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OCEAN MARGIN SEDIMENTS

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Introduction

Ocean margin sediments are largely detrital deposits of terrestrial origin that extend from the shoreline to the foot of the continental rise. Indeed, about 80% of the world's sediment is stored within margin systems, which cover about 14% of the Earth's surface (**Table 1**; **Figure 1**). Margin deposits typically consist of sand, silt, and clay-sized particles, the characteristics of which reflect the geology and climate of the adjacent continent. Some of the signals relevant to terrestrial conditions include sediment size, mineralogy, geochemistry, and isotopic signature. Upon entering the marine realm, however, sediments take on new characteristics indicative of coastal ocean processes that include waves, tides, currents, sea level, and biological productivity. Given that these numerous terrestrial and marine processes impart a signature to the sediments, ocean margins preserve an important record of Earth history, providing insights into past atmospheric, terrestrial, and marine conditions. Beyond their significance as environmental recorders ocean margin sediments support major petroleum and mineral resources. Currently, over 50% of the world's oil is recovered along ocean margins, and much of the remaining fraction is held within ancient margin deposits.

In the 1950s, early investigations of ocean margins focused on tectonic structure and how overlying sedimentary sequences developed on timescales of 10^5–10^7 years. Originally aimed at understanding plate tectonics and the nature of ocean–continent boundaries, these large-scale studies continued through the 1960s with specific interest in petroleum resources. Such efforts culminated in the publication of large scientific volumes such as Burk and Drake's *Geology of Continental Margins* (1974). At the time of these summary publications, new models of sedimentary margin systems were already being developed, notably the approach of seismic stratigraphy established at the Exxon Production Research Company. Growing out of this approach was the more general model of sequence stratigraphy, which helped establish that margin strata could be grouped into discrete packages reflecting cycles of sea-level rise and fall. These concepts represent a general approach that has been applied to stratigraphic development and margin evolution in most of the world's ancient and modern sedimentary systems. Sequence stratigraphic data has also been mated with lithologic, magnetic, and biostratigraphic

Table 1 Area of Earth's major physiographic provinces and the volume of stored sediments. Bracketed are ocean margin components with relative contributions shown

	Area^a *($10^6 \times km^2$)*		*Volume*^{b} *($10^6 \times km^3$)*	
Land	148.1		45	
Interior basins	8.7		35	
Shelves	18.4	14%	75	80%
Slopes	28.7		200	
Rises	25.0		150	
Ocean basins	281.2		25	
Totals	510.1		530	

Data from ^{a}Burk and Drake (1974) and ^{b}Kennett (1982).

records, allowing researchers to establish the history of sea-level change since the Triassic era (260 million years ago). This historic record significantly advanced our understanding of ocean margin sedimentary records, because sea level is a major control on the distribution and accumulation of margin deposits, as well as an indicator of global climate.

At a much shorter time scale, a great deal of research in recent decades has focused on sediment dynamics along modern margin systems. Aimed at understanding the fate of sediments entering the marine realm, some of the issues driving margin-sediment research included coastal hazards, land loss and development, storm impacts, contaminant fate, and military interests. In part, the field has advanced with the development of new technology such as marine radioisotope geochronology, sonar seafloor mapping, and instruments for remote wave, current, and sediment concentration measures. Recently, research programs have sought to integrate long and short geologic timescales to understand how daily, seasonal, and annual sedimentary beds are ultimately preserved to form thick millennial and longer sedimentary sequences (e.g., US and European STRATAFORM programs). Other newer initiatives are seeking to take integration a step further by recognizing that ocean margin sediments lie among a continuum of terrestrial and marine influences. Therefore, to better understand this critical accumulation zone, the terrestrial processes that are responsible for sediment input must be considered in conjunction with the marine processes that are responsible for their redistribution (e.g., US and Japanese MARGINS programs). Such efforts to integrate over various spatial and temporal scales will likely govern the foreseeable future of margin sedimentary research.

