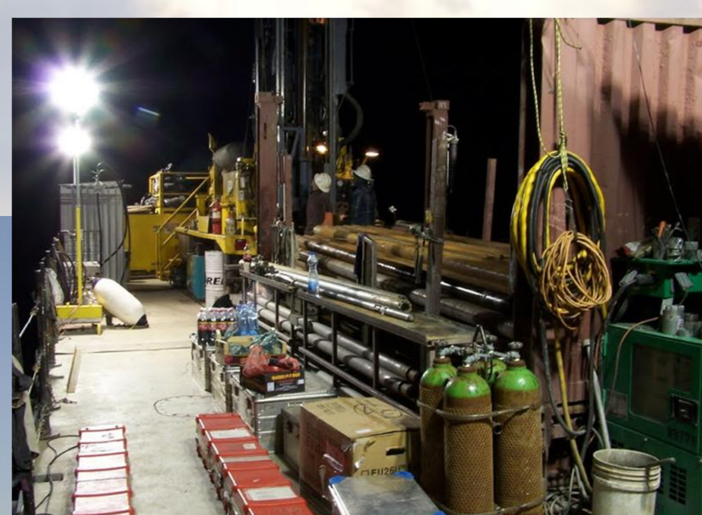
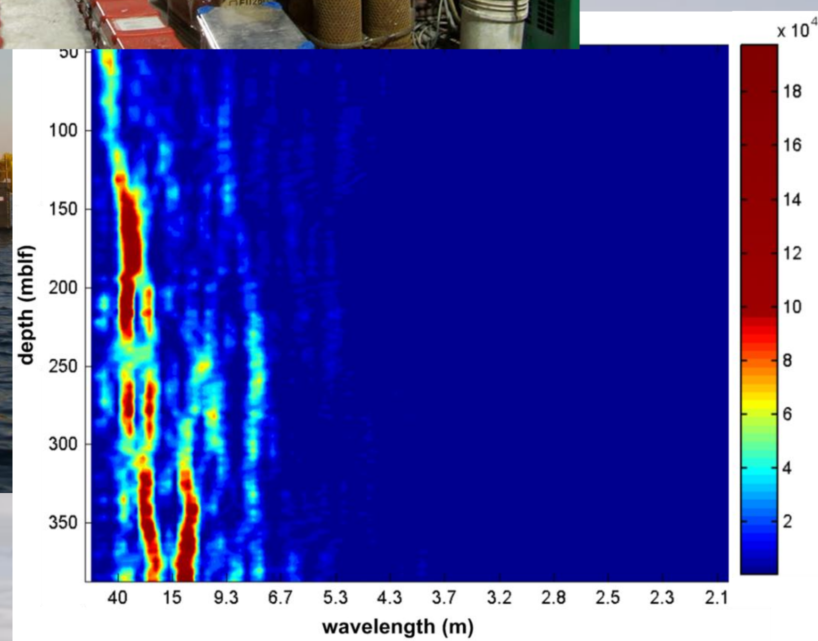
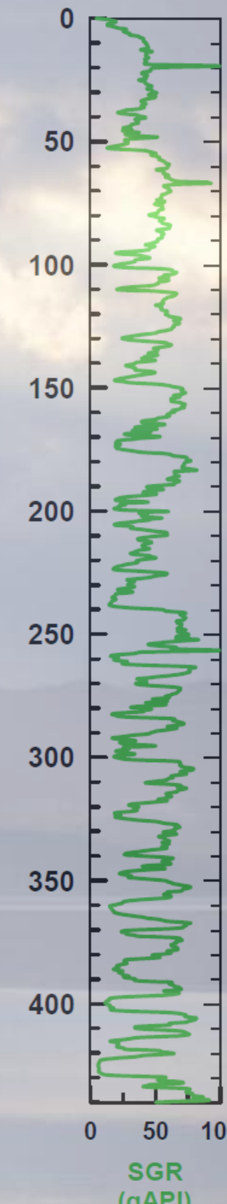
Fundamentals of downhole logging and interpretation of downhole logging data in lake drilling projects







icdp

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Outline

I Fundamentals of downhole logging

- tools and applications
- logging environment / integration of core data

II Interpretation of downhole logging data in lake drilling projects: Lake Van and Lake Ohrid

Downhole logging tools

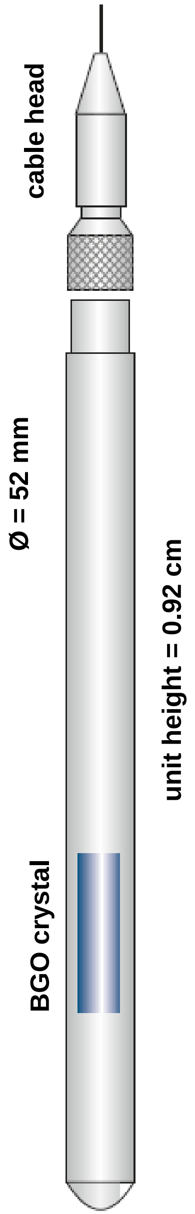
LIAG tools:

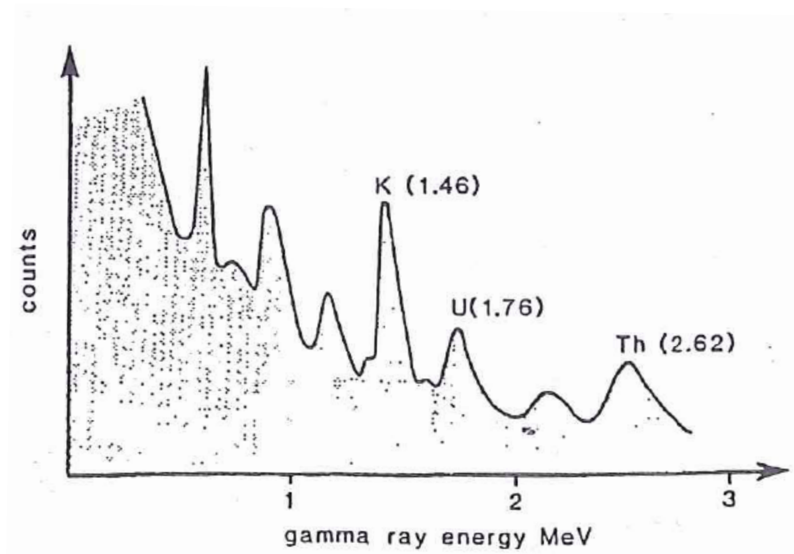
- slimhole logging for hole sizes of 75 – 250/500 mm
- open borehole wall required, cased hole limited
- temp. < 70 °C, depth < 1400 m
- digital data transmission
- logging time (single tool = 1 run) 3 - 10 m/min (180 - 600 m/h)
- tool is „run into hole“ and logged from bottom to top

Overview of methods

	tools	output
radiocative	gamma ray, spectral gamma ray	summe of gamma ray, K-, U-, Th-contents
	density	bulk density, photoelectric factor
	neutron logging	neutron porosity, water content
	gamma spectroscopy	Si, Ca, Fe, O, C, H (intensities)
acoustic	Sonic	p- and s-wave velocity
	vertical seismic profile	p-wave velocity; correlation of surface seismics
	borehole televiewer	acoustic image of the borehole wall
electric/ electromag.	dipmeter/magnetics	structural & sedimentary features, magnetic field
	Dual Laterolog	resisitivity at shallow and deep depth of investigation
	magnetic susceptibility	magnetic properties
misc.	caliper	borehole size, hole conditions, borehole path
	milieu	temperature, salinity of the drilling mud

Radioactive methods – spectral gamma ray

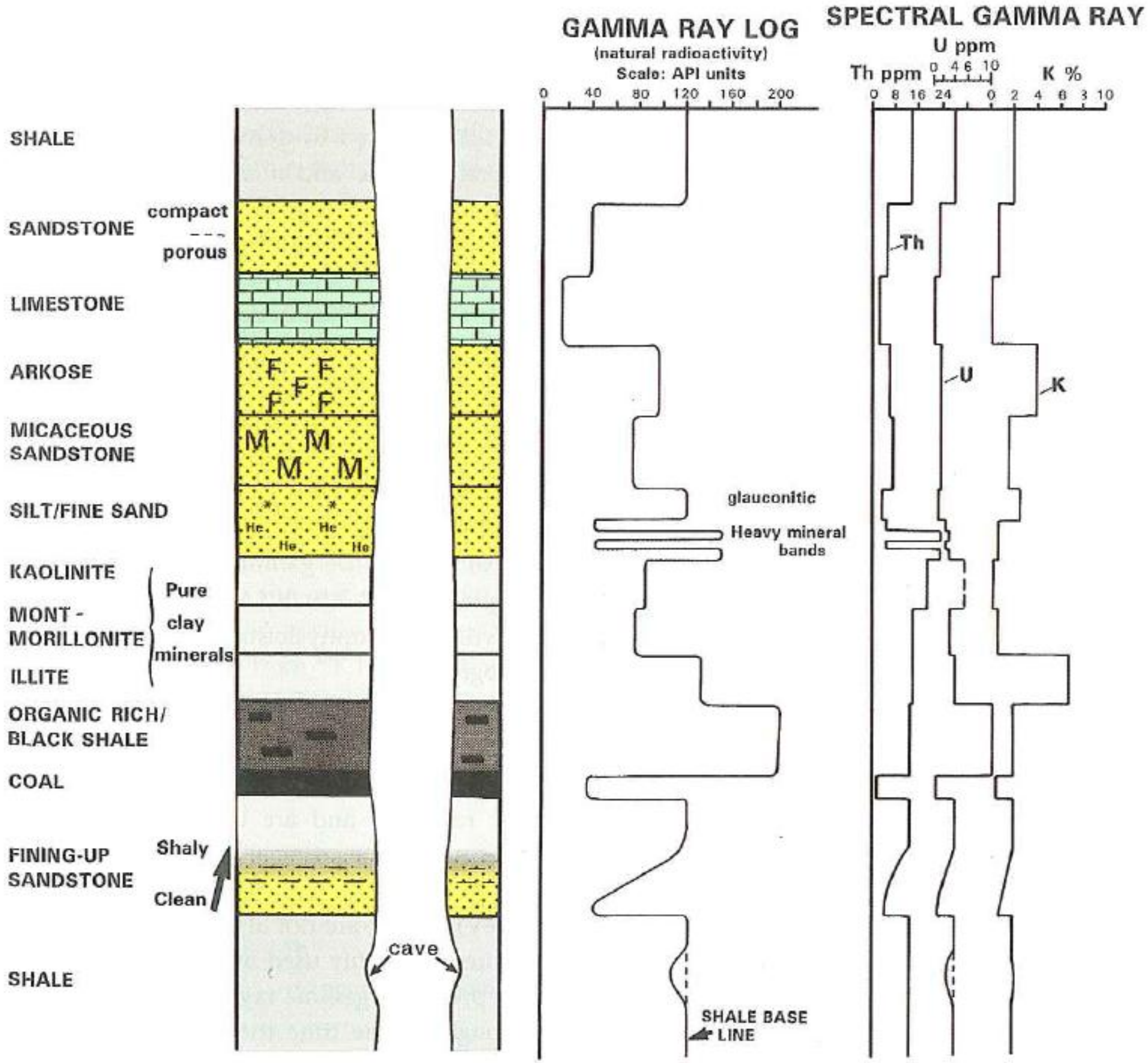




Hassan et al., 1976

- summ of gamma rays and spectral components of potassium (K), thorium (Th) and uranium (U)
- scintillation detector: Bismuth germinate (BGO; 5x15 cm)
- vertical resolution ~ 15 – 20 cm, limited by crystal-size
- gAPI unit: definded by the American Petroleum Institute in Houston (standard pit with low- and high radioactive cement)

