Marine Geophysical Data Analysis

Dietmar Müller &
Michael Hughes

School of Geosciences
Division of Geology and Geophysics

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University of Sydney
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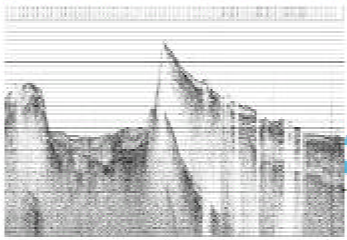

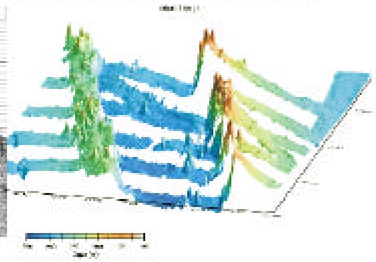

Marine Geophysical Data Analysis

MARS 3001 (MS 3)

Dynamics of Ocean Basins and Margins

GEOP 3201, Part 1

R. Dietmar Müller

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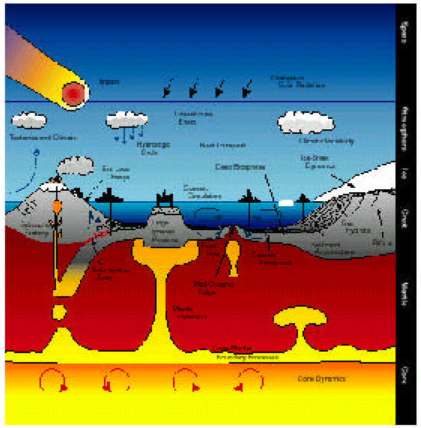


Dynamics of Ocean Basins and Margins

MARS 3001 (MS 4)
GEOP 3201, Part 2

R. Dietmar Müller

Lectures and Practicals

Dr. Dietmar Müller
Office: Edgeworth David Building, Rm 512
Phone: 9351 2003 Email: dietmar@es.usyd.edu.au

Dr. Michael Hughes
Office: Edgeworth David Building, Rm 522
Phone: 9351 5190 Email: michaelh@mail.usyd.edu.au

Lectures: Monday, Tuesday, Thursday 9-10 am
Practicals: Monday, Tuesday, Thursday 10.15 -1 pm

Edgeworth David Lab 5 (R 513)

Lecture Program

Seismic data, multibeam imagery, potential field and heatflow data (RDM)		
Week 1	Monday Tuesday Friday	Signal definitions and properties Convolution Fourier transforms
Week 2	Monday Tuesday Friday	Spectral density functions Coherence and basic statistics Seismic reflection data acquisition
Week 3	Monday Tuesday Friday	Seismic reflection data processing 1 Seismic reflection data processing 2 Seismic refraction data, integrating well and seismic data
Week 4	Monday Tuesday Friday	Multibeam seafloor imaging Potential field data Heat flow data

Weeks 5-7

Nearshore Oceanographic Data (MH)		
Week 5	Monday Tuesday Friday	Methods of tidal data collection Harmonic analysis of tidal data Tidal filters
Week 6	Monday Tuesday Friday	Dealing with rotary tidal currents Methods of wave/current data collection in the surf zone Auto- and cross-correlation analysis of surf zone waves
Week 7	Monday Tuesday Friday	Auto- and cross-spectral analysis, filtering of surf zone waves Dealing with turbulence data Measuring sediment transport in the surf zone

Weeks 8-11

Week 8	Monday Tuesday Friday	Physiography of ocean basins and margins; Plate tectonic intro Plate tectonics and rotations The magnetic field
Week 9	Monday Tuesday Friday	Modelling marine magnetic anomalies 1 Modelling marine magnetic anomalies 2 Plate flexure and lithospheric rheology 1
Week 10	Monday Tuesday Friday	Plate flexure and lithospheric rheology 2 The gravity field Gravity modelling 1
Week 11	Monday Tuesday Friday	Gravity modelling 2 Heat flow 1 Heat flow 2

Weeks 12-14

Week 12	Monday Tuesday Friday	Oceanic lithospheric evolution: depth-age, heat flow-age Introduction to Mantle convection Modelling mantle convection 1
Week 13	Monday Tuesday Friday	Modelling mantle convection 2 Sedimentary basins 1D Extensional basin modeling 1
Week 14	Monday Tuesday Friday	1D Extensional basin modeling 2 2D Basin modeling Foreland basin modeling

Assessment

The assessment for this course module is based on 75% coursework and 25% exam. The coursework assessment is based on practical exercises using Matlab and other Linux software. The examination will be 2 hours long and will be held during the examination period at the end of semester.

Bibliography

Blondel, P., and Murton, B.J., 1997, Handbook of seafloor sonar imagery: Chichester, John Wiley & Sons, 314 p.

Jones, E.J.W., 1999, Marine geophysics: Chichester; New York, Wiley, 466 p.

Emery, W.J., and Thomson, R.E., 1998. Data Analysis Methods in Physical Oceanography. Pergamon, 634 pp.

Komar, P.D., 1998. Beach Processes and Sedimentation. 2nd Edition. Prentice-Hall, 544 pp

Pugh, D.T., 1987. Tides, Surges, and Mean Sea Level. Wiley, 472 pp.

Robinson, I.S., 1985. Satellite Oceanography: An Introduction for Oceanographers and Remote Sensing Scientists. Chichester, 455 pp.

