ko Si Chang wreck site Thailand; and (h) work platform on reef at *Zeewik* site, Western Australia. (Figure 9.9a is courtesy of John Chetam; Figures 9.9b and h are courtesy of Patrick Baker and Figure 9.9g is courtesy of Brian Richards, both of the Department of Maritime Archaeology, Western Australian Museum; Figure 9.9d is courtesy of Chip Vincent and Kyrenia Wreck Excavation; Figure 9.9e is courtesy of Mombasa Wreck Excavation.)

of staff, etc. (Figure 9.9). In planning an excavation and the size and type of platform required, it will be necessary to take into consideration the number of staff members that have to be on the platform at any one time, what facilities are available for relaxation after the diving operation, catering facilities, distance from base camp, etc. The prime consideration will be to provide a safe, stable work platform where machinery and staff can be comfortably accommodated. Thus operations can range from a simple raft made up of old 200-L fuel drums to a fully equipped rig tender vessel with costs ranging accordingly.

B. Airlift

The airlift is one of the most widely used tools for removing spoil from a wreck site. It operates best in water deeper than about 5 m, but can be used in shallower water. The principle of operation is that air, under pressure, is introduced into the bottom of a tube. As the air rises up the tube, it expands and this expansion causes a suction at the lower end of the tube. The air is usually provided by a low-pressure air compressor. The greater the volume of air and the greater the vertical rise from one end of the pipe to the other, the greater the suction. A variety of compressors can be used to power the airlift, and the choice of size depends on the number of airlifts needed, the depth of water (shallow water requiring a greater volume), and the size of the surface support vessel. The efficiency of an airlift can be improved by various means. First, if the air entering at the bottom of the airlift tube is a constant stream of large bubbles, these bubbles will expand as they rise, and one single bubble may end up filling the cross-sectional area of the tube. At this point, the efficiency will drop drastically because the debris, instead of being carried up the tube in an emulsion, tends to fall through the bubbles of air. To avoid this, the air should be emulsified at the point of introduction. This can be done by drilling a series of small holes in a band around the entry point of the air and enclosing this in an external box The air enters the box and then passes, in a fine stream, through the holes into the airlift tube. Alternatively, the air supply tube can be sealed, and a series of small holes drilled into the lower end of the tube. The tube is then introduced into the airlift through a small hole in the wall of the airlift tube thus providing emulsified air for the airlift. However, in this situation there is a danger of the air supply tube causing an obstruction and blocking the airlift. An alternative is to introduce the air supply tube into the working end of the airlift, and if the airlift should become blocked the supply tube can be pulled out, thus unblocking the airlift. Additionally, using this technique, the airlift can be turned on and off (to turn off simply extract the air supply pipe) and the power may be controlled by adjusting the distance of the supply pipe up the airlift tube (the further up the less the suction).

Because the airlift pipe is buoyant when in operation, the lower end will have to be anchored to the seabed or weighted. It is possible when running small airlifts at low power to counterweight the pipe so that it is neutrally buoyant, thus making the whole thing totally mobile. In most cases, some form of anchoring arrangement will be necessary, usually a static weight. This can be attached near the working end or, better still, up the tube, just below the center of gravity. This then provides a lot of maneuverability at the working end as the airlift can be worked quite easily in an arc. Even greater maneuverability can be achieved with large airlifts by attaching a long, flexible tube to the suction end. The rising airlift pipe is firmly anchored just above the seabed, and the air is introduced at the base of this tube. The flexible tube is attached to this working end, so that it can move around the site without the need to move the anchor point (Figure 9.10). One serious disadvantage with this system is that the shut-off valve is not adjacent to the operator; in this situation, the air control system can be diverted via the operating end or the supply tube can be inserted at the working end as described previously. It is obviously extremely dangerous to operate a powerful airlift without the possibility of the operator being able to shut it down in an emergency.

It should be kept in mind that the air compressor, except when operating in deep water, will be operating in the free-flow condition against a very small back-pressure. This is not the normal working mode for some compressors, and it is worth checking with the manufacturer if this is possible. The compressor specifications will usually indicate an output volume against pressure. Running in free-flow results in a low pressure, which may affect the output and thus the efficiency. In shallow water, this may be a serious problem, because the output pressure will be related to the depth of the water. It may be necessary to put a restriction in the outlet to increase output and reduce overheating. Clearly, the compressor must be able to produce a pressure greater than the water pressure at the depth of operation.

When working an airlift in spoil or overburden, it is often necessary to work quickly or with reasonable suction. In such cases, if the spoil contains material of comparable size to the diameter of the airlift tube, it is likely that these objects can block the airlift. Therefore, certain precautions should be taken and some form of restriction at the mouth of the airlift should be introduced to limit the size of the spoil entering the tube to about 75% of the diameter of the tube. Otherwise the large objects will have a tendency to jam in the tube and cause a blockage. Unblocking can be a time-

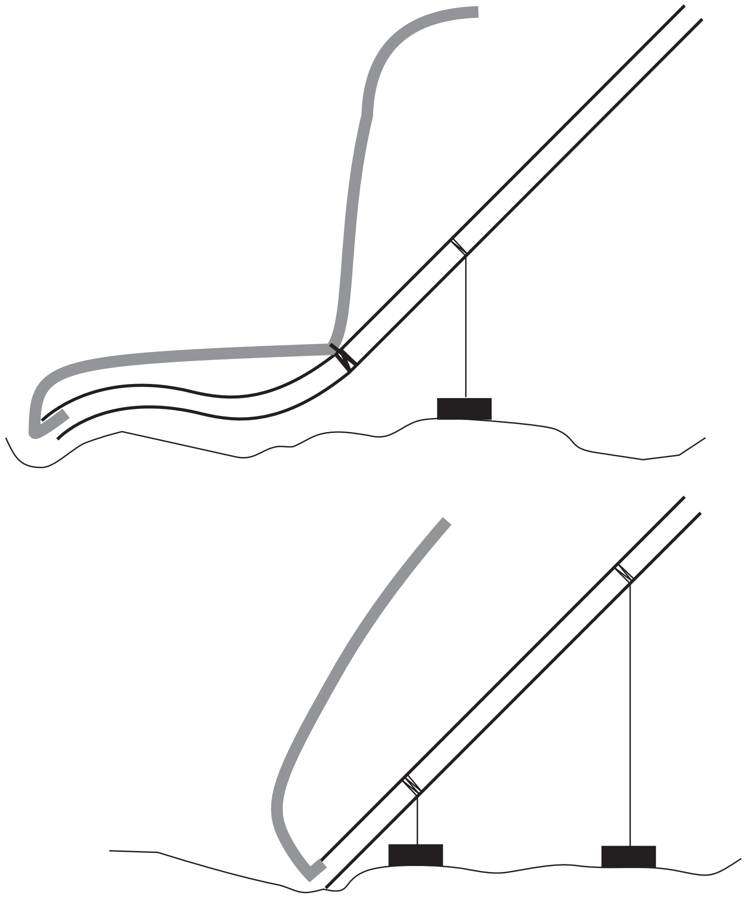


Figure 9.10 Two types of airlift design, one with a flexible hose and rigid riser and the other rigid.

consuming and frustrating operation. A removable pin fitted across the mouth of the airlift is a simple solution and there are complicated stone ejectors which can be constructed to remove an oversized object jamming the opening.

The only way to work an airlift in areas where there is archaeological material is to hand-feed the airlift with the intake about 100 mm above the seabed. In this situation, the excavator puts selected heavy material into the airlift, but hand-fans the archaeological layer. The hand-fanning removes the light sediments from the seabed which are then sucked up the airlift, leaving the water clear and enabling the excavator to reveal light, delicate

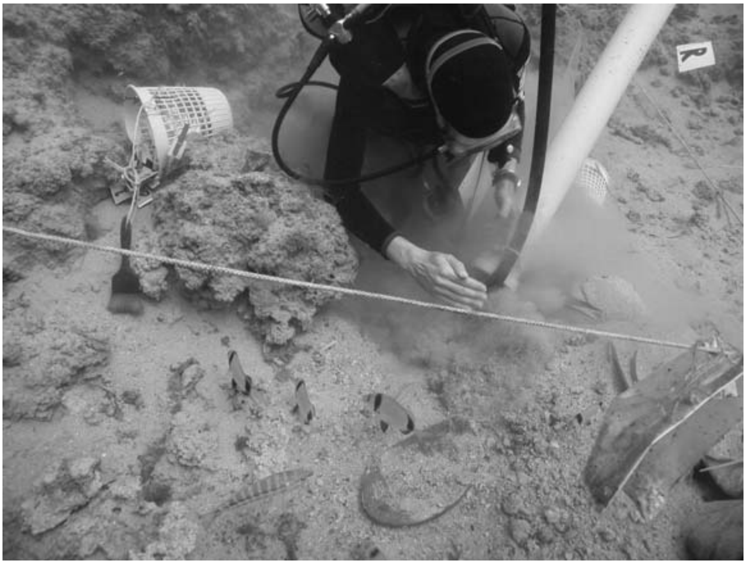


Figure 9.11 Hand fanning into an airlift on Tektash site, Turkey. (Courtesy of Jeremy Green, Department of Maritime Archaeology, Western Australian Museum and the Institute of Nautical Archaeology, Bodrum, Turkey.)

objects (Figure 9.11). This system is quite impractical when removing large quantities of overburden. In this situation, the airlift is placed just above the overburden so that it is sucked up the tube, rather like a vacuum cleaner. Great care must be taken, but if the tube is kept above the spoil, it can be removed quickly and easily should artifacts appear. The airlift should only be operated this way when the visibility is good and with two skilled operators working side by side, one operating the suction tube, the other watching the spoil. Excavation is something of an art, and operators tend to get a feel for a particular site. It is often possible to detect differences in the composition of the material being excavated, which in turn indicate that artifacts may be anticipated or that the region is sterile. Common sense dictates the method; if you know from survey that there is 1 m of sterile sand over the archaeological layer there is no point in taking a long time to excavate it. A simple test is to check the spoil mound; if there are more than one or two artifacts there at the end of the day then one's methods need to be revised.

In very shallow water there may be problems with discharging the spoil far enough off the site because the shallow depth restricts the distance that the airlift pipe can be set. In this case it may be possible to run additional lengths of pipe and float them on the surface a sufficient distance from the

Figure 9.12 Airlift in operation on a shallow water site with the pipe running on the surface discharging spoil off the site. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

site. This enables the spoil to be deposited outside the site (Figure 9.12). In deeper water, where the airlift pipe can be made quite long, the orientation of the airlift and the location of the discharge is important. No one wants a situation where the discharge spoil simply rains back down over the site, redistributing it uniformly over the site to be subsequently re-excavated. The solution is to ensure that the discharge is far enough off the site that it is clear of archaeological parts. If there is a current, this will have to be taken into account, as the current should carry the finer sediments away from the site. There will generally be a collection of the heavier material directly below the discharge and then finer and finer material off down current. In some cases the current can change direction, due to tides or other influences, and the excavator needs to be aware that the location and direction of discharge may need to be changed when the current changes.

C. Water Dredge

The water dredge consists of a long tube with a bend at one end forming an obtuse angle. High-pressure water (usually from a fire pump) is injected into the tube at the bend and directed so that the flow is axial with the long pipe. The flow of water along this pipe causes an induced suction at the working end (Figure 9.13). It is possible to attach a flexible tube to the

Figure 9.13 Working end of a water dredge showing where high-pressure water is injected into the dredge head. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

suction end to increase mobility of the dredge. The advantage of the dredge is that it can work efficiently in very shallow water as well as in deeper water. The water pump is also generally lighter than the equivalent air compressor, so that excavation can be carried out from a more mobile work platform like a small boat. The dredge does not need to be securely fastened to the seabed, although there is a force caused by the water discharge at the end which tends to drive the dredge forward.

There are a number of disadvantages with the dredge. It does not work well when inclined upward, causing problems when it is necessary to excavate in a hole. This can be resolved by keeping the main dredge section horizontal and running a flexible tube down into the hole (Figure 9.14). If there is a current the water dredge needs to be set up so that it discharges down current taking into account current changes. Additionally, the efficiency of the dredge diminishes with increasing length of discharge tube. Thus, there is a limit to the distance that spoil can be discharged off the site. It is usually not possible to discharge more than about 5–10 m with a medium-sized fire pump. This can cause problems when excavating a large site, but with careful planning spoil can be deposited off the site. This contrasts sharply with the airlift which discharges its spoil high up above the site, usually some distance horizontally off the site, and utilizes the current to carry debris even further off. One final problem is that it is difficult, at the end of operations, to coil up the fire hose used to supply the water to the dredge. It is worth

Figure 9.14 Dredge with flexible tubing which connects with dredge head (out of frame in foreground). Discharge extends behind diver. (Courtesy of Brian Richards, Department of Maritime Archaeology, Western Australian Maritime Museum.)

making a fitting that can be attached to the boat-end of the pipe so that air can be introduced into the hose to facilitate recovery, which otherwise requires a great deal of effort to load inboard when filled with water (see Negrel, 1976).

D. Water Jet

This is of limited archaeological use under water because it is difficult to control. When operated where there is any silt or light sediments, it rapidly reduces the visibility to zero. The jet requires a reverse thrust to balance the backward force of the jet. Without this back-thrust jet, the diver will be projected across the site in a random, uncontrolled, and quite spectacular manner, which is quite useless apart from entertainment.

E. Water or Air Probe

Difficulty is often experienced when trying to probe the sediments on a site. The relatively weightless diver will find it almost impossible to drive a rod into the ground by hand, particularly to any significant depth. One simple solution is to use a long, thin, hollow metal tube about 10 mm in diameter and pump air or preferably water into it. The air or water helps to clear obstructions from the path of the tube and keeps the sediments from sticking to it. Probing is, therefore, relatively easy and the nature of deposits such as pottery, wood, or metal can be determined with experience by the sound of the contact (see Chapter 5). The pressure needs to be carefully controlled, particularly in the water probe to ensure it does not become unmanageable.

F. Prop-Wash

Prop-wash systems were developed in the United States and have been used extensively by treasure hunters to remove large sand overburdens. These systems were called various names: mail box, blaster, prop-wash, etc., but essentially they diverted the water thrust from the vessel's propeller downward by means of a tube with a right-angle bend. The resultant down thrust could be used to dig extensive holes in sand overburden. An excellent illustration of how not to use a prop-wash is shown in the search for the *Atocha* where the seabed looks more like the result of an aerial bombing raid than some carefully controlled search for a site. The more

Figure 9.15 Small prop-wash mounted on outboard motor to clear overburden. (Courtesy of Catherina Ingleman-Sundberg, Department of Maritime Archaeology, Western Australian Maritime Museum.)

powerful the thrust, the greater depth at which it can work effectively and the bigger the hole that can be dug. Used carefully, the prop-wash can be a reasonably useful tool, but used carelessly, it can cause untold damage. It is best used where large quantities of sterile overburden need to be removed, otherwise it is not a good excavation tool because it cannot be properly controlled. Small prop-wash systems mounted on outboard motors have been used for shallow-water work, but the systems are not particularly efficient (Figure 9.15).

VI. RECORDING

On an archaeological site one of the most important issues is recording information and then bringing this information to the surface and it is often surprising at what little thought goes into this process. Quite often notes are scribbled onto tiny slates that are used over and over again. These notes, on arrival at the surface, are transcribed into filed notebooks and the data then removed prior to the next dive. If a transcription error has occurred there is no opportunity to check it against the original data. A better solution is to have large slates (A3 is ideal) with removable sheets of Mylar or some other waterproof writing film. This then provides a large working surface to record information and make sketches, and at the end of the dive the sheet can be removed, washed in fresh water, and immediately filed.

In addition, underwater communications can be extremely useful where data or information needs to be recorded. It can be particularly useful where one is conducting a measurement survey as the underwater operator does not have to stop to write things down, but can simply call out the reading and to be confirmed topside. Again, one is looking to reduce transcription errors in recording, and any system that helps to improve this situation is worth using.

A. Writing Slates

A simple clipboard or writing slate is ideal for recording. It is strongly recommended that proper writing slates be constructed made of rugged plastic sheet onto which a plastic frame can be clamped. Sheets of pre-cut drawing film can then be clamped between the board and the frame and removed when necessary. The sheets can be pre-punched with ring binder holes so they can be immediately filed for safe-keeping. A pencil, compass, ruler, and depth gauge can be attached to the slate and the back of the slate can be used for temporary notes; with a carrying handle the whole set makes an extremely useful piece of equipment. It is worth making a holder to put the pencil in when it is not in use. Half pencils are more economical, as whole ones usually break or get lost. Make sure there is a suitable diving knife for sharpening. An excellent alternative to a writing pencil is the Poppet Pencil. It consists of a series of short pencil leads mounted in small plastic holders, one on top of each other, in a tube. When the lead is worn away, the lead and holder is removed, inserted in the end of the pencil, and the next new lead is pushed into place.

Surprisingly, alcohol-based, fiber-tipped pens work under water, e.g., the Magic Marker or Shachihata types. They can be used to mark plastic tags for labeling objects for photography or recovery. Used on the surface, they serve as excellent markers for all sorts of work, particularly on plastic.

B. Carrying

A simple, large, net catch-bag is one option for carrying tools and equipment and for returning robust artifacts to the surface. Make sure that there are no holes in the netting and that the mouth of the bag can be clipped shut. When recovering fragile material, it is best to utilize a rigid plastic box like an old ice cream container or storage jar. These can be filled with sand to assist in supporting extremely fragile materials such as rope or leather. A spatula or kitchen fish slicer can be used to support this material as it is transferred to the sandbox. Slightly more robust material can be placed in a polythene bag filled with water and tied off with a knot so that the bag does not collapse when removed from the water. Large objects are best carried in a basket (such as a plastic wastepaper basket), and commercial fish storage baskets or any self-draining basket of reasonable rigidity is useful.

Usually each operator works in a particular area during one session, so it is best that one operator's finds are kept together and not mixed with those of other operators working in the same or different areas. By keeping the material together, the excavator can usually provide notes from the record slate or, subsequently, provide verbal information on the objects during debriefing or registration (see Chapter 10). Thus, each excavator must have collection equipment available on the site for immediate use. As the excavator works in an area, important artifacts can be plotted on a plan of the excavation area or grid. Where there is a lot of integrity in the distribution of the material, it may be necessary to take record photographs and detailed plans. In some cases, the objects can be tagged *in situ*, recorded, and then raised (see Chapter 10 for the problems of tagging).

C. Tools

Concretion always presents problems to an excavator because it usually offers no clue as to what is inside. Therefore, it is important to adopt a careful and sensible approach to such objects. In some cases, it is possible to remove the concretion to a conservation laboratory where the material can be dealt with properly and leisurely. If this is not possible, it is important to have on-site conservation facilities available to deal with the various types of material in their varying conditions. Concretion is a hard, cement-like substance that usually forms around iron objects. The process of formation of concretion is not clearly understood, but there are several easily recognizable types. The concretion formed around iron objects tends to enclose the object in a shell that is generally much harder than the object itself. The condition of the object depends on the length of time the object has been immersed under water and the type of iron of which it is composed.

Cast iron, because it has a high carbon content, forms a concretion which exactly molds to the object. The object itself varies in condition as a result of a number of complex processes. Thus, a number of concreted cannon balls from the same area will vary considerably in their state of deterioration without any obvious reason. The outward appearance of the cannon balls after removal of the concretion may be similar; they will all appear to be well preserved with details quite clearly visible on the surface. However, when they are picked up it is immediately obvious that their condition of preservation varies drastically. Some will be extremely light weighing as little as 10% of their original weight, whereas others will be almost their original weight. Sectioning the balls shows that the corrosion has proceeded from the outside inward, and there is a layer of graphitized iron surrounding a core of solid iron. In the completely deteriorated case, there is no solid iron at all. The graphitized iron is very soft and needs to be handled with extreme care.

Wrought iron tends to produce a different situation. Removal of the surface concretion of reasonably well-preserved material reveals an iron object with a type of laminated or granular structure. This is a result of the differential corrosion taking place along the lines which join individual strips that have been hammered together in the process of forging the wrought iron. Thus, in the case of an anchor, the laminate patterns show how the anchor was constructed and how the iron billets were joined together in the forging process. In advanced cases of wrought iron deterioration, there may be no iron left in the concretion at all. In such cases, the concretions should not be discarded as they can be used to cast a replica of the object.

Thus, the problem of dealing with concretion is complex. The aim is to try and break open the concretion and recover the object, if there is one. For cast iron this is difficult because the object is usually very fragile compared with the hard concretion. Where possible, concretions should be recovered intact and broken open on land, preferably in the conservation laboratory. This is particularly true for complex concretions, where an x-ray can show much of the internal structure and composition before any mechanical work is carried out (Figures 9.16 and 17a).

Using a geological hammer and a short-handled sledgehammer is a very practical way of breaking up concretion under water (Figure 9.17b). The geological hammer can be carefully positioned on the required point of impact and its head struck with the sledgehammer. All this can be done without endangering one's hands with surprising delicacy achieved with this method. The geological hammer should never be used alone to strike the concretion as it is impossible to control the point of impact.

In some situations quite robust solutions are required to extract large iron objects. During the recovery of the engine from the steamship *Xantho*, McCarthy (2000) used an oxygen powered thermal lance to great effect (Figure 9.18).

It is essential to attempt to remove concretions intact under water and to dismantle them in controlled conditions on land. So concretion excava-

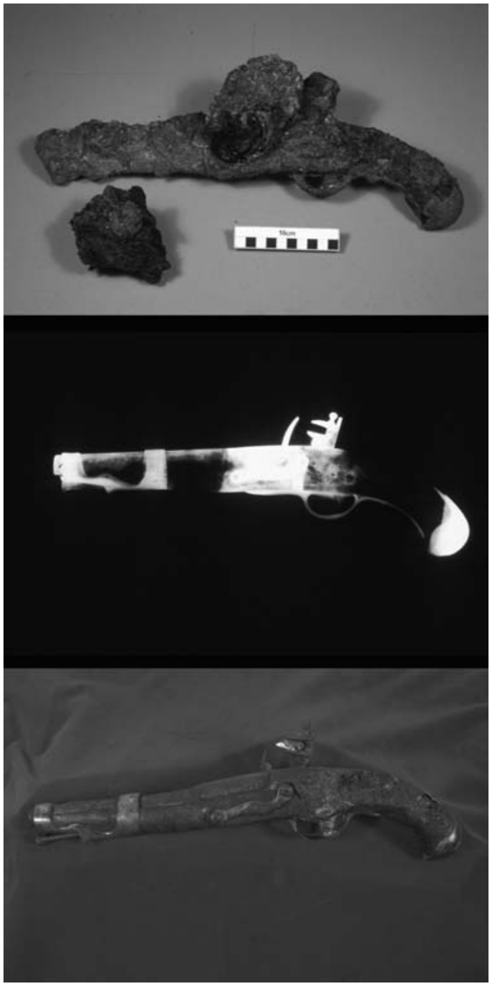


Figure 9.16 X-ray of a complex concretion of pistol from the *Pandora* wreck site. Upper, concretion; center, x-ray; and lower: pistol after conservation. (Courtesy of Jon Carpenter, Department of Materials Conservation, Western Australian Maritime Museum.)

tion should be directed toward a strategy of extracting the complete object. This is not always possible and the concretion may have to be broken under water. In such cases the temptation to drive the point directly into the concretion and to split it in one go should always be avoided, because there is no way of telling what is under the tip of the hammer. It is better to work so that flakes of the surface are chipped off bit by bit and work with the

a

b

Figure 9.17 Breaking cannon ball concretion on land (a) and under water (b) at *Batavia* wreck site, Western Australia. (Figures 9.17a and b are courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

Figure 9.18 Using a thermal lance (oxy-cutting equipment) to separate the engine from the boiler on the steamship *Xantho*. (Courtesy of Jon Carpenter, Department of Materials Conservation, Western Australian Maritime Museum.)

point away from an artifact. Never force the point down between objects because, as the point is driven in, it will tend to produce an expansion and thus a crushing effect. A lot of skill and patience is required to extract delicate objects from a concretion, and at times this can present a considerable challenge to the excavator.

Where it is necessary to lever concretions from the seabed, a crowbar can be used with caution. In some cases the concretion may be firmly attached so that it is beyond the power of the excavator and the crowbar to free it. In such cases, it may be possible to utilize a small car jack or a hydraulic ram (Figure 9.19).

D. Chainsaw

During the excavation of the *Batavia* (Baker and Green, 1976; Green, 1975), large ship timbers were uncovered. The timbers were too long to recover in one piece, so they had to be cut into sections. Because the wood was so hard, the only effective way of cutting the timbers was with a pneumatic chainsaw (Figure 9.20). This proved to be extremely efficient and quick and made the operation, which would otherwise have been virtually impossible, an easy task.

Figure 9.19 Hydraulic car jack used to free an anchor on the *Zuytdorp* site, Western Australia. (Courtesy of Jon Carpenter, Department of Materials Conservation, Western Australian Maritime Museum.)

Figure 9.20 Chainsaw being used to cut timbers on the *Batavia* wreck site.

E. Explosives

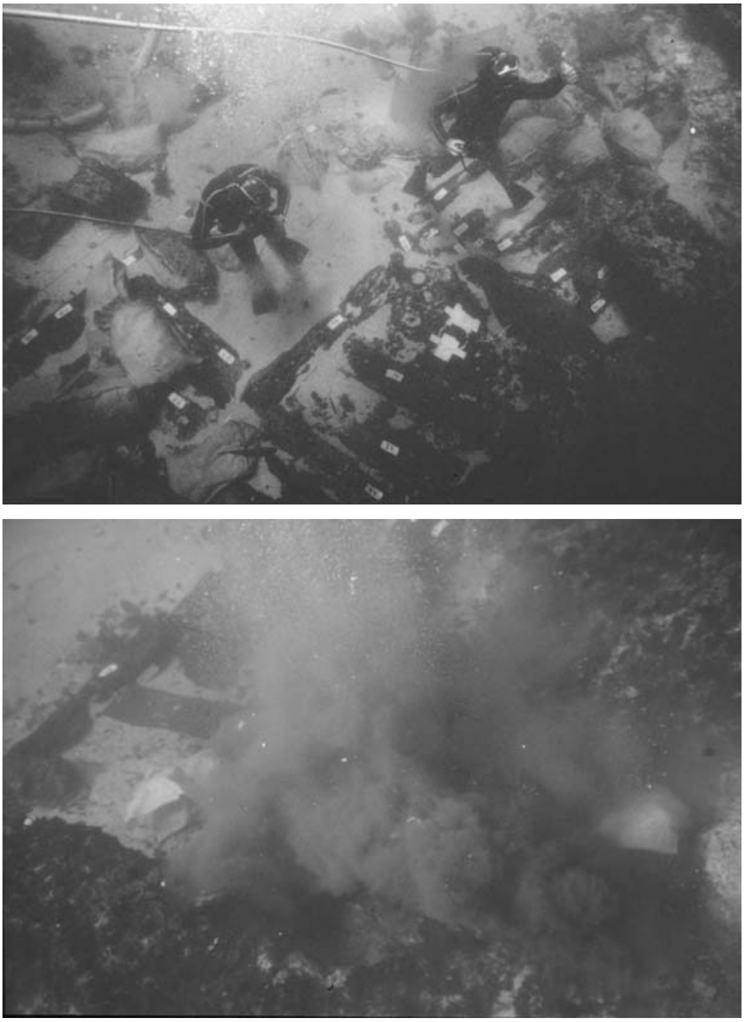
Explosives have been used with great success to break up concretion. Contrary to what one would imagine, this is an extremely effective technique if used carefully. It clearly has the potential for a disaster if uncontrolled, but this is true for many excavation techniques. A number of different types of underwater explosives are available, the most common are Cordtex, a fast, explosive detonating wire; plaster gel, a slow, gelignite-type explosive; plastic explosive (PE), a fast, easy to handle explosive; and Nitropril, a slow, home-brewed explosive that is difficult to manage. The reference to fast and slow relates to the speed at which the explosive wave travels. Thus, in summary, PE produces a sharp crack and is used extensively in cutting, whereas plaster gel produces a muffled boom and is used for breaking things. Experiments indicate that slow explosive is the best choice when dealing with concretion.

With a flat, pancake-like concretion, the best position for the explosive is in the center. Small charges of 10–50 g should be taped onto a thick rubber mat which acts as a protection for the potential damage the explosive would cause to the surface of the concretion and anything just underneath the surface. The objective of the explosion is to flex the concretion and crack it so that the concretion can be dismantled. The explosive is initiated by a Cordtex train which, in turn, is initiated by a detonator. Electrical detonation is the most convenient method of initiation (Figure 9.21).

The effect of the explosive is, in some cases, quite unusual. The shock wave seems to travel through the hard concretion cracking it, while the soft cast iron material is left undamaged. It may be that the interface between the hard and soft material creates some form of mirroring or shielding effect. The concretion can then be easily dismantled and the artifacts recovered. This process has been described as “getting cherries out of a cherry cake” (Green, 1975; Martin and Long, 1975).

F. Lifting

In most situations where material has to be recovered from a site unless the material weighs less than a few kilograms material will have to be raised using some form of assistance. For light loads, a simple line to the surface with a catch bag may be adequate (Figure 9.22). Alternatively small lifting bags can be used. Heavy objects like cannons, anchors, masonry blocks, etc., can be raised in several ways. Where a working platform is directly over the site, it is best to raise the object using a winch or endless chain hoist, and



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b

Figure 9.21 Explosives used on *Batavia* wreck site, Western Australia. (a) Placing charge on iron cannon ball concretion, the two white squares have small quantities of gelignite taped to a thick rubber mat, and (b) shows the charge exploding. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

then, if need be, load directly onto a transport vessel (Figure 9.23). Where it is necessary to bring material onto the lifting platform, some form of inboard swing is required. This can range from a simple swivel davit to an A-frame, and ultimately to a hydraulically operated, articulated arm.

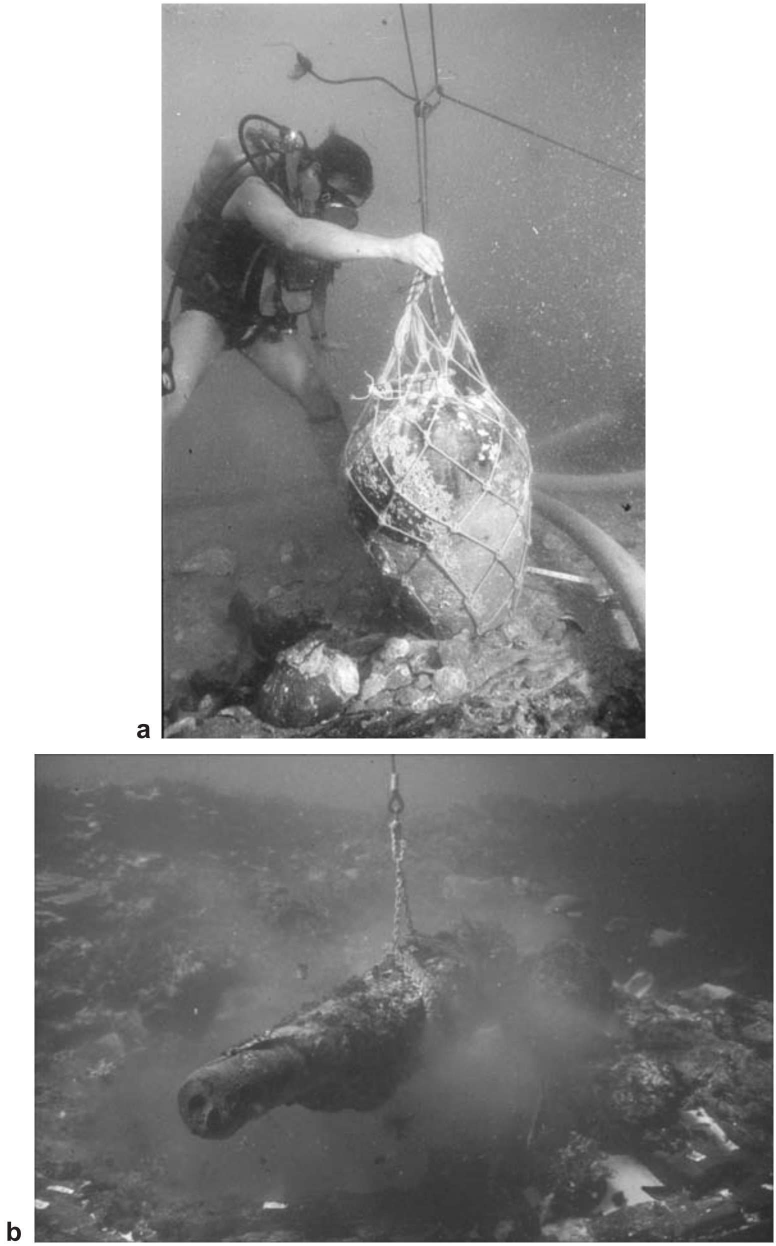


Figure 9.22 (a) Lifting using a mesh bag, Ko Si Chang, Thailand, and (b) raising a large iron cannon with rope-lifting strops, *Batavia* wreck site, Western Australia. (Figure 9.22a is courtesy of Brian Richards and Figure 9.22b is courtesy of Patrick Baker, both of the Department of Maritime Archaeology, Western Australian Maritime Museum.)