Margin Structure

All margins represent past or present tectonic plate boundaries where crusts of varying age, density, and composition meet. In general these boundaries also comprise large-scale basins that trap sediments shed from the adjacent land surface. Most ocean margins specifically denote the boundary between oceanic and continental crusts, where different densities between these adjacent blocks give rise to a steep gradient at the margin. This tectonic structure controls the physiography of the margin as well, which comprises shelf, slope, and rise settings (**Figure 2**). The landward part of the margin, the shelf, overlies the buoyant continental-crust block and is thus the shallowest part of the margin, extending along a low gradient (0.1°) from the coast to the shelf break at 100–200 m water depth. Because of the low gradient and shallow depths, shelf environments are sensitive to sea-level change and isostatic movements (crustal buoyancy) causing the shelf to be periodically flooded and exposed. The seaward edge of the shelf, called the break, is

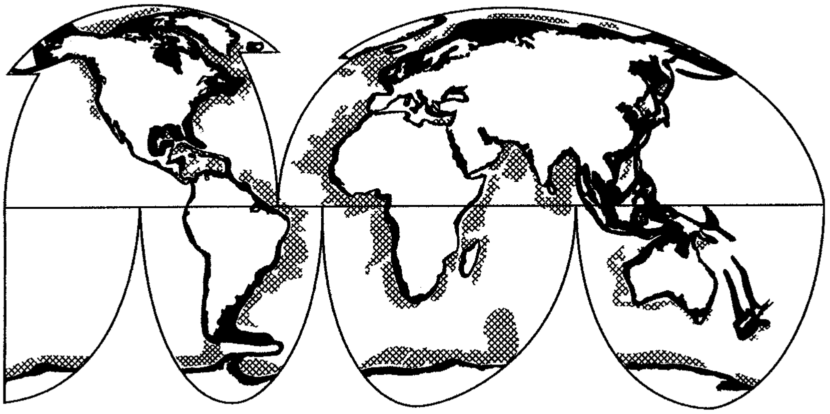

Figure 1 Distribution of major ocean margin deposits, showing extent of continental shelves (black) and rises (hatched). (Modified from Emery (1980).)

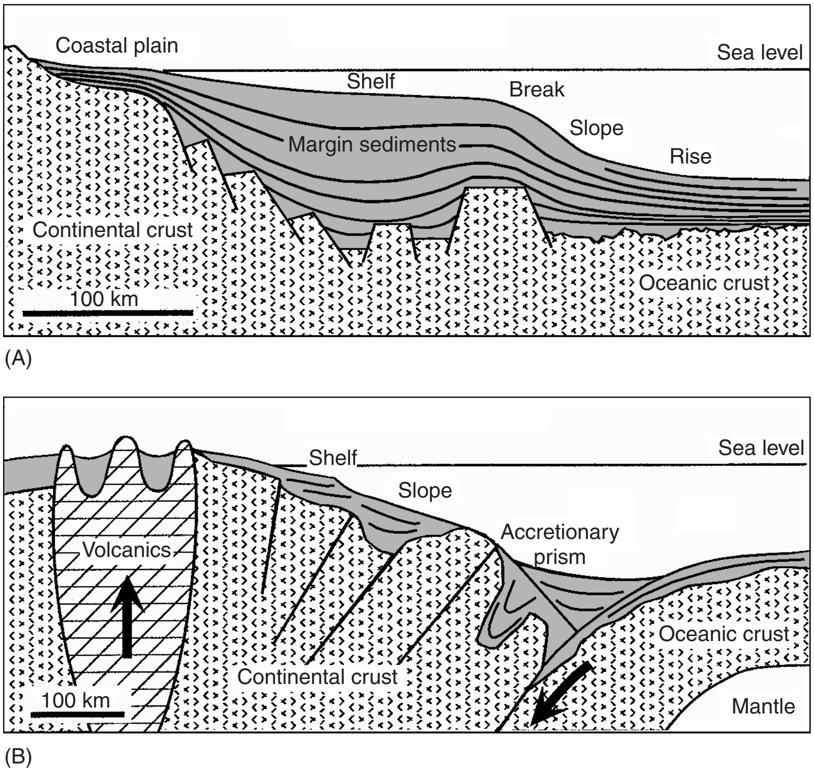

Figure 2 Generalized cross-sections of (A) divergent and (B) convergent-type continental margins. Note the different scales. The divergent margin shows thick sedimentary deposits that have prograded into the ocean basin. Margin deposits in the convergent setting are much thinner, and most deposition occurs below the shelf break in the accretionary prism.

identified by an increase in seafloor gradient (3–6°) and represents a transition between the shelf and continental slope. Roughly overlying the continental and oceanic crusts, sediment accumulation on the slope is partly controlled by processes on the shelf, because any slope sediments must first bypass this depositional region. Beyond the slope extends the rise, a low gradient (0.3–1.4°) sedimentary apron that begins in 1500–3500 m water depth. Although the rise may extend hundreds of kilometers into the ocean basin, its sediment source largely derives from sediment originating on the slope and moves as turbidity currents. In addition to the major shelf, slope, and rise features, other regionally significant marginal features may include deltas and canyons, each playing a role in controlling or modifying the dispersal and deposition of sediments.