Lecture 1

Signal Processing:

- Examples
- Basic signal definitions and properties

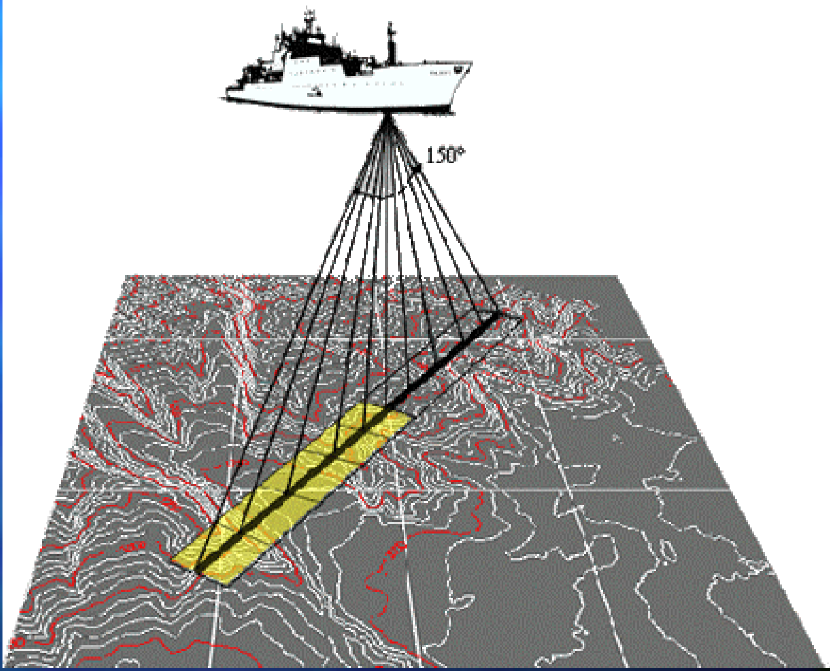
The purpose of signal processing

- Most signals in real life have one or more component **deterministic** components, while other components are **random or stochastic** components.
- most common form of a random component: **noise**
- **Noise** may contaminate a signal in a variety of ways, e.g. **additive, multiplicative, or convolutional.**

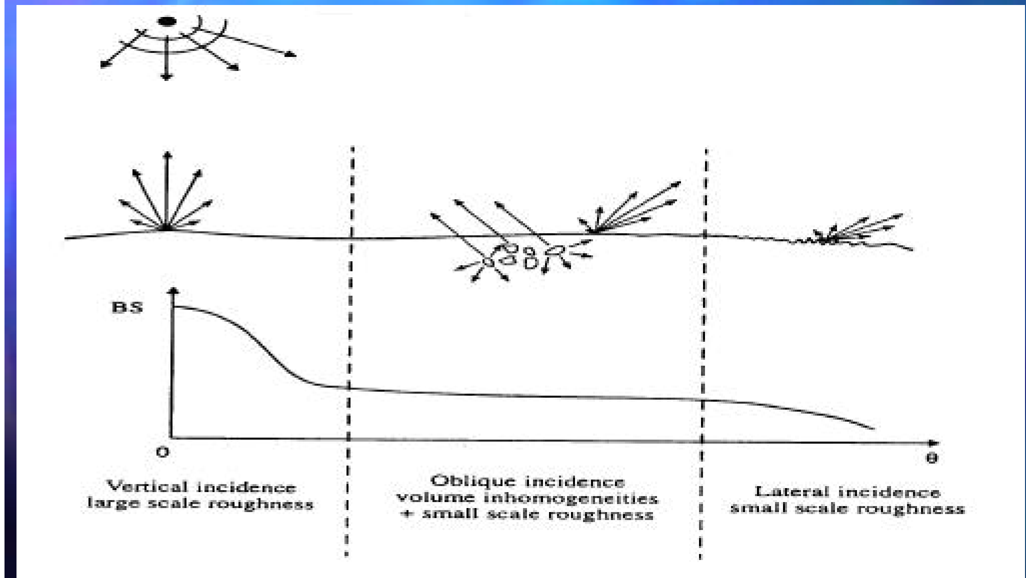
- Also the stochastics of noise can be extremely variable branch of applied statistics called **stochastic processes**
- General purpose of signal processing:
- **To extract useful information from a signal**

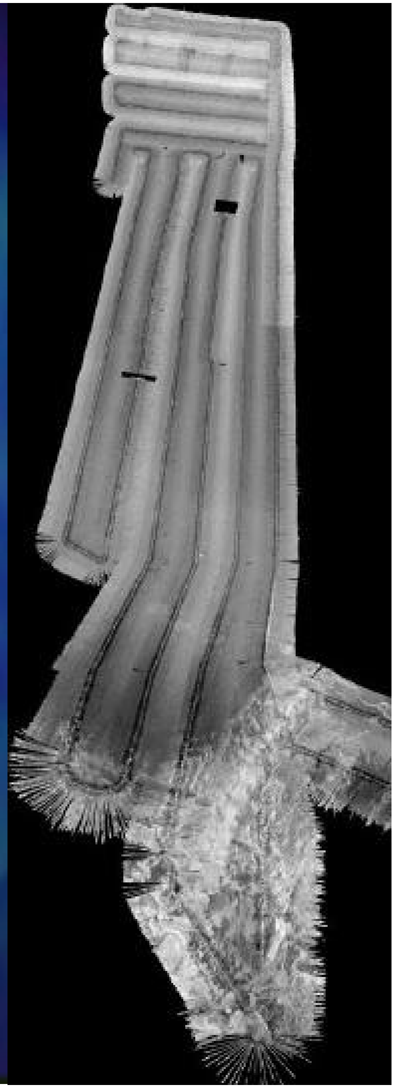
Swath Mapping

- SIMRAD EM12-D.
- 2 adjoining sonars with 81 beams each.
- Effectively 152 beams due to overlapping.