Figure 9.23 Transportation of *Batavia* timbers from the Abrolhos Islands by sea to Fremantle. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

Before undertaking any heavy lifting, the vessel should be surveyed by a qualified marine surveyor to determine the stability parameters for safe working of heavy lifts. When using wire and shackles for lifting, it is essential to provide a method of ditching the lift in an emergency. It is almost impossible to undo a shackle while it is under tension. A simple solution is to include a rope loop between the object and the shackle. This can be made up of several loops of light rope so that it is easy to cut through one strand and free the object in an emergency.

If resources are limited, some quite simple and ingenious systems of lifts can be devised. One particular system utilizes an inflatable boat with a strong board mounted amidships across the pontoons. A simple, hand-operated trailer winch is attached to the center of the board; the wire is run over a roller at the end of one side of the board, down to a snatch block, and then back up and attached to the other side of the board. This forms a pulley system with a mechanical advantage and, as the weight is well below the center of gravity of the craft, gives a stable situation. Using such a system, an object can be raised under the boat and the boat brought into shallow water under power.

Similarly, a vertical hollow tube can be welded inside the hull of the boat, amidships, near the keel. The hull is cut away from around the inside of the tube and, provided the tube rises above the water line, the boat will not sink. A tripod is mounted over the tube, from which an endless chain is supported; the lifting chain passes through the tube and out below the boat. Although the attachment point is high, any tilt on the vessel will be righted by the effect of the chain acting at the entrance to the tube at the bottom of the hull. Hence, it would be impossible to capsize the boat (although it may be possible to sink it).

There are a number of commercially available lifting or air bags. These range in lifts from a few hundred kilograms up to several tonnes (Figure 24). Air is introduced into the bottom of the bag and it inflates until the whole bag is full and maximum lift is achieved. Where possible, it is better to have a number of small bags than one big one. This is because as a bag rises, the air in it expands. Thus, if a big bag is only partially full on liftoff,

a

Figure 9.24 Lifting bags of various sizes and in various situations. (a) On the Tektash Brunu site.

b

Figure 9.24 (*Continied*) (b) On the Xantho site. (Figure 9.24a is courtesy of Jeremy Green, Department of Maritime Archaeology, Western Australian Maritime Museum and the Institute of Nautical Archaeology, Bodrum, Turkey; Figure 9.24b courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

as it rises the air inside it expands and the force of the lift increases resulting in an uncontrolled and extremely fast ascent. On arrival at the surface, the bag may exit from the water and lose a large proportion of its buoyancy, resulting in an equally fast and dramatic return to the seabed. If a number of small lifting bags are used, then on liftoff, the buoyancy of all the full bags will remain the same, and an increase in buoyancy will only occur in the one partially full, small bag. Alternatively, 200-L steel fuel drums can be utilized. The bottom of one end is cut out and chains attached in a bridle. This is a cheap method but should be used only in calm conditions and with great caution as divers can be easily injured working on them.

Most lifting bags have a vent control so that the diver at the mouth of the bag can let air out of the top of the bag and thus control the lift. With experience, a single diver can easily control the lift of quite large objects using vent control. As the lift rises the air expands in the bag and the operator lets enough air out to control the rate of ascent.

When carrying out deep-water lifts or working in murky conditions, it is important to keep a line from the surface attached to the object (not the bags). If the object breaks free from the lifting bags, or the lift fails and gets lost, this line can facilitate relocation. In most cases, during such lifts, the bags and the objects may be out of sight of both the diving team and the surface support crew. The diving team should never follow the rapid ascent of a lift to the surface and should always take every safety precaution during heavy lifts.

When towing an object supported by air bags, a buoy line should be attached to the object and streamed behind; should the object break free and sink, it can be quickly relocated. It is also essential, when towing something that could potentially sink the towing vessel, to ensure that the length of tow exceeds the maximum depth of water or that an axe or sharp knife is available to sever the towline.

Chapter 10

Recording

I. INTRODUCTION

Recording information and data either during a survey or an excavation is surprisingly difficult to do in a systematic manner and often information is lost. In this section, artifact recording, both on site and after recovery, and the subsequent management of the artifact and its record are discussed. The artifact record enables the excavator to identify an object and locate its position of discovery on the site and to obtain quickly and efficiently all up-to-date catalog and record details. This can then be used by the archaeologist in the process of the research related to each object. Thus, when it is time for the archaeological analysis, the data are available in a systematic form.

The record is also important for the efficient management of a collection. From the time an object is recovered, throughout field storage, transportation to the central repository, preconservation storage, during the conservation process, into long-term storage, and then possibly onto display in a museum, there is a need to know where the object is and what is happening to it.

II. RECORDING DURING EXCAVATION

On a site where only a small quantity of material is being collected by the excavators during the working day, it is usually possible to carry away from the site the unregistered material, together with the written records, to the work vessel or diving operations base where registration and recording can take place. Provided there is not too long a delay, the object and the record notes taken on the site can be related and the object can be properly registered with the associated information. Where there are large quantities of material involved, the situation is quite different, because the excavator is unable to correlate everything that has been recovered with the records taken on the site. In this case, some form of artifact registration *in situ* will be required.

In either case the archaeologist or diver needs some method of recording information used to identify or survey the original location of the object. The simplest solution is to use a writing slate on which the data can be noted. A simple clipboard, as discussed in Chapter 4, is ideal for this. It can also be complemented with photographs to record the location of an artifact. Alternatives to this are a cassette tape recorder that can be used under water or diver-to-surface communications to record the details.

Where artifacts have to be registered *in situ*, the most straightforward method is to tag the object under water, prior to raising it. This is particularly effective where a ship is dismantled piece by piece; each piece of timber can be tagged (Figure 10.1), photographed (Figure 10.2), and then disassembled (Figure 10.3). It is sometimes worthwhile to take large general photographs of the site to provide a general record of the layout of the material. Such illustrations can be invaluable for future reference.

When a grid system is used, some predetermined system needs to be decided upon so that each major grid unit is defined and then subdivided

Figure 10.1 Tagging timbers on the *Batavia* wreck site prior to recording and raising. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

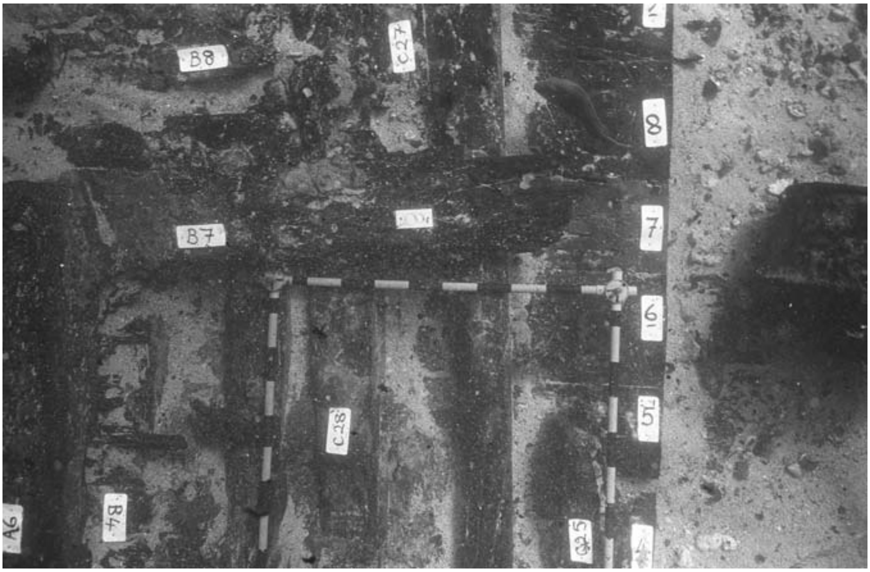


Figure 10.2 Underwater photography of the *Batavia* timbers used to record the location of individual items prior to raising.

Figure 10.3 After recording, timbers on the *Batavia* site were dismantled and raised to the work boat. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

into 4 or 16 subunits. Thus when an object is found, the excavator can identify the position by noting the coordinates of the object on the identified grid frame, or where the precise location is not relevant to the grid frame, the number and the sub-grid can be identified. It is worth considering before starting excavation what the coordinate system will be used, Figure 10.4 shows the problems likely to be encountered if one selects the mid point as the origin, where one will have positive and negative coordinates. As discussed in Chapter 9, because the grid frames are likely to move around slightly, the decision to use the grid frame as a control for recording will need to be carefully thought out. It is likely that a more rigid system will be required for accurate recording and a strategy for different types of objects decided upon.

However, some artifacts are unsuitable for tagging because they have no convenient point at which the tag can be attached (e.g., a cannon ball). Such objects can be placed in a bag with the tag. If the bags are coded, then the need to tag can be averted simply by noting the bag number and its

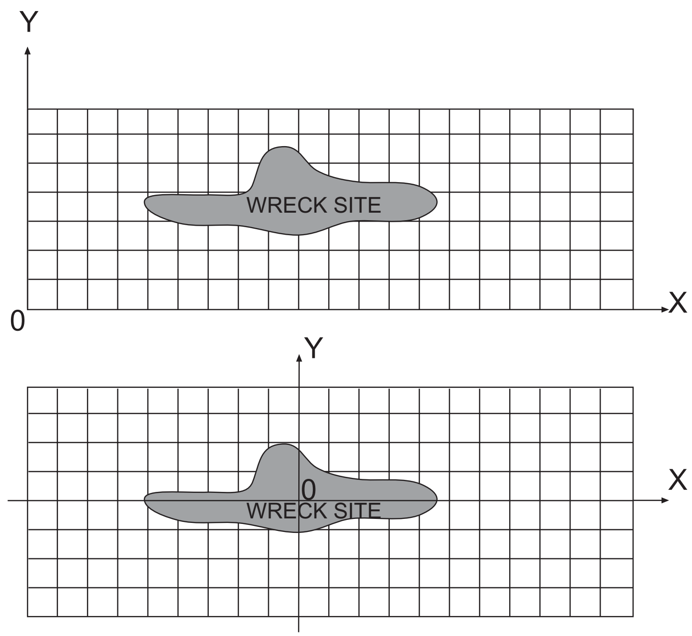


Figure 10.4 A schematic showing two different types of grid coordinates. In the upper version the origin is centered off the site so all X and Y coordinates are positive. In the lower example the origin is in the center of the site creating positive and negative X and Y coordinates.

contents. An interesting system was used by Martin (1981) on the *Trinidad Valencera* where bags were attached to a recording frame.

A very serious problem arises, however, when tagging objects under water. In general, a set of numerical tags is made up on the surface and then taken to the site. Even in the case of a ship's timbers, where the tags can be securely attached to the structure, it is almost inevitable that tags are lost or become detached from the object, so there is a constant problem in reconciling missing tags with objects. There is no simple solution to this, and unless the tagging operation is carefully controlled, it can end in chaos.

One way of dealing with the situation is to use plastic bags to hold each object while the excavator has a list of registration numbers, or a system of recording noted on a slate. On finding an object, a tag made of drawing film (preferably pre-printed with necessary information boxes) is selected and the relevant information put on the tag and on the recording slate. The tag is placed in the bag with the object and the bag sealed.

Alternatively, the tags can be made up on the surface, as has already been mentioned, with some method of attaching them to an artifact. Depending on the situation, the method of attachment may be nails, wire, or nylon string. Nylon fishing line is unsuitable because it is very difficult to tie securely. PVC plastic is one of the best tagging materials provided it is thick enough to prevent the attachment from pulling through the tag. A good way of holding the tags in numerical order without them falling into disarray is to pierce an additional hole in each tag. The tags can then be skewered on a large safety pin made out of coat-hanger wire. Each tag is then removed from the pin sequentially and attached to the artifact, and the number is noted on a record sheet together with a description of the object.

It is useful to note the object and its registration number on a sketch plan of the site, showing the location of the object (Figure 10.5). At the end of each tagging session, the tag numbers can be reconciled with the sketch plan to ensure that all the tags have been attached and that none are missing. From then, until the object is raised, it is important to ensure that the tag remains attached to the object; this needs to be checked at regular intervals. It is advisable to make one person responsible for tagging, otherwise there will be confusion due to duplicate registrations and missing tags. It is possible to use a temporary registration number for *in situ* registration; in this way, the final registration system will not have missing numbers caused by lost tags. The temporary number can then be held with the object until some point when it can be re-registered. The main drawback with this scheme is that every object will then have two numbers, thus doubling the chance of making a mistake.

Special consideration needs to be taken when recovering bulk objects or loose finds. Typically, an excavator can be faced with a grid square with a

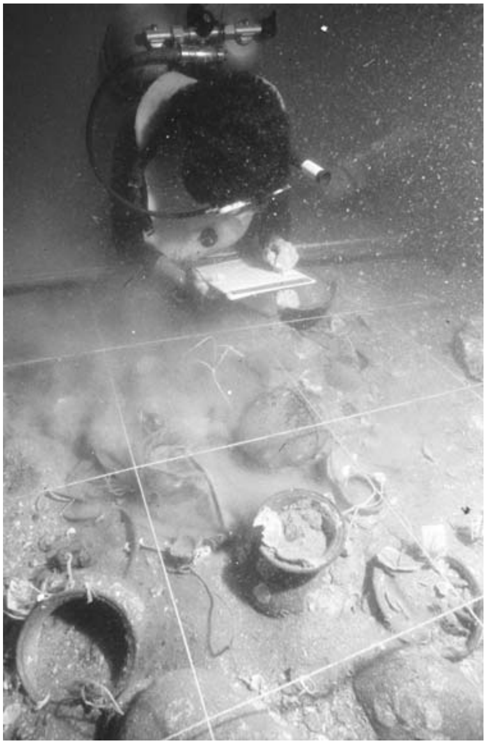


Figure 10.5 An operator making a sketch plan of a grid frame, Ko Si Chang wreck site in Thailand. (Courtesy of Brian Richards, Department of Maritime Archaeology, Western Australian Maritime Museum.)

large number of, for example, broken shards. While it is not practical or essential to register each individual item, it may well be that their location is important, either because the shard is significant in its position due to some function it had on board the vessel, or that its location will be useful in identifying other shards belonging to the same object and thus helping in the reconstruction process. Thus bulk registration can be very useful. In some cases, the objects are given a lot number or bulk registration number with their location recorded. As the material is processed, the ability to associate material from either nearby grids or from subsequent deeper layers will be possible, thus helping with the sorting process.

There are special problems involved in the registration of very fragile objects. Usually, it is preferable to excavate such objects immediately, thus reducing the danger of accidental damage. Therefore it may be possible to place a temporary tag attached to a weight alongside it, and when the object is recovered the tag can be placed with it. Care should be exercised to ensure that the tag is always kept with the object, particularly when it is being transferred from one container to another.

III. REGISTRATION

In the case where material is being raised without registration under water, objects tend to be loose in a bag or in collecting boxes, and the record information related to the objects written on a record sheet. It is not advisable to try and remember this information as it is easily forgotten, and as a general rule information should always be written down or recorded in some way. In certain unusual situations it may not be possible to carry a writing slate and therefore some alternative method of recording will be required. The project director needs to decide where and when to collect the relevant information on the artifacts from the excavators. This is best done immediately after a diver surfaces when the information is still fresh in the person's mind; there is usually a period, some time after the dive, when the recorder can sit down with the excavator to discuss and record the details of the dive. Additionally, if other staff members are going to continue work on the site, it is worth including them in the discussion, if possible. Alternatively, circumstances may favor waiting a few hours until the day's operations are over, and then having a registration and debriefing session either individually or, better still, as a group.

Debriefing provides an opportunity for everyone to discuss and understand the nature of the work and the material. The project director is strongly advised to examine the merits of this form of communication, as it can greatly assist the progress of the excavation. It is very easy to become short-sighted while locked into excavation work, so that each day a large quantity of material is recovered, but its significance and relationship with other material may be poorly understood or improperly recorded. At the same time, excavators can become remote from its importance, simply because they are not involved in interpreting or do not understand the relevance of the material. It is therefore extremely important for everyone who is working in an excavation to be cognizant of the progress and direction of the overall project, and to be familiar with the range of artifacts and their archaeological significance. It should be noted that on land excavations, differential recovery rates among volunteers have been noted, and this is thought to reflect the volunteer's individual interest and knowledge as much as the distribution of material on the ground (Clarke, 1978). As a result, because it is difficult on an underwater site for the project director to monitor every excavator, it will be necessary to ensure that experienced staff members are aware of the problem.

Indisputably, the most convenient means of registering artifacts and recording the related information is to enter the information on a computer. There are immense advantages to operating a computer in the field and a great deal of time and effort can be saved in cataloging and accessing information if this is done on site. Most mains-operated computers can be powered by a gas generator weighing about 20 kg or a small laptop computer with a solar panel can be used if mains power is unavailable. Using a database program, information can be entered quickly and efficiently and the system can provide readable and reliable data, either on a screen or on a printer. These data can then be available in a printed form for reference, or individuals can use the computer to search for particular items or to carry out specialized operations on these data. Data can be extracted from the database and used in other programs to provide immediate on-site information or analysis (see Chapter 14, Section VII.D). The great advantage of this system is that it removes one level of transcription error from the system, and once entered it can be transferred into other applications and used for other purposes without having to carry out another transcription. Handwritten catalogs should not be used in this day and age, and if there is a requirement for a hard copy then printing the computer catalog is the ideal solution.

The catalog should tabulate all the relevant information. A typical field register would include, in addition to the registration number, the date of recovery, material code, brief description, location, excavator, dimensions, weight, and additional notes. At a later date it is always possible to add extra entry categories. With a computer system mistakes are least likely to be made if the record is put directly into the computer using a look-up table to reduce the chance of spelling mistakes.

With the system of direct entry into the computer, the preparation of the database has to be thought out very carefully, and it is essential to be thoroughly conversant with the data entry system prior to going into the field. If one is unfamiliar with computers and databases, a mistake or a crash in the field could be catastrophic; similarly, an unreliable or untried system can be a danger, and it is strongly advised that the system is thoroughly tested before going into the field with regular backup made of the data when working in the field.

An excavation of a shipwreck usually results in the recovery of large numbers of objects. These are generally immediately separated into different material types for conservation purposes. Storage of the object and its conservation is largely dictated by the nature of the material. For this reason, registration of objects by material is very useful; for example, objects can be divided into groups labeled stone, ceramic, nonferrous, miscellaneous, organic, ferrous, etc. Where there are particularly large subgroups within these types, these can be given separate categories too, for example, they could be classified separately from nonferrous and organic, respectively.

Under this system objects can then be registered using a material code prefix like stone (1), ceramic (2), nonferrous (3), miscellaneous (4), organic (5), ferrous (6); coins (7), and ship's timbers (8). Thus, for example, the number 26711 immediately identifies the object as being a ceramic object (material code 2 = ceramic). The remaining four digits are the identification number showing where the object stands in a rough chronology of the excavation. This system has great merit as a sorting and subclassification method. It is easy to apply as it can be done on the spot without actually having to identify the object apart from its composition. There are problems in deciding how to register a composite object, usually the main material type can be used to overcome this difficulty. It should be noted that it is worth starting with a five figure number because it gives the potential of 10,000 registration numbers before any change is necessary. It must be remembered that the next number after 39,999 is not necessarily 40,000, it could be 310,000 or 300,000.

Registration of large groups of similar objects can be a problem. For example, if coin, musket balls, or shot were each given a separate registration number, problems in conservation could be created (imagine having to treat 10,000 lead musket balls as separate artifacts or even individually register them for that matter). It is not possible to generalize, and the decision of how to treat each problem resides with the archaeologist. But certain options can be considered. First, it is important to be able to differentiate artifacts, but this may not be absolutely necessary. Thus, 50 coins found in a group randomly in a 100-mm square area do not, initially, need to be registered individually unless there is something exceptional in their spatial context. If these coins were recovered from different places on a site they would need separate registration. So there is a possibility that a large group of similar objects coming from one particular area can be given a bulk number. It may be necessary to individually record bulk-numbered objects. In such cases it will not usually be necessary to associate the object with the recorded data; e.g., the individual weights of 5000 musket balls are important, but it is unlikely that one would need to re-associate each weight with each particular item. On the other hand, it may be necessary to make a temporary identification of a bulk-numbered group of artifacts, for example, coins from one particular place, which may be individually identified (e.g., seven thalers, four rixdaalders, four florins, total 15). After conservation they may need to be re-registered separately and re-identified because the process may have revealed new information making this necessary. Similarly, a concretion will be given a single registration number, but after conservation, several individual objects may have been extracted from the object, each requiring a separate registration number.

Dump numbers are also very useful for common types of poor quality or unidentifiable artifacts. A registration number is selected, and any items belonging to that particular type can then be registered under that number. This is particularly useful for items such as eroded musket balls, ceramic wall shards, (subdivided by material, stoneware, earthenware, porcelain, etc.), and scraps of lead or copper sheeting. The numbers can, if necessary, be used for areas or grid squares. Each time another object is added to the dump number the total is increased. In this way the register is not cluttered with needless or trivial registrations. Once again caution is recommended, and an assessment of the potential of the material should be made to determine if it is likely to be a help or a hindrance to individually register each fragment. For example, if each part of a fragmentary object is individually registered and tagged prior to conservation, it will be almost impossible to sort or fit fragments together until the often lengthy conservation procedures are completed. It is therefore suggested that a temporary reconstruction be effected as soon as possible, so that if any fragments are missing, a search for them can be initiated (Figure 10.6). It is also recommended that the object be given a single registration number. Alternatively, material that comes from a particular area may belong to a number of different objects. In this case a temporary bulk number will enable the fragments to be kept together; after sorting and temporary reconstruction, the assembled or partially assembled objects can be individually registered.

In the field, it is worth taking as many measurements and photographs as possible. This serves as a registration backup, particularly the photography. If photographs are processed and recorded chronologically and an error occurs in registration, it may be possible to retrieve the lost information from the site and field artifact photograph. In some cases, it may be worth photographing each excavator's artifacts prior to registration. A fixed camera tower, board, and scale can be set up and the excavator's material placed on the board prior to registration. A slate with the relevant details is placed in the view and a photograph taken (see the relevant sections in this chapter). Finally, taking lots of photographs is a good thing, but unless one can find or retrieve the photograph the process is worthless, so keeping records of photographs is also important.

IV. ADDITIONAL RECORDING

Although artifact drawing (Chapter 11) and artifact photography (Chapter 12) can be used to record most artifacts, there are some situations

Figure 10.6 Temporary reconstruction of a large stoneware jar from the *James Matthews* wreck site. By making temporary reconstructions, it is possible to determine if any pieces are missing and initiate a search if they are. Note completed temporary reconstruction shows only small fragments missing. (Courtesy of Jon Carpenter, Department of Materials Conservation, Western Australian Maritime Museum.)

that require a special type of recording. Ship's timber is a particular group that has a number of complex recording problems. First, the timbers should be recorded as soon after recovery as possible, because of the danger of warping, shrinkage, and cracking. There is the associated problem of working with large, heavy pieces of fragile timber that must be kept wet at all times. The timbers have to be cleaned of any dirt and loose, unimportant material, then drawn and photographed; in the field, this can be a difficult and challenging project.

To record the timbers (or any other large artifact) accurately, it is best to trace the object at a scale of 1:1 Clear Mylar is preferable as a tracing material, but it is often only available in narrow widths and it is expensive. An alternative is clear polythene sheeting, which is generally available in rolls up to 2m wide. This has two drawbacks: it is not completely transparent thus obscuring details, and it is not dimensionally stable. Details on the surface including the outline, nail and bolt holes, wear marks, tooling marks, and other items of interest can be traced onto the sheeting (Figure 10.7). The tracing has to be done as faithfully as possible and the sheets must be kept steady. There can be difficulty in aligning features that lie some distance below the plane of the tracing, because the traced position will depend on the orientation of the recorder's eye. It is therefore important that the recorder's eye be oriented vertically above the point to be traced in relation to the plane of the tracing. This can be done with a variety of aids and devices like a mirror or a simple sighting device.

A black, felt-tipped pen with an alcohol-based ink is ideal for tracing as it is extremely durable and dries very quickly. There is not much point in using colors, since most tracings will be photographically reduced later, and some colors may not reproduce because of the spectral sensitivity of the film. The registration number of the object, the date of tracing, and identification of the side being traced, together with any other relevant information should be clearly recorded on the tracing. From an organizational point of view, it is worth drawing the various faces on the same sheet so that they are kept together. Also, it should be noted how the three dimensions of the jigsaw fit together, as in some cases it is possible to confuse the position of the faces being drawn. With curved objects such as frames, the curvature can be recorded in the side view, but there are two possible ways to trace the curved surface. One way is to place the tracing sheet directly on the curved surface and trace. The other method is to place the tracing material

Figure 10.7 Tracing *Batavia* timbers after recovery from the wreck site. Polythene sheeting was laid over the timber and the outline and nail and bolt holes traced onto the surface. (Courtesy of Lloyd Capps.)

on a sheet of glass leveled over the object and use the reflection of one's eye in the glass to align the features ensuring that the tracing does not suffer from parallax. In this way, an accurate plan of the curved surface can be made. The tracing material has to be clear film, in order to see the reflection, otherwise some other sighting device can be used.

When photographing large objects, a permanent tower is preferable. The subject to be photographed should be shaded from direct sunlight and for convenience of printing the scale should be kept constant. It is absolutely essential that the camera, the object, and the scale are all leveled. A simple method is to have a table on which the object is placed. The camera is set on a tower and leveled relative to the table using a mirror (as described in Chapter 12). The object can then be leveled relative to the table, using packing. A scale is then placed on the table and adjusted to be level with the upper face of the object. A slate with the registration number and other details is then placed on the table and the photograph is taken (Figure 10.8). For details of exposure setting for timber, see Chapter 12.

Another area where special methods of recording are required is with complex objects, particularly concretions, where the material has to be systematically excavated from inside the concretion. The concretion, for example, may be broken into several large pieces and some form of preliminary re-assembly may first be necessary. Each fragment can be given a separate registration number, and its position and how it fits together can

Figure 10.8 Recording photograph of part of the stern post of the *Batavia*. The timbers were placed on a leveled table under a leveled camera. A scale and information board were always included in each photograph. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

be sketched or, better still, photographed with a tag with a registration number attached. The object may then be systematically dismantled and the various stages recorded and photographed.

Finally, it is extremely important when examining artifacts to ensure that the objects are well lit. Strong, powerful lights are indispensable for examining objects and for drawing artifacts. Good light levels help to reveal details which would not normally be visible otherwise; this is a factor which is often underrated.

Chapter 11

Artifact Drawing

I. INTRODUCTION

The purpose of artifact drawing is to illustrate an object so that it may be visualized and compared with other similar objects. It might be thought that a photograph would be the best way to do this because it is quick and produces a great deal of detail. However, there are a number of reasons why it is preferable to produce an artifact drawing in order to illustrate an object.

First, one of the best ways to get to know an artifact is to draw it. The act of drawing requires accurate measurement and examination of the object so that it can be drawn on paper. In this process, the archaeologist handles the object for some time and, as a result, becomes familiar with it. A lot can be learned about an object through keen observation and intimacy with it. The lack of intimacy is one of the great drawbacks with object photography, where the observer is usually remote from the object behind the camera relying on detailed examination of prints at a later date.

The drawing is a visual description of the object and is a method whereby the archaeologist can understand the object, even if it is not present. In order to compare objects, it must be possible to take accurate measurements from a drawing. Thus the type of projection has to be chosen carefully. The orthographic projection is the most widely used for artifact drawing. This is the type of projection used in a similar situation for engineering drawing. Drawings using this projection are very simple to produce and have the advantage over a photograph in that they can be photocopied. Whereas the photograph is extremely easy to take and produces an excellent impression of the object, it is generally not to scale over the whole three dimensions of the object, as it is a perspective rather than an orthographic projection. There is also the aforementioned difficulty of photocopying a photograph, and it is expensive in labor and materials to reprint. However, the situation has changed a lot over the past few years and with the advent of the Internet and digital cameras, it is now easier to take and transmit a digital photograph. Such images can be taken and sent half way round the world in less time than it takes to make a photocopy. Although the intimacy issues is still there, a lot of the issues regarding the time it takes to draw an object and the costs of photography have largely changed.

The drawing is, of course, an interpretation of the object and it is vital that care be taken to ensure that this interpretation is not biased or inaccurate. If the interpretation is well accomplished, the extraneous information can be left out and only the detail significant to the archaeologist shown. The drawing can also highlight or emphasize details that are obscured, missing, or difficult to see.

One of the main reasons archaeologists have been drawing objects is because of the cost. Artifact drawings were cheap and easy to reproduce in journals which used the offset printing process that published line drawings at no additional cost to the printed page. On the other hand, photographs needed to be screened and special plates made and often the pictures needed to be printed on higher quality paper, all costing more. This was one of the main, and little appreciated, reasons why objects were not simply photographed and published. So at that time archaeological reports required line drawings to illustrate objects. One must remember this was a time when cut and paste in publication meant literally with scissors and glue. The photographs had to be screened and special plates made to enable grayscale images to be printed and high-quality paper was required. All that is now gone, and a photograph can be placed in a desktop publication as easily as a line of text and at no additional cost.

The archaeologist now has to consider the relative merits of drawing an object for publication purposes rather than photographing it. Is the time involved in the drawing process cost-effective? Are there aspects of the drawing that could be managed with photography? What aspects cannot be covered by photography? It is a complex issue and one that has no easy answer. There are still compelling reasons for drawing objects, but today the question of draw or photograph is less clear cut. Very careful decisions will have to be made when faced with this problem. If one has thousands of artifacts, to photograph may be the only solution, because the drawing process would be far too time-consuming and, if time is money, too expensive. It may be that representative groups of objects can be drawn to illustrate the construction or internal features and wall thicknesses.

One of the main inhibitions affecting the drawing of artifacts is that not everyone thinks that they can draw well. Many people have a psychological block about drawing. The age-old statement: "I cannot draw because I am not artistic," is often heard from students about to be required to do their first archaeological drawing. There is no doubt that a good drawing is more difficult to accomplish than a good photograph and, in general, it takes much longer to draw an object than to photograph it, but there are aids that can speed up the drawing process. It must be emphasized that artifact drawing is a technical skill, not an art. Almost anyone can learn to draw, and it is more important, for example, to be neat rather than artistic. Once the skill has been learned, it is quick and easy to do and it becomes quite routine to produce great numbers of drawings at a reasonably fast rate.

An additional problem with drawing is that it is sometimes not possible to draw an object on the spot. It may be that it is inconvenient, there is not enough time, or that the object is too big and cannot be brought back to the drawing office. In such cases it is essential to record all the relevant information so that the object can be drawn later; this will include measurements, sketches, and photographs of the object. In this situation, as a general rule, a combination of drawing and photography is the best solution. It is, however, always preferable to produce the drawing in the presence of the object, even if it is a rough draft, because a single missing measurement means that the drawing cannot be completed properly. This poses a serious problem if the object is no longer available for measurement. A photograph may help to resolve the omission, but it is feasible that one may have to return to the object and retrieve the essential measurement. Thus, unless one is very experienced, it is always advisable to draw in the field.

In the technical details given next, I have intentionally gone into some depth with this subject mainly because there are a lot of skills involved, many of which cannot be found in literature. The few sources describing artifact drawing include Brodribb (1970), Dillon (1981), Hope-Taylor (1966, 1967), and Piggot and Hope-Taylor (1965).

II. OBJECTIVES OF ARTIFACT DRAWING

Before making a drawing it is essential to determine what the drawing is for. If it is simply a record, to be used at the scale at which you are drawing, then the problems are simplified. But if the drawing is to be reduced or enlarged, special care is needed. By reducing a drawing by one half, the appearance is generally improved markedly (provided some simple rules are observed). If a drawing is reduced more than four times, unless the reduction ratio has been taken into account, the end product will be worse. The reason for this is that the reduction process filters out information. At half reduction, small blemishes disappear, the dot density becomes more even, and the dots appear more solid. Reduction beyond this point causes lines to become so thin that they begin to disappear. Conversely, if you magnify the drawing, the errors get bigger and the appearance of the drawing deteriorates (Figure 11.1).