Tectonically, margins may be broadly divided into divergent (passive) and convergent (active) systems, each with a characteristic structure and physiography that are important to sediment accumulation and transport dynamics. Divergent margins are largely stable crustal boundaries, although the structure and movement of deep basement rocks remain a significant influence on sediment deposition and stratigraphy. Divergent margins are also largely constructive settings in which sediments shed from the continent form thick sedimentary sequences and a wide, low gradient shelf. This loading of sediment onto the margin also drives a slow downwarping of the crust, creating more accommodation space for the accumulation of thick sedimentary sequences. The resulting margin physiography is characterized by a broad shelf, slope, and rise. Margins along the Atlantic Ocean are among the best-studied examples of divergent systems.

In contrast, convergent margins are characterized by the subduction of oceanic crust beneath the adjacent continental block. Active mountain building in convergent settings frequently drives uplift of the margin, limiting the development of thick sedimentary sequences on the shelf. Thus, convergent margins tend to have narrow shelves that bypass most sediment to a steep and well-developed slope. The rise is generally not a significant depocenter because sediment transport is intercepted by trenches and elevated topography that inhibit the long-distance movement of turbidity currents. Seaward of this, though, there is frequently a wedge of deformed marine sediments called an accretionary prism that derives from material scraped from the subducting ocean crust. This situation is often found along the eastern North Pacific margin. Along margins with major trench systems such as those of the western Pacific, the rise and accretionary prism may be altogether absent.

Margin Sediment Sources, Character, and Distribution

Ocean margin sediments generally comprise small particles ranging in size from fine sands (62–125 μm) to silts (4–62 μm) and clays (< 4 μm). Larger sediments are occasionally found in ocean margin deposits, including coarse sands to boulders, but these particles are generally either relict (not actively transported), of glacial or ice-rafted origin, or biogenically precipitated (i.e. shell or coral). Overall patterns of grain-size distribution in margin sediments depend on the regional climate, geology, and sediment transport processes operating on the margin.

Three major mineral groups comprise ocean margin sediments, including siliciclastics, carbonates, and evaporites, or any combination of these. Worldwide, however, siliciclastics dominate ocean margin sediments. Siliciclastics are almost exclusively silicon-bearing minerals that derive from the physical and chemical weathering of continental rocks. Because most of the hundreds of rock-forming minerals are weathered before reaching the coast, margin siliciclastics dominantly comprise quartz and four clay species: kaolinite, chlorite, illite, and smectite. There is often a small component (several percent) of remnant feldspars, micas, and heavy minerals (sp. gr. > 2.85) as well. Quartz, although an abundant and ubiquitous mineral, is often useful for interpreting margin sediments because different grain sizes reflect varying sources (e.g. eolian input) or energy regimes. For clay minerals, though, relative abundance of the major species in part reflects regional climate, thus making them a useful parameter for interpreting terrestrial signals preserved on the margin (*see* **Clay Mineralogy**). Furthermore, within the heavy mineral fraction, more unique silicate species can help determine the specific source area (provenance) of margin sediments. This approach is often limited because of regionally common mineralogy, but researchers have begun to use isotope ratios to target more precisely margin sediment source areas. Since ocean margin sediments and deposits are closely tied to continental fluxes, such detailed studies are critical for an integrated understanding of the terrestrial-margin–marine sedimentary system.

