Tools for Stratigraphic Analysis

Contents

- Introduction
- Methods of Study: Modern Environments
- Methods of Study: Ancient Deposits
- Summary

Introduction

- **Basin analysts use a variety of methods to study modern and ancient basins**
- **For now, we will focus on the basin fill: sediments/sedimentary rocks**

Introduction

- **Questions:**
  - **Where do they come from?**
  - **How are they deposited?**
  - **What are their properties?**
  - **What are controls on deposition?**
  - **Etc.**
- **Both "direct" and "indirect" methods are used to study basin fills**

Modern Environments

- **Indirect Observation – Selected Methods**
- **Remote sensing:**
  - **Satellite imagery**
  - **Aerial photography**

Mississippi Delta

Kromme Estuary – S. Africa

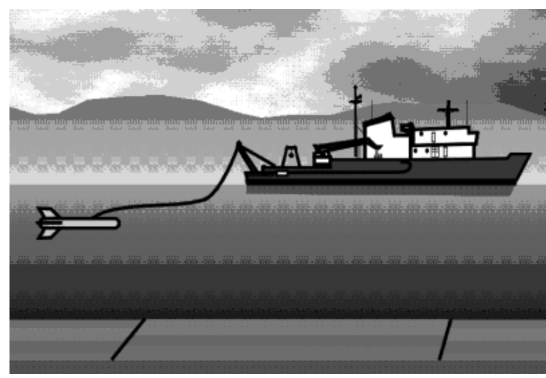
Modern Environments

- Indirect Observation – Selected Methods
- Marine realm: use sound (light doesn’t travel far through water)
  - “Low Frequencies” (<5 kHz) – penetration (sub-bottom profiling)
  - “High Frequencies” (>10 kHz) – bathymetry; (100s kHz – seafloor imaging)

Modern Environments

- Indirect Observation – Selected Methods
  - Bathymetry – measure time required for acoustic pulse to travel from ship to seafloor and back
  - Single track below ship
  - Need to know velocity of sound in water (~1450 m/s)

Distance = velocity x time



Modern Environments

- Indirect Observation – Selected Methods
  - Swath Bathymetry – beams “sweep” across seafloor (10s -> 100s kHz)
  - Generate 3-D coverage of seafloor bathymetry

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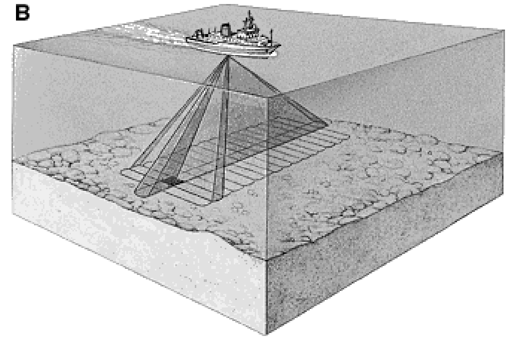
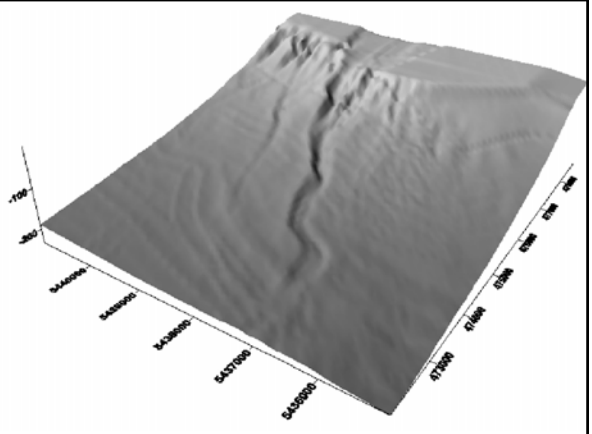
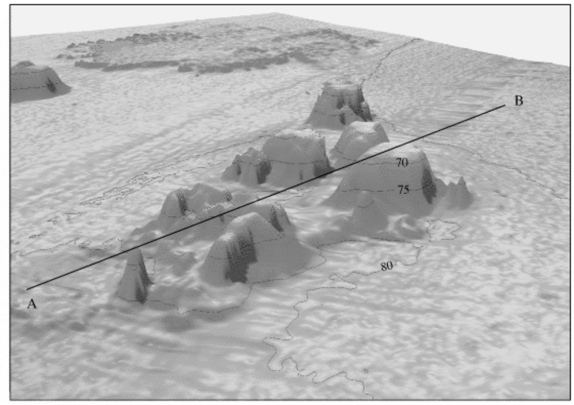
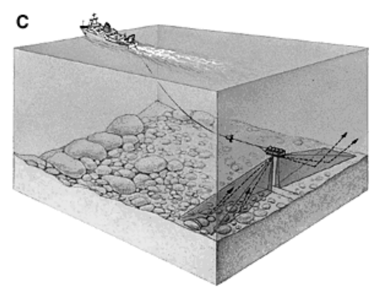