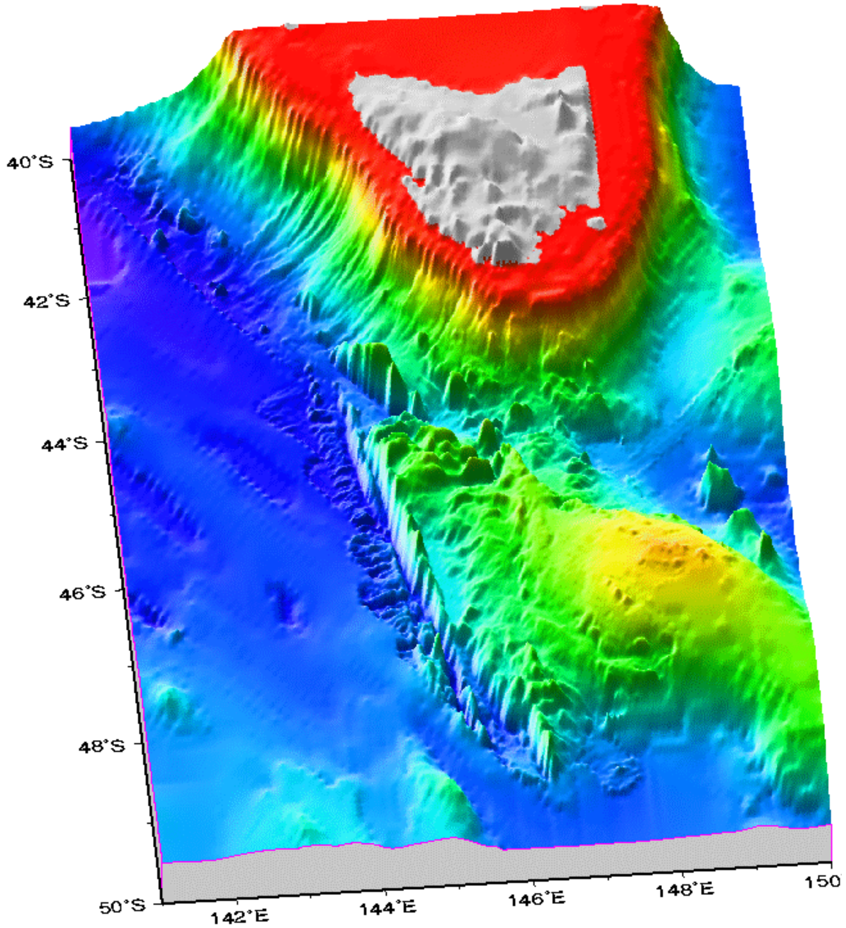


Seafloor Backscatter Image



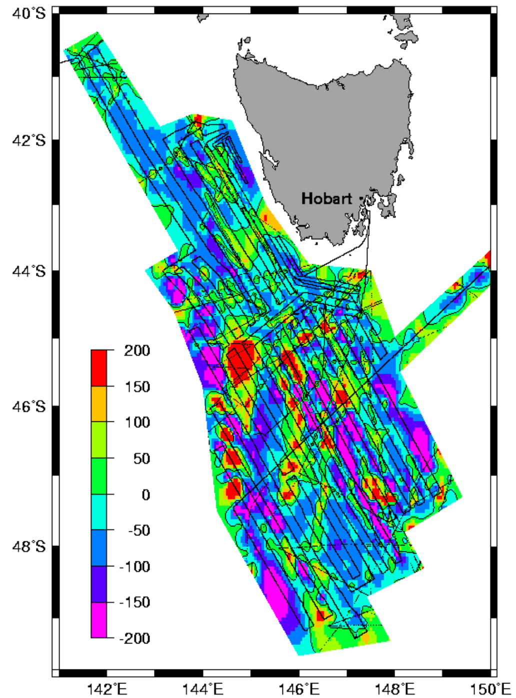


Tasmania



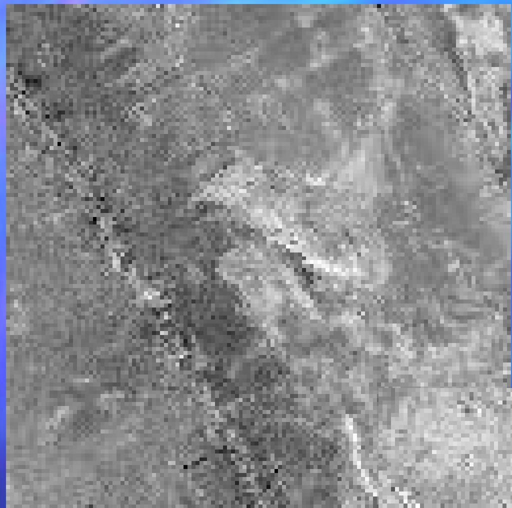
Shipboard Swath-Bathymetry + ETOPO5

Total Field Magnetic Anomaly

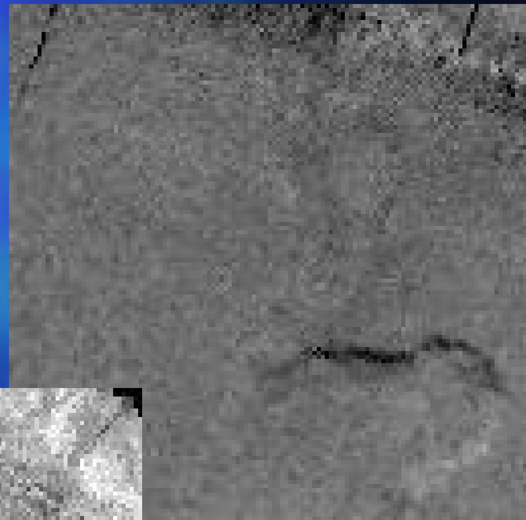


Lithology identification

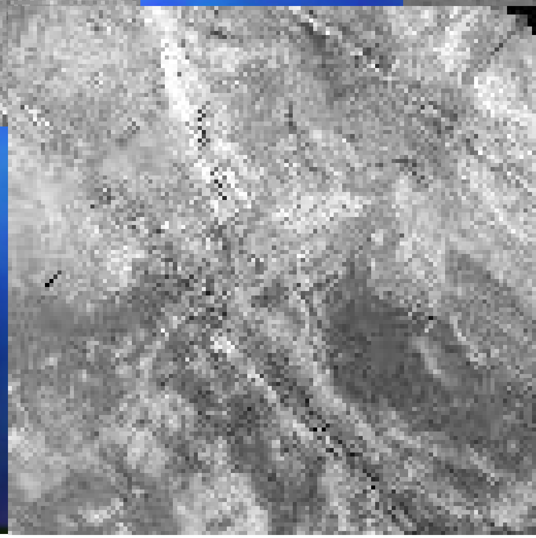
Sand/Gravel



Mud



Outcrop



Example: deterministic information corrupted by additive noise

- Signal processing aims to remove as much of the noise as possible, thus enhancing the information content of the signal –> **filtering**

- There are other important reasons for understanding signal processing, which can be loosely grouped into four categories.
- **1. Description**
- **2. Inference**
- **3. Prediction**
- **4. Control**

Description and Inference