Although nearly all siliciclastic margin sediments are derived from the continents, they may be delivered via different mechanisms such as glaciers, rivers, coastal erosion, and wind. Although the latter mechanism is important to deep-sea sedimentation, the others dominate transport to the margin. At high latitudes, glaciers are a major and sometimes sole sediment source. The characteristics of glacial margin sediments is highly variable because of the capacity of ice to transport sediments of all sizes, but in general glacial sediments are coarser and more poorly sorted near the ice front (e.g., till) and become progressively finer and better sorted with distance (e.g., proglacial clays). Examples of glacially dominated modern margins include southeast Alaska, Greenland, and Antarctica. Along most of the world's margins, rivers dominate sediment delivery to the shelf. The grain size of river sediments is typical of margin deposits, mostly including fine sand, silt, and clay-sized particles. However, the range of textures and the total amount of sediment delivered to the margin varies with many factors, including the size, elevation, and climate of the river basin. Because rivers are largely point sources, coastal processes such as waves and tides are important controls on redistributing fluvial sediments once they reach the ocean margin.

In contrast to siliciclastics, carbonate sediments are largely biogenic in origin and are precipitated *in situ* by various corals, algae, bryozoans, mollusks, barnacles, and serpulid worms. Carbonates can be a dominant or significant component of margin sediments where the flux of siliciclastics is not great, often in arid regions or on the outer shelf. Carbonates do not usually form on the slope because of unstable bottom surfaces and depths below the photic zone. In general the production of carbonate sediments is higher in warmer low-latitude waters, but they are found along margins throughout the world. Unlike siliciclastic sediments, carbonates are not widely transported and tend to be concentrated within local regions on the shelf, where the build-up of bioherms and reefs may comprise locally important structural features. Overall, areas of purely carbonate production are rare and limited to ocean margins detached from the continents, such as the Bahamas. In contrast, mixed siliciclastic–carbonate margins are not uncommon and include regions such as the Yucatan and Florida peninsulas, Great Barrier Reef, and Indonesian islands. In very arid regions, margins along smaller marine basins may also support evaporite deposits. These minerals are precipitated directly from the water column to form thick salt deposits. Evaporites are also plastic, low-density sediments that frequently migrate upwards to form salt diapirs, causing major deformation of the overlying margin strata. Evaporite margin deposits are presently forming in the Red Sea and are also an important component of ancient margin sequences around the Mediterranean and Gulf of Mexico.

Along many modern margins, relict and recently eroded sediments comprise the bulk of material that is actively transported on the shelf. An example of a relict margin is the US East coast, where modern fluvial sediment is trapped in coastal estuaries and embayments, thus starving the shelf of significant input. Thus, the shelf there is characterized by a thin sheet of reworked sands (remnant from the Holocene transgression) that overlie much older, partly indurated deposits. Along mountainous high-energy coastlines where rivers are absent or very small, the erosion of headlands can be a major source of sediment to the margin. Often these are also convergent margins with steep shelves that aid in advecting eroded near-shore sediments to the outer shelf and slope. Examples include portions of the eastern Pacific margin and south-eastern Australia (divergent).

Margin Sediment Transport

Rivers are one of the major sources of sediment delivered to the shelf, and thus the fate of river plumes is an important control on the distribution of ocean margin sediments. The initial dispersal of the river plume and the subsequent sediment deposition are controlled by waves, tides, and three basic effluent properties that include the inertia and buoyancy of the plume, and its frictional interaction with the seafloor. In general, wave energy has the effect of keeping sediments close to shore, particularly sands that may be reworked onshore and/or transported alongshore by wave-driven currents. Margins that are wave dominated are typically steep and narrow and found in the high-latitudes, such as southern Australia, southern Africa and the margins of the north and south Pacific (i.e., high wind-stress regions). In contrast to waves, tides force a general onshore–offshore movement of sediment, most significantly along the coast where tidal energy is focused. Tide-dominated margin sediments typically occur on wide shelves and in shallow marginal basins such as the Yellow or North Seas. Compared with waves and tides, the effect of river plume dynamics on sediment dispersal is more varied, particularly as complex feedbacks exist between coastal geology and riverine, wave, and tidal processes.

The fate of sediments along margins is not a simple process of transport, deposition, and burial, but rather involves multiple cycles of erosion, transport, and deposition before being preserved and incorporated into ocean-margin strata (**Figure 3**). Thus, the triad of processes discussed above largely controls the initial phase of dispersal and deposition at the coast and inner shelf. The implication is that sediments undergo a succession of transport steps prior to preservation, and between each step the controlling processes, and thus sediment character, progressively change from riverine to coastal, shelf, and marine-dominated signals. Thus, beyond the coastal zone a different set of mechanisms is responsible for advecting sediments across the margin to the outer shelf, slope, and rise. On the shelf where seafloor gradients are often too low for failure (i.e., mass-wasting events), storms can be a major agent for cross-shelf transport. Two components of storms are involved in this process.