A common mistake in drawing is failing to consider the ultimate size or scale at which the drawing is to be published. For example, preparing a 2 × 1 m site plan drawn with a 0.5-mm pen for publication on an A4 format is futile and demonstrates a lack of understanding of the drawing and publishing process. At this reduction, the lines will be 0.05 mm thick. So it is essential to first decide what the ultimate scale or dimensions of the end product will be. This may mean that two drawings are needed: one, at a large scale, for working on as a research tool, and another especially prepared for reduction for publication. Drawings are usually produced for publication at a fixed scale of 1:2, 1:4, 1:10, etc. Knowing the page size of the publication and the dimensions of the object, it is possible to choose an appropriate scale for the printed page. It is best to then make the drawing at twice the published size. It is worth remembering that publications are in portrait format, so if o a plan of a rectangular site is produced, keep the plan in portrait format or else it will need to be rotated 90° resulting in the

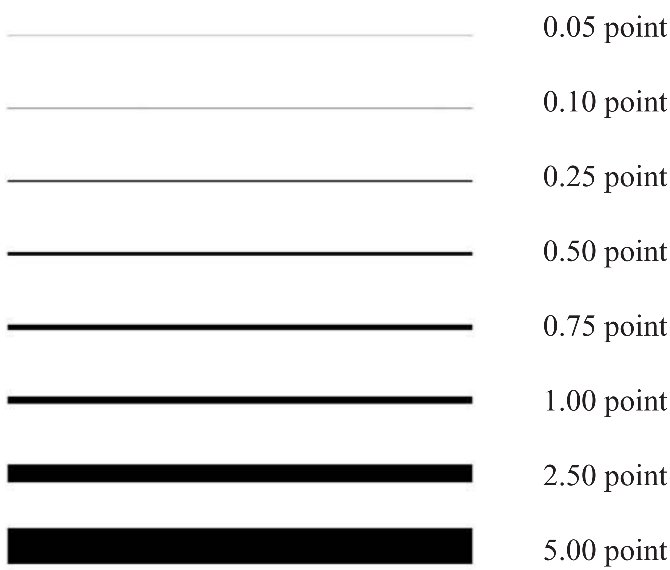


Figure 11.1 A series of line thicknesses showing how the very fine lines tend to disappear.

text running vertically. Otherwise the landscape plan will have to be printed across the portrait format, resulting in loss of detail. The next consideration is that the finest printable line is about 0.1–0.2 mm, depending on the quality of the paper and printing process. The 0.1-mm line is really very fine, so it is better to aim for a minimum printed line thickness of 0.25 mm, which on the working drawing is a 0.5-mm line. Similarly, if the drawing is to be reduced four times then the line thickness would have to be 1.0 mm. However, drawing for a 4× reduction is not easy, as one has to ensure that shading and line separations are wide enough so they are not clogged on reduction.

The artifact is generally drawn in an orthographic projection from as many viewpoints as is necessary to adequately illustrate the object. Thus, the drawing must show sufficient projections to allow any dimensional measurement of the object to be taken from the drawing. In other words, the drawing should provide enough information to be able to make a reconstruction. It is unnecessary to produce every projection of the object if this simply duplicates information that is already there, although additional projections may be of help to better visualize the object.

An orthographic projection has no perspective in it. Thus, as in any engineering drawing, distances on the plan are distances on the object. Usually, the object is illustrated with either a front elevation or a plan.

A difficult question is: Does one illustrate the object as it is, or as it should be? First, it is important to distinguish in the drawing between what exists and that which is reconstruction or guesswork; thus solid lines delineate the existing object and any guesswork is indicated by a spotted or hatched line. Where an object is damaged, flawed, or misshapen in its original manufacture, a decision has to be made to either show the object as it was meant to be or present it in its flawed state. It may be that showing the flaw will be useful because it helps in the understanding of the manufacture of the object. In the case of damage that has been sustained during or after the point at which it was abandoned, e.g., a rudder gudgeon bent in the process of the shipwreck, then it may be of more use to illustrate it in its original form, but also record which particular side was damaged, as this may help in the interpretation of the wrecking process. If it is possible to reconstruct an object in a drawing without guesswork, then this is preferable as it will make the object more understandable. If it is not possible to achieve this, then the object should be drawn as is. In complex situations, the object may be reconstructed in the drawing and then supported with a photograph.

Illustrating appendages to symmetrical objects can be difficult. Handles on pots or jars, for example, are a problem; if there is more than one and they are symmetrical, then one can be drawn in profile and the other as an exterior view. If there is a single handle as, for example, on a beardman jug, then the exterior view of the handle on the profile of the jug will show this. It is all very logical. Where there is something that cannot be illustrated simply, an additional view or detailed view may be necessary. Thus, the handle of a jug may not be circular but cordon, fluted, or square in section. The shading can distinguish between square and circular, but where it is ambiguous, a cross section can be inserted. Marks showing where the cross section was taken and the orientation of the cross section should be indicated. The question of additional views should now be answered.

The use of high-intensity lights when drawing artifacts cannot be underestimated. The high light levels help to define details which cannot normally be observed under ambient room lighting, and this factor should be taken into consideration by the illustrator.

Finally, the advent of three-dimensional drawing packages presents the archaeologist with new and exciting ways to represent objects. As we move into the electronic age the three-dimensional representations of artifacts are becoming more common and the ability to represent these objects in a three-dimensional site plan has important applications for archaeology. It is also worth considering the value of time consuming drawing rather than photography, Figure 11.2a is a photograph of object and should be compared with the photograph Figure 11.2b.

a b

Figure 11.2 Comparison between a photograph (a) and a drawing (b) of the same object.

III. DRAWING MATERIALS

A. FILM

There are several types of drawing surfaces, e.g., transparent, semi-transparent, and opaque. Most drawing suppliers will have sample catalogs of the range of drawing surfaces, so that it is possible to make a selection to suit a particular need and a particular budget. The transparent and semi-transparent surfaces usually have a plastic base (polyester or acetate) and are referred to as film. There are several types available. Plastic drawing film is usually available in a variety of thicknesses and in a transparent (clear), single-sided, semi-matte or double-sided, semi-matte finish. The transparent film is useful for drawing details of objects that can be traced through the film. Thus, copying from photographs or tracing ship's timbers are examples where detail needs to be seen through the drawing surface and maximum clarity is therefore required. With this shiny, clear plastic, the surfaces have to be kept clean and free of grease. The type of pen and ink selected must give an even, dense line which takes well to the surface. Alcohol-based, fiber-tipped pens seem to work best on this drawing material.

The matte or semi-transparent materials are excellent for line drawings and illustrations. Ink mistakes can be repeatedly scraped off using a scalpel or a damp rubber. Care should be exercised not to damage the surface excessively, as this can cause the ink to run along fine scratches. The material is dimensionally stable and, most important, completely waterproof. This is often essential when working in the field, as drawings often get wet or can be splashed or affected by extremes of humidity and dampness.

There are, however, some important disadvantages attached to using matte or semi-transparent film. The surface is prone to pick up grease, particularly from the illustrator's hands. When drawing, it is necessary to keep hands scrupulously clean and it is preferable to work with one's hand on a paper tissue. If grease gets onto the surface from a thumbprint, for example, the ink takes differently to the surface, causing uneven lines. It is, therefore, essential to prepare the surface prior to inking by treating it with inking powder. Also, plastic surfaces are not as porous as other surfaces and there is a tendency for the lines to fade; thus, if the pen is giving an uneven flow, the line density varies from thick black to a gray where the surface shows through. This creates formidable problems when photographing the drawing for reproduction. Also, where the lines or ink surfaces are thick, the ink tends to be shiny causing reflection problems in photography. Plastic film takes a long time to dry, particularly in high humidity conditions. Thus, very great care must be taken not to smudge wet lines, and ink lines must be totally dry before pencil construction lines can be erased. A hair dryer can be useful to speed the drying process. Finally, plastic is a very expensive drawing material, but its use is strongly recommended for all permanent recording work.

Other tracing papers include the cheap tracing papers of the greaseproof paper type. They take India ink extremely well, but are not dimensionally stable, and are particularly affected by humidity. In the latter case, if they get wet, a valuable drawing that has taken many hours to produce can be ruined. As it is very cheap, about one quarter the price of plastic film at the time of this writing, it is ideal for producing preliminary drawings and tentative construction plans.

B. Paper

White cartridge paper is often used for drawings and has the advantage that the ink takes well on it. The main objection is that corrections are difficult, particularly as either the paper is damaged if the ink is removed, or the porosity of the surface is altered if a white opaque covering paint is used. Drawing paper comes in a variety of grades of loading, so that those with the greatest loading have the smoothest surface. It is necessary to use care in the selection of paper. The rougher paper allows inks to run whereas paper with a lot of surface additives causes pens to clog and gives rough lines. Bristol board has an excellent surface for line drawings. There are also white plastic drawing papers made from the same materials as the drawing film. These have some of the inherent problems of film, but are extremely strong and robust.

Some very effective artifact drawings have been published using white scraper board (Kaijser, 1981). The scraper board is a card with a special surface, usually black, which when scraped with a needle or scalpel reveals a white surface. It is possible to either use a white scraper board and scrape to reveal the black, or to use a plain white surface, block the object in India ink, and then scrape this to reveal the white below. Drawings made on scraper board can have interesting surface effects which can make the material of the object, glass bottles, for example, look particularly realistic.

Graph paper usually comes in blocks of A4 or larger formats or in rolls 750 mm to 1 m wide in a variety of lengths. It can be opaque or transparent and is available in a variety of colors. However, graph paper, particularly in roll form, can be inaccurate; for example, one particular grade was oversized by +0.15% longitudinal and +0.25% in the lateral direction. One useful aspect of colored graph paper is that with a judicial choice of colors, film, and filter, it is possible to photograph an object drawn on graph paper so that the lines do not show. Thus the grid can be used as a reference when making the drawing and it is possible to dispense with mechanical drawing aids.

C. Inks

Most drawing ink manufacturers provide inks for various uses. The type of ink selected will depend on the type of pen and the type of surface to be used. It is helpful to remember that certain inks are compatible with particular pens, and mixing different inks in the pen reservoir should be avoided. In particular, etching inks can dissolve parts of certain types of pens.

D. Pens

There is an immense variety of pens for drawing purposes. They may be divided into four categories each of which is described next.

1. Dip Pens

Dip pens are used for simple artwork. Usually, they are obtained either with italic, straight-cut nibs to give different thicknesses to different parts of the letter (like Roman typeface or italic handwriting). The also come with nibs with a disk end which give lineal letters with equal thickness throughout, although the ends of letters are round-ended not square.

2. Stilo Pens

Stilo pens are produced by a number of different companies. In general, these are based on a holder with a screw-in pen tip and ink reservoir. The pen tip consists of a hollow tube with a flat end. The ink flows from the reservoir down the fine tube to the flat surface at the end of the nib. When the pen is drawn on the surface of the paper, the ink flows out across the flat nib surface giving a line equal in thickness to the tip diameter. The tips range from 0.13 to about 2.0 mm (in the DIN system the double increments are 0.18, 0.25, 0.35, 0.5, 0.7, 1.0, 1.4, and 2.0 mm). Down the center of the tube is a fine wire, the upper end of which is attached to a little cylindrical weight. This acts to control the flow of ink and to help unblock the pen when it clogs. Thus, by shaking the pen back and forth, or screwing the cap on and tapping the end on a table, the weight moves the wire similarly backward and forward, helping to clear the tube.

The tips of some types of stilo pens are made of very hard material. This type of pen is essential for working on plastic drawing film which is very abrasive. Ordinary pens, when used on film, only last a short time before the tip is worn away to the shoulder, causing an increase of about 0.5 mm in line thickness and producing very messy lines. The tips of most stilo pens are manufactured with a shoulder so that when using a straightedge, the ink is not drawn under the surface of a ruler causing blotting. The shoulder or bevel on the tip should always be kept clean (paper tissue can be used to clean the tip), as ink, dirt, and film debris tends to accumulate around the bevel, especially when drawing straight lines. This accumulation often causes the line to thicken and can cause the ink to run under the ruler, which is just what it is designed not to do. These pens are compatible with a range of stencils, so that various styles of lettering can be made for each pen size (see Section VI).

One of the most serious problems with stilo pens is that they seem doomed to clog. A variety of methods of humidification and air-tight holders have been devised, but if the pens are left open for any length of time they block up. To unblock the pen, I have found that there are two alternative methods:

1. Ignore the manufacturer's instructions and take the pen apart, extract the little weight with the fine wire, and clean the pen out. Then try to put the fine wire back into the pen, which you will not be able to do without breaking it and ruining the pen, exactly as the manufacturer said it would. Then buy a new pen at great cost and inconvenience to yourself. In reality, it is possible to remove the wire if it is 0.7 mm or thicker, but it is usually not possible to get anything smaller back into the pen.
2. Get a small glass jar with a lid, or buy the more expensive cleaning unit recommended by the manufacturer, fill it with warm water and a bit of washing-up liquid. Take the cap and the cap insert apart and wash in warm, running water to remove superficial ink (use a toothbrush if necessary), then pop the cap and all the parts into the jar (this is really worthwhile as a caked cap will cause the pen to dry out more quickly). Take the reservoir off the pen, empty the ink out, and wash it. Take apart what you are allowed to take apart according to the instructions, wash and place in the jar. In particular, most pens have a complicated air passageway between nib and holder which allows air, but not ink, to pass up to the reservoir, thus relieving the pressure caused by the ink flowing out. This should be carefully scrubbed with

a toothbrush to ensure the passageways are clear. You can often tell when this breather is blocked, because as the pen is held, the warmth of your hand causes the ink to be forced out of the tip and drip over your almost complete artwork. Leave everything in the jar for several days, preferably a week, change water from time to time, and thoroughly wash out under a water faucet each time. This is really the only way for the very fine pens. There are some ingenious aerosol pen cleaning kits in which the nib screws into the can and the cleaning fluid is forced through the nib.

3. Fiber Pens

A number of excellent fiber-tipped pens are now available. It is important with these pens to test if the ink is really waterproof. This can be done by drawing a few lines on paper and film and then wetting the surface (giving a reasonable few seconds to dry). If the ink runs, then the pen should not be used, even for general writing. For example, if a field register is left out in the rain and the ink runs, a lot of very important information may be lost. The felt or fiber-tipped pens are available in a variety of tip shapes which can be quite useful, particularly, when drawing a plan or object at very large scale prior to reduction (see Section VI about reduction). There are also a number of fiber pens with nibs encased in a metal tube that give a constant line thickness of 0.2 and 0.4 mm, although the ink is a little thin.

4. Other Pens

With the gradually improving inks, ballpoint pens are coming back into vogue. They are a great improvement on the greasy, uneven lines that were produced when the Biro first came out. Some of the better quality pens can be used for artwork.

E. Pencils

There are many different types of pencils for different types of drawing, ranging from soft to hard. It should be noted that, because plastic drafting film is exceedingly abrasive, there are special problems when using pencil on it. Hard pencils (8H), when used on film, tend to produce thick lines like a soft pencil (4B) would on paper. To produce a light, fine line pencil work on film should be as light as possible with a hard pencil; if too much pressure is exerted it will scratch the surface. There are also pencils (F) available especially for use on film. When working on film, the pencil point will need to be constantly sharpened as it wears down; a piece of fine emery paper is ideal for this. Clutch pencils are also useful, particularly because some have an easy-to-use sharpening tool attached to their end. A useful alternative are fine propelling pencils with leads of 0.3- and 0.5-mm diameter which are held in a push-click button pencil holder. Thus, leads are continually used up, but the line thickness is constant. The various hardness of the leads makes very little difference on film, although it is a different story on paper, where it is best to select a medium-grade pencil for fine-point lead. An 8H pencil will scratch a paper surface as well as leaving a fine line, making it difficult to erase. Using a sharp HB softly on paper gives clear lines that can be easily erased.

IV. DRAWING EQUIPMENT

A. Drawing Box

One of the most useful items for a person who does a lot of drawing work in a variety of places (home, work, expeditions, visits to other collections, etc.) is a drawing box (Figure 11.3). This holds all the basic equipment

Figure 11.3 A standard drawing box showing the range of equipment generally required for artifact and general site plan drawings.

for any type of drawing. From personal experience, it is amazing how often departmental or group equipment is either missing, broken, or unusable when it is needed for a vital, rushed job, whereas with one's own equipment there is only one person that can be blamed if it is not there. In general, you know exactly what you have, and that it is all in one place. But beware, there will be constant harassment by people wanting to borrow pens that are always in working order. The following is what the author keeps in a drawing box:

- A3 drawing board with parallel rule, rotating head; in this case, a Rotring Rapid, but others are just as good and some possibly cheaper
- 50 sheets of pre-cut A3 drawing film and some A3 metric graph paper
- 1 set of 9 drawing pens 0.13–2.0 mm, Rotring Sec-o-mat Isograph "F" pens
- Compass set, small circles, large circles, and compass beam radii up to about 250 mm
- 500-mm stainless steel flat ruler
- 10-m retractable tape measure
- Circular protractor, diameter 300 mm
- Set of large calipers, 500-mm jaws
- Set square
- Vernier calipers, 250 mm
- Vernier depth gauge, 250 mm
- Programmable calculator
- Set of scalpel blades and blade holders, emery board for sharpening blades, and some backed razor blades
- Scale rules (1:2, 1:4, 1:2.5, 1:5, 1:7.5)
- Set of stencils for Isograph pens
- Fine-point pencils and leads (0.2 and 0.5 mm)
- Felt-tipped pens, various colors, tip shapes, and sizes
- Rubbers, ordinary for ink on film and rod rubbers and holders
- Various inks
- Profile devices
- Blue Tac and sticking tape
- Scissors
- Paint brushes
- Proportional dividers and standard dividers
- Measuring devices

The small retractable steel tape is one of the most useful measuring devices. It is compact, flexible, and ideal for measuring large objects (about 10 m maximum). Scale rules are used for drawing, particularly for working plans at fixed scales like 1:2, 1:4, 1:5, 1:10, 1:20, and 1:100. These, provided they are read correctly, simplify the drawing process; for example, 34.81 m at a scale of 1:5 requires a division and then the use of a ruler, whereas a scale rule requires only the use of the rule.

Measuring the outside and inside diameter of objects ranging from ceramic pots to gun barrels can present some problems. Vernier calipers are useful for outside diameters and just inside the necks of tubes. Otherwise large double-arc calipers can be bought or made for use on outside and inside diameters, provided in the latter case you can extract the caliper without altering the reading. It is worth having mild steel calipers chromed to prevent rusting. This is particularly important if they are taken anywhere near the sea, otherwise without the chrome they rust very badly.

There are various ways of measuring in places where a direct measurement cannot be made. For example, it is not normally possible to measure the wall thickness inside a jar with conventional calipers because when the calipers are extracted, the separation changes. Home-made scissor- or X-calipers are one method that can be used in this situation (Figure 11.4). The point of separation on the bottom caliper is duplicated on the top, thus while the inaccessible bottom one is in the inside position the reading can be taken from the top. Alternatively, it is possible to utilize ordinary calipers with a small block placed against the outside surface of the vessel. The calipers measure the thickness of the wall of the object together with the block, the increased caliper jaw separation allows the calipers

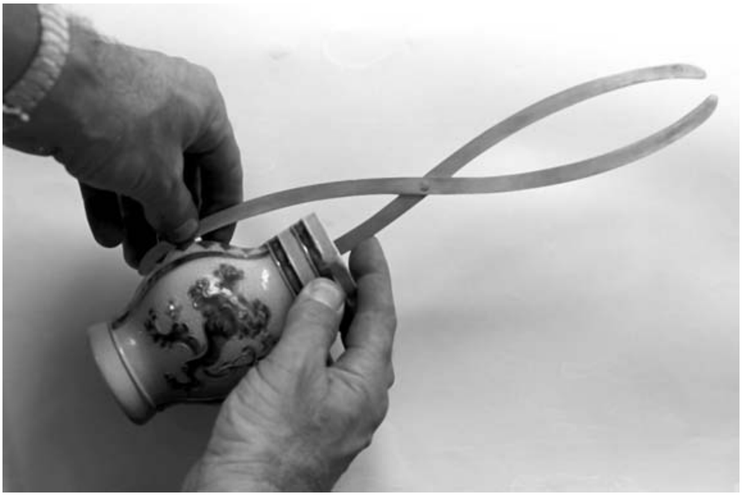


Figure 11.4 X-calipers used to measure the wall thickness inside jars and pots. The calipers are set so that the gap is identical at each end of the caliper.

to be extracted without disturbing the setting. The thickness is then obtained quite simply by subtracting the block thickness from the overall measurement.

B. Drawing Aids

Several different drawing boards are available varying in size and price. The simplest is the A3 clipboard in which the paper is held in position by a magnetic clamp. Vertical and horizontal grooves at the edge of the board give facility for a parallel rule arrangement. The rule slides up and down or across in these grooves. The rule has a groove too, so that another rule can run at right angles. There are rotating heads available which can be set at any given angle. It is a cheap and cheerful version of the drawing head on a proper drafting stand. These boards are very useful and convenient; the A3 size is about twice that of an illustration in a publication, so, as discussed above, drawings can be photographically reduced by one half to give a much better finished result.

Large-scale drawing stands are useful for a large office setup; they are expensive, but often essential. Some manufacturers now produce a cheap drawing machine that can be fitted on an ordinary drawing board, and this offers a compromise in size and money between the A3 board and the large drawing stand (Rotring A2 Portable Drafting Machine). These are really useful in field situations where large plans are needed, but where it is impossible to put a drawing stand. As the last resort, an old fashioned T-square,

Figure 11.5 Proportional dividers used to scale measurements. The dividers have the common proportional measurements set so that the proportionality ratio can be set.

set square, and compass together with a drawing board can be used in field situations or where one is working on a low budget.

C. Profiling Devices

A number of interesting and ingenious profiling devices have been invented to transfer the profile of an object, say a small pot, onto drawing paper. One approach is to use an Aerial Sketchmaster (normally used for tracing aerial photographs onto maps) (Figure 11.6). Another, simple approach is to actively trace the profile of the pot onto the paper (Stevens, 1982). In this case, a set square is mounted on a base so that one edge stands upright and vertical from the plane of the drawing (Figure 11.7a). The pot is carefully mounted on a ring of Blue Tac, plasticine, or plastic silicon rubber so that it stands by itself, level and horizontal. The set square has a fine pencil lead inserted at exactly the junction between the edge of the set square and the drawing board surface. By tracing round the pot with the edge of the set square always touching the surface of the object, a pencil outline of the pot can be drawn. A lot of care is needed to set the pot up

Figure 11.6 Tracing device known as an Aerial Sketchmaster. Used mainly for photogrammetry, it can also be adapted to draw small artifacts. The instrument is set so the operator looks through a prism and can sketch the image on the paper below. The scale is usually set at 1:1.

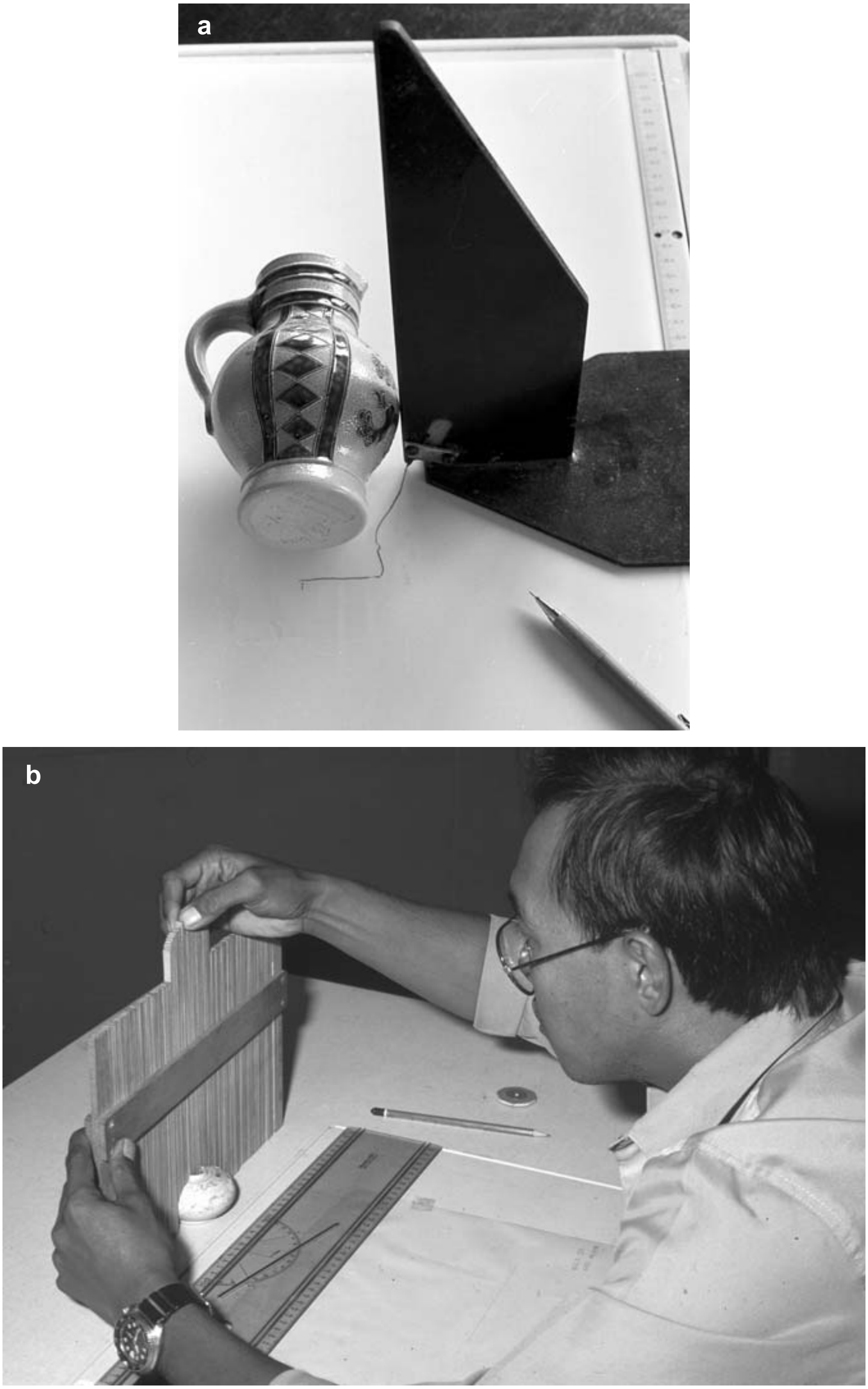


Figure 11.7 (a) A simple profiling tracing device used to trace the outline of small artifacts. A small pencil lead is set at the join between the base and the upright so that the vertical profile can then be traced on the paper. (b) A profiler is made up of a large number of strips that can be pushed down on an object to record the profile. Once the strips smoothly contour the object, the profiler is removed and its outline traced on the artifact drawing. In this case the operator is recording the profile of a small porcelain jarlet. (Figure 11.7b is courtesy of Brian Richards, Department of Maritime Archaeology, Western Australian Maritime Museum.)

to a predrawn axis. It is, therefore, easier to trace around the pot and then set the axis. Also, one needs to be patient and possess the skill of a contortionist, because it is essential that the pot must not move. This requires one hand to hold the pot at all times, while the other hand operates the profiler, which has to go all the way round the hand holding the pot. So it is important to think where you want to start.

Another profile device is an array of thin strips of wood, plastic, or metal in a holder. The strips are pushed against the side of the pot thus duplicating the profile. The profile machine is then laid down on the drawing surface and the profile traced out (Figure 11.7b). It is much easier to operate than the previous system, but it only makes a profile of one edge of the object and often only part thereof, so that additional measurements need to be made to get the profile in the correct orientation with the axis of the pot. Both machines described above are cheap and easy to make with minimal tools and a bit of skill.

Slightly more complicated to make, but really useful, is the profiling stand (Figure 11.8). This instrument consists of a flat baseboard with a vertical post with a ruler attached. Sliding up and down the post is a block that can be clamped in position. The block has a horizontal slot in which another ruler is set and can slide in and out. The horizontal ruler has a pointed end and this is set against the object to be profiled. To profile an object, it is placed on the baseboard with the profile in line with the vertical post. The horizontal ruler is set against the profile at regular vertical increments and the horizontal and vertical measurements taken. The great advantage of this system is that the measurements can be transferred directly to a drawing using a drafting machine.

It is often necessary to determine the radius of curvature of objects, particularly pottery wall shards, so that a reconstruction can be effected in the drawing. Simple trigonometry and a hand-held calculator can simplify this and give accurate results. Essentially, it is necessary to know the amount that the arc is displaced between two fixed points A and B (Figure 11.9b). Thus, if two fixed points are distance $2D$ apart and the maximum distance from the straight line between these two points to the wall of the object (the chord–arc distance) is d, then the radius of curvature R is given by:

$$R = \frac{(D^2 + d^2)}{2d}$$

Care has to be taken to ensure that the chord–arc distance d is to be a point that is in the plane of symmetry of the chord. For example, the orientation of the shard to the axis of symmetry is correct when taking the measurements and that the chord lies in a plane at right angles to the

Figure 11.8 Profiling device used to measure the shape of a large object. In this case the X and Y coordinates are read off the scales on the profiler and transferred to the artifact drawing. (Courtesy of Brian Richards, Department of Maritime Archaeology, Western Australian Maritime Museum.)

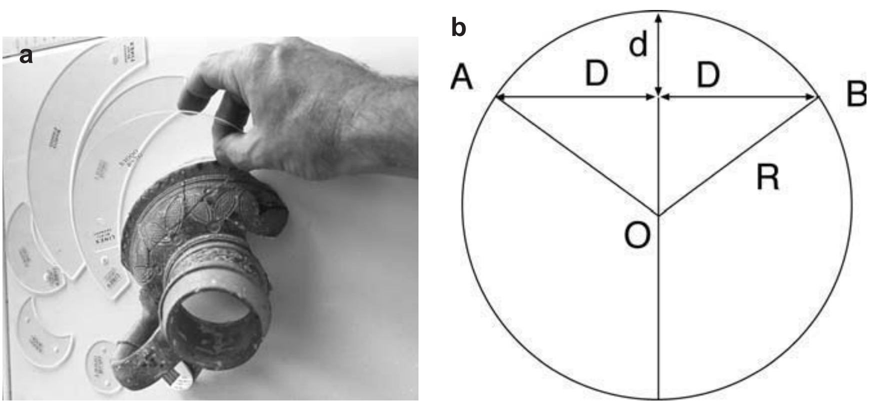


Figure 11.9 (a) Curvature measurement using fixed curves. (b) Basics of calculating the radius of curvature.

axis of symmetry. This may be a problem with a wall shard where it is difficult to determine its symmetry, whereas a rim or base fragment will be simple.

An alternative method of measuring the diameter is to make a series of stiff, plastic arcs of inside and outside curvatures, with fixed and known diameter. Again, care is required to ensure that the plane of curvature of the measuring device is perpendicular to the axis of symmetry of the pot (Figures 11.9a and 10). Another helpful item is a plastic sheet with concentric circles drawn on it, so that base and rim diameters can be measured from fragments.

V. DRAWING TECHNIQUES

In making an artifact drawing, it is usual to start the drawing in pencil. Light construction lines can be drawn onto the plan and the main outline and important features can be drawn in. It is essential to keep the pencil lines as light as possible because they will eventually have to be rubbed out. It is best to postpone the inking until the drawing is complete and one is satisfied that the drawing is correct. This is important because it is much easier to erase pencil lines than ink lines.

Before starting ink work, it is worth recalling some important rules that have already been mentioned: (1) prepare the drafting film surface using inking powder or some other agent to clean the surface of grease and dirt; (2) keep hands as clean as possible, and preferably work resting on a tissue so that the surface does not pick up grease from one's hands; (3) when using a ruler, ensure that the shoulders of the pen are not clogged, otherwise the ink will run under the ruler; and (4) to help the ink dry quickly, so that there will be less danger of smudging, a hair dryer can be used to artificially speed the drying process. However, inked lines should not be worked on with a rubber until the ink has completely dried which usually takes 24 hours.

One very effective solution to the problem of erasing pencil construction lines on inked work is to do the pencil work on one side of double-matte film and to do the inked work on the reverse side. In this way, there is less chance of the eraser damaging the inked work.