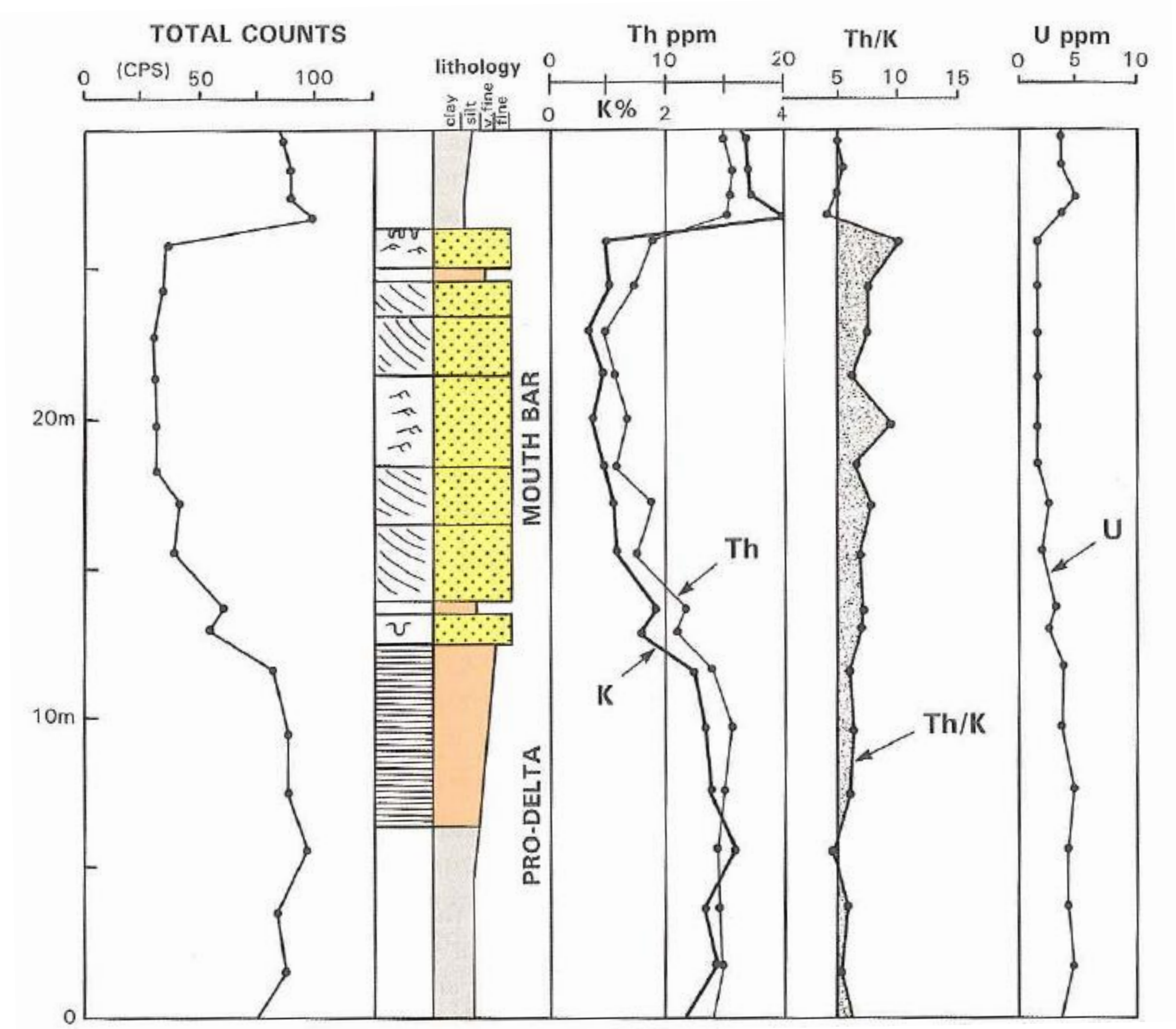
SGR - typical log response



- useful discriminator between shale and sand based on abundance of K, Th and U in clay minerals
- increased gamma ray in e.g. K-feldspars rich sands / silts or acidic volcanic deposits
- spectral components provide additional information about gamma ray „source“