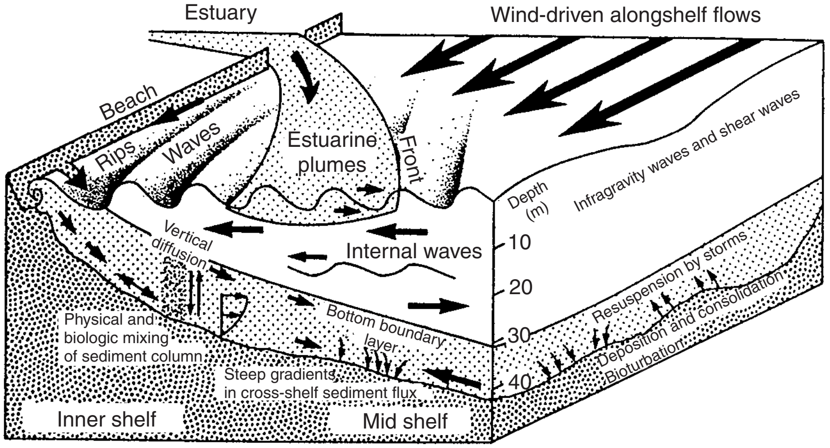

Figure 3 Conceptual diagram illustrating the major physical processes responsible for transporting sediment across the continental shelf. Note the many processes that contribute to the resuspension, erosion, and transport of sediment in this region. (Reproduced with permission from Nittrouer and Wright, 1994.)

First, strong winds generate steep, long-period waves that can resuspend sediment at much greater depths than fair-weather waves (e.g., a storm wave with a 12 s period will begin to affect the seafloor at ~ 110 m depth). Second, resuspended sediments may be transported offshore via a near-bottom return flow (set up by wind and wave stresses) or by group-bound infragravity (long period) waves. Although these mechanisms for seaward sediment transport are well recognized, their magnitude, frequency, and distribution are not precisely known.

A second and well-described mode for sediment transport across ocean margins is the suite of gravity-driven mass movements that includes slumps, slides, flows, and currents (**Figure 4**). This suite comprises nearly a continuum of properties from the movement of consolidated sediment blocks as slumps and slides to the superviscous non-Newtonian fluids of debris and sediment flows to the low-density suspended load of turbidity currents. Mass wasting events are common, widespread, and most frequently occur where slopes are oversteepened and/or sediments are underconsolidated (i.e., low shear strength). These last two factors are related since the threshold for oversteepening is partly a function of the sediment's shear strength, with possible failure occurring at gradients $< 1^\circ$ in poorly consolidated sediments (e.g., 80–90% water content) and relative stability found on slopes of 20° for well-consolidated material (e.g., 20–30% water content). Many other factors also contribute to mass movements including ground-water pressure, subbottom gas production, diapirism, fault planes, and other zones of weakness. In addition to these intrinsic sedimentary characteristics, trigger mechanisms are an important control on mass movements. Triggers may include earthquakes, storms, and wave pumping, each of which may have the effect of inducing shear along a plane of weakness or disrupting the cohesion between sediment grains (i.e., liquefaction). Where trigger mechanisms are frequent and intense, such as along a tectonically active or high-energy margin, mass wasting may occur in deposits that would be stable in a passive, low-energy setting.