A. Erasing Ink Lines on Film

There are two options when a mistake has been made: leave it to dry or deal with it right away. Both options have advantages and disadvantages. Generally speaking, small smudges or blots that require cosmetic work, or

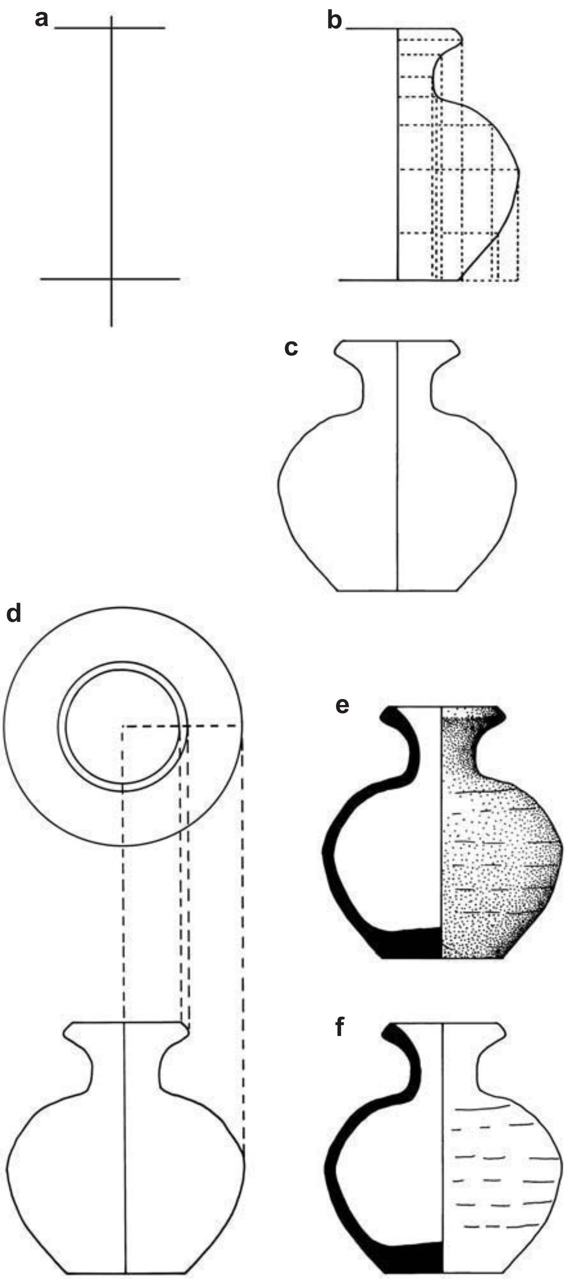


Figure 11.10 Stages of drawing a small jar showing the views and the construction method.

Figure 11.11 Drawing of a large storage jar form Ko Si Chang, Thailand.

pencil construction lines that must be removed, should be worked on when the ink is dry; so these are best left until the next day. Major blunders are usually cleaned up at the time of occurrence as they otherwise hold up the drawing.

Smudges on lines are best corrected with a sharp scalpel blade. A scalpel holder with a replaceable surgical scalpel blade is recommended, together with a blade with a curved edge (a straightedge will usually score the film with its point). If the blade is blunt, do not discarded it as it can easily be sharpened on fine emery paper. It is very important to have a sharp blade as it scrapes off the ink more efficiently. Then, starting at the edge of the line and working away from the line, scrape off the offending ink. You may end up with a glassy surface if you are too rough; in that case it is better to rub out the whole area. As a rule, be gentle and try not to scratch the surface. In particular, it is important to avoid using the point of the scalpel, as this will scratch the surface.

To remove a line or a badly blotted line a fine film rubber (usually white plastic) or a coarse ink rubber (usually gray and abrasive) and an erasing shield are useful. The shield can be made by using scraps of old drafting film. It is then placed over the work to be protected and the exposed offending ink work is erased. The film rubber works best if it is damp (use the tip of the tongue or a damp cloth) and rub in the direction of the line holding the shield firmly over the material to be protected. The other option is to erase the beginning of the line with a scalpel and then use the fine rubber to erase the rest of the line, thus avoiding the possibility of the rubber smudging the line more. If the scalpel breaks into the good work and the line has to be touched up, use the coarse rubber to smooth the surface where the scalpel has been. This helps to improve the surface in preparation for the new ink. It may be worth selecting the next finer pen if you find it the line thickening too much.

When correcting wet work there is no point in using a scalpel as it will simply move the ink around on the film. The best method is to use absorbent paper tissues first to dry the mistake, and then to use a hair dryer to dry the work so that it can be worked on with a rubber. Using the rubber, clear as much of the error as possible, and then work with the rubber parallel to the direction of the lines so that the smudging is confined to the line itself. If the work is reasonably dry, an eraser shield can be used. Often, after a line has been erased, a ghost line will be noticed, either of the line or of the smudge. This is caused by the rubber drying a fine layer of greasy ink on the film. It can be removed with either a damp, fine rubber or a coarse rubber.

B. Erasing Ink Lines on Paper

Erasing ink on paper is very difficult, and it is one of the reasons why paper is not recommended for drawing. The only real solution is to use typewriter correcting fluid to block out the error. If the offending ink can be isolated it may be possible to paste a piece of white paper over the mistake and re-draw it. If the correction is in a complex piece of artwork, the drawing over the correcting fluid is very difficult, because its surface tends to be soft and takes the ink differently from paper. It is advisable to experiment with correction fluids before using them.

VI. LETTERING

Drawings and plans usually require some form of lettering for which there are four choices: either free-hand lettering (usually italic), stencils, applied lettering (e.g., Letraset), or laser-printed text. The free-hand lettering requires considerable calligraphic skill, but the effects can be excellent. The lettering is usually done with a calligraphic pen with various nib widths. Italic is one of the most effective styles, but it requires considerable practice and skill to perfect.

Stencils compatible with the stilo-type pens are the easiest and cheapest method of lettering, particularly because one can use the same pens for drawing and stenciling, rather than having to buy a new set of pens solely for stencil work. Stilo script tends to be rather dull, partially due to the round-ended lines of the pens. Some variation can be introduced with italic stencils. Special care is required to ensure that the letters are well formed and spaced properly, otherwise the results are extremely poor and not pleasing to the eye.

A more preferred method of lettering is to use applied lettering. Letraset is one of the best known systems with hundreds of styles and sizes. With such a bewildering array of options, it is best to standardize with one or two typefaces. For san serif work, Helvetica Medium is good; this can be varied with Helvetica Light. Serif typefaces have to be treated with caution, particularly typefaces with extremely thin strokes (Baskerville Old Face), as photographic reduction causes the thin strokes to drop out. These typefaces should not be used when the artwork is to be reduced. There are special serif typefaces with less contrast between thick and thin strokes that are suitable for reduction, but in the author's view san serif lettering looks best on plans or artifact drawings.

Letraset is extremely expensive and thus should be stored with great care. The techniques of application are quite simple and guidelines for laying out and spacing are provided. Other application materials include tones, textures, and colors that can be applied on either side of translucent drawing film.

By far the most desirable form of lettering is to use a laser printer to print the required text on paper or film. The text can be cut out and stuck onto the artwork. The same problems with san serif letters apply to laser-printed text, but the flexibility of the fonts, sizes, and type styles, together with the control of design and the correct spacing and kerning, makes the text extremely attractive and easy to produce (Figure 11.12). It is simply cut out and mounted on the artwork. In time, much of the drawing process may eventually be done entirely on a computer using a computer-aided drawing (CAD) program. Presently, where a drawing requires a moderate to large amount

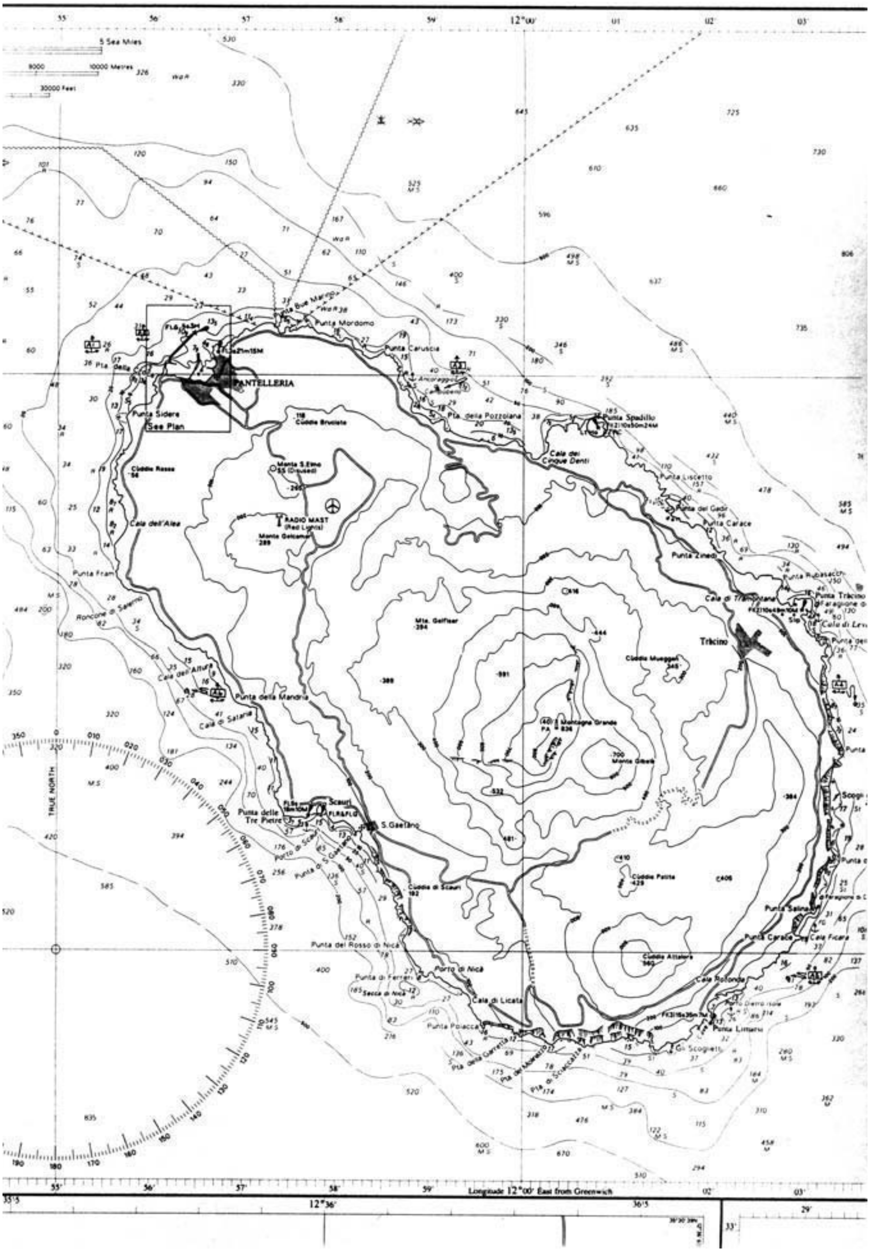
Figure 11.12 Lettering that shows the difference in readability between (left) serif (Times) and (right) sans serf (Arial) fonts.

of text applied to the drawing, it is probably best to complete the drawing without any text on it, scan it, import the scan into a vector graphics package, and place the text using the text feature of the program (Figure 11.13).

VII. SHADING

There are two simple ways of shading an object drawing: stippling or hatching. The former is most suited to regular smooth objects (ceramics), the latter to rougher objects with texture (iron and wood). The object of shading is to give the impression of body and shape to the two-dimensional drawing. If shaded well, the results can be superb, if not, they can be deleterious, detracting from the value of the line drawing and wasting a great deal of the illustrator's time. Shading requires practice and a certain amount of boldness in the approach to the subject. Some simple rules apply to shading, particularly stippling.

First, it is important to decide which way up an object is to be published. Once this has been determined, an illumination convention has to be decided upon. In general most illustrators assume that the object is illuminated from above, either in the upper right- or upper left-hand corner. Taking a simple example of an object, for example, a sphere, the area closest to the light source will have the highest level of illumination (2 o'clock). Around this, in a series of crescents, will be progressively darker areas,



a

Figure 11.13 (a) A scan of a map of the island of Pantelleria. This has been traced in a vector graphics package and retitled (b)

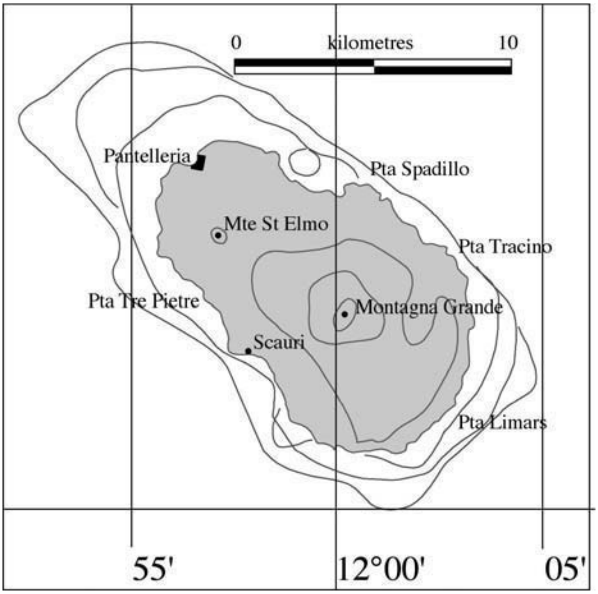
b


Figure 11.13 (*Continued*)

culminating in the darkest area at the outer periphery (from about 6–10 o'clock). It is best to start shading from the darkest area outward to the lightest. The general rule for shading is to examine the curvatures. There are generally two curvatures, one curvature rotates about a vertical axis, the other rotates around a horizontal axis, and the shading should relate to these curvatures. For example, for a cylindrical object with a semicircular, cross section of beading running around the cylinder, the beading should be shaded first in the horizontal plane (i.e., dark at the left getting lighter toward the right), and then shaded in the vertical plane (light at the top of the beading to dark at the bottom, see Figure 11.14a). As one gets more proficient at shading, it is worth considering using another shading convention. Consider two possible lighting situations: one where the light comes from the top right, but in the plane of the object; the second, where the light comes from top right, but out from the plane of the paper (or the object), between the object and the viewer. In the former convention for a sphere the brightest point would be top right, at the periphery, whereas in the latter, it would be top right, but in the center of the top right quadrant (Figure 11.14b and c). Note the Figures 11.14b and c were drawn using a computer graphics package, the latter convention produces a more realistic three-dimensional effect.

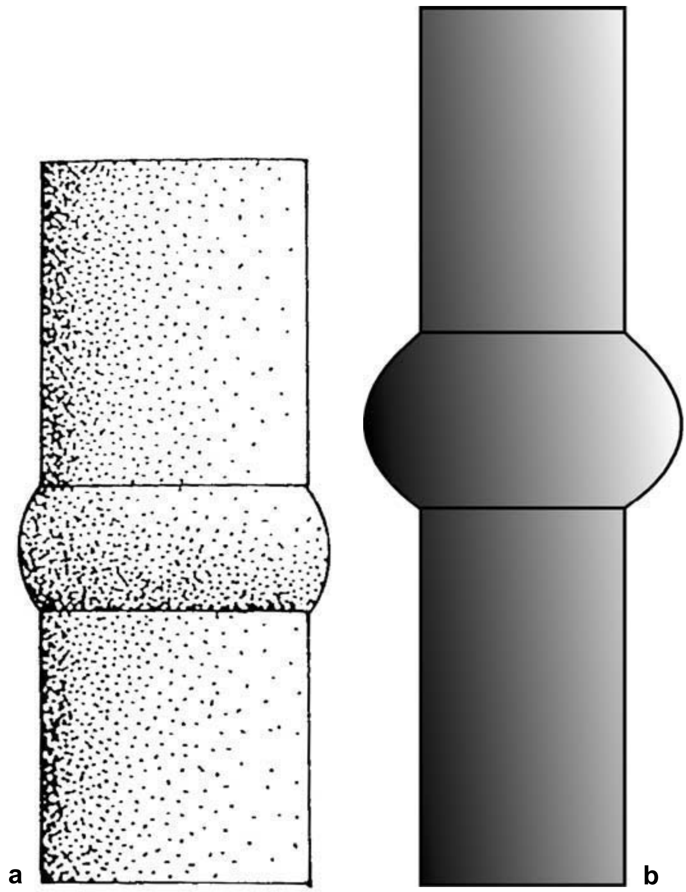
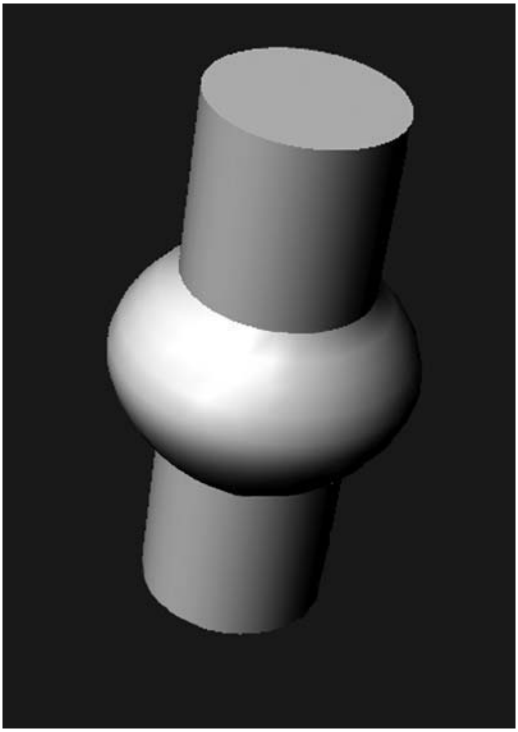


Figure 11.14 (a) Hand-drawn shading; (b) computer-generated shading with light coming from the upper right.

To learn how to shade effectively, start by practicing on some simple geometric objects, spheres, cylinders, and cones and then develop some more complex geometric objects (the Death Star from Star Wars, a wine glass, etc.). Once shape can be given to an object, techniques to show texture and even color can be developed. Texture can often be inferred very effectively using hatching, and this is particularly useful for wrought iron and wooden objects where the grain can be indicated with the hatching (Figure 11.0 shows the progress of drawing an object).



c

Figure 11.14 (*Continued*) (c) computer-generated shading, light coming from the front.

The development of high-resolution scanners also raises interesting possibilities for artifact recording. One example is to scan artifact drawings and save the data in a database that allows graphic images to be stored along with text. Another possible application is to link a video camera to the computer to record objects, thus completely avoiding having to draw the object. Even if a drawing has been made it may be more useful to scan it and store the data for use later). Finally, with the increasing sophistication of graphics programs for computers, it will not be long before artifacts will be regularly drawn using a computer. Most of the more advanced CAD programs have the capacity to do this type of work. This will speed the drawing process and enable the drawings to be stored electronically in the artifact database. Modification or re-drawing will be much easier and drawings can then be placed directly, by file transfer, into the publication.

VIII. PROJECTIONS

A. Objects with Axial Symmetry

An object with axial symmetry is usually illustrated by a side elevation. Pots, for example, are often made on a wheel and generally have a central axis of symmetry, i.e., rotating the pot gives the same profile. This is also the case for a number of metal and wooden objects that are turned on a lathe. Thus, on the simplest level, the only view required to illustrate a pot is a front elevation. The drawing of the object should then be divided down the middle, one side used to illustrate the exterior of the object, and on the other side of the illustration, the interior view including the profile of the wall of the object. It does not matter on which side the profile is shown, provided one maintains that convention. A cursory perusal of Old World archaeological reports seems to favor a left-sided profile.

B. Isometric Projections

As well as the standard orthographic projection, another means of illustrating a three-dimensional object in two dimensions is by using an isometric projection. In this projection, an object is drawn in perspective, but without perspective scale change. This is particularly effective for rectilinear objects and architectural views. Two of the rectangular coordinate axes are set at right angles, and the third is angled at 30° to the X-axis, between the two, as if viewed in perspective. The scale along the third axis is linear and usually set slightly smaller than the (equal) scales on the other two axes. The resultant drawing shows the objective in perspective view, but in a way which measurements can usually be made in three dimensions (Figure 11.15). All measurements in the isometric projection must be made on or parallel to the isometric axes. A line which is inclined to the isometric axes is called a nonisometric line and does not appear as a true length. Therefore it cannot be used to take measurements from the drawing. As a general guide to the construction of an isometric projection, all vertical and horizontal lines, i.e., all lines parallel to the X- and Y-axis, are drawn horizontally (for the X-axis) and vertically (for the Y-axis) and lines that are parallel to the Z-axis make an angle of 30° to the X-axis (see Morris, 1988).

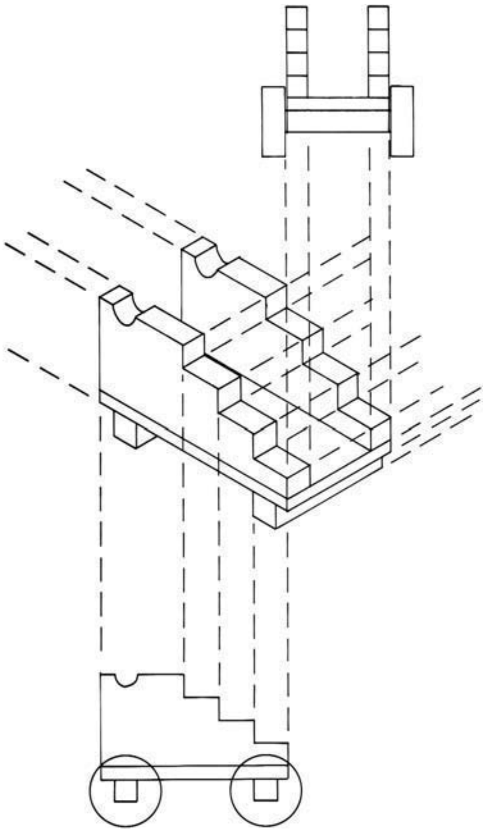


Figure 11.15 Drawing showing the basics of an isometric. In this case, a gun carriage is shown.

IX. COMPUTER-AIDED GRAPHICS

The CAD packages that followed the computer revolution provide some interesting options for the archaeologist who wants to illustrate artifacts. These techniques, which have been discussed in Chapter 7, consist of using a computer to draw lines rather than using pen and ink to create object drawings. Alternatively, a computer-aided drawing of an object can be made from a scan, a digital camera photograph, or a scan of a conventional photograph. All three options produce a digital image of the object in a raster format (a format where each point or pixel in the image is individual and unique, if the size of the graphic image is doubled, then each pixel will double in size too). The CAD work will be vector graphics whereby lines, shapes, shades, and anything else are essentially equations. If you double the size of the image the lines will stay smooth and will not pixilate; additionally these image files are relatively small compared to raster images. It is possible to scan an artifact using flatbed scanners. With care and a good quality scanner with a reasonable depth of field, three-dimensional objects can be scanned (the best results are with objects with limited thickness). Given the quality and speed that an object can be scanned, there are very real advantages to this system. Results can be very impressive, although the limitation is obviously the size of the object (it has fit on the bed of the scanner) and the height or thickness of the object.

The table shows a number of choices, all of which need to have a computer-based end product:

Technique	Pro	Con
Draw the object conventionally and scan into raster graphics	Easy to do	Large file size, cannot enlarge greatly
Draw the object conventionally, scan it and trace drawing with vector graphic	Small file size	Time-consuming, lots of drawing
Digital photograph or scan the object, trace scan using vector graphics	Small file size	Difficult with complex three-dimensional objects
Digital photograph or scan the object and keep in raster graphic format	Easy to do	Large file size, difficult with complex three-dimensional objects, cannot enlarge greatly

X. THREE-DIMENSIONAL GRAPHICS

The use of three-dimensional graphics to illustrate artifacts is very much in its infancy. Clearly, the use of three-dimensional models of artifacts used in the Tektash survey are particularly interesting, because so many of the objects were identical. The technique was applied essentially to objects with axial symmetry and surface rendering of the wire-frame model was simple shading. As this technology improves, the option of draping a digital image of the surface over the wire frame will be an exciting possibility. Furthermore, the development of PhotoModeler as a three-dimensional technique for complex models and with the potential to drape the surface of the object from photographs will present new and interesting options for archaeological object illustration.

XI. SHIP'S LINES AND NAVAL ARCHITECTURE

The representation of the shape of a ship on paper is not easy. In the late 18th and early 19th centuries naval architects devised a standard convention for producing plans of hull shapes using a series of three plans to represent the shape of the hull. The first plan is a side view of the vessel viewed perpendicular to the keel and is known as the sheer plan or elevation. The second plan is a view from the fore and aft of the vessel, usually with the planks removed, showing the outlines of the timbers and is known as the body plan or projection. Finally the half-breadth or horizontal plane is a view of the hull from below. Onto these plans various sections are drawn which help to define the surface. The sections can be imagined to be formed by slicing the solid hull into a series of slices of equal thickness in the three different planes. Thus the horizontal slices form a series of water lines, the vertical longitudinal slices form a series of sheer lines, and the vertical lateral slices form the shapes that the frames will have. Additionally, the body plan sometimes shows the diagonals, which are lines that would be formed if the ship was cut longitudinally, parallel to the keel, at an angle, usually 45°. A number of authors (Chapman, 1769; Steel, 1805) show early ship drafts which are useful reference material and Lyon (1974) gives a good introduction to the various types of ships' plans and their sources in the National Maritime Museum at Greenwich.

There are a number of computer-based programs which enable ships' lines to be drawn from a table of offsets. These programs usually allow the entry of X, Y, and Z coordinates for various sections of the hull and then calculate and produce a series of line drawings (Figure 11.16).

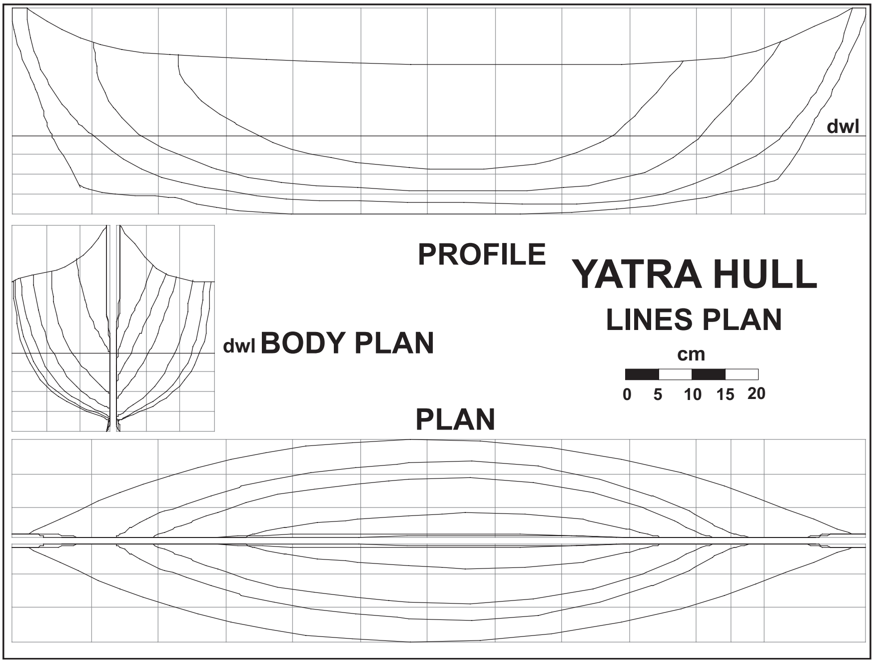


Figure 11.16 Line drawing of a *Yatra Dhoni* in Sri Lanka. The line drawing enables naval architects to make calculations about the performance and capacity of the vessel. This plan is used in the construction of the vessel. (Courtesy of Brian Richards, Department of Marine Archaeology, Western Australian Maritime Museum.)

Figure 11.17 Large-size calipers used to measure diameters. (Courtesy of Brian Richards, Department of Marine Archaeology, Western Australian Maritime Museum.)

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Chapter 12

Artifact Photography

I. OBJECTIVES OF ARTIFACT PHOTOGRAPHY

The artifact photograph is a technical image that can be used to illustrate an object. From this the archaeologist has a record giving an excellent visual impression of the object and from which simple measurements can be taken. In some cases the photograph may be used to record a structure on a site and its survival over a number of years (Figure 12.1). Artifact photography is not intended to be artistic, although there is no reason why it should not be so. The photograph is a perspective view, so that unless special techniques are used, it is only possible to take measurements from the plane in which the scale lies. The main criteria for a good artifact photograph are that (1) the scale should be well placed so measurements can be taken of the object, (2) the object should be evenly illuminated against a sensibly contrasting background with no harsh shadows obscuring the profile, (3) the view should be symmetrical about the major axes of the object, and (4) the object and the photograph should be able to be easily identified.

A major problem with artifact photography is that, although it is easy to take very large numbers of photographs of objects, unless the photographer has a very clear understanding of what is being photographed and why, the whole process is a waste of time. Additionally, it is important to ensure that it is possible to locate a photograph once it has been taken. Therefore, the photographic collection has to be administered in an efficient manner.

Figure 12.1 Photo over time showing the gradual disintegration of a guano mining machine on Pelsart Island in the Houtman Abrolhos, Western Australia. (a) Image taken in 1943, (b) image taken in 1976, and (c) image taken in 1979. (Photograph courtesy of the Neville Collection.) (Figure 12.1a is courtesy of Brian Richards and Figure 12.1b is courtesy of Patrick Baker, both of Department of Marine Archaeology, Western Australian Maritime Museum; Figure 12.1c is courtesy of Battye Library of Western Australia History, Western Australia Library Board.)

II. EQUIPMENT

A. Cameras

The 35-mm, single-lens reflex (SLR) camera with interchangeable lenses has been the most widely used camera for artifact photography. There are numerous makes and types available. In the upper quality range are the

Nikon, Canon, Olympus, Pentax, and Minolta, all of which produce a number of different camera types with different features, but each doing basically the same things. The SLR camera has a variety of interchangeable lenses ranging from ultra wide-angle (focal length 10–24 mm), wide-angle (24–35 mm), normal (35–80 mm), or telephoto (80–300 mm). There are also zoom lenses which have variable focal lengths, most commonly 28–55 mm, 40–80 mm, and 80–200 mm, and macro lenses which are close-up lenses capable of focusing from infinity down to object-to-image ratios of 1:2 or 1:1. There are also fast lenses with f-stop numbers down to f 1.2.

The use of many of these lenses lies beyond the scope of this book and readers are referred to standard textbooks and manuals of photography (Hedgecoe, 1977). For general archaeological photography, the standard lens used is the 55-mm macro lens. The 24-mm wide-angle lens is a useful additional lens for general expedition photography. It is very effective for close quarters, for example, on a boat or for landscapes and used with color film and a polarizing filter, dramatic effects can be achieved. However, care must be taken to avoid perspective distortion in architectural work (Figure 12.2).

Another useful lens is the macro telephoto of either 100- or 200-mm focal length for accurate, detailed object photography. This lens reduces perspective effects in object photographs, but as it typically has a narrow depth of field, great care is required to ensure all of the object is in focus. A good general purpose lens is a 35- to 105-mm macro zoom lens. This covers the basic requirements of general artifact and expedition photography, although it does not coverthe useful 24-mm wide-angle range.

Most 35-mm SLR cameras have a through-the-lens metering system, which measures the light arriving at the photographic surface. The meter reading can usually be observed in the viewfinder, so the operator adjusts the speed and aperture without needing to remove the eye from the viewfinder. Many cameras are now fully or semi-automatic, so the operator has merely to press the shutter release without worrying about the light reading or setting the controls. Some automatic cameras allow the through-the-lens metering system to be coupled to a flash system, so that the flash duration can be controlled automatically to give the correct lighting. This, too, is very useful in a variety of applications.