Rider & Kennedy, 2011

SGR - grain size sensitivity

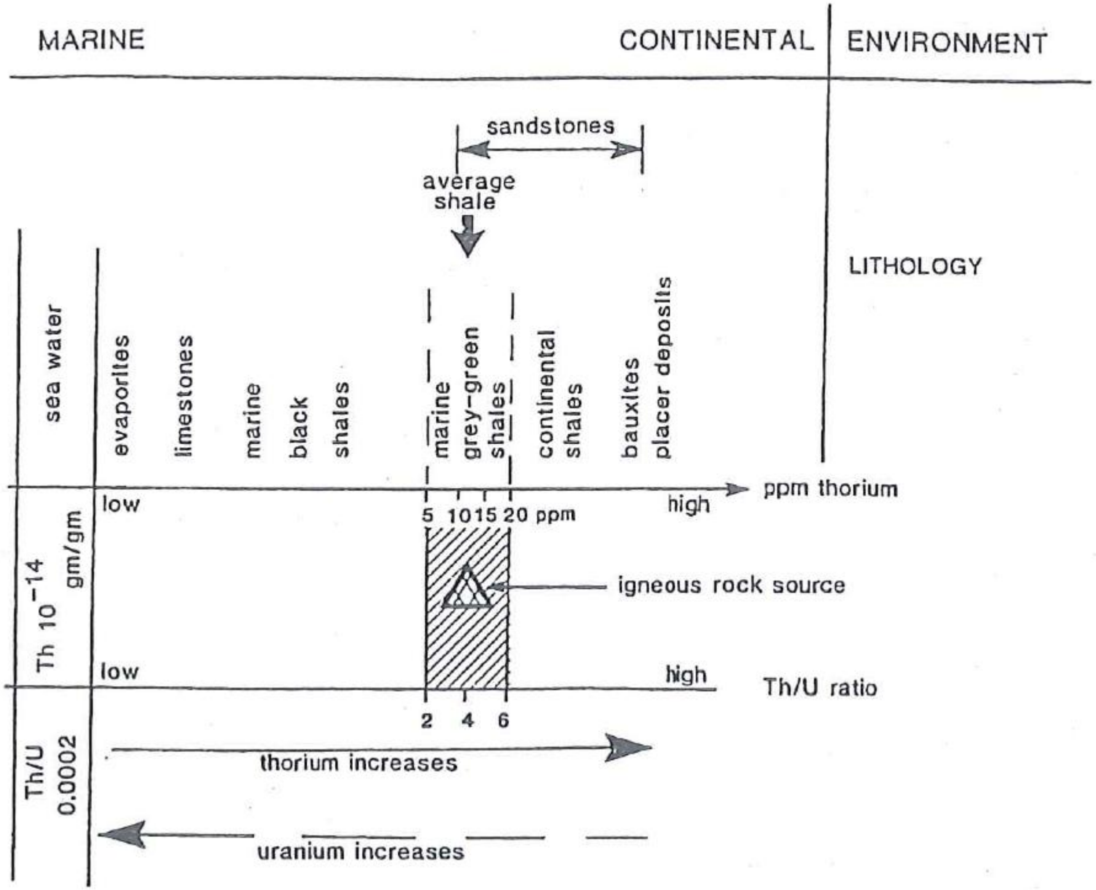


Rider & Kennedy, 2011

Response in coarsening upward sequences

- **relative decrease of total gamma ray**
- **Th/K ratio increases, more Th in coarser grained sediments**

SGR – environmental interpretation

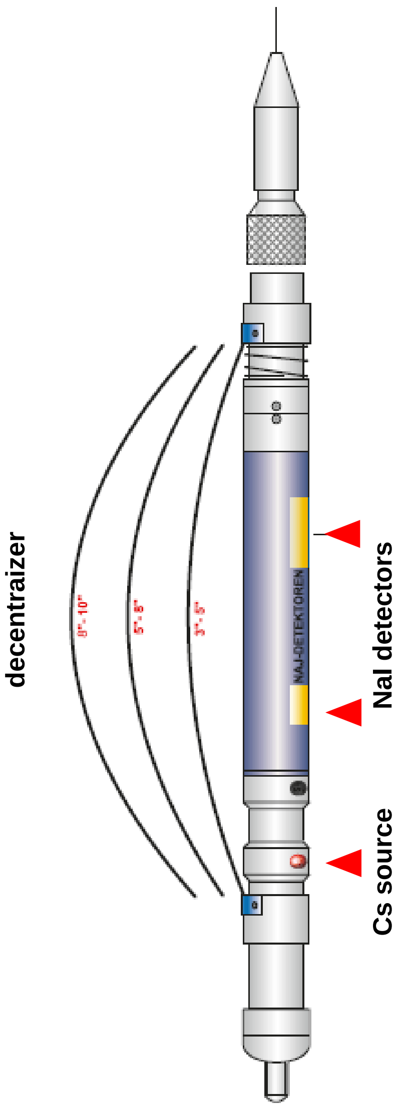


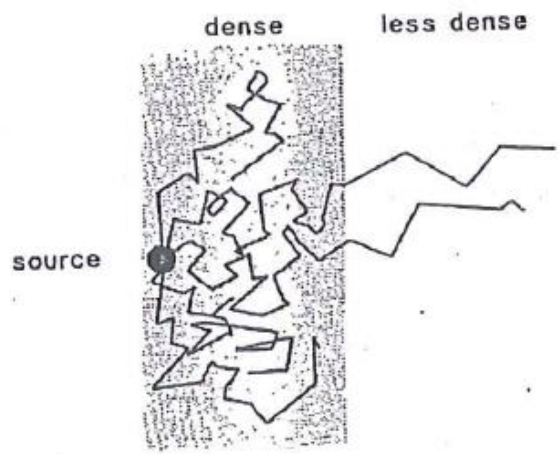
Rider & Kennedy (2011)

Use of Th/U ratio

- **Possible indication of more continental depositional environment**
- **Th: resistant to weathering, reflect detrital input**
- **U: sollubility depend on redox state, often associated to organic matter**
- **high Th/U: continental environment**
- **low Th/U: less continental influence**