Although storm activity can be important on the shelf, mass movements are by far the most dominant mechanism for transferring sediment to the slope and rise. Indeed, estimates indicate that up to 90% of continental rise deposits derive from turbidity currents. In terms of their occurrence, slumps (movement of consolidated sedimentary blocks) are most common along steep gradients such as the

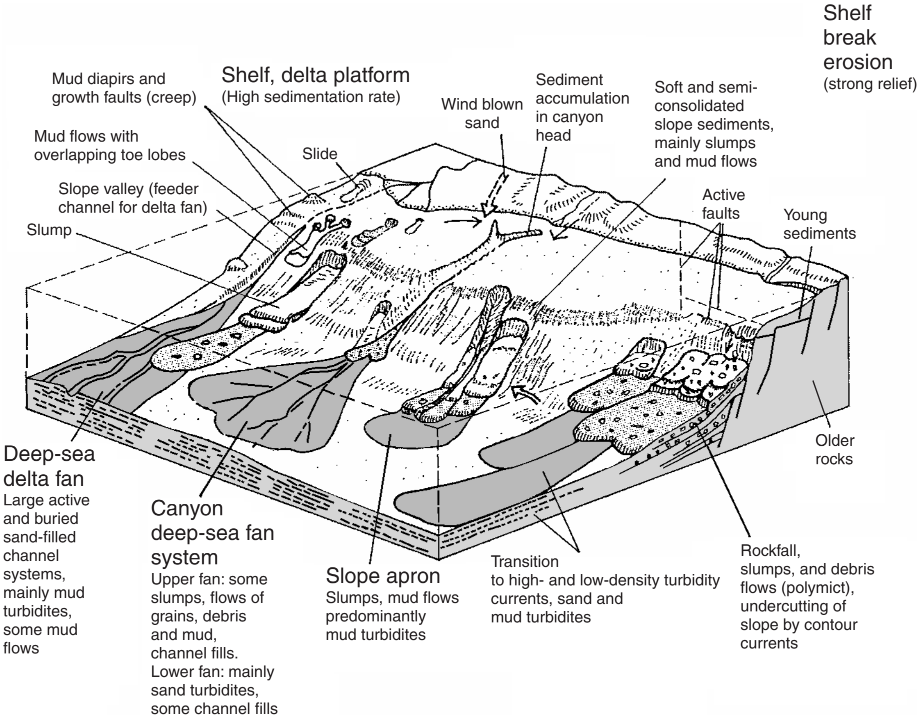

Figure 4 Summary diagram of sedimentary features and transport mechanisms typical of continental margins. Note the variety of mass-wasting events that originate on the slope and extend onto the rise. (Reproduced with permission from Einsele G (1991) Submarine mass flows, deposits and turbidities. In: Einsele G *et al.* (eds) (1991) *Cycles and Events in Stratigraphy*. New York: Springer-Verlag.)

continental slope or along the channels and walls of submarine canyons. Slumps and slides may move over distances of meters to tens of kilometers, and at rates of centimeters per year to centimeters per second. Although slumps and slides do not frequently travel great distances, these energetic events often generate turbidity currents at their front, which can travel hundreds of kilometers across shallow gradients of the continental shelf. Although turbidity currents occur throughout the world, the development of thick and extensive turbidite deposits is largely a function of margin structure, where the trenches and seafloor topography of collision margins inhibit the propagation of these flows (see earlier discussion of **Figure 2**).

Margin Stratigraphy

Strata Formation

Because of the important role that margin sediments play in geochemical cycling (both natural and anthropogenic inputs), there has been a great deal of interest in how seafloor strata are formed and what sort of physical, biological, and chemical impacts sediments undergo before being buried. These processes and controls on strata formation are also of great significance for interpreting the record of Earth's history preserved in ocean-margin deposits. Initially regarded as a one-way sink for organic carbon, dissolved metals, and coastal pollutants, the role of margin sediments has since been shown to be complicated by physical and biological processes that may alter chemical conditions (e.g., redox) and continue re-exposing sediments as deep as several meters to the water column and biogeochemical exchanges. Thus, through mixing processes, seafloor sediments may remain in contact with the water column for 10^1–10^3 years before being permanently buried. In order to quantify the effective importance of biological mixing relative to burial rate, the nondimensional parameter (G) states that

$$G_{\mathrm{b}} = \frac{D_{\mathrm{b}}/L_{\mathrm{b}}}{A}$$

where D_{b} represents the rate of biological (diffusive) mixing, L_{b} is depth of mixing, and A is the sedimentation rate. Field values of G are often 0.1–10, which falls within the range of codominance between mixing and sedimentation. Although the parameter G_{b} reflects the intensity of biological effects, physical mixing (G_{p}) may be better represented by $T_{\mathrm{p}}/L_{\mathrm{p}}$ for the upper term, where T_{p} and L_{p} are the recurrence interval (period) and depth of physical disturbance, respectively. A diffusive coefficient is not relevant here because physical mixing is primarily caused by resuspension, which results in a complete advective turnover of the affected sediments. The notion that natural mixing intensities fall in the range of codominance is shown by the frequency with which sedimentary sequences are found to be partially mixed (at various scales), displaying juxtaposed laminated and bioturbated strata. Such patterns indicate that mixing is more complex than represented here, but the idea that strata preservation and geochemical availability are a function of sedimentation rate (i.e., burial) versus the rate and depth (i.e., exhumation) of mixing remains a useful, if imperfect, manner in which to consider these processes.