- **Description** aims to identify the **principal components**, which constitute a given measured signal
- e.g. describe signals in terms of their frequency components, i.e. **spectral representation** of signals.
- **Inference** refers to the process of **making plausible hypotheses about the underlying mechanisms which gave rise to the measured signals**:
- What can we learn about physical processes in the earth from various geophysical signals?

Ocean Drilling: JOIDES RESOLUTION


Dipole shear imager


Logging tools

Downhole logs versus data from physical property measurements

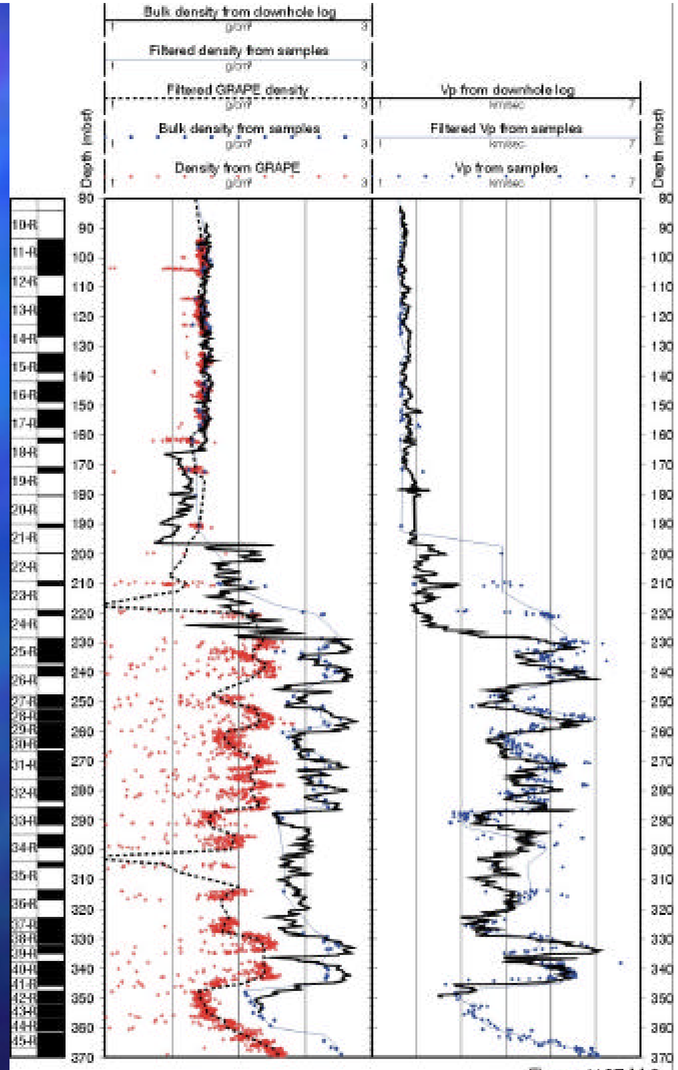


Figure 1137-M-2

Prediction and Control

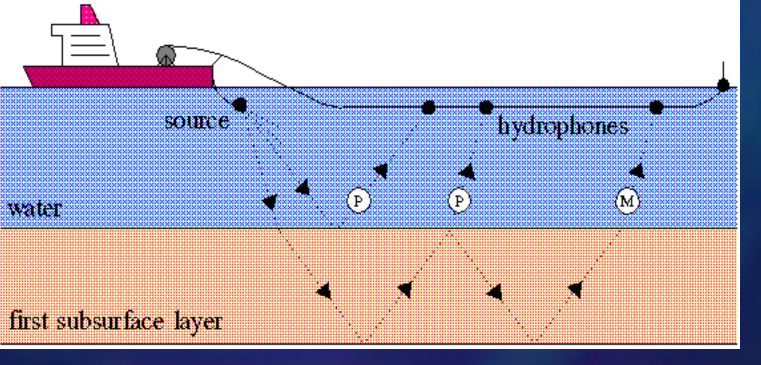
- **Prediction** is the process of **making intelligent forecasts about future behaviors of a measured signal**.