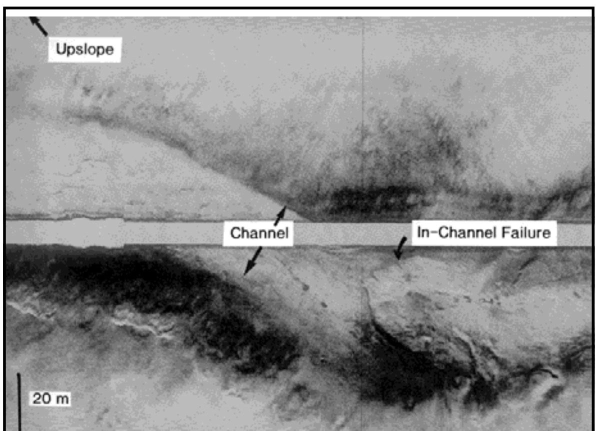




Modern Environments

- **Indirect Observation – Selected Methods**
  - **Side-scan sonar**
  - **Backscatter from high-frequency (10s, 100s of kHz) sweep provides image of seafloor**
  - **No true bathymetry information**
  - **Digital manipulation for geometry correction, mosaics**



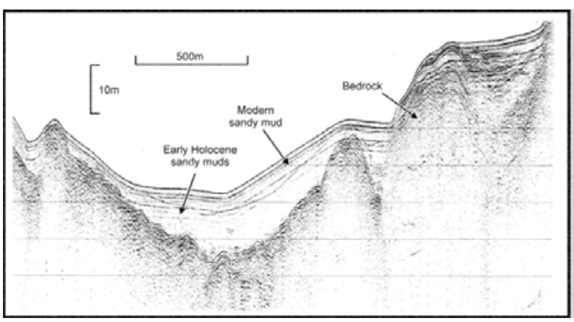


Modern Environments

- **Indirect Observation – Selected Methods**
  - **Sub-bottom profiling ("single-channel seismic", "high-resolution seismic")**
  - **Lower frequencies (100s Hz -> ~ 5 kHz) penetrate the seafloor**
  - **Reflections at changes in physical properties ("bedding")**
  - **Resolution proportional to frequency (F)**
  - **Penetration inversely proportional to F**

Modern Environments

- **Indirect Observation – Selected Methods**
  - **See internal structure of seafloor features**
  - **Penetrate meters -> 100s meters**
  - **Vertical axis in time (two-way traveltime)**

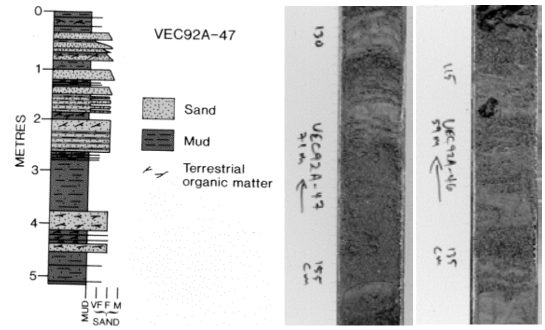


Modern Environments

- **A variety of "direct" methods are used to study modern environments**
  - **Observation/measurement**
  - **Sampling**

<u>Shoaling wave ripples</u>

<u>Planar laminations - Beachface</u>

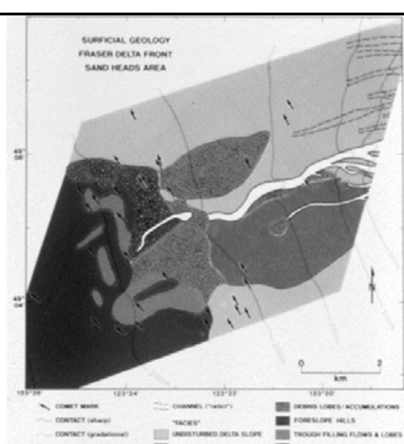


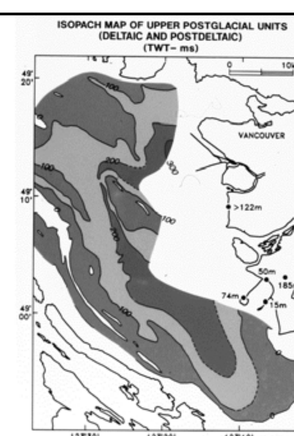
•Cm -> dm-scale intebedding of sand and mud
•Seasonal discharge variability with superimposed tides
  • Sands deposited during spring peak discharges from suspension

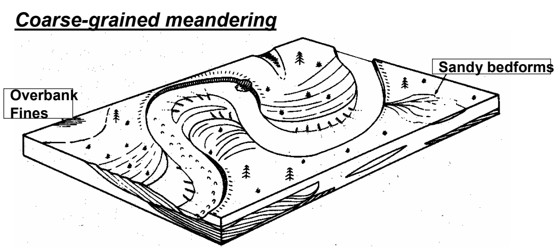
Coral Reef – Red Sea

Modern Environments

- **Some Products:**
  - **Maps – surficial features, isopachs (thickness), isochrons (thickness in time), grain size, etc.**
  - **Facies models**