In a spatial sense, the dynamics of strata formation varies systematically across the ocean margin with changes in the controlling processes. Near to shore, the relatively constant processes of waves, tides, and river discharge support the frequent deposition of very thin strata (mm to cm). Although short-term rates of sedimentation are often high, the thin nature of each deposit gives them a low chance of being preserved due to physical and biological mixing. In contrast, mean sedimentation rates on the outer margin are often relatively low, but deposition is dominated by stochastic events such as storms and mass wasting which generally produce thicker deposits. Therefore, mixing between sedimentation events may only affect the upper portion of the deposit and thus preserve lower strata. Another consideration is that the intensity of biological mixing is generally less in offshore regions than near the coast.

Sequences

One of the most difficult problems in sedimentary geology is scaling up from short-term strata formation as discussed above to longer-term preservation and the accumulation of thick (10^2–10^3 m) sediment sequences that comprise ocean margins. Because the majority of sedimentary deposits formed over a particular timescale have a low chance of being preserved, geologists can only model strata formation across two to three orders of magnitude (e.g., incorporation of a 1 m thick deposit into a 100 m thick sequence, or the chance of a seasonal flood layer being preserved for several decades). In reality six or more orders of magnitude are appropriate, as kilometer thick ancient-margin sequences comprise millimeter scale strata such as tidal deposits, current ripples, and mud layers. Although stratigraphic reconstructions

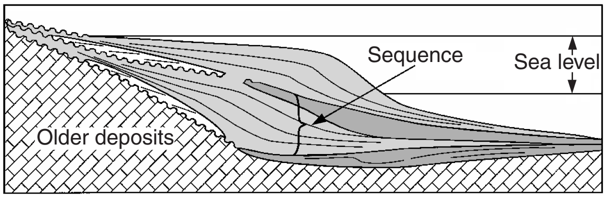

Figure 5 Generalized structure of continental margin sequences formed during cycles of sea-level change. Shown here are two sequences that reflect two periods of sea-level rise and fall. Transgressive deposits (□) are associated with rising seas and the highstand deposits (▨) with a high, stable sea level. The lowstand deposits (■) form under falling and low phases of sea level. Reconstruction of these features from continental margins has provided a record of sea-level change over the past 200 million years.

across this large scale remain too complex, geologists do have a good understanding of the incorporation of meter-scale strata into sedimentary packages that are many tens to hundreds of meters thick. Called *sequences*, these stratigraphic units are defined as a series of genetically related strata that are bound by unconformities (surfaces representing erosion or no deposition) (**Figure 5**).

Sequences are the major stratigraphic units that lead to continental margin growth, with deposition generally occurring on the shelf during periods of high sea level and sediments being dispersed to the slope and rise during sea-level lowstands. Forming over 10^4–10^7 years, the major factors in sequence production are: (1) the input of sediments, (2) space in which to store them (accommodation), and (3) some function of cyclicity to produce unconformity-bound groups of deposits. These factors are largely controlled by tectonics, sea level, and sediment supply. In the long term, tectonics is the major control on accommodation, whereby space for sediment storage is created by isostatic subsidence in response to sediment loading and crustal cooling along the margin. At shorter time scales, sea level controls both the availability of accommodation and its location across the margin. Thus, it can be considered that sea level partly controls the formation of sequences, whereas sequence preservation is dependent on tectonic forcings. Sediment supply is perhaps the fundamental control on the size of a sequence, and thus partly affects its chance for preservation. Sediments of riverine and glacial origin are the major sources for sequence production, and changes in these sources with varying climatic conditions is one mechanism for generating the unconformity bounding surfaces. Sequence boundaries can also be generated by tectonics and eustatic (global) sea-level change, with the latter being significantly affected by the growth and retreat of continental ice sheets.