One of the main disadvantages with the 35-mm format is its small size. Because photographic film has a finite grain size, there is a limit to the amount the negative can be enlarged. This is usually not a problem because the selection of a suitable lens will give the optimum use of the format (i.e., full frame). However, where a very big enlargement of the frame is required, grain can pose a problem. Another drawback is that manufacturers of photographic paper do not produce photographic paper in the same format ratio as the 35-mm negative (paper ratio is 1:1.25 whereas film ratio

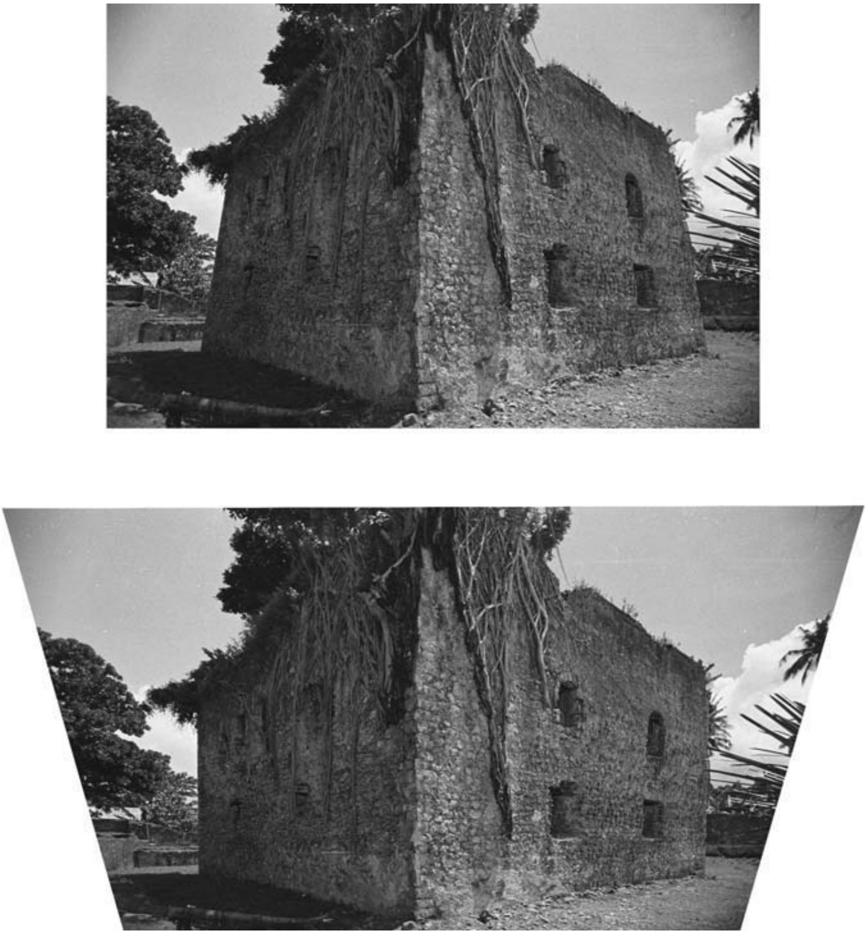

Figure 12.2 Picture showing perspective distortion of a fort in Hila Ambon, Indonesia, and the correction of this distortion using a computer graphics package.

is 1:1.5). Thus, the choice is wasting 17% of the photographic paper to include the full width of the print, or cropping the edges of a carefully composed photograph to save paper.

In the case of the 120 format camera (57-mm square), a similar paper format compromise exists. However, the format is 3.5 times larger than the 35 mm one and consequently gives a greater resolution. This resolution is, however, obtained at the expense of a small depth-of-field close-up, of limited frames per roll of film (12, although some cameras have facilities for 24 or 70 exposure backs), of a considerable increase in cost of the unit, and of bulk. One advantage with some 57-mm square format cameras is that they have interchangeable film magazine backs. This is very practical as different film types can be held in different backs and with this format can be changed rapidly, without having to move the camera, thus saving expensive camera duplication. This option is unfortunately only available on one 35-mm camera system (Rollei SL).

In archaeological work, the main requirement for a large format is to copy large-scale plans. This is best done with either a monorail camera, or on a reproback on an enlarger system, using 120× 100-mm format sheet film (13 times larger than the 35-mm system). In the reproback enlarger system, very accurate alignment of the camera axis with the plane of the subject ensures that there is no tilt in the system. Such systems are not portable and tend to be used only at the homebase for copying line work.

Digital cameras are now a serious contender in the range of ways of taking pictures and, as has been described in Chapter 10, the use of scanners overlaps this area too. The digital camera is now capable of producing images that are as good or almost as good as the conventional camera. There are two basic types: the simple system with a zoom lens and relatively self-contained system; and the complex camera, essentially an SLR camera with a digital back and usually very expensive. The enormous advantage with the digital system is that it obviates the need to process film and as such is part of the evolving digital photographic revolution.

B. Exposure Meters

The exposure meter is an instrument used to measure either the light incident on, or the light reflected from the subject. The meter can be either hand-held or, as previously mentioned, located inside the camera. In the latter case, it can only measure the reflected light. Some through-the-lens metering systems give a weighting to the lower center of the photograph, which is usually the area required to be correctly exposed. The bias to the lower part is to reduce the effect of the upper part of the photograph which is generally the sky. It is necessary to consult the instruction manual for the particular camera, as these systems vary.

Reflected light metering assumes that the object has an 18% reflecting surface. It measures the light reflected from the surface of the object and calculates the exposure accordingly. In normal scenes, and in open-air photography, the range of subject reflection is considerable, so that the integrative effect works well giving an average value between the extremes. In other words, the meter assumes that the subject is gray and, as the average light level of a normal scene is gray, this gives the correct exposure value.

An alternative metering system measures the incident light on a subject, i.e., the amount of light falling on the subject. Incident light can be measured using either an incident light cone (or attachment) on a reflected light exposure meter, or a true incident light meter. Using this method, the meter is placed flat on the illuminated surface and is used to measure the light falling directly on the subject. This then gives the correct reading for any type of subject, and can be used to ensure that the lighting is even across the whole field of view.

When taking a photograph, there are three basic types of contrast situations: dark, medium, and light subjects. It should be remembered that each requires careful consideration. In the case of a dark subject: Should the image of the dark subject be shown in its correct contrast or should it be artificially lightened by changing the contrast? For example, a ship's timber is usually very dark with a lot of detail such as tooling marks, nail holes, etc., all appearing in low contrast (small variations in dark grays and blacks) on the almost black surface of the timber. If the light value is set according to the incident light, the details will be virtually lost because the timber will appear totally black against a correctly exposed, neutral gray background. If the reflected light value is gauged to determine the exposure, the measurement will assume that the black surface is, in fact, the 18% gray, and, as a result it will give a much longer exposure (thinking that the gray surface is poorly lit). The print will show the gray background incorrectly exposed as white, and the surface of the plank showing all the details as gray. By adjusting the development of the print (or in the case of digital images the levels), fine changes of contrast can be controlled, and thus all the required detail shown (Figure 12.3).

In the case of a neutral gray subject, the incident and reflected light readings will be the same. If the gray subject is surrounded by a highly contrasting background, the incident light reading will be correct, as will the reflected light reading provided it is taken off the surface of the subject.

The final case is that of the light subject such as a line drawing on white paper. Here a few black lines are depicted on an otherwise totally reflecting surface. This causes a high reflected light reading, and because it is getting high light levels, it assumes that the 18% reflecting gray surface is brilliantly lit. The resultant photograph is thus underexposed. The incident light meter is used in this situation because enhanced contrast (as was required in the case of the timber) is not needed. Alternatively, if the subject is a white object with a lot of light detail (say white lacework), the reflected light measurement is used.

Figure 12.3 Illustration showing the effect of contrast on a dark object, in this case the stern post timber form the *Batavia*. Although the timber is very black, the right-hand exposure is probably correct in reality, but it obscures the features. By lowering the contrast and lightening the image, the features become more clear. (Courtesy of Patrick Baker and Jeremy Green, both of the Department of Maritime Archaeology, Western Australian Maritime Museum.)

If an incident light meter is unavailable, a neutral gray test card can be introduced into the field of view to obtain the correct exposure. The card is placed near the subject so that it receives the same incident light as the subject. The through-the-lens meter can then be used to determine the correct value. It is a good general rule to check both the incident (or gray scale) exposure reading and reflected light reading. If there is any discrepancy, one can be sure that there are surface reflection problems, and some thought will have to be given to the choice of exposure setting. When using a high magnification ratio (1:5 or greater) and a hand-held exposure meter, some account of the magnification formula is made to obtain the correct exposure.

C. Illumination

The lighting of an object is a complex and often difficult problem. Adequate light is required to illuminate the object and to produce good contrast, while avoiding unnecessary shadows and reflections that can obscure outlines and details. It must again be emphasized that the artifact photograph serves a different purpose to the general photograph of an object, where the use of high key and shadowing helps to produce a dramatic and striking photograph. If color film is used, extreme caution is needed to ensure that the lights are correctly balanced for color, or that the film matches the type of lighting used.

There are four choices of illumination. Tungsten lights are the most common form of lighting; they are cheap and convenient to use, but suffer from a number of drawbacks. First, they are hot, which can be inconvenient when dealing with close-up photography or where the artifact can be damaged by heat. Second, the photoflood illumination can be rather localized, unless large reflectors are used to diffuse the light. This type of lighting can be used with color film provided a tungsten-type film is used. It should be noted that daylight-type color film can be used with tungsten light using a filter (80 series). This is not recommended for critical work as there can be some distortion of the color balance. Tungsten-type color films (Type B) can be used in daylight with a filter (85 series).

Another illumination choice is fluorescent light. It is a cool, diffuse light, ideal for black and white work. This light creates soft shadows and a uniform lighting. One of its best applications is illuminating plans or drawings, where the extended light source gives an even illumination over the subject, and does not cause the hot spots or strong shadows that occur with tungsten light. Its main drawback is that it is very difficult to use with color film, because the exact correcting filter for a particular fluorescent tube is difficult to determine.

Flash is another lighting choice, but it is notoriously difficult to handle, particularly in object photography. This light source is intense and localized and, more importantly, it is almost impossible to predict the results because of the instantaneous nature of flash. In effect, one only sees the success or failure of a photograph in the printed result. This is unlike the previous two situations where one can adjust the illumination until satisfactory conditions are obtained. In some studio flash systems a tungsten light is included with the flash. This is used to illuminate the subject while the camera and lighting positions are changed so that some idea of the effect of the flash can be obtained. The intensity of the flash can be softened with umbrellas (a white painted umbrella into which the flashgun is fired). This can be one of the best lighting options, as it gives diffuse, high light levels allowing large depths of field without having to worry about camera shake or unwanted shadows. The flash systems with electronic control are quite useful, and it is possible to get a flash which is controlled from within the camera. In this case, the internal photocell measures the light reflected from the film plane and controls the flash duration accordingly. This is excellent for close-up work, where flash meter readings or calculations of correct exposure are difficult. An example of the use of the internal metering is in taking pictures of the internal decoration in the body of a porcelain object. With this system, the flash shines through the body illuminating the hidden decoration.

Natural light can be a good source, simply because if handled properly, it can create shadow-free photographs. It is limited to black and white work, because with color there are problems with color balance. This is particularly true where the light is reflected off walls or buildings that are colored, thus giving a color cast to the photograph. However, natural light is not always possible to utilize, as direct sunlight causes strong shadows and high contrast. It is necessary to wait for an overcast day or possibly to make use of indirect sunlight. This may imply low light levels and thus problems of long exposures and depth of field. The inflexibility of natural light tends to make it difficult to use, although silver or white reflector boards can be used make it easier.

Reasonably high light levels are preferred for a number of reasons. First, high light levels give a crispness to the subject, as long as care is exercised to avoid shadow effects which can obscure profiles (Figure 12.4). High light levels also allow faster shutter speeds (reducing the effect of camera shake) and higher f-stop numbers (for greater depth of field). Additionally, at higher light levels, the film speed can be reduced, and the lower the film speed the finer the grain. For artifact photography, very fine grain film (PAN F) is essential for high-resolution work.

III. TECHNIQUES

A. Identification

As has been mentioned above, identification of an object in a photograph is important. The problem of looking at an object that has no scale and no identification in the view occurs often. The photograph may be a printed digital image or printed from a negative, but there are usually no clues. So the photograph can be almost useless. It is so easy to place some form of identification in the field of view so that the artifact and the photograph can be identified. A simple peg board used to mark the prices of items is ideal. This is usually a black, plastic peg board where plastic numbers and letters of various sizes can be attached. The results are neat and easy to read and the system is inexpensive and very compact.

Another option is good quality print-labeling systems (Dymo). Alternatively, a printed label off a desktop printer can be used and as a last resort, a handwritten note of the necessary details is better than nothing. The registration, date, and other minor details can be set up on the board in a neat

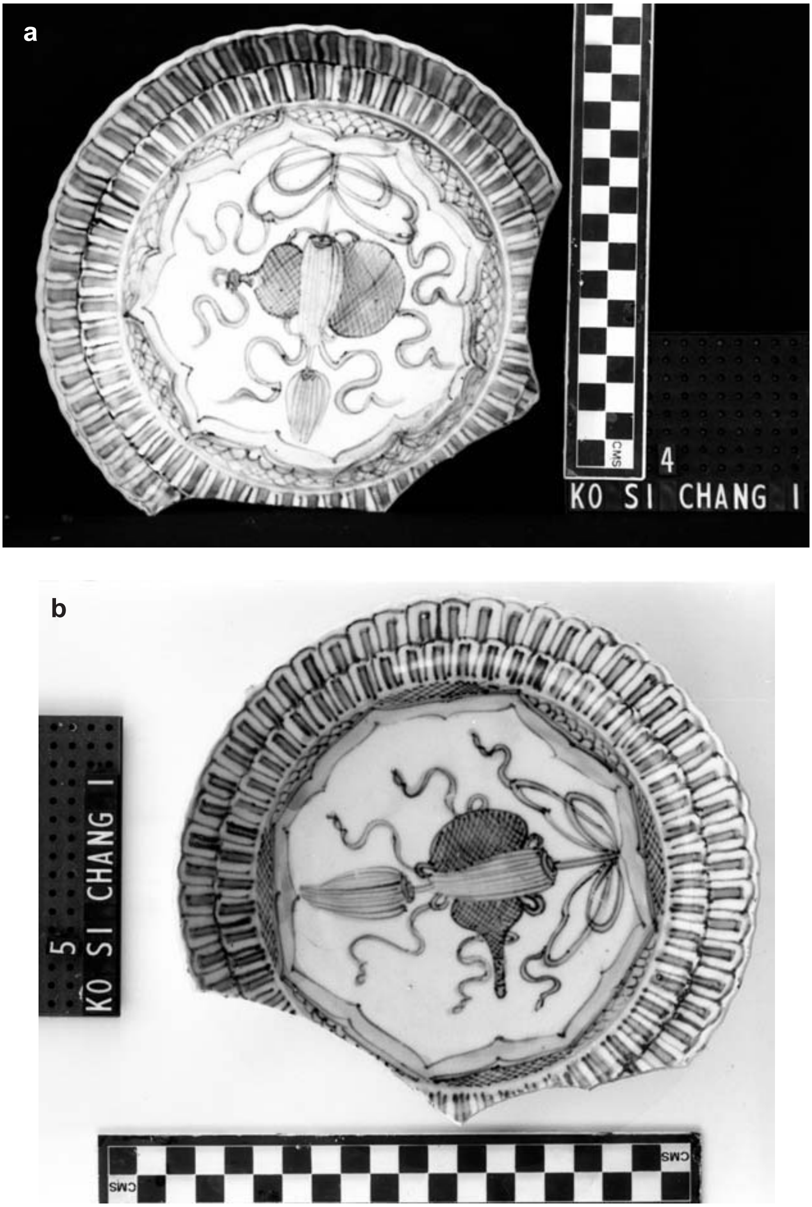

Figure 12.4 High- and low-key backgrounds. Compare the visual impression of a light object against (a) dark and (b) light backgrounds.

and clear way. As digital cameras are becoming more widely used for photographic recording, archaeologists will need to be even more careful to properly record what is being photographed, because in the past both the negative sheets and the color slides generally had information about dates, places, and material recorded on them. With digital cameras the images are usually simply filed in folders with the minimal possibility for detailed information. However, many digital cameras have file naming conventions that record date and a sequential number. Unless one becomes highly organized, data is going to become lost. Like all computer systems getting an organized filing structure is essential, this cannot be overemphasized with digital photography. One needs to place images in carefully thought out file or directory structures, possibly with a date (in year-month-day format: 20031224) to help order images chronologically and then a brief description. Metadata, the information associated with the photographs need to be recorded too, possibly in a header word document at the top of the digital image directory. This sort of data: who took the pictures, what the subject was, etc, was, on conventional photographs written on the contact sheets, negative files or on the slide frame. It is too easy to forget all this in the enthusiasm of digital revolution and suddenly find you have no idea what the images are or where they came from.

B. Scale Positioning

Every artifact photograph requires a scale in the view, however, if the scale is not meaningfully positioned, its inclusion in the photograph has only marginal value. In the case of an object with axial symmetry such as a pot or a cannon, the scale and the plane of the film are arranged so that they are both parallel. The camera is positioned in line with the center of the object and the scale is arranged so that it coincides with the outline of the object (Figure 12.5). It should be possible to use a photograph of this type to produce a scale drawing of the object. Remember that the scale is only correct in the plane perpendicular to the optical axis of the camera in which the scale lies (the scale plane). For this reason, the scale should be placed to coincide with the outline of the object. Thus, if the object is a cylinder, the height of the cylinder is only correct at the vertical edges or outline of the object in which the scale plane lies. The perspective effect of the photograph gives a heightening of the cylinder toward the center, and measurements anywhere outside the scale plane will require a magnification factor to correct them to true scale.

Similarly, in the case of a flat object, the plane of the surface of the object must lie in the scale plane. A useful technique here is to place a small mirror

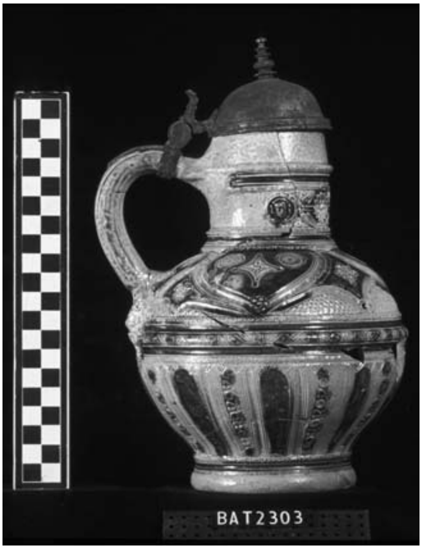

Figure 12.5 Westerwaldware jug with the scale placed in the plane of the outline so that the profile can be measured.

on the surface of the object. By observing through the viewfinder the reflection of the front of the lens in the mirror, the camera can be adjusted on the tripod so that the image is symmetrical in the viewfinder (Figure 12.6). This is a very easy and convenient method of leveling a camera, particularly when the focusing screen has a cross wire or central circle engraved on it. It is also very useful for leveling the camera when copying plans and documents where the camera also has to be accurately level.

The scale in the photograph is thus placed in such a way that the scale plane lies either in the plane of the outline of the object or in the plane of the detail. It is obvious that in some cases it may be necessary to place two scales or to take several photographs with the scales in different positions.

Various types of scales can be used for photographic purposes. For fine scales, millimeter graduations of the edge of a white scale rule can be used. Larger centimeter scales are most conveniently produced by computer graphics (Figure 12.7). To do this, first draw the scale, for example, a 200-mm long checker board (black and white with 10-mm graduations), which can be printed on transparent drafting filmthe printed result is a cheap, handy, waterproof scale that has a variety of uses. Glued onto plastic, it forms a rigid strip scale, or mounted on a wooden block, it can be used as a stand-up scale. For larger scales, one can use a 1-m rule painted black and white at 100-mm intervals or, alternatively, plastic or aluminum round or square section tubing. It is recommended that the size of the graduations

Figure 12.6 Optical alignment of the camera. In this view we are looking into the viewfinder of the camera that has been set up perpendicular to the object plane. A small mirror, seen in this view, is used to ensure that the camera is exactly perpendicular to the object plane. (Courtesy of Brian Richards, Department of Maritime Archaeology, Western Australian Maritime Museum.)

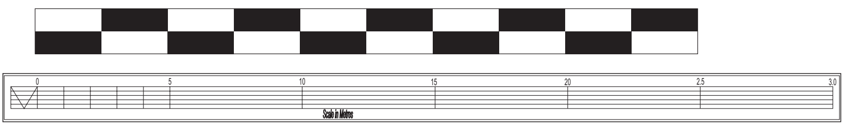

Figure 12.7 A scale generated on a computer graphic package.

are recorded on one scale interval. Thus, "10 mm" or "CMS" helps to identify the scale size avoiding any doubt.

Finally, it is important that the scale be placed so that it can be cropped out on the picture in the printing process, should this be necessary. In this way, objects can be printed at the correct scale but the (sometimes) unsightly rules do not have to be included in the final illustration. The figure caption describes that the scale, or a uniform and standard scale, for a particular publication can be placed adjacent to the photograph (see for example Figure 12.4).

IV. BACKGROUNDS

There are four general solutions to the choice of background material.

A. Black Background

A black background, preferably velvet, can be used with all light objects. It is one of the best materials to use because it prevents shadows and reflections. Great care should be taken not to crease the material and to keep it clear of dust and foreign matter. It is of no use for photographing very dark objects because of the lack of contrast, but it may be used with almost everything else.

B. White Background

This is usually white paper and it is one of the most difficult materials to use because of shadows. If the shadowing effects can be removed, however, the resultant photograph is extremely pleasing, appearing less heavy than the black background (see Figures 12.4 a and b). Various methods can be used to eliminate shadows. The use of a ring flash is a solution for small nonreflective objects although, as mentioned previously, there is always the worry of the unpredictability of the results. Because of the generally low power of the ring flash units, they are not of much use for larger objects. Problems can also occur when working with materials that have flat, reflective surfaces, because the reflection of the flash is directed back into the camera lens and these effects may not be realized until the film is developed. The ring flash is used for coins, small ceramic objects, and small metal objects. There is another way of removing shadowing occurring behind standing objects; place the object on a slightly raised stand with the background some distance away. The background can then be separately illuminated, and if the foreground illumination is reasonably high and to each side of the object, the shadows that exist will not be seen. Other solutions include a light tent, the use of diffuse daylight, and judicious use of development.

C. Glass

Objects can be placed either on a glass plate some distance above a white illuminated surface or, alternatively, on a light box. Using this technique, the supplementary lighting burns out any shadows. This light box approach can be extended by creating an L-shaped white or opal Perspex surface which allows back illumination. When three-dimensional objects placed on the surface are illuminated from the front, any shadows cast will be burned out.

D. Matte Surface

A matte textured surface such as sacking or canvas can be used effectively in certain circumstances. It reduces the contrast effects of the shadows while still giving a pleasing background to the object.

V. INCIDENTALS

A. Camera Box

A camera box is the most practical means of storing the many pieces of photographic equipment needed for field work. There are two different types of camera box—one for underwater cameras and another for land cameras. Because underwater cameras are quite robust, they only require a simple carrying box. The box does not have to be watertight, because the cameras are naturally watertight and the spare lenses have watertight back caps. However, for land cameras, the situation is quite different, because the cameras and the associated equipment are fairly delicate and need to be carefully padded to prevent damage, particularly to stop them rubbing together during transport. A commercially available robust, watertight camera box is a good choice. This can be compartmentalized to fit cameras, a large flash, a flash meter, lenses, and a slide-copying system, together with numerous accessories, filters, tools, etc. The lid can be quite simply modified to hold about 50 film cassettes, a small bottle of CRC, and lens cleaning fluid (Figure 12.8).

The camera box then contains every requirement for field photography. It can be taken into the field, on expeditions, or for small field trips, and it is small enough to be accepted as hand baggage on most airlines. On mobile reconnaissance on foot, such a system would be quite impossible to carry very far, as it would weigh as much as 18 kg; a waterproof shoulder bag is recommended for mobile work.

B. Tripod

A heavy-duty tripod is another essential item of photographic equipment particularly when taking photographs of objects at low light levels. Some care is needed in the selection of this, as a flimsy tripod can magnify the movements of the mirror and shutter on an SLR camera. Additionally, a lateral arm enabling the camera to be mounted off-center from the tripod, to take downward views of maps and plans, is recommended.

Figure 12.8 A camera box showing the range of photographic equipment usually needed for field photography.

VI. SLIDE-COPYING

A mobile slide-copying unit is a handy piece of equipment, not so much in the field, but for visits to colleagues or people working in related fields who may have slides that would be useful to duplicate for research. Again, desktop slide scanners are largely replacing this system and the resulting graphic images are simply stored in a graphics image database. It usually takes less than a minute to scan a 35-mm slide at high resolution, so the process is both quick and efficient.

VII. MANAGEMENT

A. Cataloging

Anyone who has experienced handling a large photographic collection will appreciate the problems of adequate subject recording. As has already been stated, it is essential that every artifact photograph has a registration number included somewhere in the frame. Without this method of recording, each photographic negative has to be registered or identified separately by hand; this can be an exceedingly time-consuming operation. It is so simple to place the registration number together with the scale unobtrusively in the corner of the picture, so that they may be cropped out of the picture if necessary.

It is essential to get the registration number correct, as it can be very easy to forget to change the number between objects. If this should occur and it is noted immediately after taking the photograph, then it is advisable, on the next frame, to take another photograph of a large piece of paper on which a note of the error is made with a thick, felt-tipped pen, so that it will appear clearly in the contact sheet. If the error is discovered subsequently, a note of the mistake or the correction should be scratched onto the negative after development to ensure that the mistake is permanently inscribed as such.

Digital images have the same requirements as film images, however, it is possible to name the image file with the registration number too. In this way a digital catalog can be developed in a logical and systematic manner. The file will be named with the registration number, remembering that in alphanumeric systems it will be necessary to decide how many zeros are required; for example, the object with registration number BAT21 will need to be registered in an eight-figure format as BAT00021 so that it will appear in a sorted format in the directory or folder of the BAT registration sequence.

B. Data Storage and Retrieval

Like all collections, photographic ones can only grow in size, and if they are not organized and managed properly the result will be chaos. On the day that it is easier to re-photograph an object rather than to try to find the negative, it is the day that the photographic system has become useless. Some people persist in believing that they can remember it all, laboring under the illusion that as long as one person knows where everything is located, the system is working perfectly. Unfortunately, this system only works for one person. If that particular person is not present no one will know where anything is. It is essential to consider the management aspects of photographic collections right from the very beginning.

All negatives should be stored together in an organized system contained within the working environment and close to the darkroom. The negative holders should be robust and bear the film identification number, the date of exposure, subject matter, and photographer. The reference material is the contact sheet, which is numbered with the film number and bound in a central filing system together with descriptive details included. Copies of particular contact sheets can be held under subgroupings by individuals, thus particular collections or subjects can be filed separately and cross referenced against the master contact sheet number. It is worthwhile making a duplicate set of contact sheets; one can remain permanently for reference while the other is used for work purposes.

At the simplest level, a computerized subject catalog is the best way to reference material. This can be of immense help when looking for a particular photograph. Simple headings such as cannon, ceramics, navigation equipment, site under water, etc., can cut down the search time. The listing only needs to refer to the film number, as the time required to visually search a single contact sheet is insignificant.

The optimum management system is, of course, the computer database. Although many people advocate systems that identify each individual photograph, it is questionable if these systems are worthwhile. It can take more time registering photographs than actually taking them, and it is totally impractical to consider such a system when the system is large. In establishing a system one needs to put a great deal of thought into its design. A photographic database can become extremely large and full of information that is irrelevant to the objective of finding a photograph in a collection. If the system is to be used to help to find photographs as quickly as possible, then there are certain headings, such as name of site, date, registration number, and type of object. But be careful that the time taken to enter all these data does not become exorbitant, thus counteracting any time-saving benefits.

C. Digital Collections

What was previously stated for conventional photographs is also true for digital photography and digital images in general. To some extent the solutions that worked for conventional photographs will provide a "road map" of how to deal with the digital material. However, there are some complexities. First, digital images, like conventional photographs, can be divided into four basic categories: underwater general, underwater technical, artifacts, and general land-based. Within these categories the nature of the techniques used to make the digital images will include: conventional scanning, digital camera images, conventional scanned hard copy, and, possibly, vector graphics. How should these be cataloged?

The first issue is to determine what will be the method of storing the data. It is worthwhile making a rough estimate of what the total storage requirements for a year will be. If it is larger than a gigabyte, then some very careful thought needs to go into a secure image server, because access to the data will be important. It may be that these data merely need to be archived or that they need to be worked on and the files will change from time to time.

If the data will remain static, then burning onto a CD-ROM or a DVD ROM may be a good option. CD-ROMs currently are relatively small for storage of large graphic files; their capacity is around 600–800 MB. DVDs, on the other hand, are much larger and can store up to 10 times the quantity of data. Other options include getting a very large hard disk, 100GB-disks are now relatively cheap and should last a considerable amount of time, or downloading to an Internet service provider (ISP) that can provide off-site storage, or in a big organization utilize the system server for storage.

Having decided how and where the images will be stored, the issue of relocating images needs to be resolved. Currently, a number of software packages have an interface which provides thumbnail reviews of graphic images (ACDSee, iPhoto, Camedia, Photoshop 7, etc.). So instead of seeing a list of meaningless or nearly meaningless file names, a small image of the graphic is shown with the file name. This is like an electronic contact sheet and is extremely useful. This makes the process much easier. Then all that needs to be done is to ensure that the labels of the files bear some sensible information relating to their content. At the Department of Maritime Archaeology at the Western Australian Maritime Museum, we have been developing procedures to ensure that digital images can be stored and retrieved efficiently. The objective of the project was to determine how digital images should be stored on the museum's server. The digital images referred to are the high-quality images suitable for publication and not low-quality images used for the Internet. The images are high quality because it takes no longer to scan it in high quality than low quality. Therefore, it is more efficient to scan all images at high quality and in color (where appropriate), and then use the high-quality image for the source of an image that would subsequently be saved at lower quality for the Internet. Digital images included the following types of material:

1. Scanned black and white, and color negatives from the negative collection; these include 35-mm, 5 × 4 inch, half-plates, and glass plates
2. Scanned slides from the color slide collection, essentially 35-mm slides
3. Scanned hard copy images, pictures, maps, prints, etc.
4. Digital camera images
5. Artifact object photographs with registration number and scale included in the picture that can be created from any of above categories

The negatives were stored in the small 12-drawer metal filing cabinets and cataloged on a FileMaker Pro database. The fields included: film number, date, location, keyword subject, and keyword category. The negative collection was indexed by negative number—the number referring to the film number which had been created in a chronological sequence. The database catalogs what is on each individual film.

The color slide collection is stored in the large four-drawer slide cabinets and on a FileMaker Pro database. The fields include: drawer, title, description, supplementary, file (prefix on slide registration number), and slide number range. This database is used to list what is in the drawers or to search for individual subjects.

From time to time people need to scan images of this type and this is usually done on slide scanners or flatbed scanners (reflective and transmissive). Because the negatives and slides all have a unique registration number (slides have a prefix code and then a number and negatives have a film number and frame number), this was used as the basis for naming the files. Black and white negative naming conventions were adopted within a folder on the server in Graphic Image Store named "black & white scans." Within this folder were subfolders with a range of 1000 images (0001–1000, 1001–2000, 2001–3000, etc.). Any negative that is scanned was named with a film number (this must be a four-digit number) and then the two-digit frame number. After this a description was included to help identify the slide. For example, "1209/08 CAndreas theodolite" indicated that it was a scan of frame 8 of film 1209 showing a theodolite at Cape Andreas. When scanning negatives it is best to use at least 1200 dpi, possibly 2400 dpi. When the images are saved there is a choice of file formats (see Chapter 7). At this level photographs reproduce to magazine quality to something a bit less than A4.

Color slide file-naming conventions were determined according to the storage arrangements in the department. Color slides are stored in drawers in cabinets. Within each drawer there are varying subsections with coded prefixes, and within these categories the individual slides are registered numerically; as more slides were received they were added to the collection. In the color slide scan folder, folders were created corresponding to the drawers in the cabinets; each drawer had a code number and this was used as the folder name. Thus the folder setup created on the server exactly duplicated the physical storage system. The scanned image files were named with the registration number on the slide and the image file was then placed in the correct drawer folder. The same scanning issues relate to color slides that were described for black and white images. Color slides were scanned in color even if they were to be used for black and white publications.

Digital images included images from digital cameras, graphic images from outside the museum collections, and scans of hard copy material and were generally more difficult to catalog. With digital camera images the person taking the pictures reviewed the images from the camera, discarded the images that were of no use, and downloaded the useful images into a folder. It was occasionally possible that the images would fall into more than one subject, so each subject or group was placed in a folder with a six-figure date-prefix (YYMMDD) and the subject. Where the subject falls into a broad category then the digital image folder can be placed in this sub-folder. This enables people to see very quickly what the subjects are and go directly to the images. It is also useful to put the suffix UW where images are underwater images. The images can be left with just the autonaming system of the camera (that is usually the month and day and a cumulative number for that day). It is essential, however, that when a group of images is put on the server a short Word document is created explaining what the images are, who took them (particularly important for crediting), when, why, etc. (This is called the folder description file or metadata.)

For digital images taken by non-museum staff, these go in the non-museum images folder with some indicator of the source of the images in the folder description file together with any copyright and reproduction restrictions. Scans are a even more difficult to store as they generally do not come in large numbers and are not date related. Usually they are simply given a title with the main subject as the start of the file name.

When the file is digital images of artifacts, the images need to be named with the registration number of the object and stored in an artifact image file. This file is used as part of the artifact database system which then calls up these images as part of the operation.

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Chapter 13

Post-Excavation Research

I. INTRODUCTION

Post-excavation archaeological research has been singled out for a special chapter of its own because it is the *raison d'être* of maritime archaeology. Archaeology can be defined as a science which is used to study the past. History and archaeology share common goals as they both seek to understand and interpret the structure and mechanisms of past societies. They differ in that historians use written records as their raw material, whereas archaeologists investigate the physical remains of these societies and cultures. Maritime archaeology is part of the spectrum of archaeology. Many people misunderstand what maritime archaeology is about, thinking it involves only excavation and the subsequent publication of a catalog of finds. Such misconceptions play into the hands of treasure hunters whose interests are served under the guise of archaeology. This simplistic notion of maritime archaeology greatly impedes its progress toward a scientific discipline and although it is well accepted today as an academic field of study, it lacks some of the rigorous precepts of science. Theoretical frameworks are still lacking and many workers in the field labor under the problem of trying to establish these frameworks.