Density

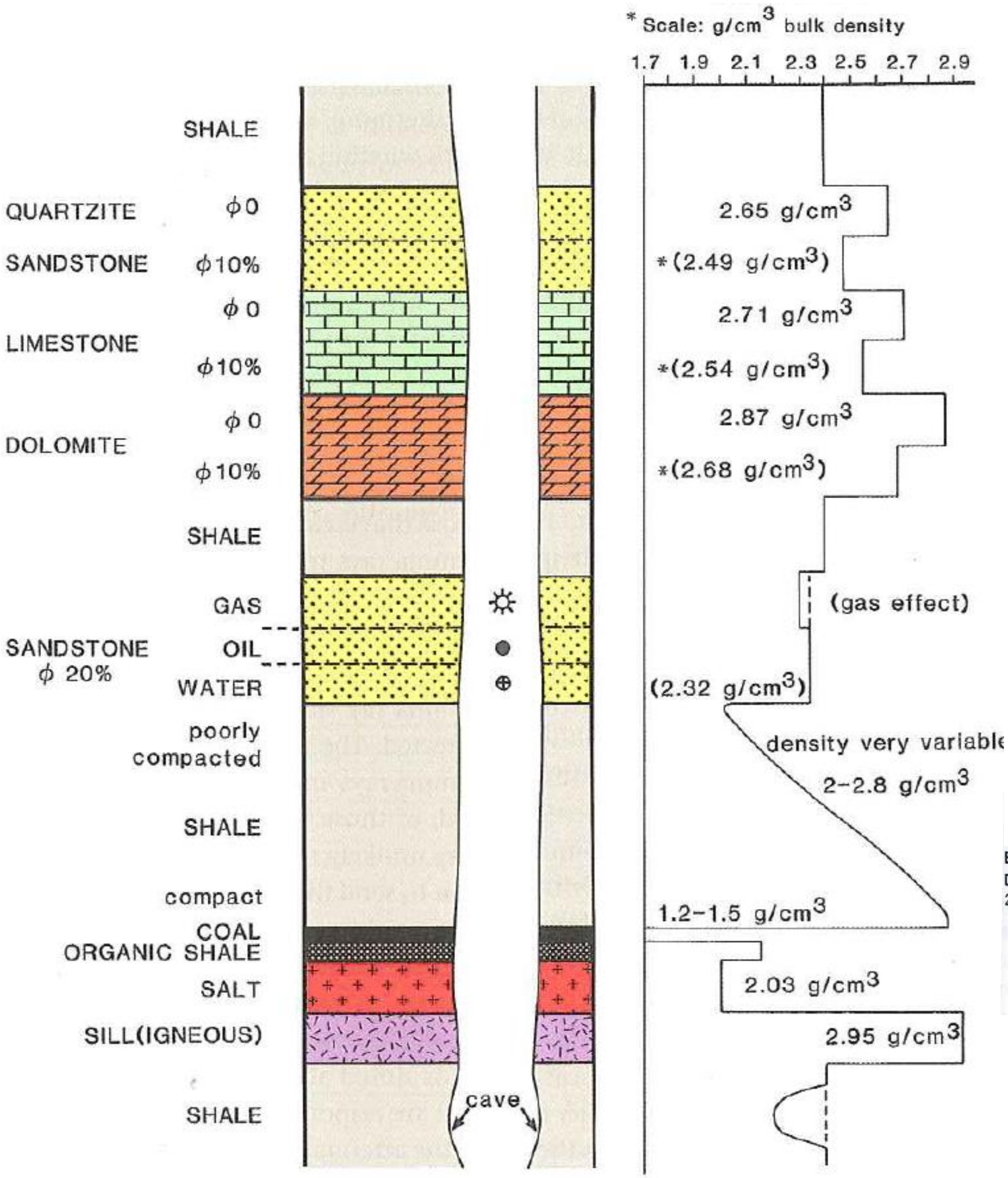




Lavenda, 1985

- active emission of gamma rays by a caesium source (^{137}Cs)
- interaction with formation and detection of secondary radiation
- Compton scattering: collision between gamma rays and electrons produces lowering of energy
- response depend on formation density
- use in foreign countries difficult!