Conclusions

Although the study of ocean-margin sediments began more than a century ago, the field has grown most significantly in the past 50 years with the birth of marine geology and oceanography. Typical of geological systems, however, relevant research extends across a range of spatial and temporal scales and incorporates a variety of disciplines including geophysics, geochemistry, and sedimentary dynamics. The future of margin sedimentary research lies with the continued integration of these various scales and disciplines, moving toward the development of coherent models for the production and dispersal of margin sediments and their ultimate incorporation into margin sequences. The impacts of such capability would greatly benefit the world's growing population in the areas of energy and mineral resources, climate change, coastal hazards, sea-level rise, and marine pollution. Ongoing research initiatives are currently advancing the field of ocean-margin sediments toward these goals, and nascent programs are providing a promising lead to the future.

See also

Beaches, Physical Processes Affecting. Calcium Carbonates. Clay Mineralogy. Deep-Sea Sediment Drifts. Geomorphology. Glacial Crustal Rebound, Sea levels and Shorelines. Mineral Extraction, Authigenic Minerals. Origin of the Oceans. River Inputs. Sea Level Change. Sea Level Variations over Time. Sediment Chronologies. Storm Surges. Surface, Gravity and Capillary Waves. Tides. Turbulence in the Benthic Boundary Layer.

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OCEAN RANCHING

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Introduction

Ocean ranching is most often referred to as stock enhancement. It involves mass releases of juveniles which feed and grow on natural prey in the marine environment and which subsequently become recaptured and add biomass to the fishery. Releases of captive-bred individuals are common actions when critically low levels of fish species or populations occur either due to abrupt habitat changes, overfishing or recruitment failure from other causes. Captive-bred individuals are also introduced inside or outside their natural geographic range of the species to build up new fishing stocks.

At present 27 countries (excluding Japan) have been involved with ranching of over 65 marine or brackish-water species. Japan leads the world with approximately 80 species being ranched or researched for eventual stocking. This includes 20 shared with other nations and 60 additional species. **Table 1** shows an overview of the most important species worldwide. Many marine ranching projects are in the experimental or pilot stage. Around 60% of the release programs are experimental or pilot, 25% are strictly commercial, and 12% have commercial and recreational purposes. Only a few are dedicated solely to sport fish enhancement.

The success of ocean ranching relies on a knowledge of basic biology of the species that are captive bred, but also on how environmental factors and wild conspecifics and other species interact with the released. This article provides general information on life histories of the three major groups of animals that are being stocked, salmon, marine fish and invertebrates, and an overview of the status and success of ocean ranching programs. It also devotes a short section to the history of ocean ranching and a larger section on how success of stock enhancement is measured.

History

Ocean ranching has a long history going back to 1860–1880 that commenced with the anadromous salmonids in the Pacific. In order to restore populations that had been reduced or eliminated due to factors such as hydroelectric development or pollution, large enhancement programs were initiated on various Pacific salmon species mainly within the USA, Canada, USSR and Japan. In addition, transplantation of both Atlantic and Pacific salmonids to other parts of the world (e.g. Australia, New Zealand and Tasmania) with no native salmon populations was attempted.

Around 1900, ocean ranching was extended to coastal populations of marine fish. Because of large fluctuations in the landings of these, release programs of yolk-sac larvae of cod, haddock, pollack, place, and flounder were initiated in the USA, Great Britain, and Norway. It was intended that such releases should stabilize the recruitment to the populations and, thus, stabilize the catches in the coastal fisheries. There was, however, a scientific controversy of whether releases of yolk-sac larvae could have positive effects on the recruitment to these populations. In the USA the releases ceased by World War II without evaluation. In Norway evaluation was conducted in 1970 when it was shown to be impossible to separate the effect of releases of yolk-sac larvae from natural fluctuations in cod recruitment, a conclusion that led to termination of the program. Recent field estimates of the mortality of early life stages of cod suggest that only a handful of the 33 million larvae, an amount normally released, survive the three first months.

Larvae and juveniles of European lobster (*Homarus gammarus*) have been cultured and released along the coast of Norway for over 100 years. In 1889 newly hatched lobster eggs and newly settled juveniles were released in Southern Norway on an island which has its own continental