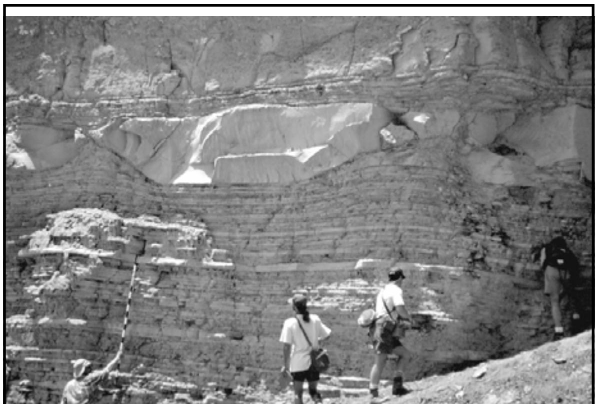






Ancient Environments

- Direct Observation - Selected Methods
  - Outcrop – measured sections, samples, paleocurrents, paleontology
  - Core – measured sections, samples, micropaleontology
  - "Photogeology" (panoramas, mosaics)



Cretaceous Shoreface/Shelf Deposits, Book Cliffs, UT

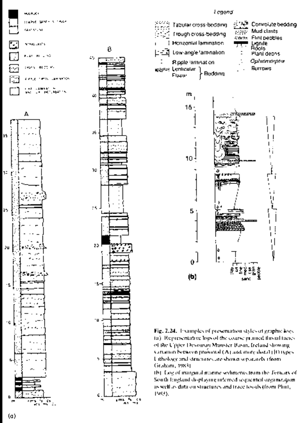
Proterozoic Turbidites, Cariboo Mountains, BC

Ancient Environments

- Outcrops: What to Measure:
  - Lithology
    - Grain size, mineralogy, colour, etc.
  - Thickness of stratigraphic units
  - Sedimentary structures
    - Type, orientation
  - Fossil content
- Take samples
  - Petrography
  - Fossils
  - Geochemistry
  - Etc.

Ancient Environments

- Measured sections are drafted as "graphic logs"
  - Show vertical changes in lithology, grain size, sedimentary structures, etc.
  - Usually show a "schematic" drawing



Graphic Log

Displays outcrop description

Vertical axis: elevation above base of section

Horizontal axis: grain size

Symbols for lithology, structures, etc.

Drilling:

A source of subsurface information

Ancient Environments

- Cores may be taken during drilling
  - Oil patch – cores taken "infrequently" (expense); Canada: cores must be given to government repository
  - Mining – cores commonly taken (small diameter); cores sometimes/often(?) discarded

Ancient Environments

- Cores: What to Measure:
  - Lithology
    - Grain size, mineralogy, colour, etc.
  - Thickness of stratigraphic units
  - Sedimentary structures
    - Type
  - Fossil content
- Take samples
  - Petrography
  - Fossils
  - Geochemistry
  - Etc.

Ancient Environments

- Measured sections are drafted as "graphic logs"
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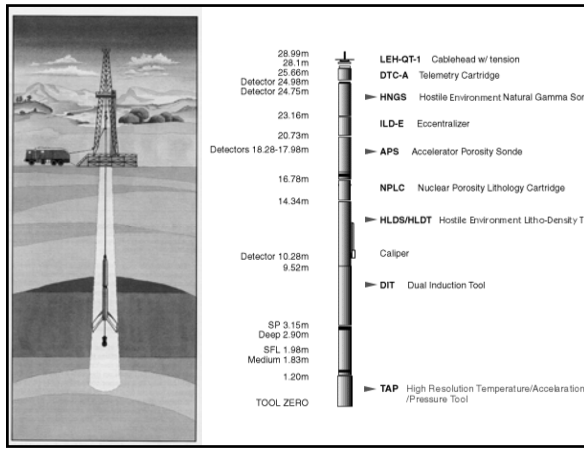
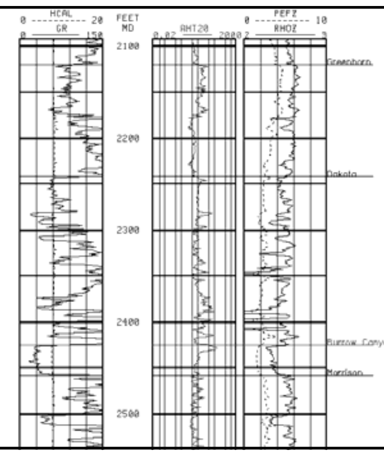
Ancient Environments

- **Indirect Observation - Selected Methods**
  - **Wireline logs**
  - **"Sonde" pulled up borehole after drilling**
  - **Measures properties of rocks/fluids**
    - **Gamma Ray – natural radioactivity (lithology)**
    - **Resistivity – electrical properties (fluids)**
    - **Etc.**
  - **Correlation, formation evaluation, etc.**





Gamma Ray Log

- **Principles**
- **Three naturally radioactive isotopes abundant in nature:**
  - **Uranium series – fixed by fine-grained organic material**
  - **Thorium series – absorbed by clay minerals**
  - **Potassium-40 – part of clay mineral composition (particularly illite)**