The objective of this chapter is to explain how to analyze and interpret the archaeological record. Previous chapters have discussed the technical methods of recovering the archaeological information through survey, excavation, recording, and documentation. The theoretical questions which must now be addressed relate to the interpretation of this information, firstat an object-oriented level, and, by extrapolation, to the deeper patterns of cultural systems.

Archaeological research is the process of studying all the information collected from the site and interpreting its significance. The manner of the study will be determined by the particular theoretical framework the researcher applies to these data. There are several schools of thought governing maritime archaeological research: historical particularism (see, for example, Bass, 1983) and an anthropological approach. Historical particularists are artifact orientated and are concerned with the artifacts and their functions. This approach is particularly appropriate for the archaeology of shipwrecks, because, being a relatively new field of study, the material artifacts are often not well understood. It is important, therefore, to build up a clear understanding of the material before constructing deeper hypotheses. Bass (1983) stated that one of the most important objectives for maritime archaeology was simply to build up catalogs of material from wreck sites in order to create a springboard for the generation of hypotheses.

The anthropological perspective is concerned primarily with the development of hypotheses which can be used to study societies and the way they operated. This approach is mostly used once the artifact assemblages have been classified and there is a clear understanding of the material. Gould (1983a,b) published some interesting papers illustrating these approaches. More recently, with sites belonging to the post-medieval period, the use of an integrated approach has been widely used. Here, both the archaeological and historical record are combined to produce a clearer overall picture. For example, many items will not appear in the archaeological record of a shipwreck; perishable items may disappear, the origin, destination, and the reason for the voyage may not be known. Conversely, the historical record may not record items onboard the ship or the way the ship was built and its type. Through the careful integration of both sources a much more informed picture emerges, giving us a deeper understanding of the significance of the site. This is not always possible, but it is clear that an integrated approach will produce a better result.

Post-excavation research will initially focus on the artifacts through their classification and identification. At this first level the objective is identification. Scientific techniques may be applied to assist in determining the type of material the object was made of and its dating. Additionally, the historical record may be helpful in the identification and dating of objects where there are contemporary descriptions of similar material. At the next level, archaeological research becomes involved with the interpretation of the function of the object and its relation to the other objects on the site. For sites that have a supporting written record, the documentary evidence can be very important, because it can provide information to explain why particular objects were present and what their function was. The final stage is reached with the study of the pattern of the material in relation to other sites and its relevance to broad historical interpretation. This leads to the formulation of the theories or hypotheses that can be used to explain major trends or processes. Irrespective of which theoretical framework is adopted, the objective of a maritime archaeologist will be to find out as much as possible about the material. This can then be used in conjunction with other information of a similar or associated nature to gain a broader concept of its significance on the site and, subsequently, its relevance in broad historical terms. The following sections deal with the analysis of artifacts, scientific methods, experimental archaeology, and historical evidence.

II. ANALYSIS OF ARTIFACTS

The artifact from an excavation is only one part of the archaeological record. The location and context in which it was found provide a record that will assist in identification and interpretation of the artifact. Additionally, as excavation techniques are constantly evolving, it is becoming evident that other types of material, which were previously overlooked, can add to this record. For example, sieving the residue of storage jars can provide information on the original contents. Similarly, the microscopic analysis of the sediments from the bottom of the hull of a ship can reveal information about the environmental conditions onboard the ship, the diet, and standards of hygiene. It is therefore important that the archaeologist is unbiased in sampling the archaeological record and is aware of modern techniques.

It is impossible to deal with the question of analysis of every conceivable artifact that can come from a site; however, some general guidelines can be suggested. The ultimate objective in analysis is to explain the significance of the artifacts in the context of the site and then to attempt to determine their relevance in terms of the history and society of the time. The first step of the analysis is to attempt to identify each individual object. Some well-known objects can be easily identified whereas others may be more difficult to identify because their function may be uncertain. Finally, there may be objects that cannot be identified. For each group it will be necessary to consult standard works on the subject for reference purposes. In the case where the object is well known, there will be a large body of literature on the subject. However, reference material should always be treated with caution and read critically. For example, a particular reference may not reflect the latest thinking on the subject, or there may be more up-to-date material available. It is quite possible that the author has made an error, or, even worse, has repeated another author's mistake.

The fact that wreck sites belong to a particular point in time imbues the artifacts from these sites with a special significance, particularly in relation to dating. They offer a precise chronology which usually cannot be drawn from other types of collections, and it is important to study the artifacts in as great a depth as possible. It is not uncommon to find that artifact chronologies have been established from evidence that cannot be supported by scientific dating and, as a result, the chronologies are uncertain. For example, some chronologies have been based on art historical considerations; parallel material from wreck sites has recently lead to a number of re-assessments of these dates.

It should also be recognized that objects from shipwrecks often do not have a parallel in land archaeology. For example, it is unlikely that the rigging and parts of a sailing vessel would be found anywhere on land. By far the most common place to find such items is on a wreck site, and it is improbable that comparative archaeological material would be found on a land site, except at a port or shipyard (see, for example, Marsden, 1979). Therefore, written records or illustrations may provide the only source of comparative information. On the other hand, some types of material found on wreck sites are also commonly found on land sites. The domestic wares such as everyday items used by the people onboard the ship and trade goods may all be found in domestic and production contexts on land. So there may be interesting comparisons to be drawn between the findings from land sites and water sites, and conclusions can be drawn about the social status of the context in which the material was found.

Although the research into the identification of the artifacts is important, it should not be forgotten that part of the archaeological objective is to place these artifacts into an historical and social context. It is therefore necessary to attempt to determine the function or purpose of the object after it has been identified. First, some broad functional categories have to be determined. It may be instructive to refer to the subdivisions that have been used in Verenigde Oostindische Compagnie (VOC) research (see Section IV). Various subdivisions have been defined that relate to the various functional groups to which the objects belonged. These groups include the ship, its hull, mast, rigging and sails; the equipment used to sail and operate the ship, navigation equipment, defensive equipment, equipment for maintenance and repair, etc.; supplies to feed and clothe the crew; the trade goods; personal possessions; etc. Naturally, there are many different ways of subdividing the various items that were onboard the ship, but essentially the purpose is to establish a synthesis of the artifacts. It is inevitable that the archaeological record will almost certainly be incomplete; many items will have decayed or been destroyed and many of the fragile types of items only rarely survive. In the historical period, where written records survive, there is a strong case for the fusion of historical and archaeological research. This type of approach is best illustrated in the *Amsterdam* project (Gawronski, 1985, 1986, 1987) and the issue of the interaction between material, written and iconographic, sources has been widely discussed in these publications (see, for example, Kist, Parthesius, and Gawronski in Gawronski, 1985, 1986, 1987).

Where written records do not survive, or are only available in limited quantity, the problem is different. In some cases there will be an historical interpretation of the existing evidence and this may or may not coincide with the material record. For example, until recently it was held that ancient Chinese shipbuilding traditions were confined to ships with flat bottoms and no keel. This belief was held because, although the limited written Chinese sources were obscure, from 19th century evidence they could be interpreted in this way. The recent discovery of two 13th–14th century ship structures has shown that the Chinese did in fact build ships with a deep V hull and a keel.

III. SCIENTIFIC ANALYSIS

There are a number of different scientific techniques that can be used to assist in the analysis of archaeological material. One of the most commonly used techniques is the application of quantitative methods to the analysis of data. Doran and Hodson (1975), Orton (1980), and Shennan (1988) are important reference books on the subject. Quantitative methods can be used by the archaeologist to help analyze the archaeological data and to find patterns and relationships within the record. For example, a statistical analysis of measurements from a survey can be used to determine the reliability of those measurements. Muckelroy (1978) made an analysis of types of wreck sites, examining the statistical relationship between the physical conditions on the site and the archaeological remains. However, statistics is a difficult technique to use because both mathematical and factual considerations are involved and the relationships that are being looked for are never perfect.

The two other main forms of scientific analysis are dating methods and material analysis. There are several different methods of dating including radiocarbon, thermoluminescent (Aitkin, 1985), dendochronology (Fletcher, 1978), and thermoremnant magnetic dating (Aitkin, 1978). All are highly specialized fields. General methods of dating, particularly related to authenticity, have been reviewed by Flemming (1975). Material analysis includes the various forms of chemical compositional analysis (see, for example, Bishop *et al.*, 1982) and radiography, all of which can be used to learn more about the structure of the artifacts and how they were made. Other types of scientific study involve investigation of bones to determine health and diet, and pollen analysis which can provide information about the climate (Scott, 1986). The list of different types of scientific study are endless.

IV. HISTORICAL MATERIAL

The use of historical material will vary according to the types of maritime archaeological sites under investigation. Some sites can be classified as submerged terrestrial sites, these include sunken harbors as well as sites which were originally constructed in the water such as lake villages and defensive structures. There are also ships—either wrecked under water or, more rarely, buried on land. It is the nature of the archaeological object or site that dictates the way in which it will be studied and interpreted; if it is under water, the techniques discussed in this book will be appropriate to survey the site and then, if necessary, to excavate it. However, it is in the archaeological interpretation of the respective sites that the distinctions become evident. Submerged habitation sites are an extension of the process of archaeology that is carried out on land, just as the ship buried on land falls more within the scope of shipwreck archaeology.

Examples of ships on land include the 7th century Saxon Sutton Hoo site, where the vessel was brought onto the land to be part of a ritual burial, as well as vessels that sank in places that have become dry land. Similarly, terrestrial sites can range from port sites such as Caesarea, which have partially subsided into the sea and were partially built in the sea, to inundated cities such as Port Royal, to crannogs, and lake villages. Within these areas of study, written history or records may survive which have relevance to the site or the material from the site. Because there is written history of one form or another from very early times, most sites will usually have some component of research related to historical matters. In the land-based sites, the historical study, together with the archaeological interpretation is well established. However, for shipwreck sites the situation is different. Apart from some early, land-based excavations of Viking ships, the archaeology of shipwrecks is quite new. As a result, the techniques of interpretation of the archaeology and the integration of the historical record are even less well understood. The historical records for some periods, for example, the Greco-Roman ages, may give information only of a general nature such as the conditions of society at the time, giving almost no information about how boats were built and for what they were used. This is true in the Far East too, where even though writing was common, it was confined to religious and bureaucratic matters. Even though, for example, Chinese monks were regularly traveling from China to India they mainly commented on poetic matters and rarely on what the ships were like. It was left to Marco Polo to make the first substantial commentary on Chinese ships and how they were built. Alternatively, the historical record may be very detailed, giving information on how ships were built and for what they were used. In the post-medieval and modern times, the records may give a wealth of information, even identifying the vessel and giving the reason for its sinking. Steffy's (1994) book on shipbuilding is an invaluable reference.

The integration of this written history with archaeology can thus be difficult simply because it is often not clear how the two forms of information should be synthesized. Some writers have complained that almost every shipwreck excavation report is accompanied by an extensive historical background. It has been suggested that history and archaeology should be separated in publication, except where one bears directly upon the other, and that it is in the combination of these two disciplines in publication that archaeology has lost out. It is true that in some cases maritime archaeological projects have suffered from poor methodology and, in order to compensate, there has been an emphasis by the authors toward the historical component. However, the historical component has an essential part to play in the interpretation of sites. Just as the archaeological methodology must be properly applied, the historical approach to the subject must be treated with equal rigor.

In the case where there is a large body of historical information, there has been considerable debate within the profession as to how this material should be treated with respect to the archaeology. Currently in historical maritime archaeology, there is a need for more thoughtful use of the material record and the historical documentation in published research. It is notable that there is a great deal of difference between the way an historian uses the written record and the treatment by the archaeologist of documentary material. In general, an historian is looking at broad developments in history over a period of time. More often, a maritime archaeologist is addressing problems that belong to a particular point in time and, therefore, will use these records differently. Where maritime archaeology is involved with sites that have little or no written record, the archaeologist has less of a problem because there is no historical dimension to take into account.

There has also been a significant discourse within the field of historical archaeology questioning how that field of study should develop. The debate is relevant to maritime archaeology because there are parallels between the two fields; and maritime archaeology, as a younger discipline, will inevitably face similar problems in the future.

One of the first major symposia in historical archaeology was on the subject of its role in relation to historical, anthropological, and government issues. It took place at the Conference on Historic Site Archaeology in 1967 and was followed by other important meetings, particularly in 1975 at Charleston, SC. A number of definitions of historical archaeology were discussed on these occasions; however, the real issues have been obscured at times by the excessive use of jargon: "Words that cloud the minds alike of those who use them and those who read them" (Fowler, 1968). For example, Binford (1972, p. 123) suggested a "nomothetic paradigm or Hypothetico-Deductive-Inductive Process: historic site archaeologists should be actively engaged in nomothetic studies aimed at the specification of general propositions suitable for testing," whereas Dollar (1968, p. 11) suggested "an idiographic particularistic paradigm or Particularistic archaeology . . . where the historical archaeologist deals with a person or persons . . . [who] must therefore be dealt with historically or deductively," and Walker (1967, p. 24) suggested a "humanistic paradigm or archaeology in the humanities . . . Far from being a science . . . [archaeology] is one of the most subjective studies in the field of intellectual research" (see South, 1977). Webster described historical archaeology as "the scientific study of material remains of past human life and activity" and Hume ". . . as the study of the material remains of both the remote and recent past in relationship to documentary history and the stratigraphy of the ground in which they are found" (see Schuyler, 1978).

The debate continues and there is still no consensus within historical archaeology as to how the subject should be studied. At the 1987 annual meeting of the Society for Historical Archaeology at Savannah, GA, it was noted that historical archaeology had still not produced the insights into human cultural behavior or evolution that had not been anticipated. There is a danger that maritime archaeology, in trying to define itself, could fall into a similar trap and obscure the subject with jargon. There is really no reason why complex subjects have to be even more confused by the excessive use of words that can only be understood by an elite group of people. It seems then, at present, historical archaeology cannot be used as a model for the integration of historical documentation into maritime archaeological research. Probably, the developing problem for maritime archaeology is not this debate at all but how it can operate within cultural resource management (see the following sections).

From a maritime archaeological perspective, there are a number of different ways that the historical record might be employed. In shipwreck archaeology, there is often a variety of information that may have relevance for the study. The record may describe what type of ship it was, what it was doing when it was lost, and where it was wrecked. It may be possible to discover the name of the ship. If this information can be traced, the lists of cargo may be helpful in predicting the range of material likely to be found on the site, particularly as some things perish in time and are no longer part of the archaeological record. By using an integrated approach to the subject, the history can improve the depth of the archaeological study. The written record will help in the identification of the site, it may explain the way the ship broke up in time, and how that has affected the distribution of the material on the site, and its present-day appearance.

The volume of the historical record obviously varies according to the times. For the Classical period, information on shipping and ships is limited to the few authors who wrote about the subject and to the few iconographic representations of ships. There are periods, particularly the Dark Ages, during which almost nothing was written or illustrated about the subject; for example, most of our knowledge about Viking ships comes from archaeology rather than history. In the post-medieval period, from about the beginning of the 17th century onward, there is a cumulative body of information, albeit not always as comprehensive as might be expected. Whereas it may be thought that shipbuilding in the 17th century is well understood, there are only two major Dutch works written on the subject. This is in spite of the fact that the Dutch were one of the greatest shipbuilders of the time.

Toward the end of the 17th century, more detailed records and accounts survive, so that as we move into the modern period, the quantity proliferates. Likewise, the trade that the ships were conducting and the social life onboard are described in greater detail. From the 18th century onward, the quantity of historical information becomes overwhelming and the maritime archaeologist may have difficulties in coming to terms with the abundance of information. Some people, notably maritime historians, voice the opinion that there is little point in doing serious maritime archaeology in this period because nearly everything about a particular ship will be recorded in the archives, and that there are detailed plans and descriptions of the ship. Therefore, it is argued, the archaeological study is superfluous. This view is, of course, taken from the perspective of an historian who is more interested in broad issues rather than the particular details. The maritime archaeologist is concerned with details, and it is these details that are often incomplete or unavailable in the written records. More interestingly, when the information does exist, its significance has, at times, been overlooked by the historically motivated research person.

It has been suggested by some historians that maritime archaeology is stimulating the development of new areas of historical research. Some of the most interesting aspects of the historical–archaeological research involves the study of the cargo of a ship and its structure. Both these subjects are extremely important, because they provide information about trade patterns and the development of the technology of ships. The study of shipwreck remains is significant for the insight it provides as to how ships were built, how the techniques developed, and why they changed. The ships and the associated artifacts provide a field of study which rarely exists on land. Artifact assemblages are rarely found in such quantities as when they occur as part of a ship's cargo. Parts of these assemblages relate to a technology that existed on the sea rather than the land and, therefore, are again not commonly recorded from land sites. Additionally, the unique or precise dating that a wreck site has is important. These factors can make maritime archaeology a highly innovative field of study.

The use of the historical–archaeological process will necessarily be adapted according to particular research needs. This can be illustrated by looking at two different time spans. First, in the Classical period in the Mediterranean, where there is a moderate amount of "historical" source material, we can take the example of the study by Professor George Bass of the Institute of Nautical Archaeology of the Cape Gelidonya wreck site (Bass, 1967). This was the first full report of a maritime archaeological site where the archaeology was carried out using the same principles as those applied on land. The report covers the excavation procedure, and then in a series of specialized analyses, various groups of artifacts were examined. It concluded with a discussion of the significance of the ship and its cargo.

This early publication established a benchmark for maritime archaeological reports. The site was quite small and did not involve a large number of artifacts, but it proved, that with careful excavation and thorough subsequent archaeological research, maximal information could be obtained from a small quantity of material. It also showed how the proper study and analysis of shipwreck material, together with the study of the associated historical sources, could produce interesting and important conclusions. For example, the ox hide and the copper ingots together with the copper and bronze scrap found on the site were shown to be part of the cargo. It was thus suggested that there was possibly a metalworker onboard the ship and that the metal was a trade item. This type of trade showed, through illustrations in contemporary Egyptian tomb paintings, that the ingots were brought to Egypt in ships by merchants known to have connections with

Cyprus and the Levant. Bass' study illustrates that judicious use of the limited historical record helps to explain the significance of the finds and their relevance as part of the cargo of the ship. He was able to show, among other things, an extensive Phoenician maritime activity at a time prior to that previously believed. Bass states

> More significant, the excavation at Gelidonya has lead to a careful re-study of the types of objects carried onboard, and this re-study of parallel material from other sites, even *without* the finds at Gelidonya, would have lead to the conclusion that a great deal of commerce was in the hands of Phoenician seamen and merchants.

Without this research, it would be impossible to see the Gelidonya site in any other way than a single event in part of what must have been a complex and involved trade. The problem is that a single site may not be representative of the maritime trade at the time. Even though there was no supporting evidence from other wreck sites of the same period, the study of the comparative material led to the above conclusions. Thus we may see that even though the Eastern Mediterranean has only a limited written history, the material from the site provoked further research allowing new conclusions to be drawn. Interestingly, Bass *et al.* (1984) have now discovered and excavated a much larger Bronze Age site at Ulubrunu (Figure 13.1) and it will be fascinating to compare the Gelidonya findings with this.

The second time span that will be discussed here, the period of the VOC trade, illustrates a very different situation from George Bass' discovery. For example, the quantity of historical or archival material related to the VOC shipwrecks often outweighs the archaeological material. The extremely rich source of documentary evidence presents the archaeologist with an unusual dilemma, one which is outside the normal experience of either maritime or terrestrial archaeology. Without historical documentation, artifacts from a wreck site can usually be identified only at a relatively simple descriptive level, for example, "this object is a wood saw." Where detailed historical records exist, such as in the case of the VOC wreck sites, the problem is that the written records describe such objects as being used in a number of different contexts. It is possible that the archaeological record may help to determine its purpose on the ship through the association of the item with other objects on the site. The archaeological objective is to interpret this sort of information so it is important for the practitioner to be familiar with the archival information, in this case the source material in Algemeen Rijksarchief, and to be able to read the necessary manuscripts.

A number of different approaches have been adopted by authors wishing to classify material from the excavation of VOC ships (see, for example,

Figure 13.1 Museum exhibition of the Ulubrunu, a 14th century BC shipwreck in the Bodrum Museum, Turkey.

Gawronski, 1987; Gawronski and Kist, 1984; Green, 1977b, 1986b; Ingelman-Sundberg, 1978; Larn, 1985a and b; Marsden, 1974, 1976, 1978; Martin, 1972; Pijl-Ketel, 1982; Sténuit, 1974). In some cases, authors have classified material according to their functions on the ship, which has relevance to the written record. In other cases, objects have been classified according to material type (Green, 1977b). Classifying by material type has a number of advantages: the classification process is simple and straightforward, and can be applied from the moment of recovery, making it a very practical system for the management of a collection without reference to the written record. This mode of classification also suffers from a number of disadvantages. In particular, the system is completely arbitrary, so that artifacts having the same function are dissociated. Therefore it is more difficult, for example, to integrate with the historical information. In the functional approach, there is the problem of identification of the function. This is a complex issue and, if historical material is to be used, it requires a detailed understanding of the system used by the ship's company and a working knowledge of the disposition of the source material.

If the functional approach is used, the material can be divided into various categories such as equipment and materials related to the use onboard the ship, ship's supplies and provisions, personal items, supplies for the Indies, trade items, etc. For the archaeologist, this can be a unique opportunity to determine the complete inventory onboard the ship. We know that before each company ship departed for the Indies, a comprehensive list was made of all the material taken onboard. On the ship's return from the Indies, there was a reconciliation with this equipage list. Thus every item that had been put onboard prior to departure had to be accounted for. Originally, these lists were handwritten, but later, as the ship's company became increasingly standardized, the lists were printed and the numbers of items filled in by hand and then signed for. The equipage lists, therefore, are itemized accounts of everything that would be required by the different specialist groups of people who were basically responsible for getting the ship to the Indies. The steersman would be supplied with charts and navigation equipment that would enable him to set the course. The cook would be allotted the requisite utensils and equipment to cater for the crew, the passengers, and the soldiers on the voyage. The constable would be responsible for the arms and ammunition necessary for the defense of the ship. Additionally, there were the provisions with which the ship was supplied for the voyage.

Of great importance, of course, was the cargo that the ship carried. This might be divided into two parts: the supplies for the company at the Cape of Good Hope and in the Indies, and the goods for trade in the Indies. None of this is easy to quantify. The archival sources do not have regular cargo lists of these items. Even though only a few equipage lists survive, we may assume that the equipage was virtually the same for each ship of a particular size, because the company resolved that this would be standard each year. However, the supplies for the Indies and the trade goods varied considerably from year to year. The main source of information comes from the *Eijsch* (or requisitions) from the Indies. Each year, the Governor General and the council at Batavia sent a list of requisitions for the following year to the company in The Netherlands. These requisitions included supplies for the company in the Indies, requests for money to conduct trade, and trade items that were deemed to be profitable for trade at that time. Unfortunately, only a few of these requisition lists still survive, and as they relate only to the mid-17th century, they are of limited use. A further complication is that it seems that the requisition lists were frequently disregarded by the company at home as there are numerous instances of letters from the Governor General at Batavia complaining that the requisitions and requests had been ignored. Thus the lists give only an indication of the types of goods that were required in the Indies.

Another group of documents from the same period records the supplies that arrived in Batavia on particular ships. Only some of these inventories have survived, but they are very helpful in indicating disposition of cargoes among the ships of the fleets. Finally, in the resolutions of the *Heren* XVII, there are some lists of requisitions from the Indies and of goods shipped on the various fleets, but these tend to deal only with major items.

Another component in the inventory of items to be found on a company ship and, perhaps, the most difficult to estimate, is the private possessions that the crew, soldiers, and passengers brought onboard. Individuals going to the Indies were allowed by the *Heren* XVII to take with them a prescribed amount of goods. The volume of things was limited to a chest of dimensions specified by the Artyckel Brief of the VOC, and could include food, a small amount of money, and some trade goods. There may well have been a much larger quantity of smuggled goods and, certainly, there is evidence that the company became very concerned about this illegal trade. However, the quantity of trade goods of this nature would have been small in comparison with the overall cargo.

Finally, there is the ship itself with masts, rigging, sails, anchors, guns, etc. Surprisingly little is known about the building and construction of ships for the company. The resolutions of the *Heren* XVII contain specifications for building a particular ship and defining its class; from time to time, the specifications for the various classes would change.

Thus it can be seen that there are an extremely diverse and complex group of documents available that may help to identify the type of items found on a VOC shipwreck. These lists are an invaluable source of information about the complex society of trades and skills that existed on the ships and the function of the vessels themselves. All this information is obviously indispensable for the maritime archaeologist working on the wrecks of such ships.

V. EXPERIMENTAL ARCHAEOLOGY: RECONSTRUCTIONS, REPLICAS, AND MODELS

Over the past few years there have been an increasing number of maritime archaeological projects which come under the general heading of experimental archaeology. These include two basic approaches: (1) one where the work is centered around conducting a series of experiments to answer a particular problem, and (2) one where the work involves building a replica of the original, either as a scale model or at full scale, in order to study methods of construction (see McGrail, 1977).

By using the first approach a series of experiments was done to determine the rowing characteristics of an Athenian trireme (Morrison, 1988) where iconographic evidence was used to produce a series of hypotheses about how the oars were arranged. From this a full-scale, working trireme was built and then used to test the various arrangements. Likewise, full-scale replicas of Viking ships and the Kyrenia ship II have been used to investigate sailing characteristics of these vessels.

Figure 13.2 The reconstruction of the original timbers of the Kyrenia ship, Cyprus, following excavation and conservation. This was the first time a complete excavation involving the dismantling of a wreck site culminated in the rebuilding of the vessel.

The second method includes the research model and full-scale reconstructions to investigate the methods and techniques of ship construction. In reality these two fields often overlap; for example, the Kyrenia ship II was built according to plans made from the original construction (Figure 13.2). Likewise, the "new" *Batavia* (Figure 13.3) was constructed in The Netherlands according to historical information. This replica can be compared with the reconstruction of part of the original *Batavia* in the Western Australian Maritime Museum, Fremantle (Figure 13.4). Other replicas or projects involved in preserving and reconstructing hulls of ships that have been excavated from underwater sites include the Bremen cog in West Germany (Ellmers, 1979) (Figure 13.5), the Kedelhaven ship in The

Figure 13.3 The modern *Batavia* replica almost completed at Lelystad, The Netherlands. This project involved building a modern replica of the VOC ship *Batavia*. The work, supervised by Willem Vos of the Stichting Nederland bouwt VOC-Retourschip, was based on historical information. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

Figure 13.4 The reconstructed timbers of the *Batavia*, Western Australian Maritime Museum, Fremantle. Only a small portion of the hull structure survived and this was dismantled *in situ*, raised, recorded, conserved, and then rebuilt.

Figure 13.5 A view of the Bremen cog in Deutsches Schiffartsmuseum, Germany, prior to its immersion in a large conservation tank. The vessel was built in about 1380 and raised in 1965.

Figure 13.6 The 17th century Kedelhaven ship, The Netherlands.

Netherlands (Figure 13.6), the *Mary Rose*, Portsmouth, UK (Figure 13.7), the *Wasa* in Stockholm, Sweden (Franzen, 1961; Figure 13.8), the Quanzhou ship in Fujian Province, the People's Republic of China (Green, 1983a; Figure 13.9), and the Shinan ship, Korea (Figure 13.10; Green, 1983a; Green and Kim, 1989).

Steffy, in a series of models, has pioneered a study of Classical shipwreck structures. Using information from the excavation, he has been responsible for the reconstruction of the Kyrenia ship II (Steffy, 1985) and the ship from Serçe Liman (Steffy, 1982), together with construction of a number of other models, in particular, the hull of the Byzantine shipwreck from Yassi Ada (Bass and van Doorninck, 1982). Steffy indicated that one of the main reasons for building an experimental model of the Byzantine wreck was that the ship appeared to violate a number of naval architectural practices. He notes that "If these models helped us to form conclusions, not the least of these was the realization that this ship was not a freak at all, but rather another design from another age with which we had not been familiar." (Bass and van Doorninck, 1982, p. 84).

Figure 13.7 The *Mary Rose*, photographed in the Mary Rose Museum in Portsmouth, UK, after its recovery.

Figure 13.8 The Swedish warship *Wasa* in the old Wasamuseet, Stockholm, Sweden, display area prior to the construction of the modern museum facilities.

Figure 13.9 The Song dynasty Quanzhou ship in the Museum for Overseas Communication History, Quanzhou, Fujian Province, Peoples' Republic of China.

Figure 13.10 The Shinan ship model in the Mokpo Conservation Laboratories, South Korea. (Courtesy of Jeremy Green, Department of Maritime Archaeology, Western Australian Maritime Museum and the Institute of Nautical Archaeology, Bodrum, Turkey.)

VI. INTEGRATION

The final phase of any archaeological research is the integration of the whole into some form of coherent summary. This is often a difficult thing to complete because the nature of research is neverending. Each new answer often poses another set of questions which, in turn, leads the investigator along more and more detailed research pathways. It is important, therefore, to attempt to review from time to time the research being undertaken in order to keep some form of perspective. This is best done by writing up the work and publishing at regular intervals. The act of writing is, in itself, stimulating, because it forces the committal of thoughts and ideas to paper and this helps to put the work into a particular context. Reports and publication are discussed in Chapter 15.

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Chapter 14

Cultural Resource Management

I. INTRODUCTION

Most maritime countries have an underwater cultural heritage and many have a long and important history in maritime activities. In some cases, this underwater heritage—largely ancient shipwreck sites—has been looted by divers and treasure hunters and, as a result, what little that survives needs to be preserved. In such cases, the immediate task is to set in place measures that, in the long and short term, will actively discourage the destruction of underwater cultural heritage. What is required is appropriate legislation and a cultural resource management plan.

To achieve this there needs to be a public (local, national, and international) desire that such a site should be protected. To achieve this archaeologists and underwater heritage managers need to take a proactive stand. It is no longer reasonable for archaeologists to be totally engrossed in the academic aspects of their work; after all it is the public that funds most of this. Nor is it appropriate for cultural resource managers to make the access to sites difficult. How many times does one hear a practitioner in the field lamenting the fact that a treasure hunter has managed another piece of good publicity, yet the practitioner does not like the media. It is a war. A war that requires people who care about archaeology and heritage to get out and sell their product.

Management is part of this process. Going back to fundamentals, it is necessary first to change attitudes. There will be a number of people with a vested interest in underwater heritage (often referred to as "stakeholders" in the current management vernacular), who must be persuaded to recognize the benefits of preserving sites. Without the support of some local group, it will be very difficult, if not impossible, to effect change.

Naturally, with management, comes the need for legislation and effective processes to preserve the underwater cultural heritage. The recent convention on the *Protection of the Underwater Cultural Heritage* (adopted on 2 November 2001 by the General Conference of UNESCO at its 31st session) will have an enormous impact at an international level (see Chapter 16, Legislation). These objectives cannot be achieved without implementing a program to change existing attitudes toward shipwreck material—a long, difficult, and complex process. Attitudes can be changed, albeit slowly, and it is important that such programs are undertaken to start the process at the local level. When this is done, the programs can be supported through international efforts. It is no good waiting for some big international organization to provide funds to do the basic groundwork. If the basic groundwork can be done then it may be possible to access other funding sources to support the work.

Three avenues in which to effect change are education, legislation, and community participation. Each of these will be discussed in detail later. It must be emphasized at the outset that the traditional method of relying on legislation alone to preserve shipwreck sites rarely works. Legislative measures will only succeed if supported by education programs to promote a change in public attitudes (for divers and non-divers alike) and to encourage community involvement. Legislation still has an important role to play in the management of sites. It provides the legal framework for site management, defines the management process, encourages the positive aspects of preservation and, ultimately, makes provision for punishing miscreants.

The following is one of a number of different approaches. Different countries and different situations will require different approaches. What is described here is the situation where there is no management so one is starting from the beginning. It is not the only plan that could be developed, but it can be used as a theoretical starting point from which more complex situations can be considered. The first part outlines a management plan to deal with the underwater cultural heritage, the second part details a methodology to achieve the objectives of the plan, and finally, there is a discussion on structure and strategic goals for such a program.