- **Control** is the process of **initiating or modifying other signals based on the information extracted from one or more measured signals**. Control processes are very important in engineering and in designing particular sound sources for seismic experiments and exploration.

Examples of Signal Processing:

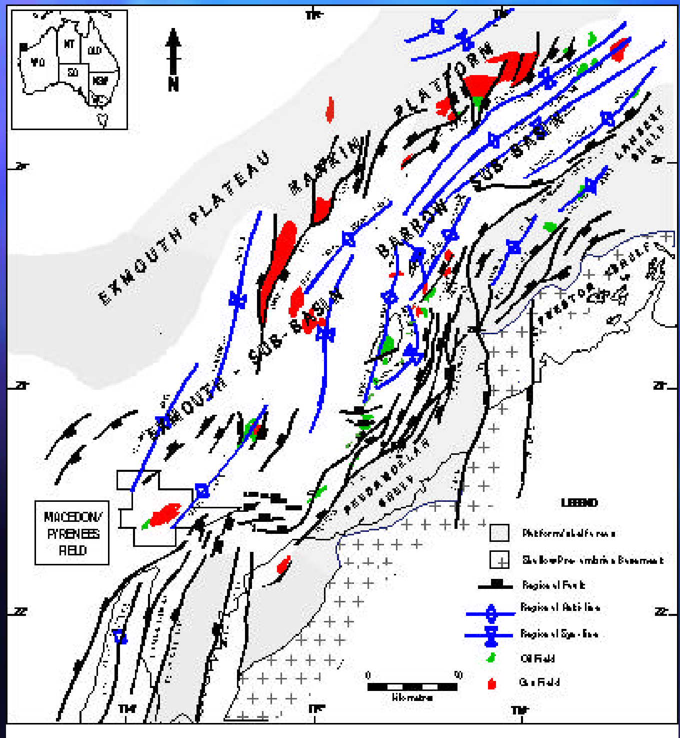
1) *Reflection Seismology*

- **Seismic waves** are generated at the surface of the earth, for example at earthquakes or due to an artificial source.
- They are directed downwards and may penetrate the sediments, crust, the mantle and core.