Gamma Ray Log

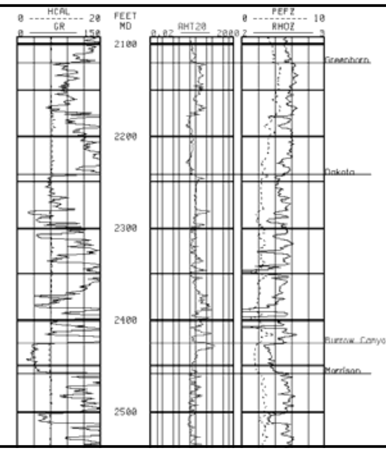
- **Gamma ray tool: scintillation detector (originally Geiger counters)**
- **Measured in American Petroleum Institute (API) units**
  - **Arbitrary scale**
  - **Calibration in API test pit at U. of Houston – 200 API = 2x average "mid-continent shale"**

Gamma Ray Log

- **Shales *tend* to be more radioactive than "clean" sandstones, limestones**
  - **Exceptions: feldspathic sandstone (k-spar), uranium mineralization in carbonates, etc.**

Gamma Ray Log

- Uses:
  - Broad-scale lithology: "clean" versus shaly units
  - Quantification of shale content
  - Stratigraphic correlation
  - Depositional environment identification



Spontaneous Potential ("SP") Log

- Measures natural electrical potentials that occur in boreholes
  - "Battery" mechanism caused by drilling with fluid that has a different salinity from formation waters
  - Ions diffuse from more concentrated solution (generally formation water) to more dilute
  - Ion flow an electrical current
  - Potential measured in millivolts

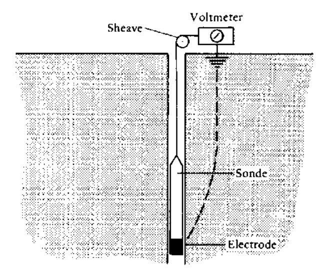
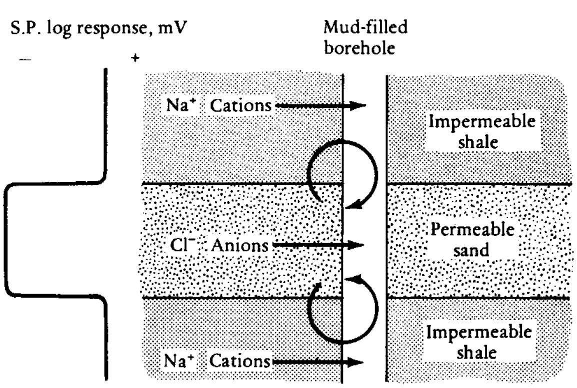
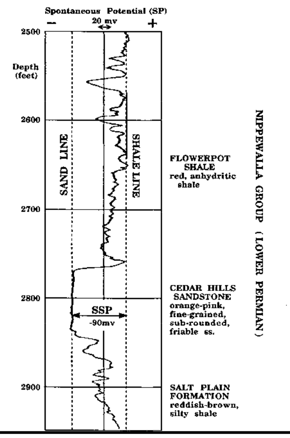


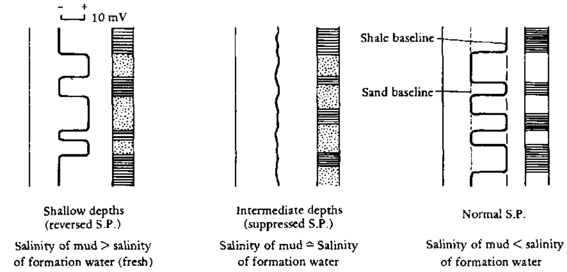
FIGURE 3.18 Basic arrangement for the S.P. log.



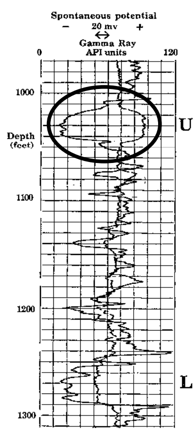
Spontaneous Potential ("SP") Log

- Generally resembles the gamma ray log
  - Porous sandstones/sands deflect to the left if formation water salinity > salinity of drilling fluid
  - No deflection if salinity the same
  - Deflection to the right if formation water "fresher" than drilling fluid