Density – typical log response



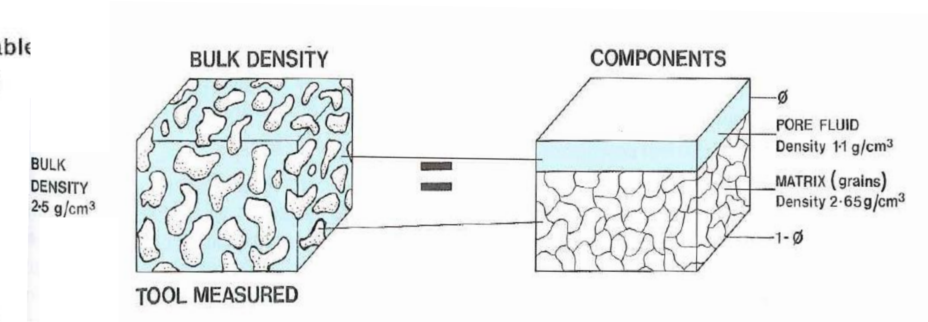
Rider & Kennedy, 2011

<u>**tool reads bulk density!**</u>

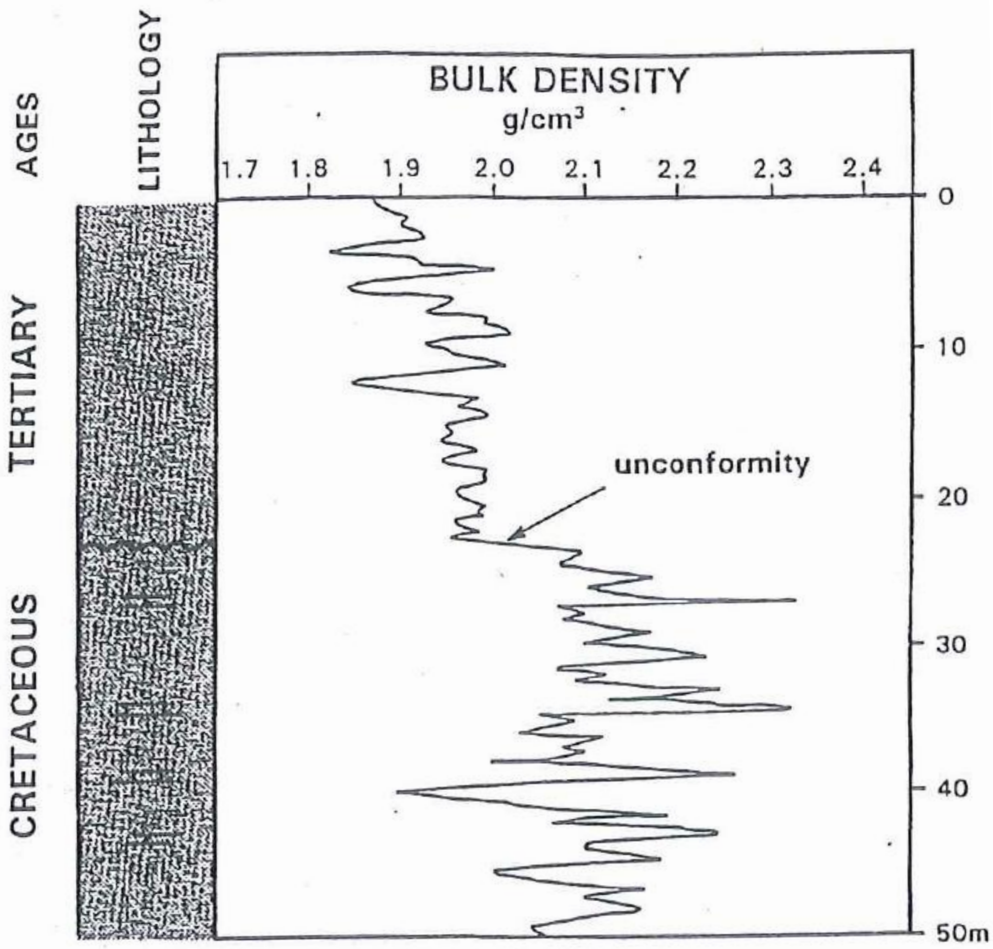
<u>bulk density</u> = grain density + fluids

depends on:

1) **porosity**
2) **fluids**
3) **lithology**

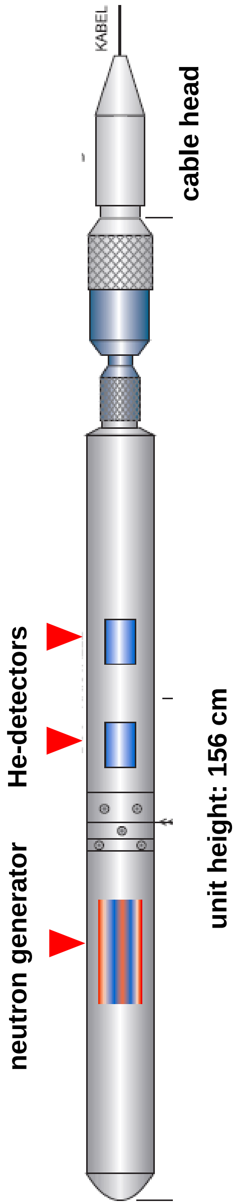


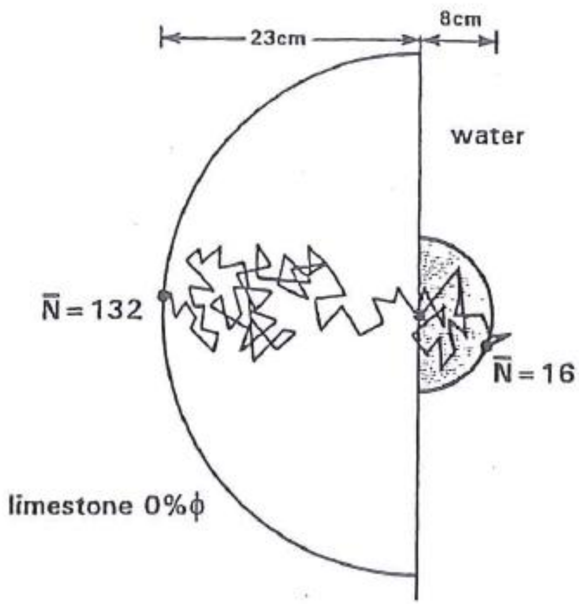
Density Logs – stratigraphic boundaries



- example of density logging in Cretaceous and Tertiary shales
- unconformity marked by strong contrast in bulk density