II. OUTLINE OF GENERAL OBJECTIVES

The general objective in managing underwater cultural heritage is to develop a plan that will ensure long-term protection. In formulating such a plan, and in the program that follows, it is important to ensure that a balance is achieved between the operation of management and the archaeological requirements. It is often observed that archaeological needs are disregarded by management; and, conversely, archaeological process ignores management issues and the protection of sites. The management plan needs to be a multidisciplined program involving cultural resource management (CRM) and archaeological research. In devising a CRM plan, it is useful to adopt a step-by-step approach:

1. Identification of the issues
2. Identification of the resource
3. Identification of the interest groups
4. Establishment of the infrastructure (the organization and equipment)
5. Locate sites
6. Develop plans and implement these plans to manage sites
7. Educate to create attitudes that understand the need for protection of sites
8. Training
9. Publication

Planning an archaeological research program involves devising strategies and allocating resources for fieldwork and scientific work related to the sites including:

1. Geophysical survey to determine the extent of the area that is to be managed
2. Location of archaeological sites
3. Predisturbance recording of the sites
4. Archaeological investigation and excavation of the sites
5. Education, which is the process of communicating the archaeological information to as wide a group as possible including the general public, divers, local people, the tourist industry, and professionals

III. CULTURAL RESOURCE MANAGEMENT

Cultural resource management implies a system where a resource is protected and preserved for the future. There is some confusion that CRM actually means that sites should not be disturbed as this is the only way to effectively preserve them. This argument has been used on a number of occasions, particularly in cases where the administrative structure is either underfunded or is unfamiliar with archaeological techniques. A pragmatic approach to CRM is a mix of *in situ* preservation and archaeological excavation. The CRM should uphold a philosophy which maintains that the sites, and the material in the sites, be made available for the public. It would be the responsibility of the managers to ensure that this process does not result in loss of material or deterioration of sites.

Whereas CRM is the process of looking after and preserving sites, it does not preclude excavation. On the contrary, in many cases, excavation is an effective management tool. There may be good archaeological reasons why a site should be excavated, but the reasons for any excavation need to be considered within the overall management strategy.

Through the careful integration of archaeological practice, resource management and museum and communication skills, sites can be brought to the attention of the public who can then be made aware of the significance and importance of the resource. The archaeological process is the method of gathering the information which provides, first, the scientific basis for the work, and then disseminates information for the public and scientific community alike. The public can then become involved and participate in the management of the resource. There are examples of other programs in which the public have become involved in the decision-making process. One has only to examine the conservation and the green movements to be aware that public opinion can reverse strongly held attitudes. The basis of these movements has been to make the public aware of the long-term advantages of protecting resources and to seek public support in reversing existing policies and attitudes that threaten them. In a similar way, the CRM process should be aimed at preserving sites by changing public opinion through management strategies which draw on the continuing archaeological research.

Sections IV, V, and VI will outline the main issues relating to CRM in general, describing the different types of potential resources, and identifying the various groups involved in underwater cultural heritage. Section VII will examine means of promoting public interest in, and regulating public access to, the maritime resource and propose a typical management system. Within this section we will also touch upon some of the other concerns of a CRM program by briefly discussing how the location and management of sites operate within the CRM process and the role of education and training.

IV. IDENTIFICATION OF THE ISSUES

One of the most important issues that a CRM program needs to address is how to effect a change in the existing attitudes of looters and those who are not interested in preserving sites and, at the same time, promote the positive attitudes of people who are keen to preserve sites. These matters are discussed in Section VI.

First, there is the need to establish efficient management practices. The practices will provide that the protection of sites be set firmly within government and institutional policies, ensuring that the protection process has long-term stability.

Another crucial issue is how to change the existing perception that maritime archaeology is the realm of the academic, with little benefit filtering down from academe to the public sector. This widely held perception has, in many cases, a basis of truth and has resulted in a marginalization of the general public and alienation of the diving community, who see a limited ability to be involved in this type of work. The general public has little idea of the issues involved and their main exposure to the field is in the more sensational aspects of treasure hunting. This will be discussed further in the next section.

V. IDENTIFICATION OF THE RESOURCE

The resource—underwater sites—will generally fall into three main categories: (1) sites that are known to the authorities; (2) sites that are known to some people, but not the authorities; and (3) sites that have not been found. Location of sites requires a complex strategy. This includes negotiation with people who know of sites but are reluctant to reveal their location, searching for sites in shallow water, and searching for sites in deep water.

Locating sites involves the use of one or more different strategies; for example, visually searching for sites using divers, informants, and remote sensing techniques. The visual search will be the most time-consuming and most difficult to manage, requiring training and a carefully prepared survey program and has been discussed in Chapter 3. The use of informants raises the sensitive issue of how to manage and influence individuals who know the locations of sites. Remote sensing is expensive and produces limited returns for the financial outlay. Assuming that many of the deep-water sites are probably known through bottom trawling or fishing activities, remote sensing may be best employed to locate precisely the position of these approximately known sites. The general issues of locating sites has been discussed in Chapter 3.

The ultimate protection of sites requires the development of strategies that will ensure they are not disturbed. This can only be achieved when the majority of the people involved agree that these sites need to be protected because it is beneficial to do so. Cultural tourism can play an important role in this process, because in many countries tourism is likely to be one of the most important industries. In other areas this may be less significant, although the local dive industry can benefit. Recording the sites will require the cooperation of volunteers and will require infrastructure to help ensure that the sites are properly managed and maintained in the future.

Once sites have been located, they need to be appropriately managed. Indeed, the management needs to be clearly defined before the sites are found (see Section VII.C). The management plan should address all of the issues related to the long-term objectives of underwater cultural heritage management. This is still related to the identification of the resource, because individual sites will present different resource potentials.

This process should relate to the management plan, with precise stages, objectives, and reporting structures. With this type of situation long-term planning will be required and may only be possible in certain circumstances. For example, a three-year plan could be developed with a clear objective stating that by the end of three years, the methods of management should be defined, understood, andappropriately managed.

Assuming that about 30 m is the normal maximum, practical (low-cost) archaeological working depth for conventional scuba equipment, and that one ignores sites at extreme depths (deeper than 200 m), archaeological sites of interest can be divided into three basic categories:

1. Shallow-water wrecks, i.e., up to 30 m
2. Medium-depth sites, i.e., between 30 and 60 m, in the workable, but high-cost, range
3. Deep-water wrecks, i.e., in depths beyond 60 m, where remotely operated vehicles (ROV) and unconventional or commercial diving technology would be required

It is assumed, if the area is populated, that visible shallow-water sites are all going to be known and probably dived on by local people. In most areas there will be a history of local diving, an active fishing industry, and access to scuba equipment. The medium-depth sites present the greatest potential because they are more difficult to find and will be better preserved. However, being more difficult to find means they are less likely to be looted, but it also makes the chance of their discovery more remote. The deeper water sites will probably be known through bottom trawling, although they are even less likely to have been exploited.

It is important to remember that most sites that have been heavily looted are still likely to contain a large quantity of archaeological information to be extracted, but archaeological expertise will be required to access and exploit the information.

VI. IDENTIFICATION OF THE INTEREST GROUPS

There will be a wide variety of interest or stakeholder groups who are either of direct or indirect relevance to CRM program. It is important to identify each group, assess their potential impact (positive, neutral, or negative), and establish a role for each or a management regime to address any potential threat that it may present. The various interest groups fall into a number of basic categories:

1. General non-diving public
2. Recreational diving public (non-local)
3. Diving public (local)
4. Commercial salvage—treasure-hunting divers (amateur and professional)
5. Commercial dive charter and tourist operators
6. Commercial—other
7. Non-government organizations (NGO) and amateur organizations
8. Government sector agencies with overlapping or associated responsibilities
9. Archaeological concerns

These groups represent a wide cross section of the community, including some whose members present direct threats to the program, some who have the potential to benefit the program, and some who are already fully committed. The management plan needs to be designed to address the needs of each of these groups and, where necessary, propose ways that their attitudes can be influenced or changed. Change can only be effected when there are clearly demonstrated advantages to the group or groups involved, and this has to take into consideration the individual or group's characteristics. The following lists some issues for consideration in adopting a positive stance for these groups:

1. In order to gain a financial advantage, dive charter operators may reveal site locations to the authorities. They will see a long-term benefit of ensuring that the sites are not looted and by working in cooperation with the program can benefit from advice, information, and training, thus providing a value-added experience for their customers.
2. Adopting a high-profile survey demonstrates that, through survey, these sites will be discovered anyway so that cooperation will assist this process.
3. The amateur potential is very important. By ensuring that this group is properly regarded and maintained, the program can rely on a continuing diver-based support. This will help to counteract the negative group and in addition can provide key support for the program.
4. Consideration should be given to the concept of a reward for discovering or revealing the location of a site. The reward should be clearly

based on the state of preservation of the site, thus discouraging the concept of looting sites and then revealing their presence for a reward. Care should be taken in the assessment of the sites. A number of countries have adopted a reward system. This reward system does not need to be financial, but could include a civil award instead.

5. The results of the work should be publicly available. A museum is an ideal venue for this. It is essential that there is a forum where all members of the public (diving and non-diving) can see the results of the work and, more particularly, become involved in it. At the very least this should be some form of physical and visual description of the work; then the public can see and understand what the objective and outcome of the program is. A Web site is a useful additional method for achieving this.

A. General Non-Diving Public

It is difficult to assess the attitude of the general public toward underwater archaeology. Its understanding of the subject is likely to be limited, simply because archaeologists have not generally worked in the public forum. There are few popular books that give a true picture of the subject and the media is usually saturated with stories of treasure hunting. Museum displays, popular articles, publications, the Internet, wreck trails, and television documentaries have all proven to be successful ways of enabling public access to information and encouraging public involvement.

B. Recreational Diving Public (Non-Local)

This group represents one of the main threats to underwater archaeological sites in any region. As the group that is likely to have the largest impact on underwater cultural heritage, it is the most important one to influence. Within the group, there are possibly three subgroups: a minority of dedicated divers who are extremely interested in wishing to help or be actively involved in the preservation of this heritage, a majority of divers who remove material from sites out of ignorance, and divers who purposely set out to loot sites for financial or personal gain. The first two groups can be encouraged to be involved in programs and training courses like those provided by the Nautical Archaeological Society (NAS). The third group is unlikely to be influenced by involvement in the program. It is probably better to attempt to marginalize them, using protective legislation to curb their activities. It is possible that, over a period of time, through the object lesson of the involvement of amateurs in a constructive and rewarding program, members of this group may revise their strategy. However, in the long run, a pragmatic approach is to ensure that the third group does not recruit new members thus resulting in a continuation of their activities.

C. Diving Public (Local)

This is a complex group, although small in number it is likely that they have an enormous amount of knowledge. It is usually the case that the local diving people know of sites and they may or may not be willing to reveal their location. This again is complex and it is difficult to generalize. In some countries this group is poor and the income that can be made recovering this material or working with treasure hunters means they have an important financial resource at their disposal. Issues of national socioeconomics will depend on the counties concerned. In some places there will be strict enforcement of the law, in other cases little or none. The general objective is to influence this group where possible and redirect their activities by demonstrating the advantages of a different approach. The key issue is to show that having sites protected and implementing a positive program will result in real benefits to the region. Thus, if local public opinion can be persuaded to support preservation, this will put pressure on local divers to support the program.

As for the locals who are unwilling to reveal their knowledge of sites, the reasons for such attitudes are complex: they may be deriving financial benefit from the knowledge (selling artifacts); they may have a dislike of authority (the "dog-in-the-manger" attitude); or they may consider it to be "their" site, like a possession, of which they would lose "ownership" by revealing it. If this group could be involved as inspectors and local representatives reporting to the central administration, they could play an important community role and gain recognition from this.

D. Commercial Salvage—Treasure-Hunting Divers (Amateur and Professional)

In many cases this is probably only a small group. Because this group often relies on public funding, it requires at least some form of legitimacy. The capital investment required for these types of operations makes it unlikely that they will operate in an area where they could be arrested and have their equipment confiscated. This group's main impact is likely to be in extraterritorial waters where the legislation is currently unclear. This means that they likely operate in areas that are extremely remote and where the legislation is uncertain, so they are reasonably sure prosecution can be avoided. Alternatively, this group makes deals with governments that license them to search and recover material on the agreement that they will pay the government and share the proceeds. Such situations cannot be changed at the level of this discussion and will require international pressure to encourage a different approach to underwater heritage.

E. Commercial Dive Charter and Tourist Operators

Dive charter operators are a group who are likely to gain considerable financial benefit from a progressive CRM program and, once convinced of its merits, can become strong advocates for protection. If sites can be protected and made available for operators to take their dive groups to visit, then they are likely to increase their business. The program should involve the operators in understanding the nature of the sites through education and training. This would help the operators to improve service. As new sites are discovered, they could participate in the process. This could work in various ways, e.g., operating on a similar basis to guides who take the public on tours of museums and ancient sites. Additionally, the operators could take on roles as inspectors and monitor sites and provide feedback to the government agency. In addition, the program would represent considerable "value-adding" for any tourist. Anything that is likely to engage the visitor and to enhance their visit benefits the tourist industry. By enriching their experience—if positive—tourists will be encouraged to revisit and to persuade others to come.

F. Commercial—Other

Several groups, including local fishermen (line, net, and trawler), exist within this category This group usually has no incentive for or interest in involvement with underwater cultural heritage, other than that material recovered could potentially be sold, or that the knowledge of the position of a site could be revealed for financial benefit. There are exceptions, but overall this is a difficult group to influence. Possible solutions may be a reward system for information on sites or recruitment as inspectors, although the latter should be treated with caution as, unlike the charter operators, the fishermen will have little motivation. Similarly, survey companies working commercially for the gas and petroleum industry, cable laying operations, dredging, port operations, and geophysical surveys may, incidentally, come across cultural heritage information such as wreck sites.

G. Non-Government Organizations

Essentially, this group will be amateur divers and possibly non-diving interest groups who have formed an association of some kind to promote or be involved in the sites. This is a very important and potentially powerful group who can have immense effect on these types of programs. Such groups can assist with the fieldwork, monitor sites, help in management, work at the local level to promote preservation, and lobby at a political level. It would be an important part of a CRM program to identify this type of group and recruit their assistance or, if such a group does not exist, attempt to create one.

H. Government

The government management department will be the key organization with overall responsibility for underwater cultural heritage and this program. However, there are other government agencies that should be identified as having interests in this area. The greater the intergovernmental cooperation in underwater CRM, the greater the public service profile the program will have. The State Museum of Western Australia has relationships with the government departments of fisheries, conservation and land management, heritage, marine police, transport (marine), land administration (survey), and the Navy. Such relationships need to be formalized and this could be achieved by creating an advisory committee (see Section VII.C).

I. Archaeological

The key members of this group are included in either the government management agency or at the national and international level in universities and maritime archaeological institutions. The role of the archaeologist in such a program is to oversee the archaeological work. The CRM work can be administered by an archaeologist or by a person with administrative expertise. Whatever course of action is taken in the eventual program, there will be a need for clear archaeological direction. This is a complex issue, however, it is vital that if this program is to succeed, there should be somebody with archaeological expertise controlling the archaeological work. If no archaeologist is available, then one should be contracted for a period of time from outside until locally trained archaeologists become available.

VII. STRUCTURAL REQUIREMENTS

Structural requirements relate to the land-and underwater-based programs. This section deals with the various ways that a program can provide information for the visiting public and how this can benefit the region. Such programs should attempt to work within, or be associated with, other regional programs related to tourism, cultural heritage, and the natural environment. The objective of these initiatives is to get information to the public.

A. Land-Based Programs

1. Exhibition

Exhibitions and museum-based displays are an important means of getting a message across to the public. A typical venue would be a museum or center to promote the shipwrecks program. The facility would provide a public forum for the work and will have important implications for many of the stakeholders that were discussed earlier.

2. Land-Based Wreck Trails

The public can be part of a wreck site program through wreck trails (Figure 14.1). Starting in the regional center, a series of "look-out" points can be set up at appropriate positions, which can provide information about nearby underwater sites. These information posts would link back to more detailed information in the exhibitions in the regional center. These can be integrated into a wider, land-based heritage trail program, where the visitor, with a simple map and signage, can follow a trail that takes them to all the important sites in the region. There is no reason why significant wreck sites cannot be sign-posted to add a maritime dimension. Anchorages and known wreck sites can be indicated on the brochure with signs at appropriate panoramic viewpoints. This can be promoted in the museum and, wherever possible, should involve local residents.

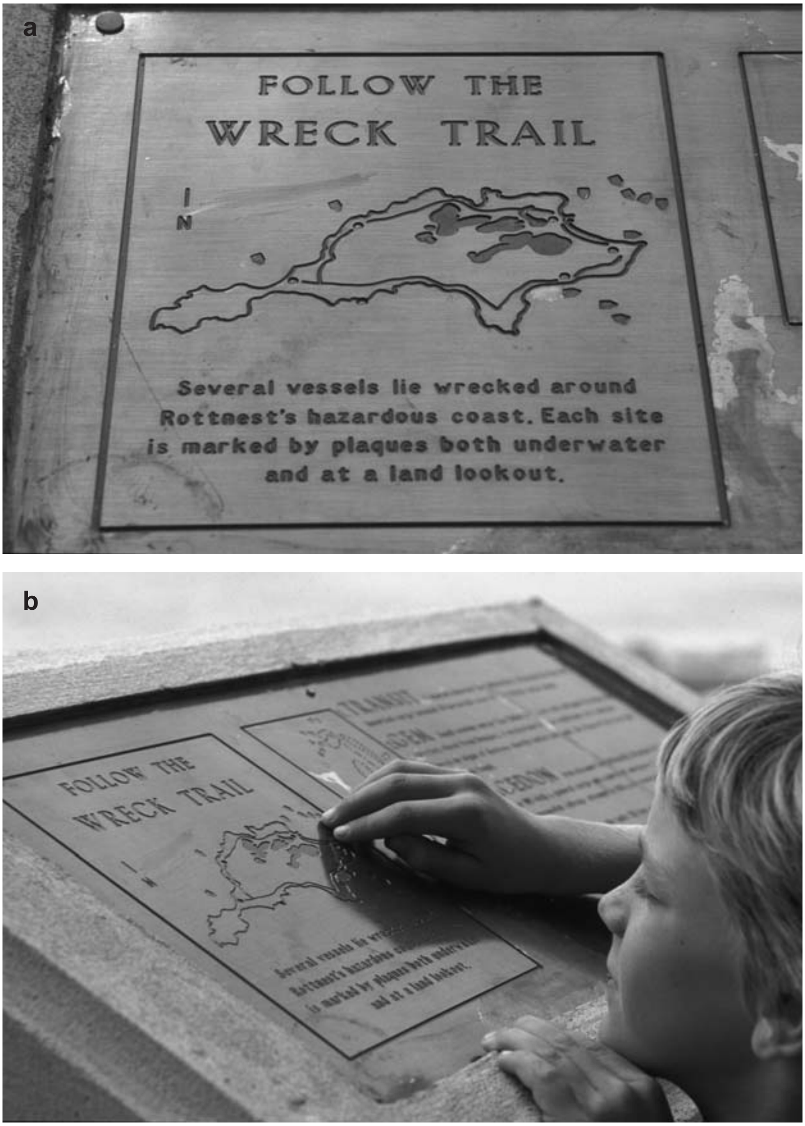

Figure 14.1 Wreck trails. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

3. Publishing

Printed material in just about every form has been proven as an effective means of promoting the principles of conservation and preservation of land-based or underwater cultural heritage. This can range from inexpensive A4 pamphlets or brochures (Figure 14.2), to a medium-priced and more detailed descriptive history with site details, and to large-format glossy publications. The pamphlets are the most effective as they are easy to produce, can be easily changed, and provide basic information that can be provided for a large number of people.

B. Marine-Based Programs

Allowing divers to have access to a wreck site is a risky exercise. It needs to be coordinated with a thorough educational and public relations program. In the end, however, divers are going to access sites anyway, so the provision of education and information is crucial in order to maximize the likelihood that they will behave in an appropriate manner.

Figure 14.2 Publications. (Courtesy of Patrick Baker, Department of Maritime Archaeology, Western Australian Maritime Museum.)

1. Maritime Wreck Trails

Providing basic information to the diver will help to ensure that the individuals who dive on sites are informed of the correct position, the risks that the site presents, what is on the site, and where things are located together with what they may and may not do. This gives at least one opportunity to influence divers in a positive way. Hopefully, they can be made aware of the program in the museum and be encouraged to report anything unusual that they may see on the site. If divers have a positive experience when visiting a wreck, they are more likely to become more interested in preserving sites.

An example of a simple and effective way to inform and encourage divers in site-sensitive behavior is to produce waterproof information sheets that the divers can use to locate and orient themselves while diving on the site. These sheets should provide general information on each site, guidelines on appropriate behavior, and sources for further information. This could be coordinated by the museum-based center and, again, should involve the locals as part of the program.

In Western Australia and elsewhere, many sites have been marked with plinths or site markers (Figure 14.3). These markers serve several purposes: they establish that the site is known, they provide information about the site, they provide a focal point for coordinating diving on the site, and they inform the diver about what may or may not be done on the site. Such aids are very useful as they establish an implied presence on the site as well as providing information for the diver. Plinths are simple and easy to construct. The information sheets that are mounted on the plinth are usually of bulletproof glass, with the information etched on the inside of the glass sheet.

Another issue to be considered is the damage that can be caused when boats anchor on a site. The program could include the option of providing proper anchoring points for vessels visiting the site. The buoy could have information about the site and any restrictions that apply to it. If this system was to be implemented, the author recommends a screw anchor as the best anchoring system, as it provides great holding power in both the horizontal and vertical direction. This avoids having a long chain dragging on the site, because the buoy chain is almost vertical.

In some places the diver pays to access the site and is provided with a permit. This simplifies site management, because anybody found on a site is clearly breaching the rules. Legislation would need to be enacted to support this process. If the permit system is paid by the user, then this has the advantage of generating revenue. It is debatable, however, whether a user-pays and revenue generation system is better than treating the situation on a trust basis. Divers in Western Australia have free access, but they

Figure 14.3 Trail plinths. (Courtesy of Scott Sledge, Department of Maritime Archaeology, Western Australian Maritime Museum.)

are largely local divers. In other places where most of the visitors may be non-local, a user-pays system may be more appropriate.

2. Dive Charter

As discussed earlier, the dive charter business could become an important component in the program. First, the operators need to be organized and agree to some code of practice. If they agree to cooperate with the program, information about the sites could be provided to them and, through workshops, special arrangements could be developed to assist them in their operations. A decision would need to be made as to whether, in the long term, the charter operators could become inspectors. Experience in

Western Australia has shown that the appointment of inspectors is worthwhile, as it provides an additional group of people who are authorized to administer the legislation. In most cases, the inspectors provide feedback on the sites, but they are also empowered to prosecute people who are breaking the law.

Experience in Australia has demonstrated that cooperation with dive charter operators and tourist agencies can be very helpful; and they, in turn, are generally extremely pleased with the information and assistance that is provided. The dive charter operators could also help to maintain the anchoring points for the sites and monitor the sites for any recent disturbance. If the program is successful it will be in their long-term interest to ensure the sites are not looted.

3. Publications

There is a wide range of publications that can be made available to the public (diving and general), some of which have already been mentioned. As discussed, simple waterproof information sheets can be sold directly to the divers and charter operators. These can be taken underwater and would provide basic information, directions to find the site, its GPS coordinates and a site plan, obviously with information on what should not be done on the site.

As a complement to this, a small guidebook to the wrecks of the area could provide the basic information shown on the diver information sheet, but with more details about the sites and the kind of material that would be found on the sites—amphora types and lead anchors—together with references to further reading. Again, the basic information and rationale as to why the protection of these sites is so important should be included. The book or booklet could be illustrated in color and would make it an attractive and, possibly, revenue-generating project.

4. Management

Ultimately, the preservation of these sites will depend on the effectiveness of the management system. The hierarchical system would presumably have a project manager (an archaeologist) under whose direction would be various levels of specialists. It is important to ensure that the system is well balanced. There is a need for good management of field staff and that the program has access to senior management. It is also important that in the management of sites there is an awareness that the archaeological program is an essential part of the operation as it provides new and important information that will keep the program dynamic.

An important management arrangement would be the establishment of an advisory committee. It is inevitable that the administration of such a program is likely to become difficult and contentious. If there is no clear involvement of the various stakeholders, they will be fragmented by different pressure groups. A way of avoiding such a division is to create a formal "advisory committee" which advises the director of the government agency responsible for the management of sites. This allows the project director to bring issues to the advisory committee that can be discussed and recommendations tabled. Provided there is wide representation on this committee, it is unlikely that any resolution will be passed without majority support. This provides a double advantage of ensuring that issues are properly discussed and that decisions are seen not to be made by one agency, but rather by consultation in committee. This is a useful way of deflecting criticism of contentious decisions, because one agency has not made the decision.

5. Location of Sites

The methods of locating sites have been discussed previously, however, it is important to examine how the process of locating sites will fit into the CRM process, as it requires careful management. Also, achievable goals need to be established and a work program formulated with a realistic time frame. For example, in any given time a small team of divers can search a fixed area of seabed. An estimate of the time required to survey a known length of coastline would be needed as well as the area expected to be able to survey within, for example, a five-year time frame. What would be expected to be achieved within this period, a 1% coverage, or a 10%, 20%, or 50% coverage? In addition, what area of deep-water seabed could be realistically surveyed in, for example, a three-week survey period?

The most significant requirement for this work is to establish a geographical information system (GIS). This will allow the archaeologists and managers to record and assess the development of the program and monitor the status of the sites. A GIS gives excellent visual representation of numerical and visual data, so that the progress of the project and the condition of each site can be easily monitored. Additionally, the development of a shipwreck database is an essential management tool.

C. Management of Sites

A CRM plan must give a clear definition of how the site management will operate. Sites need to be regularly inspected and a program developed where the management of the sites has clearly identified objectives. Management needs to ensure that the site is stable and that it is not being adversely affected. This requires a periodic monitoring or inspection program and probably cooperation with dive tour operators who, as part of the program, could provide information on the current state of the site and report any changes.

D. Shipwreck Database

The shipwreck database is one of the most important tools for managing shipwreck sites. The database provides a wide range of information essential or useful to the manager. The construction of such databases requires considerable thought. Several national databases have been constructed that are currently on the Internet including the Australian National Shipwreck Database which was started in 1985 (http://www.ea.gov.au/heritage/lists/shipwrecks.html) and includes over 7000 known Australian shipwrecks; and the Northern Shipwrecks Database (www.northernmaritimeresearch.com), which features more than 100,000 North American shipwrecks and is a research project of Northern Maritime Research.

The structure of such databases is extremely important. In the case of the Australian National Shipwreck Database, considerable debate occurred before the primary variables were decided. These variables were essentially either historical information or location information. It was appreciated from the outset that the establishment of a national database was likely to be a very complex and time-consuming project. First, the various state bodies accumulating the information were doing so on a variety of different computers using different database programs and inputting information in different formats. The first part of the project was to determine how best to gather these data from the various state bodies and how to import information into the most appropriate database program. The second problem was that there was no common agreement on how the information contained in the variables should be recorded. Thus some states recorded the vessels' known dimensions in feet and inches using at least three different forms (3 ft 6 in, 3′6″; 3.5 ft) together with a metric system. Similarly, dates were recorded in various ways (6 July 1888, 6-7-1888, 6/7/88, etc.). It was essential to resolve these conflicts and to assess the significance of the variables.

In consultation with the state working groups it was decided that some of the fields were either unnecessary, redundant, or required modification. The main purpose of the database was originally thought to be for research, and in particular the gathering of statistical information. Later it became clear that there was a growing management use involved in the database, so that gradually more fields were introduced that related to management. In reality, most states now have their own database that is based on the core fields of the national database but includes fields relating to the internal management of the various departments administering the National Shipwrecks Program.

Currently, the field structure of the database can be divided into the following general categories: historical, name, type, construction (iron, steel, wood, wood clinker, wood carvel, composite, Al); tonA; tonB; country built; port built; when built; port registered; official no.; registration no.; length; beam; draft; engine; crew; when lost; passengers; deaths; sunk code; sinking; port from; port to; cargo; master; owner; builder; industry primary, (lookup); industry secondary, (lookup); sources; geographical location, where lost, region, location box (LATMAX, LATMIN, LONMAX, LONMIN), GPS, state; administrative, comments, found (Y/N), inspected (Y/N), protected, (state, federal, other); protection notes; when found; found by (contact details); dates inspected; vulnerability; significance; and file number. Although this is not necessarily meant to be a general solution, the reader will get some idea of the potential for such a system.

Currently, the database can be used as a predictive tool for identifying wreck sites. For example, if a person reports a shipwreck at a particular geographical coordinate and indicated its approximate size and construction material, then he can search for the unknown wrecks that lie within the location box specifying the construction and a size range. The location box will provide details of all wrecks within a variety of boxes. It will list all vessels in subregion, region, and the whole area (corresponding to descriptions such as lots in the Metropolitan Perth region, Central Western Australia, and the coast of Western Australia). It also enables the monitoring of sites, indicating when sites were last inspected.

E. Education and Training

Education and training are dealt with together in this section, both forming an important element in the management plan. Education operates at three different levels: staff education and professional training, which provides work-based programs to improve operational skills; training for commercial-sector operators, who would benefit from an educational program to assist them in providing a better service for their clients; and visitor education, for the diving and non-diving public.

Staff training would provide comprehensive skills for the NGO group, as the staff will be involved with some of the basic responsibility for implementing the management plan. The essential objective would be to train the group in techniques and methodology for the whole program, which would include search and survey techniques, advanced maritime archaeological techniques, and resource management training.

The CRM program, following the basic training, would then move on to recruit local commercial-sector operators–in both the dive charter and the normal tourist area—who would be interested in cooperating with the program. With the identification of additional interest groups, a series of workshops could be conducted to involve them in the program.

Training and education programs could be run for visiting tourist divers, to assist the program. These could operate along the lines of the NAS Training Program. They could be conducted in conjunction with the local tourism industry mutually benefiting all parties.

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Chapter 15

Reports and Publications

I. GENERAL CONSIDERATIONS

Publication is an archaeological responsibility. There is no point in doing archaeology unless the work is properly published in the form of a final excavation report. This type of report normally collates all the information and material from the excavation and the subsequent research and, together with a detailed discussion of the findings, gives an analysis of the results and a conclusion. If this is not done, it can be argued that the work is incomplete. Few archaeologists would disagree publication is an essential part of archaeology.

The purpose of this chapter is to discuss the problems and methods of writing archaeological reports of various types, and the possible avenues of publication for this material. In the 1950s, publication of archaeological reports was relatively simple, and it was not difficult to find publishers who would accept a good quality archaeological report for publication. In the 1960s, publication costs started to increase, and it became more and more difficult to publish full reports. There was, at that time, a growing concern voiced by a number of authors that the future of full archaeological reports was in jeopardy since it was becoming increasingly hard to find publishers (see for example Grinsell *et al.*, 1974). Although it was generally accepted that archaeologists should publish their work in full, there was a minority, notably the publishers, who suggested that the details should be deposited in an archive and only the summary published. This was a difficult period for the maritime archaeologist because there were no journals specializing in maritime archaeology, nor any archaeological journals that would publish maritime material (with the exception of Bass, 1967).

Since that time, the situation has changed dramatically and there are a number of alternatives. The inauguration of the *International Journal of Nautical Archaeology* in 1971, by the late Joan du Plat Taylor, provided the maritime archaeologist a venue for publication. Material of up to 5000 words is accepted and the bi-annual publication means that material gets to press without undue delay. For larger reports, the journal *British Archaeological Reports* is an alternative offering a very fast publication time. The series accepts both British and international archaeological reports and although the printing is not of the highest quality, the publication is widely circulated, the cost of a volume is modest, and authors may, if they wish, provide the work properly typeset greatly improving the appearance. A number of maritime archaeological reports have been published in this series including Cederlund (1983), Fenwick (1978), Fletcher (1978), Green (1977a,b; 1989), Langley and Unger (1984), Lipke (1984), McGrail (1977, 1979), McGrail and Kentley (1985), and Redknap (1984). More recently Kluwer Academic/Plenum Publishers have commenced a high quality–low cost series: The Plenum Series in Underwater Archaeology (Staniforth, 2003; Ruppé and Barstad, 2002; McCarthy, 2001; Sousa and Gould, 1998; Babits and Tilberg, 1998). There is the possibility of commercial publication, but it is difficult to persuade a publisher to print a maritime archaeological report because these works appeal to a limited audience and even with an outrageous price tag they are usually not economical. As an alternative, some authors have utilized in-house publication facilities to produce very high-quality works (Bass and van Doorninck, 1982; Bruce-Mitford, 1975). Other authors have found scholarly monograph series to publish their work (Bass, 1967; Frost, 1981; Tchernia *et al.*, 1978). Some institutions have published a series of medium-quality archaeological reports, e.g., the Rijksdienst voor de IJsselmeerpolders, Smedinghuis, Lelystad (Reinders, 1977, 1982, 1983; Reinders *et al.*, 1978, 1980, 1984); the Statens Sjøhistoriska Museum, Stockholm (Cederlund, 1981, 1982, 1985; Kaijser, 1981); and the Department of Maritime Archaeology, Western Australian Maritime Museum (Green and Stanbury, 1988; Stanbury, 1973, 1974, 1979, 1983). The National Maritime Museum at Greenwich also produces a series of reports in conjunction with *British Archaeological Reports* (Fenwick, 1978; Lipke, 1984; McGrail, 1977, 1979, 1979; McGrail and Kentley, 1985; Redknap, 1984). Other organizations and journals that accept maritime archaeological material are the *Proceedings of the Conference on Underwater Archaeology* (Arnold, 1978; Cockrell, 1981; Johnston, 1985; Watts, 1981), which is now published by the Society for Historical Archaeology, *The Bulletin of the Australian Institute of Maritime Archaeology*, *Archaeonautica*.