"Fresh" water in clean sandstone

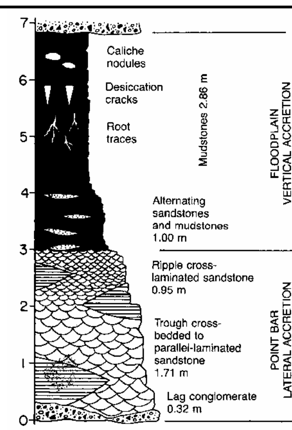


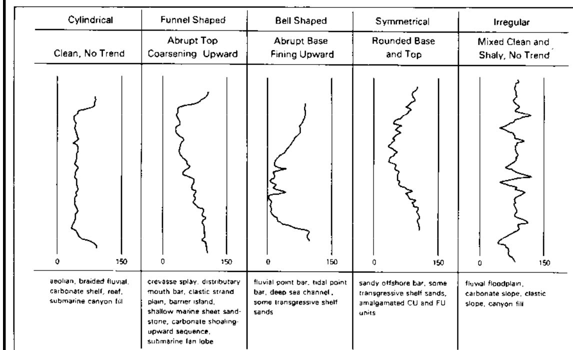
Spontaneous Potential ("SP") Log

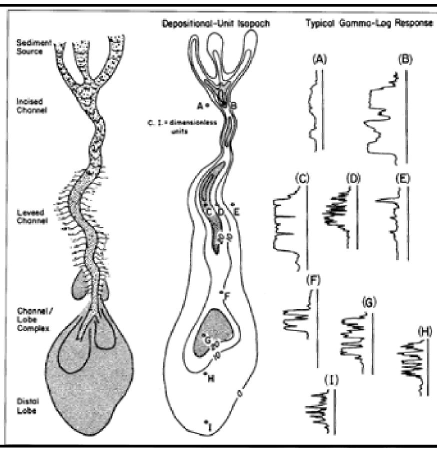
- **Used to calculate formation water salinity, correlation, Vsh, depositional environment (log shape)**
- **May not have GR in older wells, need to use SP curve**

Log Shape – Depositional Environments

- **Gamma ray and SP curves sensitive to "shaliness"**
- **Different types of depositional environments produce stratigraphic columns that show characteristic changes in lithology/shaliness**
- **Use vertical GR or SP profiles to identify depositional environment**







Log Shape – Depositional Environments

- Caution: Similar curve shapes may be produced in a variety of depositional environments
  - E.g., "cylindrical" – braided fluvial channels, submarine channels, sharp-based shorefaces, carbonate shelves, etc.
- Use in conjunction with other lines of evidence (core, lateral correlations, seismic data, etc.)

Other Logs

- Other types of wireline logs are collected and used for a variety of purposes
  - Density (density of strata)
  - Sonic (velocity of strata)
  - Resistivity (how hard is it to put a current through the rocks?)
  - Etc.

Start here

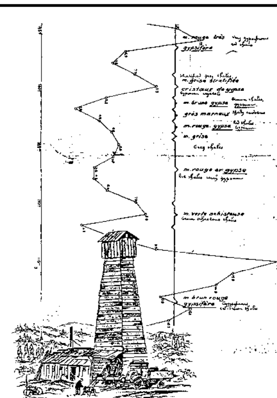
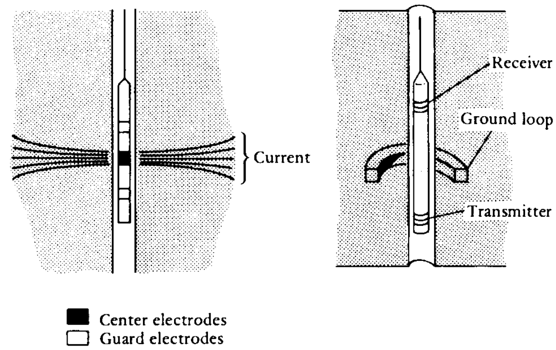


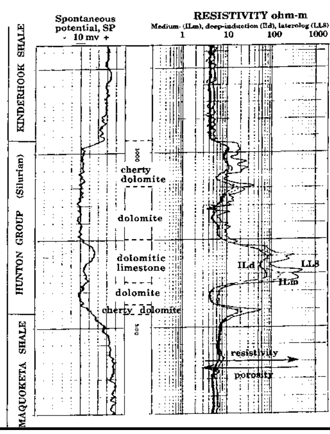
FIG. 1.– The first electric well log, Pechelbronn, France, September 5, 1927.

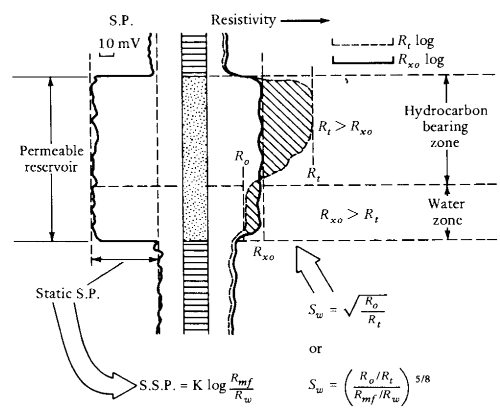
Resistivity Log

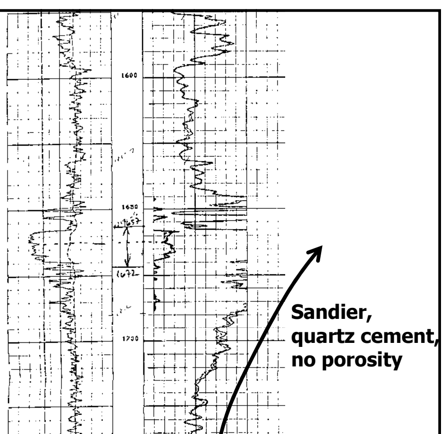
- **Measurement of strata's resistance to transmission of an electrical current**
- **Related to:**
  - **Fluid content (hydrocarbons/water)**
  - **Porosity**
  - **Mineralogy**
  - **Temperature**
- **Measured in several ways**



Laterolog **Induction Log**







Correlation

- **Need to be able to identify how stratigraphic bodies *correlate* from one area to another**
  - **Depositional history/basin analysis**
  - **Identify laterally continuous "flow units"**
- **Styles of correlation will be discussed later (lithostratigraphy, sequence stratigraphy, etc.)**
- **Here we focus on log correlations**