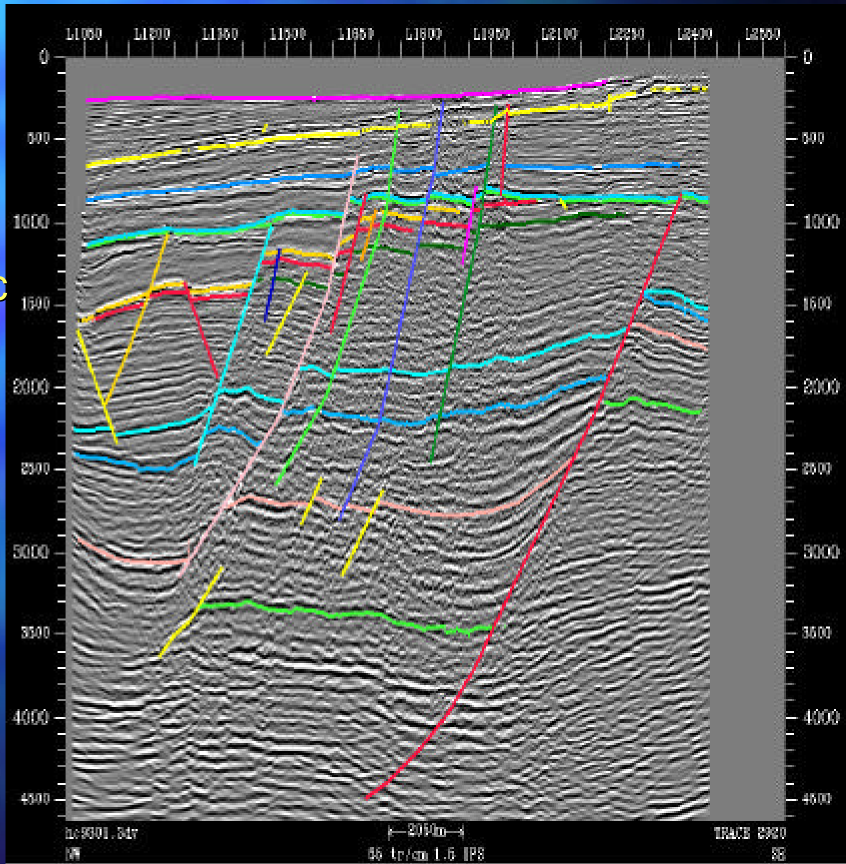
3D seismic data

- 60 km N of Exmouth
- 700 km^2 seismic grid



Seismic reflection structural analysis

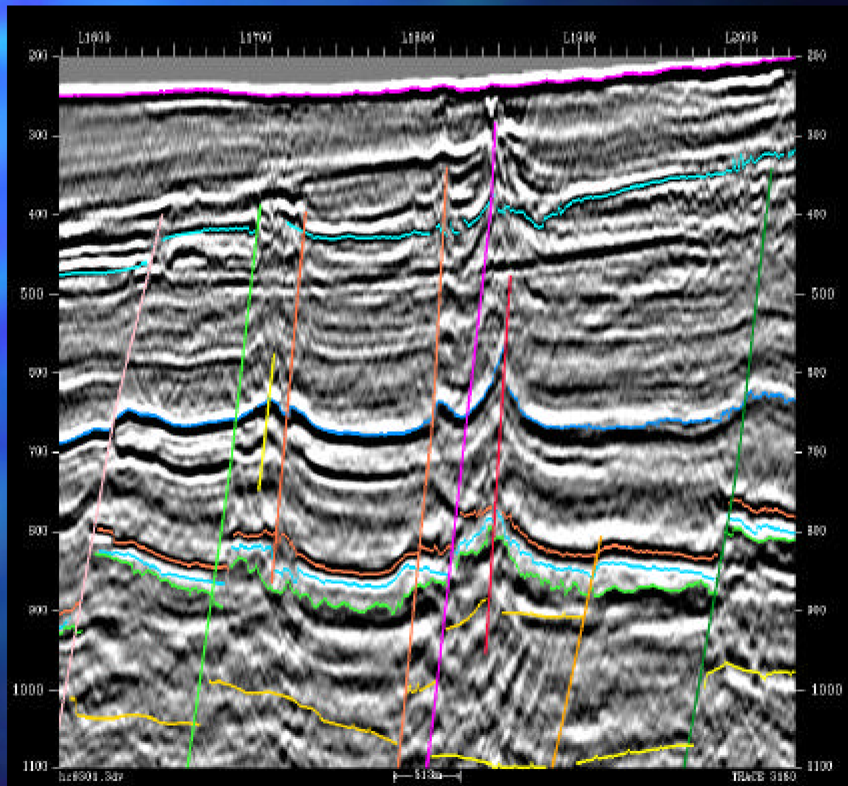
- Horizons mapped to represent major tectonic events on NWS
- Analyse timing and styles of faulting



Seismic data structural analysis

Timing of fault activity

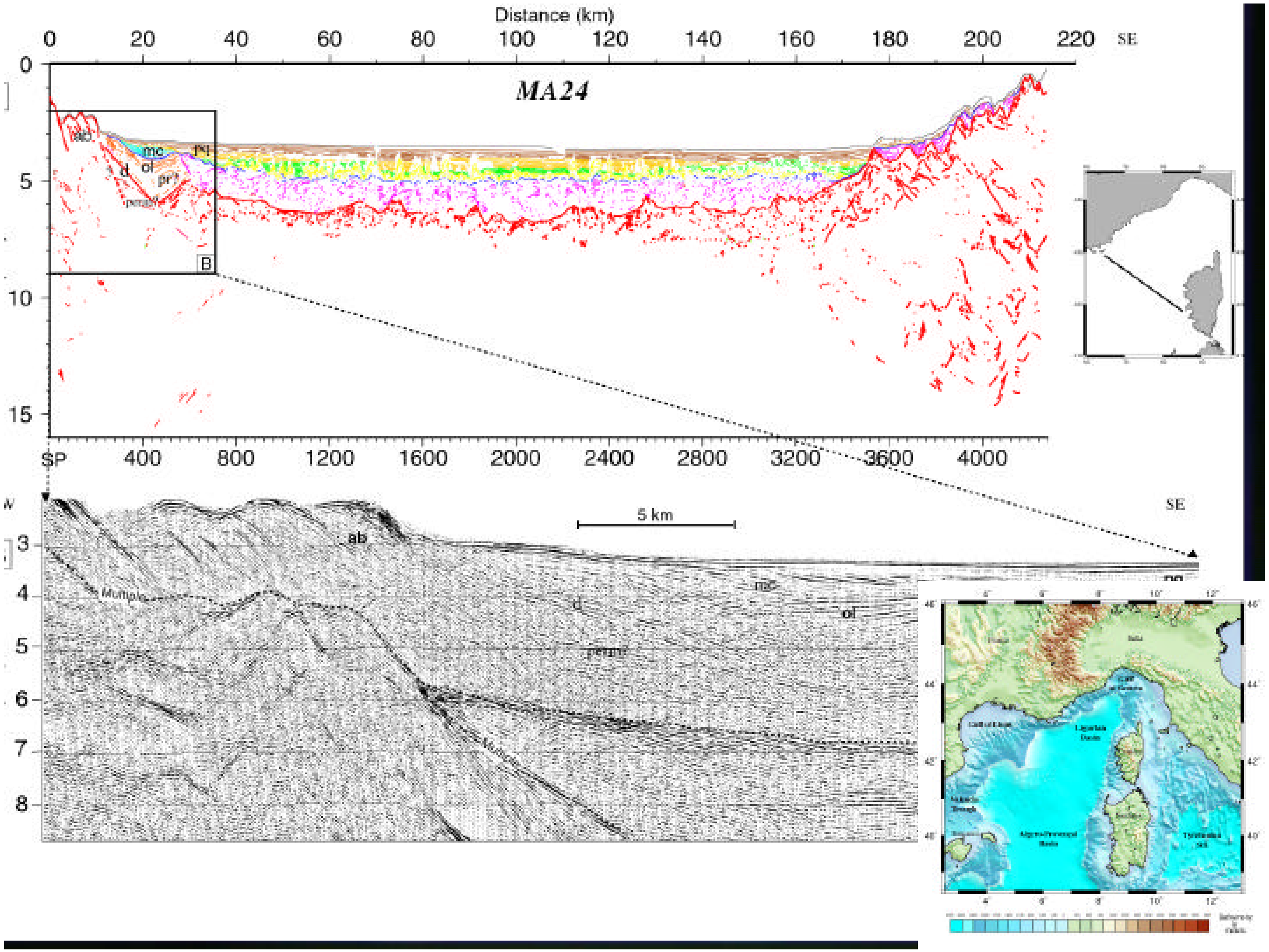
- Timing of fault activity - correlate with well data
- Min age of fault
  Reactivation can be assessed by inversion structures or significant changes in dip θ though similar lithologies
- E.g.: Purple fault has changed sense through time



The **recorded signals** contain information about the subsurface structure and lithology, but the seismic signal is a complicated mixture of a multitude of possible signal components including

1. source signature	- deconvolution
2. random noise due to scattering	- stacking
3. signal energy loss due to attenuation	- true amplitude recovery
4. interference from 50Hz power lines	- notch filtering
5. corruption by ground-roll	- muting & band pass filtering
6. multiple reflections	- predictive deconvolution
7. distortion due to ray-pathing	- migration
8. reflectivity sequence of the earth's layers	- desired signal

The **first component above** (Earth's reflectivity sequence) is the information the geophysicist needs to infer structure and lithology. All the remaining components need to be removed.