There is also the option of private publication. This may seem, at first, to be a rather attractive option, but it has to be thought out very carefully if it is to be successful. It may be that a limited number of reports will be sufficient to fulfill obligations to sponsors and funding organizations, with the remainder selling at a small profit for the project. With computer typesetting, a report can be printed by a small offset printing house at a reasonable cost, provided you are prepared to do the time-consuming work and complex typesetting. It should be remembered that it not easy to produce a professional quality layout and typesetting experience will be required. Another important consideration is that it will be difficult to achieve a wide circulation for the report, and that it may not be possible to get the report to the audience for which it is intended.

Since the publication of the first edition of this handbook, the Internet has created another huge area of publication potential. It is today, arguably, far easier to get to a large public and academic audience through the World Wide Web than by any other means. However, this form of publication has its own limitations. Often there is little or no editorial control over material published in this format and as a result there is a lot of good material and a lot of rubbish. Possibly, one of the most interesting aspects of this form of publication is the ability to publish reports and documents that would not normally be economical to do through conventional print medium. This material is often referred to as "gray literature." So here is the dilemma: Should you publish on the Internet and forgo any profits, or should you go to the printed format, with the promise (usually unfulfilled) of modest profit? It is a balance and it is unclear how electronic publishing will evolve.

II. WRITING

Archaeological writing is not as difficult as many people think. It is merely the art of putting logical thoughts into a literary form. The following are some very brief guidelines which may be of help to those who have not written before, or who feel less confident in writing. General advice on writing archaeological reports can be found in Blake and Davey (1983) and Grinsell *et al.* (1974). There are also a number of useful dictionaries and reference manuals about writing and publication, in particular, the Australian Government Publishing Service (2002), Butcher (1981), Fowler (1968), Lloyd (1982), Onions (1968), Oxford English Dictionary Department (1981), and Oxford University Press (1983).

There are several different types of report that may need to be written at various times. These can be divided broadly into technical and popular.

The technical writing may include the initial proposals, progress reports, newsletters, interim or annual reports, final reports, and specialist reports. The popular writing may include press reports, newspaper and magazine articles, and popular books. All these different types of written work may need to be produced; it is beyond the scope of this book to deal with each one in detail.

The final report will be the basis for the following discussion. This will generally be the longest and most complex form of writing undertaken and is the most appropriate to discuss here. Additionally, many writers find that it is best to write the full archaeological report first, and then distill out specialist and popular works for subsequent publication.

Before starting it is advisable to work out a structure. What exactly do you want to say? What is the scope of the work? For what audience is it intended? What are the broad headings of the subjects? This gives the overall intention and purpose of what is going to be written. Having done this, a list can be made of the general headings which may then be used to break up the work into logical sections or chapters. Each chapter then can be subdivided into section topics. This can be used as the basic working strategy for the publication.

It is always difficult to start to write. As the introduction is usually rather general in nature and introduces the rest of the text, some authors defer writing it and get straight into the main part of the work. It is much easier to start the part that has already been mentally worked out and to leave the introduction until later. It is strongly recommended that long and complex sentences be avoided, and that every effort be made to keep the writing as simple and as easy to read as possible. Jargon should be avoided as this can confuse not only the reader, but at times the writer also.

In the past there was a choice between writing directly onto the computer or handwriting drafts which were then be put onto the computer. Today almost everything is done on the computer. However, when a word processor is used to enter the text, it is often edited from a printed copy (many copyeditors prefer to work with hard copy rather than use the computer, as they find it easier to work from hard copy). Once the first draft is produced it should be re-read and corrected. It is also important not to go too far with the work at the first stage; computers are seductive devices and can tempt a writer into refining the details of the work at a far too early stage, when the overall structure is not set in place. At this stage it is a good idea to get some outside advice on structure. It is recommended that it be read by someone with literary, rather than archaeological skills, as someone relatively ignorant of the field will not get bogged down with criticism of the technical implications, but will be able to advise on literary inadequacies. What you write should be able to be understood by any reasonably intelligent person, so a second opinion will find out if you are making sense.

Criticism should always be used constructively; although critics may be quite severe, it is always best to use this criticism positively. Finally, it should be understood that many drafts may be required before the text is ready for publication. At times six or seven drafts may be produced. With practice this number may be reduced to about three or four, but initially one must be prepared to do a lot of drafts. It is a rare person who can start up a computer and go into print in one go, and usually the more drafts the better and more polished the work becomes.

Figures and plates always tend to be a problem when working on drafts because they are difficult to incorporate into the text. Marginal notes and annotations can help where figures are required. With drawings or plans, it is best to try and incorporate them in the text so that the annotation can be referenced and checked properly. Microsoft Word is particularly good in this area, although as will be explained below it should not be used for typesetting. With some low-quality scans and graphic images put in the document the reader will be able to see the material that is being referred to, and this is a great advantage in the editorial stage.

The final report may have a somewhat uneven style, because some information or research may have proceeded much further in some areas than in others. This should not be a great concern provided the reasons are carefully explained and that eventually there is consistency. It may not be necessary to itemize every shard in the catalog, but it will be essential to provide information on the weights, numbers, etc., of the various groups of material. The object of the report is to provide information to others so that it will be possible to compare data and results and eventually build up a more comprehensive picture than would be possible from a single excavation report.

III. REFERENCING

Using references is fairly straightforward; you can either use the author–date system or footnotes. The author-date or Harvard system (used in this book) is favored by scientific journals, for example, the *International Journal for Nautical Archaeology*. Footnotes tend to be used by historically orientated journals. Publishers find footnotes difficult to typeset and usually recommend that authors keep them to an absolute minimum and use them as endnotes rather than footnotes. (Footnotes appear at the bottom of the page and can create enormous difficulties for typesetters, and endnotes appear at the end of the publication and are much easier to deal with, although less accessible for the reader.) If the information is nonessential, it can be incorporated in footnotes, but in many cases it may be more appropriate to include it in the main body of text. Many modern word-processing packages can handle footnotes automatically and, if such a system is used, their incorporation into documents may not be a problem. Word-processing packages are not typesetting packages, so there a need for caution here.

When using a referencing system the format should be carefully worked out beforehand or there will be inconsistencies in the text. If a typist is entering the text it is suggested that a sample format is supplied so that the entries can be entered in a uniform and logical manner. A suggested format, used by the *International Journal for Nautical Archaeology*, looks like this: for main text references, Bloggs (1969), (Bloggs, 1965), (Bloggs and Nitwit, 1988), Wally *et al.* (1989). This type of reference is used either when referring to the author directly in the text: 'It was found by Wally *et al.* (1989) that . . . ,' or as an indirect reference: 'Animal bones have found on only one site in the area (Bloggs, 1969), although they have been found elsewhere (Bloggs, 1965; Wally *et al.*, 1989; and Bloggs and Nitwit, 1988).' Note in the latter case a decision is necessary on how to treat the date when several publications are quoted within the parentheses, for example, should they be ordered alphabetically or chronologically. The list of references, generally included at the end of the work, have the following style:

1. Book: Martin, C.J.M., 1975, *Full fathom five: wrecks of the Spanish Armada.* Chatto and Windus, London.
2. Journal: Martin, C.J.M., 1979, *La Trinidad Valencera*: An Armada invasion transport, lost off Donegal. Interim site report, 1971–76. *International Journal of Nautical Archaeology*, **8**(1): 13–38.

Note the difference between the book reference, where the title is in italics and the journal reference where the title of the journal is in italics. The name of a ship should also be in italics; if it is in a book title, then the ship's name would have been set in the reverse typeface, i.e., Roman. If you cannot alter the style of the font, then there are standard conventions for marking the text for the printer. Writers now underline text to indicate to the typesetter to set it in italics. It should be noted that this is only intended as a guide, there are other conventions for references and for more detail readers should refer to the standard texts such as the Australian Government Publishing Service (2002), Butcher (1981), and Oxford University Press (1983). References are most editors' nightmare, not only do authors often not follow the convention of the publication, they also can be inconsistent and inaccurate. It is always important to ensure that there is consistency between the in-text references and the references.

It is also strongly recommended that a style sheet be prepared for reference by the author and the publisher. The style sheet should list the referencing conventions, the style for the layout of the typing, preferred spellings, etc. When a particular problem occurs, the decision can then be added to the style sheet for future reference.

IV. PUBLISHING

The final form a written work takes depends on how it is to be published. A commercial publisher or journal will generally require a draft and illustrations, and they will do the rest. They will usually indicate how the text should be presented and marked up, and it is only necessary to follow these guidelines. To produce a report yourself, an electronic copy will be required. There are now two options: either print the pages on high-quality paper using a high-quality printer and take these to a copying service, or take the electronic version to a pre-press, get the copy converted to film, and then go to an offset printer. There are economics involved in this decisionwhich depend on the size of the publication and the number of copies to be printed, and you will need to investigate these options carefully.

The alternative is to publish your work on the Internet. To do this a site is required which will be the place where you material will reside. Here, you need to be careful. Although it is possible to open your own site and publish the material there, you have to consider how long you will keep this site open, what happens if you can no longer afford to pay the Internet service provider (ISP), and what happens if the ISP goes bust. It is important therefore to try and find a location that will have some expected permanency and to try and distribute copies over a number of sites. This will help to ensure that the work remains available. This of course is a very new area and standards and protocols are still evolving. It should always be remembered that, unlike hard copy that can reside in multiple libraries in perpetuity, the Internet is volatile. Although publishing material on the Internet gets the material to new and diverse audiences, it does not necessarily mean that it will be there forever.

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Chapter 16

Legislation

The question of legislation in relation to maritime archaeology is a complex issue. In most countries, land archaeological sites are protected by some form of legislation. Unfortunately many countries choose not to afford underwater archaeological sites the same level of protection. The debate is complex. There are those who want sites protected and others who, for various reason, want them left unprotected. There are divisions between the interested parties on both sides. An underwater archaeologist will argue that all sites should be protected. The sport diver may argue that protective legislation could prevent the acquisition of artifacts from sites, or possibly restrict reasonable recreational access to sites. The more pecuniary minded would see such legislation as preventing the commercial exploitation of sites. Even government departments may have vested interests in legislation. In some countries substantial sums of money are realized through legal agreements with commercial organizations over the disposition and sale of archaeological artifacts from wreck sites within their territorial waters. Many museums acquire material from the treasure hunter seeing this as the only way to acquire this type of material.

If legislation reflects the wishes of society, then it is quite clear that in some countries the society does not wish to have protective legislation for maritime archaeological sites. The various ways that countries have enacted maritime archaeological legislation has been thoroughly discussed by Prott and O'Keefe (1981, 1984) and Roper (1978). Readers are referred to these texts for information, together with a review of international legislation relating to maritime archaeology (Brown, 1996; Carducci, 2002; Dromgoole, 1999; Fletcher-Tomenius and Williams, 1999; O'Keefe, 2002; Prott and

Strong, 1999; Prott *et al*. 2000; Strati, 1999; UNESCO, 1995). This chapter will discuss the different viewpoints of the various interested parties and give examples of the different types of legislation that have been applied.

Let's start at the extreme end with the non-archaeology, or the profit-motivated approach to archaeological sites taken by the treasure hunter. A sort of mythology has developed around treasure hunting, perhaps arising from the terrestrial treasure hunter of the last century and the beginning of this one, the Indiana Jones-type who has now disappeared. Today, underwater archaeology is one of the few places where this type of activity can still be practiced. A typical quotation from an author writing about an underwater treasure hunter (M. Hatcher) is:

> Unfortunately many archaeologists refuse to work with salvage companies. They find their concern with profit unattractive: if they had their way no treasure would be sold off for commercial gain, only saved for posterity in museums. Hatch [Hatcher] has had to become a diplomat to deal with the enemies of his profession. He says he has to balance the demands of the archaeologists with his loyalty to his financial backers and the men that work for him. But in the end he holds the trump cards. It is only his bravery and initiative that makes the finds possible. Unless he can dispose of any valuables he recovers on the market, he will not continue. And there will be fewer breakthroughs in underwater archaeological knowledge (Thorncroft, 1987).

On the other hand, archaeologists such as Professor George Bass lament the inroads the professional treasure hunter has made into archaeological cultural heritage. Bass (1985) wrote a spirited attack on the "treasure hunter" mentality by responding in a letter to a large number of the treasure hunters' claims against archaeologists. His letter was in support of the U.S. Senate bill which was designed to provide protection of historic shipwrecks, structures, and artifacts located on the seabed or in the subsoil of the lands beneath waters of the United States. Bass (1985) writes:

> Treasure hunters have been called in the press good underwater archaeologists, more competent than many professional archaeologists with university degrees. [Bass argues] Who would go to an amateur dentist? What is the difference between an amateur archaeologist and an amateur brain surgeon?. . . . [the treasure hunters claim] There are thousand of shipwrecks, enough to go around. Why should archaeologists have them all? [Bass' reply is] There are thousands of land sites. Why not give most of them to pot hunters? Why not let some "free-enterprise" treasure hunters have some Egyptian pyramids and half the classical temples on earth—there are plenty to go around.

Because treasure hunters' motives are to find treasure in order to make money, any legislation that would restrict this practice is an anathema to them and this is why they loath the UNESCO Convention on the Protection of Underwater Cultural Heritage. There is no doubt that some have an interest in archaeology, but in many cases this is simply a method of gaining respectability. It is the profit motive, which in turn leads to the sale of artifacts, that is the problem. The archaeological profession has no problems in condemning treasure hunting as it exists today. However, should the treasure hunters consider carrying out careful excavations in order to keep their collections together, conserved in proper environmental conditions, in a museum so that they may profit from the admissions and bookshop sales, then the story would be quite different. Such a situation has not occurred yet, and it will no doubt cause even more debate when it does. Certainly the move toward privatization in the UK and a general move internationally to become more cost-effective has worrying implications, because the treasure hunter has a profit-motivated pathway to achieve this.

The amateur diver is another interested party for which legislation may have an effect. There appear to be two extreme attitudes held by this group: either, that anything lying on the seabed is free to be collected and kept as souvenirs; or, alternatively, the diver has an intense interest in maritime archaeology and would like to find ways of fulfilling this interest. In many countries the Merchant Shipping Act 1894, or its equivalent, protects property rights and controls salvage. For example, any wreck (including flotsam, jetsam, lagan, and derelict) recovered from British territorial waters must be declared to the Receiver of Wreck. The duty of the receiver is to post notice of any wreck that has been received so that it may be claimed by the owner. The receiver keeps the wreck for a year during which time the owner may claim it and "upon paying the salvage, fees and expenses due, be entitled to have the wreck or the proceeds delivered up to him" (*Merchant Shipping Act* 1894, Section 521). The objective of this act was to prevent the plundering of wrecks, to ensure the rights of the proper owners, and to ensure the proper distribution of the salvaged property. The receiver was empowered, if the wreck was unclaimed, to

> sell the same and shall pay the proceeds of the sale (after deducting there from the expenses of the sale, and any other expenses incurred by him, and his fees, and paying there out to the salvors such amount of salvage as the Board of Trade may in each case, or by general rule, determine) for the benefit of the Crown (Chippendale and Gibbins, 1990).

Thus it is quite clear that the concept of collecting undeclared souvenirs from a wreck is illegal; it has been, however, a traditional pastime of the amateur diver.

There now appears to be a growing international concern for conservation, particularly in relation to the marine environment. Many amateur divers are aware that there are only a limited number of wrecks and if these are destroyed then future generations of divers will no longer be able to enjoy this aspect of the sport. There is even a commercial dimension to this argument, because dive tour operators, who take groups out to wreck sites, are acutely aware of the problem of souveniring and at least they discourage this activity. Within maritime national parks, conservation of the environment is an important issue which affects not just the marine life, but in many cases the cultural heritage as well.

In Australia the provisions of the Historic Shipwrecks Act 1976 enable wreck sites to be protected for reasons that include educational and recreational criteria (Amess, 1983, McCarthy, 1983). Under this form of legislation, wreck sites are perceived as a type of multifunctional, cultural property; sites can be considered as part of the society's cultural heritage, but are to be freely available for all members of the society to enjoy (see Amess, 1983; Crawford, 1977; Green and Henderson, 1977; Green *et al.*, 1981). Additionally, the Australian government signed a pioneering maritime archaeological agreement with the Dutch government (the Australian-Netherlands Agreement on Old Dutch Shipwrecks; ANCODS) whereby the Dutch government granted any rights that they had to the VOC shipwrecks on the Western Australian coast. The basis of this agreement was that the archaeological collection should be kept together in Western Australia and with small representative collections of duplicate material being allocated to the Dutch and Commonwealth governments, but that at any time the collections should always be available for study (Bolton, 1977; Green and Henderson, 1977, 1983b).

Two countries that have considerable problems with legislation are the UK and the United States. In the UK attempts have been made to improve the legislation protecting archaeological wreck sites. Redknap and Dean (1989) noted that:

> Not only is it perfectly legal to destroy archaeological sites within British territorial waters, Part IX of the Merchant Shipping Act 1894 actually encourages such destruction by financially rewarding people for recovering archaeological material, regardless of whether removed by a grab on the end of a crane, or during disciplined archaeological excavations.

The authors identified three weaknesses in the existing legislation: (1) the Receivers of Wreck have no training nor expertise to deal with material recovered from an archaeological wreck site, nor can the Receivers officially receive advice from expert bodies; (2) there is no procedure to ensure that archaeologically significant material is preserved; and (3) the system of awards is unsatisfactory and in fact penalizes archaeological bodies and museums engaged in underwater excavation (Joint Nautical Archaeology Policy Committee, 1989). An example of the type of situation that can occur was illustrated by the authors:

This system [archaeological material handled by the Receiver of Wreck] even applies to material recovered from sites designated under the 1973

Protection of Wreck Act, such as the Bronze Age wreck site at Dover. A ludicrous situation developed when the British Museum and the National Maritime Museum funded professional archaeological work which was supported by volunteer help from the local sub-aqua club. As the finders of the site, the volunteers were technically the "salvors in possession." After the excavation more than 300 bronzes had to be purchased by the British Museum from the receiver at the estimated market value, even though the museums had effectively paid for their "recovery" during the archaeological work. The local diving club received 100% of the purchase price less the receiver's expenses, commission, and value-added tax (Redknap and Dean, 1989).

The Protection of Wreck Act 1973 in Britain has been:

> . . . passed like an unwanted child from the Department of Trade and Industry, to the Department of Transport, to the Department of the Environment, and then to the Department of National Heritage, now Culture, Media, and Sport (Fenwick & Gale, 1998).

The management of archaeological sites on land together with the procedures and practice of protection and preservation were developed through the Ancient Monuments Act 1882. As a result the management of archaeological sites on land is well established and the sites enjoy reasonable protection. The practice of archaeology on land has firmly established the indivisibility of the site and the associated artifacts. Attempts are now underway to rectify the situation regarding the disparity of underwater archaeological sites. Archaeologists argue that underwater sites are under extreme threat, because there is no legal mechanism to determine if a site is of historical or archaeological significance, and that the existing legislation is encouraging the destruction of sites (see Joint Nautical Archaeological Policy Committee, 1989; Chippendale and Gibbons, 1990).

The Protection of Wreck Act 1973 allows the designation of a restricted area around a wreck site for archaeological, historical, or artistic importance. Activity of any sort on a protected site has to be undertaken under license: either a survey, excavation, visitor, or survey recovery license. As Fenwick and Gale (1998) point out: "The Act has not lived up to expectations." At the time they wrote this there were 45 historic wrecks designated in British waters. Darrington (2002) refers to the Archaeological Diving Unit (part of the Department of Culture, Media, and Sport) sending staff to Australia for training in underwater excavation techniques. He also stated that "Lack of professional archaeologists has created a unique situation. Many amateurs and a few commercial divers are leading the fight to preserve Britain's maritime past." This is a depressing professional situation to say the least.

In the United States, a different type of situation exists. Partially because of the federal nature of the government and issues related to the rights of the states to legislate in maritime matters, the legislation has been complex and confusing. States that have attempted to enact legislation or to restrict the operation of treasure hunters have had cases overruled. The most well-known case is that of Mel Fisher of Treasure Salvors and the wreck of the *Atocha*. Over the years a number of courts in the United States have ruled in various cases between Treasure Salvors and the State of Florida and the U.S. Federal Government as to who owned the *Atocha*. In the early 1980s, it was decided that shipwrecks inside state waters and those in federal waters came under the jurisdiction of Admiralty Law. The courts then ruled against the claims of both the State of Florida and the Federal Government that they owned the *Atocha* site and, provided Treasure Salvors remained salvor in possession of the site giving them title to the wreck. The case of the *Atocha* is extremely complex, and from the early beginnings in 1962 up to the spectacular auction sales of 1988 and 1989, the site and the work that has been done on the wreck has created an immense debate and considerable disagreement. Treasure Salvors employed an archaeologist, Duncan Mathewson, who was responsible for the archaeology done on the *Atocha* and the sister ship *Margarita*. It is far from clear what archaeology was in fact done on the site, and certainly in the beginning there was very little, however, Mathewson has yet to publish an excavation report so it is difficult to judge. There is no doubt that a large proportion of the artifacts have been sold, and with their sale goes any opportunity to study the material further. In spite of Mathewsons's claim that ". . . our work on these sites will eventually vindicate my conviction that good archaeology is possible during a commercial salvage effort" (Mathewson, 1986), the artifacts have been sold and as a result archaeologists claim that as archaeology, this work lacks integrity.

The introduction of the Abandoned Shipwreck Act 1987 affirmed the state's role by declaring that the states were the owners of all abandoned shipwrecks that lay effectively within state waters and that were eligible for inclusion under the National Register of Historic Places. In 1988 only 36 sites were listed in the National Register; by 1998, 579 were included. The passage of Abandoned Shipwreck Act 1987 was a long process, but one that engaged a wide and public debate. For the first time the treasure hunters were exposed to a wide public audience that became aware of the long-term implications of treasure hunting. The debate was an important opportunity to educate the general public on the objectives of "protection."

In some countries, agreements are made between treasure hunters and the government of the country, permitting the treasure hunters to salvage material from wreck sites on the condition that some proportion of the proceeds of the work, either financial or material, is kept by the country. Whereas such arrangements may seem very attractive, particularly to underdeveloped countries, the short-term financial gains are questionable when compared with the long-term disadvantages. Not only is it unlikely that the country will be able to develop the expertise to manage the underwater cultural heritage properly in this type of situation, but it is also likely that most of the energy will be directed toward ensuring that the terms of the agreement are adhered to, in other words policing the work. In the meantime the heritage is depleted, and the country will be left with a collection of artifacts which have little meaning as there will be no one to interpret the work and no expertise developed in the field.

On the international level the UNESCO Draft Convention for the Protection of Underwater Cultural Heritage was adopted by the Plenary Session of the 31st General Conference by 87 affirmative votes, thus becoming UNESCO'S fourth Heritage Convention. Four states voted against and 15 abstained from voting. The convention stated the following:

> Acknowledging the importance of underwater cultural heritage as an integral part of the cultural heritage of humanity and a particularly important element in the history of peoples, nations, and their relations with each other concerning their common heritage,
>
> Realizing the importance of protecting and preserving the underwater cultural heritage and that responsibility therefore rests with all States,
>
> Noting growing public interest in and public appreciation of underwater cultural heritage, Convinced of the importance of research, information and education to the protection and preservation of underwater cultural heritage,
>
> Convinced of the public's right to enjoy the educational and recreational benefits of responsible non-intrusive access to *in situ* underwater cultural heritage, and of the value of public education to contribute to awareness, appreciation and protection of that heritage,
>
> Aware of the fact that underwater cultural heritage is threatened by unauthorized activities directed at it, and of the need for stronger measures to prevent such activities,
>
> Conscious of the need to respond appropriately to the possible negative impact on underwater cultural heritage of legitimate activities that may incidentally affect it,
>
> Deeply concerned by the increasing commercial exploitation of underwater cultural heritage, and in particular by certain activities aimed at the sale, acquisition or barter of underwater cultural heritage,
>
> Aware of the availability of advanced technology that enhances discovery of and access to underwater cultural heritage,
>
> Believing that cooperation among States, international organizations, scientific institutions, professional organizations, archaeologists, divers, other interested parties and the public at large is essential for the protection of underwater cultural heritage,
>
> Considering that survey, excavation and protection of underwater cultural heritage necessitate the availability and application of special scientific methods

> and the use of suitable techniques and equipment as well as a high degree of professional specialization, all of which indicate a need for uniform governing criteria,
>
> Realizing the need to codify and progressively develop rules relating to the protection and preservation of underwater cultural heritage in conformity with international law and practice, including the UNESCO Convention on the Means of Prohibiting and Preventing the Illicit Import, Export, and Transfer of Ownership of Cultural Property of 14 November 1970, the UNESCO Convention for the Protection of the World Cultural and Natural Heritage of 16 November 1972 and the United Nations Convention on the Law of the Sea of 10 December 1982,
>
> Committed to improving the effectiveness of measures at international, regional and national levels for the preservation *in situ* or, if necessary for scientific or protective purposes, the careful recovery of underwater cultural heritage,
>
> Having decided at its twenty-ninth session that this question should be made the subject of an international convention, Adopts this second day of November 2001 this Convention.

As one can imagine this was not an easy process, it had taken over a decade to reach this conclusion and was again a reaffirmation that society considers the protection of underwater cultural heritage more important than its exploitation. Prior to the UNESCO Draft Convention on Protection of Underwater Cultural Heritage there was no international instrument to provide significant legal protection to underwater cultural heritage: shipwrecks, sunken cities, underwater cave paintings, and so forth. Although some nations possessed laws to provide protection in their own waters, others did not. This led to confusion about the rights of nations to protect their cultural heritage, whether submerged in its own waters or another nation's, or on the high seas. Listed next are the main features of the draft convention.

1. No activity directed at underwater cultural heritage may occur without a permit, no matter where the heritage is located.
2. To provide guidance on the permitting process, including from which party the permit must be sought depending on the location of the heritage.
3. To cover all traces of human existence having a cultural, historical, or archaeological character which have been partially or totally underwater, periodically or continuously, for at least 100 years.
4. To require the consideration of on-site preservation of underwater cultural heritage as the first option before allowing any activities directed at it.
5. To be responsible for non-intrusive access to observe or document on-site underwater cultural heritage: it "shall be encouraged to create public awareness, appreciation, and protection of the heritage. . . ."

6. Underwater cultural heritage may not be commercially exploited.
7. Signatories have the exclusive right to regulate and authorize activities directed at underwater cultural heritage in their territorial sea and contiguous zone, and may enforce this right.
8. On matters in a signatory's exclusive economic zone (out to 200 nautical miles), however, the draft convention does not provide any new enforcement authority.
9. Several provisions make it clear that the convention must be interpreted consistent with international law, including the UN Convention on the Law of the Sea.
10. Signatories must require their nationals to report any discovery of underwater cultural heritage (even if discovered in another signatory's waters), and must prohibit them from engaging in activities directed at the heritage without a proper permit. They may enforce those regulations against foreign-flag nationals and vessels, at least in the territorial sea and contiguous zone. For further information on the Convention see Brown, 1996; Carducci, 2002; Dromgoole, 1999; Fletcher-Tomenius and Williams, 1999; O'Keefe, 1999; Prott, 2003; Prott *et al.*, 2000; Strati, 1999; and UNESCO, 1995.

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Chapter 17

Conclusions

This book is not only written as a guide to the practice of maritime archaeology, but also with the objective of furthering the study of the subject. When I wrote the first edition I said: "The situation which currently exists in maritime archaeology inevitably leads to the conclusion that, as a field of study, it is not well established and suffers from a lack of respectability." This is no longer the case. Look at the important advances that have occurred in the field and you can feel confident making this statement. This book deals with the technical and technological advances that have occurred in the practice of maritime archaeology, there are a number of other works that could also be written on the theoretical developments that are arising from the discipline; for example, shipbuilding technology, trade relationships, maritime societies, maritime cultural landscapes, maritime historical studies. Possibly one of the most interesting aspects of this last area is what an important and little understood part ships have played in the great events of history. One is tempted to think of the Spanish Armada of 1588 as an example, however, you can read Braudel's *The Mediterranean* to see how the Armada was a tiny wheel in the enormous historical time machine of the 16th century, and how the geography, politics, religion, and economics were interwoven with the ability to trade and fight at sea. So too, we see the Slavic *Völkerwanderung* of the Huns, Goths, Visigoths, Ostrogoths, and Vandals who emerged from Central Europe and seemed to wander nonchalantly across Western Europe, building boats when it seemed necessary to cross from one side of the Mediterranean to the other. We also see the kingdom of the Vandals established in North Africa which followed the movement from Central Europe, the Barbarian invasion of the Iberian peninsula, and the crossing to North Africa where these nomadic pastoralists adapted and became formidable pirates.

It is, at times, tedious to read the Euro-centric writings of authors who extol the achievements of 16th century Europeans who 'discovered' the Indian Ocean! Who brought, it is claimed, nails to the poor souls who built sewn boats. The fact that people were trading across the whole of the Indian Ocean when these Europeans were painted in woad and building log boats is quietly forgotten. More time is spent on discussing whether the Chinese did or did not reach America when there is so much evidence that the Polynesian people explored and discovered the whole of the Pacific. Across this stage, the oceans of the sea, people sailed in boats. Maritime archaeology seeks to find out who these people were and why they were there.

By reading Villiers *Sons of Sinbad* we learn that in the late 1930s the Arabs trading from the Persian Gulf down the East African coast had lost the art of deep sea navigation and were simply coasting. But what sailors they were! Villiers describes his arrival in Zanzibar in the dhow the *Triumph of Righteousness:*

> Meanwhile our sailors continued to sing and there was such a banging of drums as I never heard before . . . They sang so much that they could hear no orders . . . Now we were off the anchorage, our keen bow slicing through the sea. "Lower the mainsail!" suddenly from Nejdi [the *nakoda* or master]. No answer from the mariners, singing more lustily than ever, hearing nothing else. "Lower the mainsail!" Hamid bin Salim [the *muallim* or mate] screamed, rushing to the break of the poop. "Lower the mainsail!" Still no answer from the mariners singing away: no answer and no obedience. The ship was charging at the assembled moored vessels . . . There were fifty Arab ships swinging there. We could see the faces of some Persians in the nearest *Boom* watching with mild interest. I wondered why they did not fear for their lives for it looked as though we should be charging into them within ten seconds. I reckoned without Nejidi. He excelled at such seamanship as this.

Villiers goes on to describe the eventual lowering of the yard, the vessel careering into a gap in the raft of vessels, and crew members jumping overboard with lines that were used at the last moment to check the vessel's way.

> She was coming in so quickly and she had so much way—for she was a ship of near 150 tons, and she still had more than 100 tons of cargo—that the sudden checking of her way . . . Nejdi, using these checks brilliantly, and very rapidly, eased his big vessel through the gap and alongside the Indian, bringing her there so quickly that the maneuver was accomplished almost as soon as I could perceive its aim.

No amount of archaeology could tell that story, but it does emphasize that archaeology is all about people, not just little bits of pottery, a pile of silver coins, or some bits of ship's timber. Real people who crossed oceans made amazing voyages and did strange and often incomprehensible things.

Bass recently wrote (Bass, 2002):

> "Now we have stepped over the threshold of a new millennium. What does the future hold? More academic programs will be formed, more maritime museums established. More state and national agencies around the world will have specialists in underwater archaeology. I would even hazard a guess that the most important archaeological discoveries of the first half of the 21st century will be made under water."

If we aspire to protect the remaining underwater cultural heritage of this planet, then we must mobilize resources. Public involvement through education is a key element in this process. Academics and administrators working in the field of underwater cultural heritage must engage the public, because it through public opinion that attitudes can be changed. No amount of legislation will protect heritage unless the will of the majority supports the process. This book is intended to provide some help in developing the tools that can assist in this process.

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