Neutron porosity

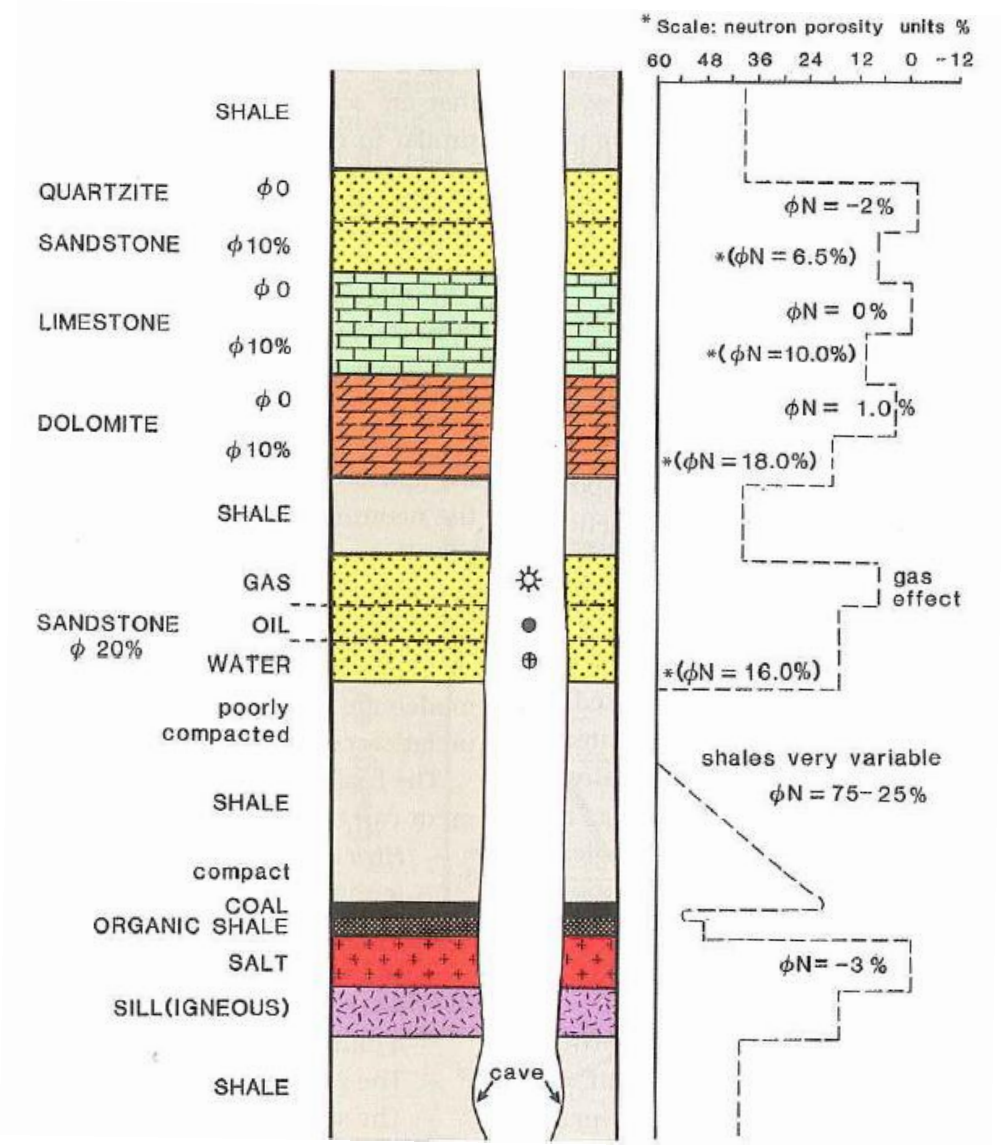




Ellis, 1987

- neutrons interact with formation, energy loss by elastic scattering
- strongest slowing down / loss of energy by collision with hydrogen (mass ≡ neutrons)
- detectors measure energy loss after passing through
- response depend on water content