Correlation

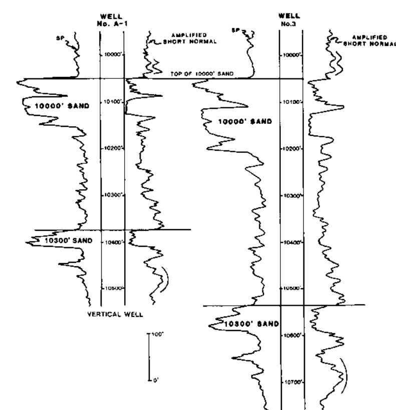
- First resistivity logs (1927) used to identify subsurface stratigraphic units and trace them laterally
- Gamma ray (and SP) logs may be used to identify stratigraphic features – units of different lithology
- Use GR and SP logs for correlation purposes
  - Use in conjunction with resistivity logs

Correlation

- Approach 1 – Marker Beds:
  - Log response of a bed or series of beds may be diagnostic; may not know lithology of marker or its origin
  - Find beds/markers that may be tracked laterally on a regional basis
    - E.g., flooding surfaces, condensed sections
  - Trace marker(s) from well to well
    - Thickness, lithology may change laterally

Correlation

- Approach 2 – Pattern Matching:
  - Identify distinctive log patterns
    - Vertical facies successions, "parasequences", etc.
    - Identify/map systems tracts
  - Trace patterns from well to well
    - Thickness, lithology may change laterally
  - Need to make assumptions about expected rates of change in thickness, lithologic trends, etc.



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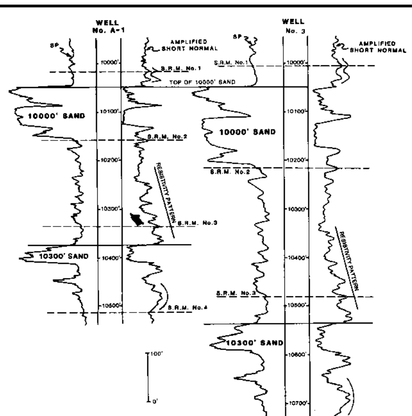

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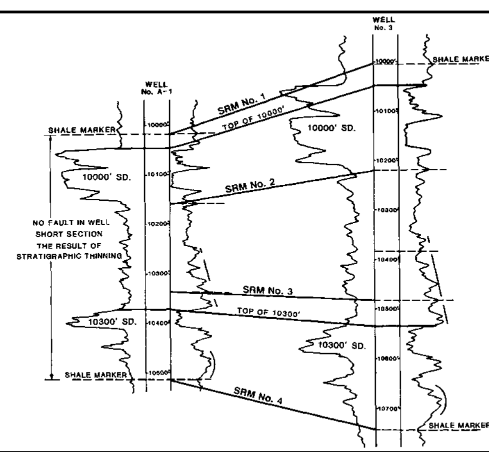
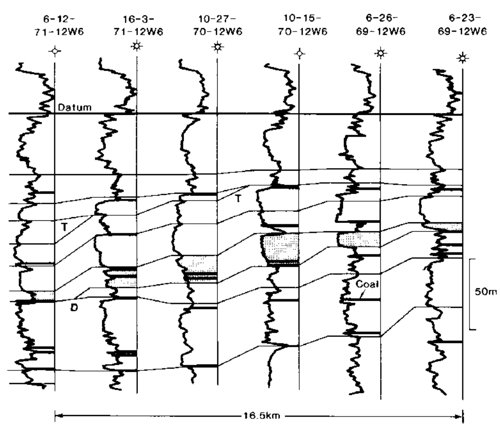


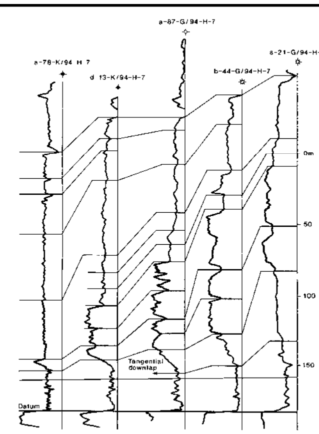
Correlation

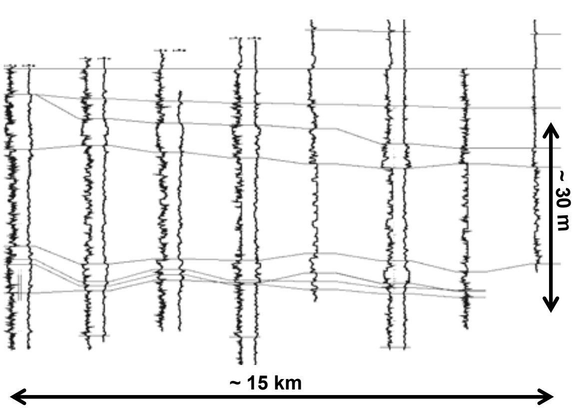
- Correlations will typically be presented as log cross-sections
- "Structural" cross-sections: show existing structural relationships
  - Use sea level as common reference
  - Analyze and display dip, anticlines, synclines, faults, etc.