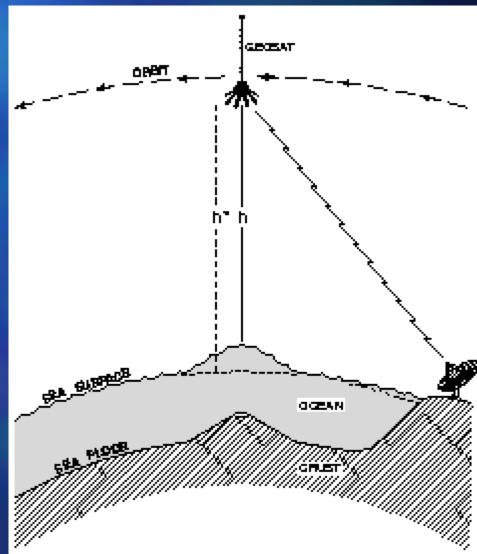


Distance (km)
0
20
40
60
80
100
120
140
160
180
200
220
SE
MA24
ab
mc
ol
d
pr?
5
10
15
B
SP
400
800
1200
1600
2000
2400
2800
3200
3600
4000
5 km
SE
ab
Multiple
d
ol
3
4
5
6
7
8
Gulf of Lion
Ligurian Basin
Algero-Provençal Basin
Tyrrhenian Sea

Examples of Signal Processing:

2) *Satellite altimetry*

- **Satellite radar altimeters map the distance between themselves and the sea level.**
- By measuring the sea surface heights, the altimeter **maps the marine geoid** as well as **"noise" from oceanic currents, waves, and tides.**



What is "noise" and what is "data"?

- What is noise to the geophysicist (currents, waves, tides) actually represents the physical oceanographer's data, whereas the oceanographer's noise (geoid anomalies from density anomalies in the earth) represents the geophysicist's data.
- Difficulties in tracking of the satellite result in apparent DC- (very long-wavelength) shifts in the height of the geoid so that repeat cycles cannot be simply stacked to reduce the noise. The solution to this problem is differentiation of the geoid heights before stacking, and integration after stacking.
- The integration is replaced by a frequency domain operation called Hilbert transforming, which allows us to compute gravity anomalies directly from the horizontal derivative of the geoid heights.

The altimetry records and processing operations include

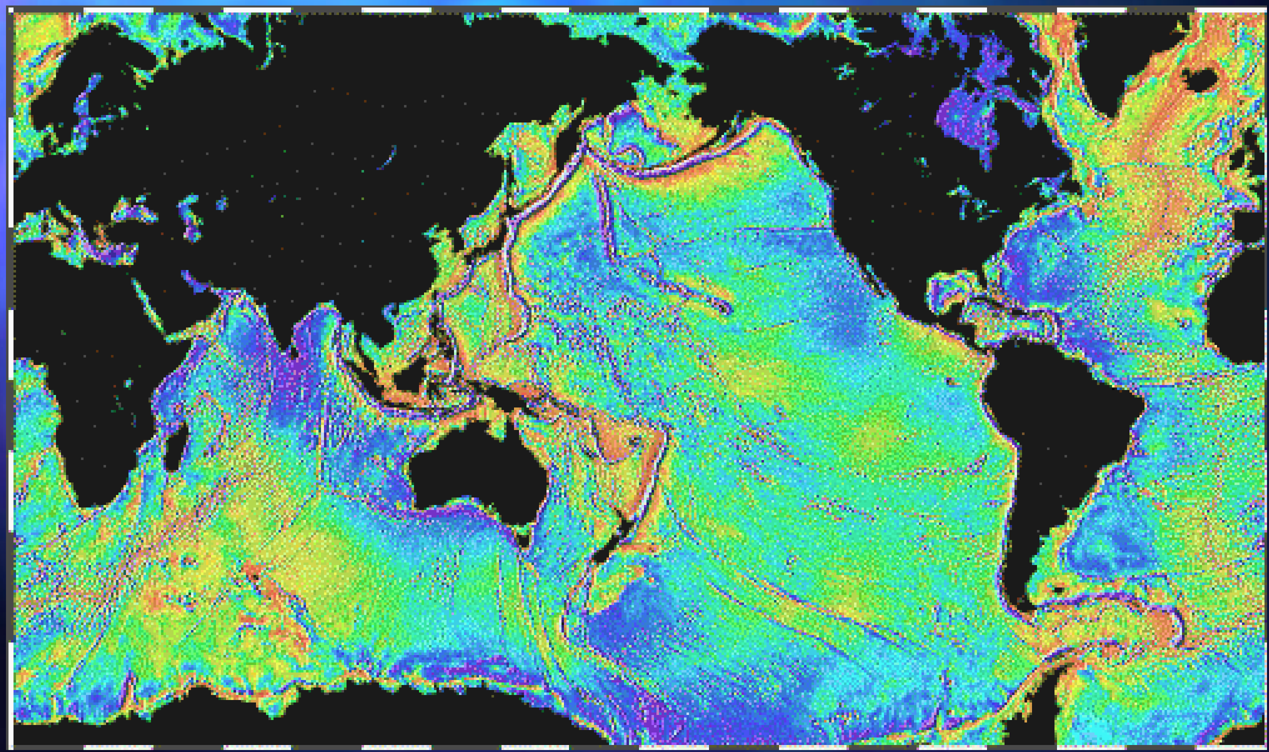
- 1. data over land and ice - editing
- 2. ocean tides - correction applied
- 3. solid earth tides - correction applied
- 4. ionosphere and troposphere delay - correction applied
- 5. sea surface height which reflects geoid - desired signal
- 6. low frequ. radial orbit error (unknown bias) - differentiation (results in the horizontal gravity gradient)
- 7. high frequency noise - stacking of repeat cycles
- 8. vertical gravity anomalies - obtained from stacked horiz. grav. grad. data by Hilbert transformation

- The and result of several decades of collecting satellite altimetry data is a global marine geoid map, which has been used to compute a marine free-air gravity map

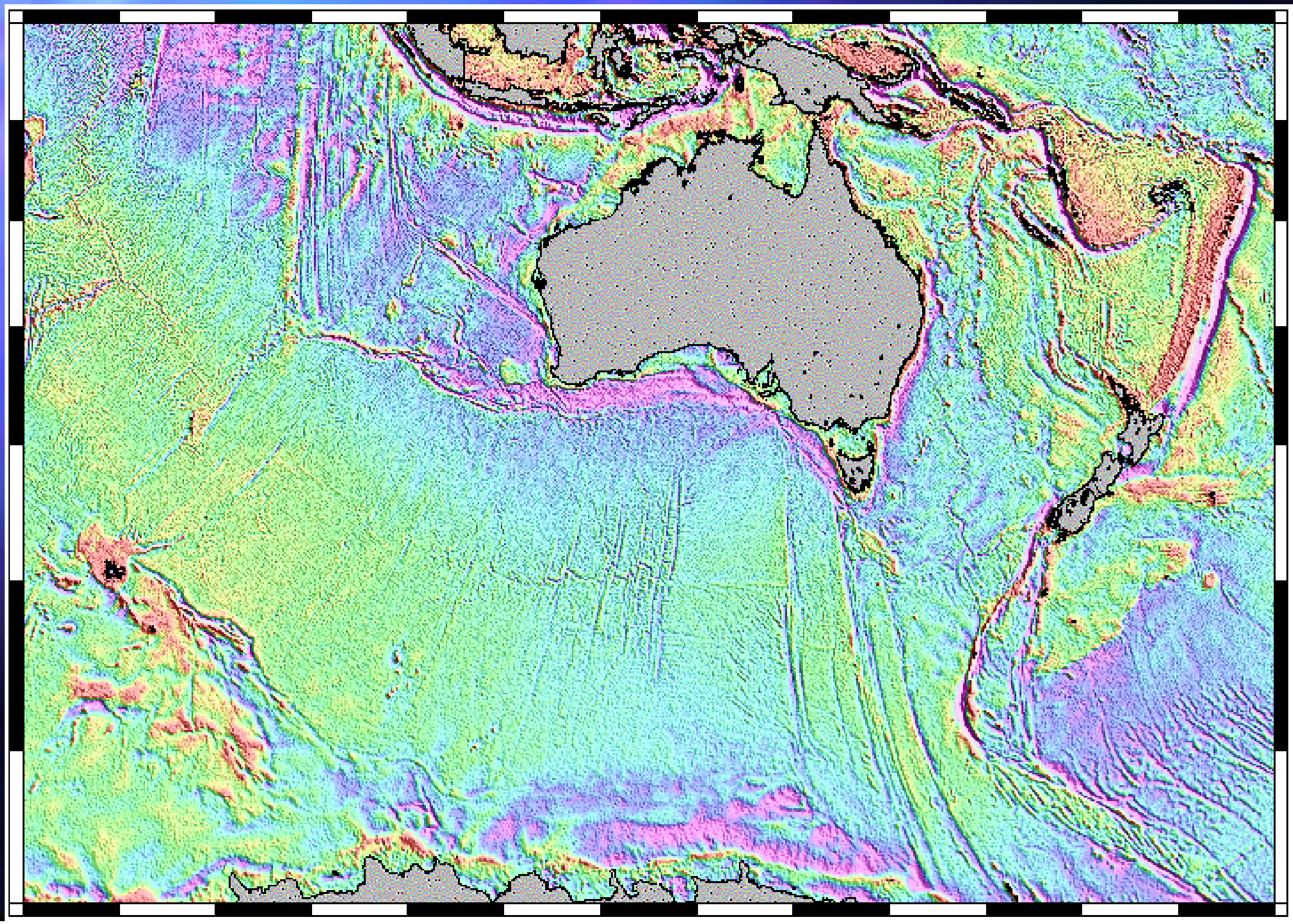
Radar altimetry

Measuring the distance between the satellite and the sea surface by radar. These data are used to provide a geoid map. The geoid is an equipotential field, and describes the Earth's shape. A gravity map can be derived from the geoid data. Marine gravity data reveal many tectonic features of the ocean basins in detail.

Marine free-air gravity grid



Marine gravity field from GEOSAT



Digital signals

- Discrete-time (digital) signals are represented by a variable with an **integer subscript**, such as x_t

- The subscript t can be thought of as the sample number, but we will commonly take $-8 < t < 8$ even though the signal may have only a finite number of non-zero samples.

- The time interval between samples is assumed to be a fixed constant called the **sampling interval** or **sampling rate**. The $t=0$ sample is called the time origin of the signal.

Analog signals

- Continuous-time (analog) signals are represented in the usual functional notation given to functions of a real variable.

$$x(t) = cos(2\ p\ t/T)$$

represents a continuous time cosine wave of frequency $1/T$