Correlation

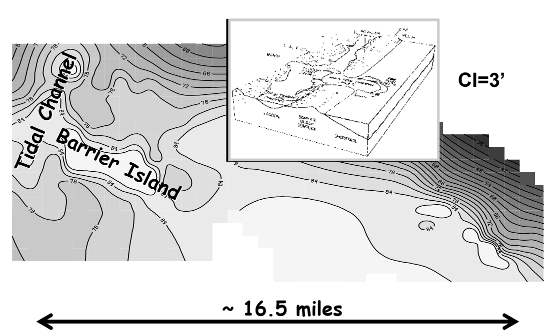
- "Stratigraphic" cross-sections: remove effects of structure to show "depositional" geometries
  - Choose a stratigraphic "datum" that will be displayed as horizontal
    - Surface needs to be originally almost horizontal, have good lateral continuity (flooding surfaces, condensed sections)
  - Analyze & display (sequence) stratigraphic correlations, unconformities, permeability barriers, stratigraphic thickness changes, facies changes, etc.







Two Wells Gross Thickness (ft)



Logs – Advantages

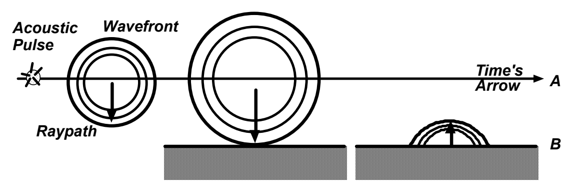
- May be only subsurface information available in places
- May be common in densely drilled areas (hydrocarbons)
- Good vertical resolution (10s of cm)
- Useful for defining lithology, pore-filling fluids, etc.

Logs – Disadvantages

- Only "see" a short distance into the surrounding strata (cm -> m)
- Poor lateral resolution: how to correlate, structure not always obvious

Ancient Environments

- Indirect Observation - Selected Methods
  - Seismic data – use sound to image subsurface
  - Marine/onshore surveys
  - Lower frequencies (10s Hz) & much more energy than sub-bottom profiles (penetrate kilometers)
  - Now: use interactive computer systems for interpretation (formerly – paper)

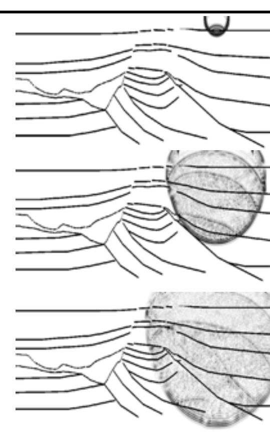


A (very) simple model

McGill

Ancient Environments

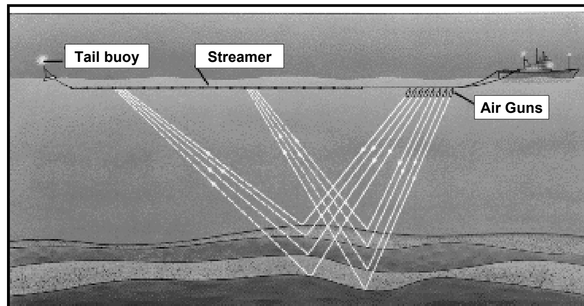
- Reflections are generated where there is a change in physical properties of the strata
  - Velocity, density (Acoustic Impedance
- Changes in rock properties often associated with changes in lithology



Complex stratigraphy and structure

Full wave equation used to show expansion of wavefront, reflections

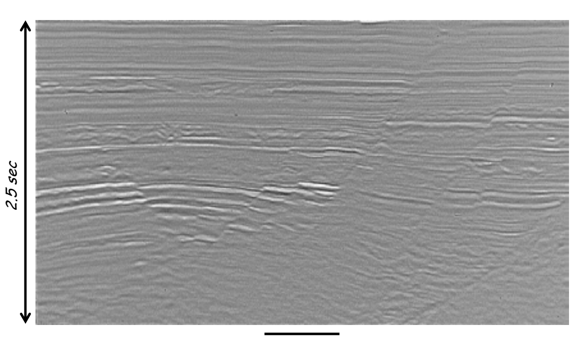
McGill

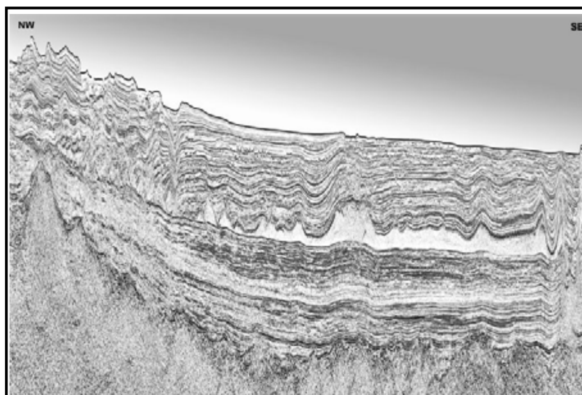


Marine seismic vessels typically tow arrays of air guns and streamers containing hydrophones a few meters below the surface of the water.

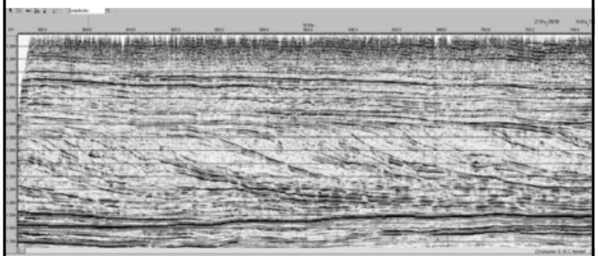
Seismic Data

- By moving the source and receivers, a seismic profile may be collected
- Seismic profiles *resemble* geologic cross-sections, and as a first approximation may be examined and analyzed as such





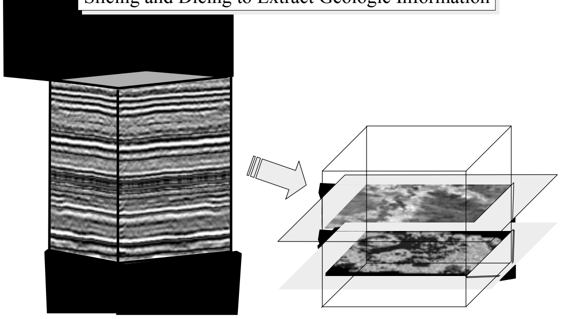
Seismic line from NW Mediterranean Sea



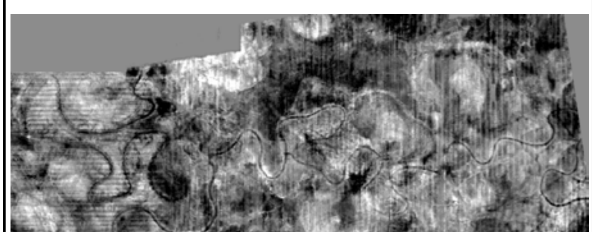
Ancient Environments

- **Indirect Observation - Selected Methods**
  - **2-D Seismic data – Vertical sections, resemble geologic cross-sections**
  - **3-D seismic data – "Volume" of seismic data: vertical sections, horizontal sections ("timeslice"), other visualization techniques**

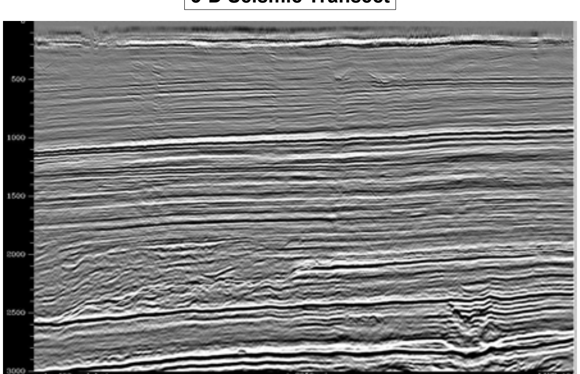
Slicing and Dicing to Extract Geologic Information

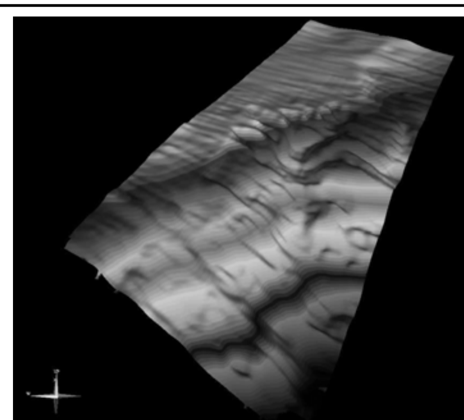


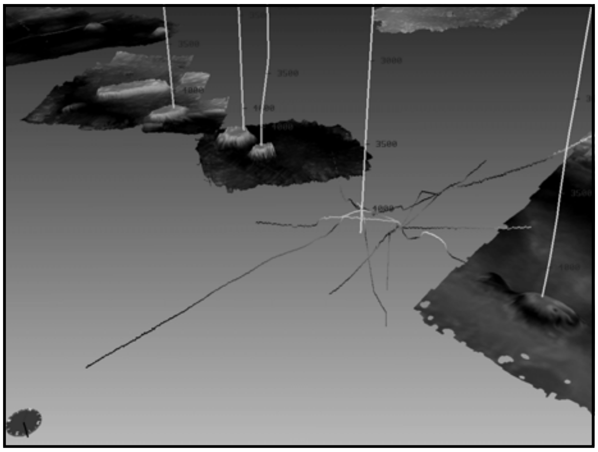
3-D Seismic Timeslice



3-D Seismic Transect







Seismic – Advantages

- Good lateral resolution
- Good definition of structural features
- May be only data type present in some areas (exploration)
- Conducive to digital analyses
  - Lithology prediction, etc.

Seismic – Disadvantages

- May be expensive to collect
- Vertical resolution is poor
  - Depends on frequency content of seismic data
  - 10s of meters common
- Difficult to collect good-quality data in places
- Non-unique answers possible

Summary

- Toolkit of sequence stratigrapher/basin analyst varied
- Knowledge of both modern and ancient deposits
- Seismic data, especially 3-D seismic, providing major breakthroughs
- Integration of various data types important