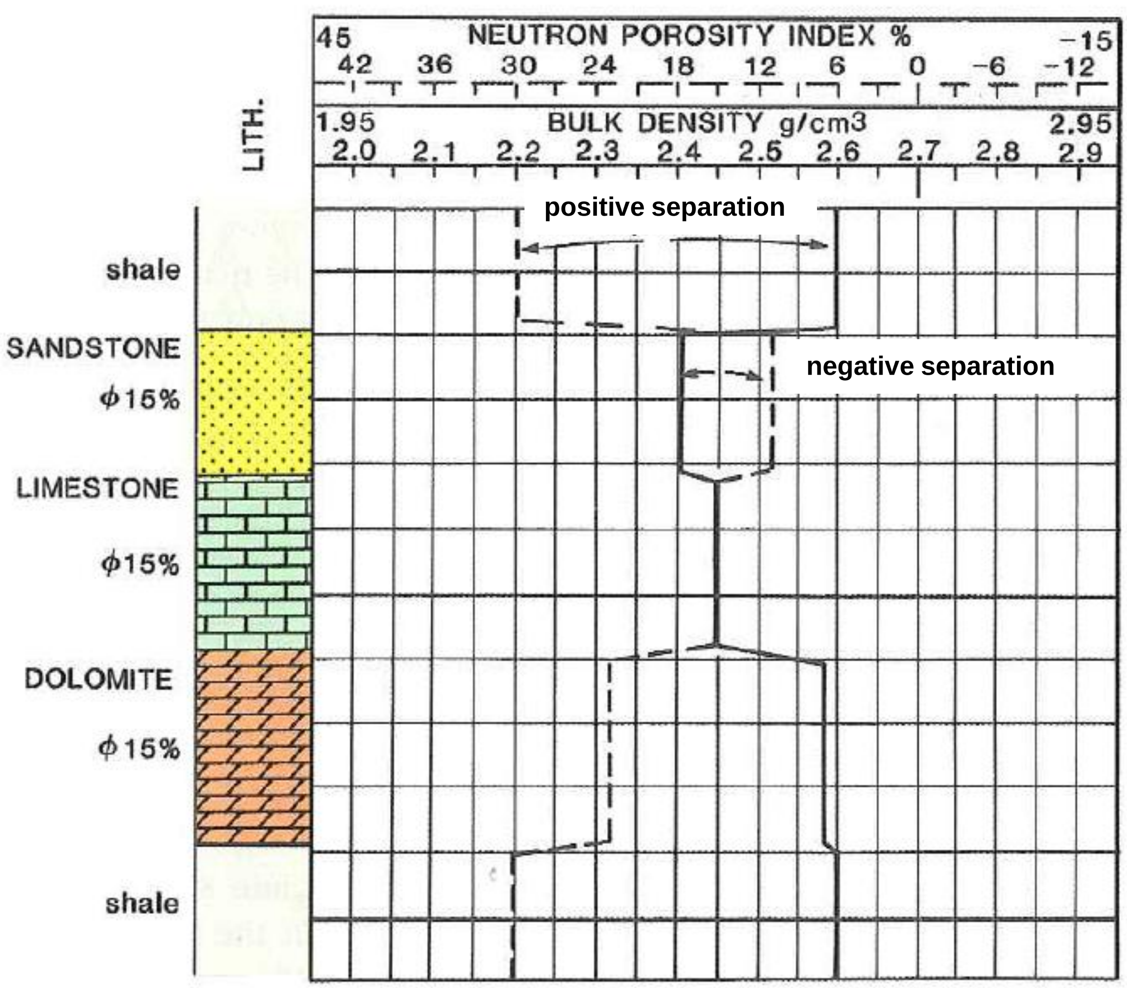
Neutron porosity – typical log response



- tool calibrated in limestone matrix
- neutron porosity ≠ porosity
- other rocks / sediments: correction needed
- response from pore water + clay bound water + water of cristallisation!
- high apparent neutron porosity values in clay bearing formations but no effective porosity

Rider & Kennedy, 2011

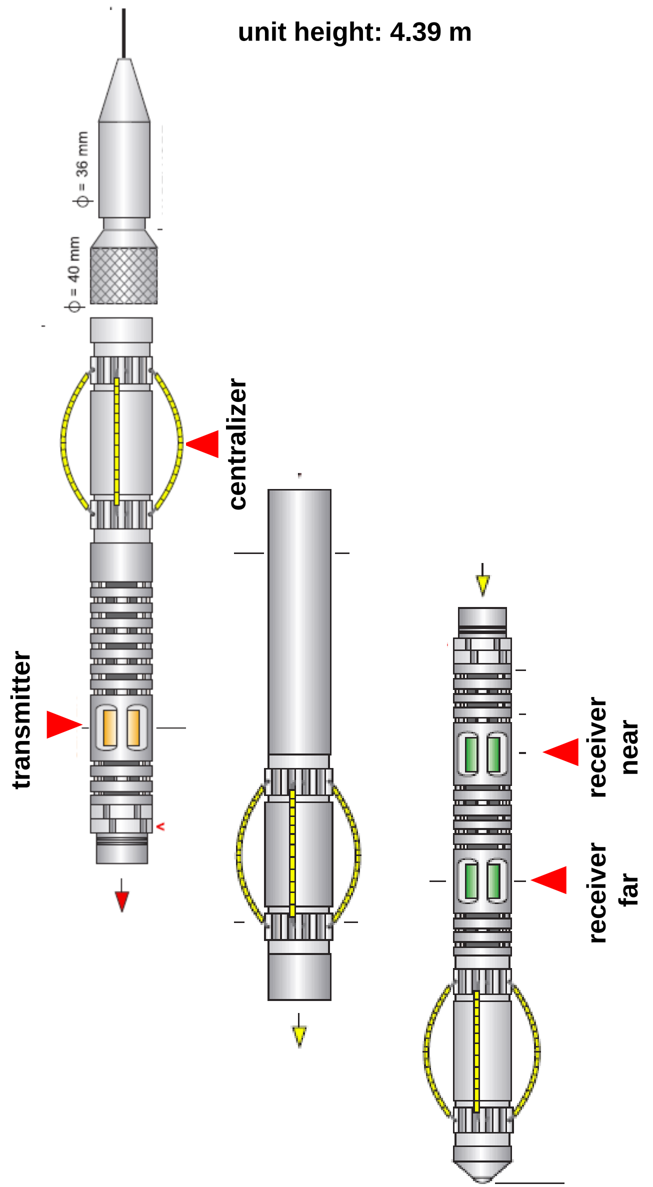
Overlay technique: combination of parameters



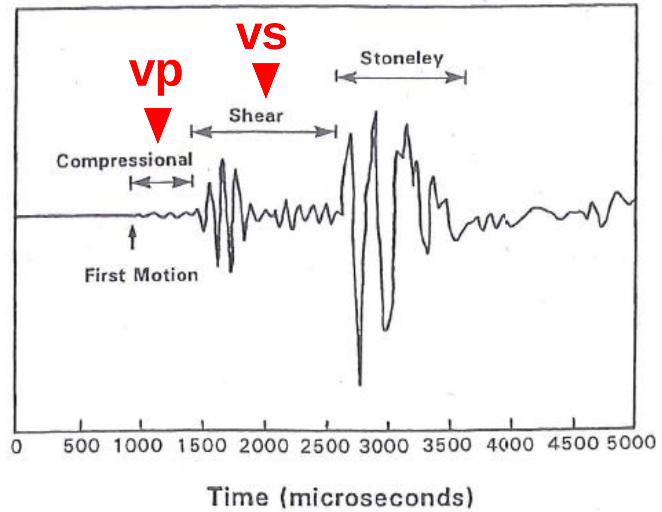
Rider & Kennedy, 2011

- very good lithological discriminator
- scaling technique with reference to limestone matrix
- „Quick look“ interpretation, developed for identification of porous sandstone (reservoir)

Sonic

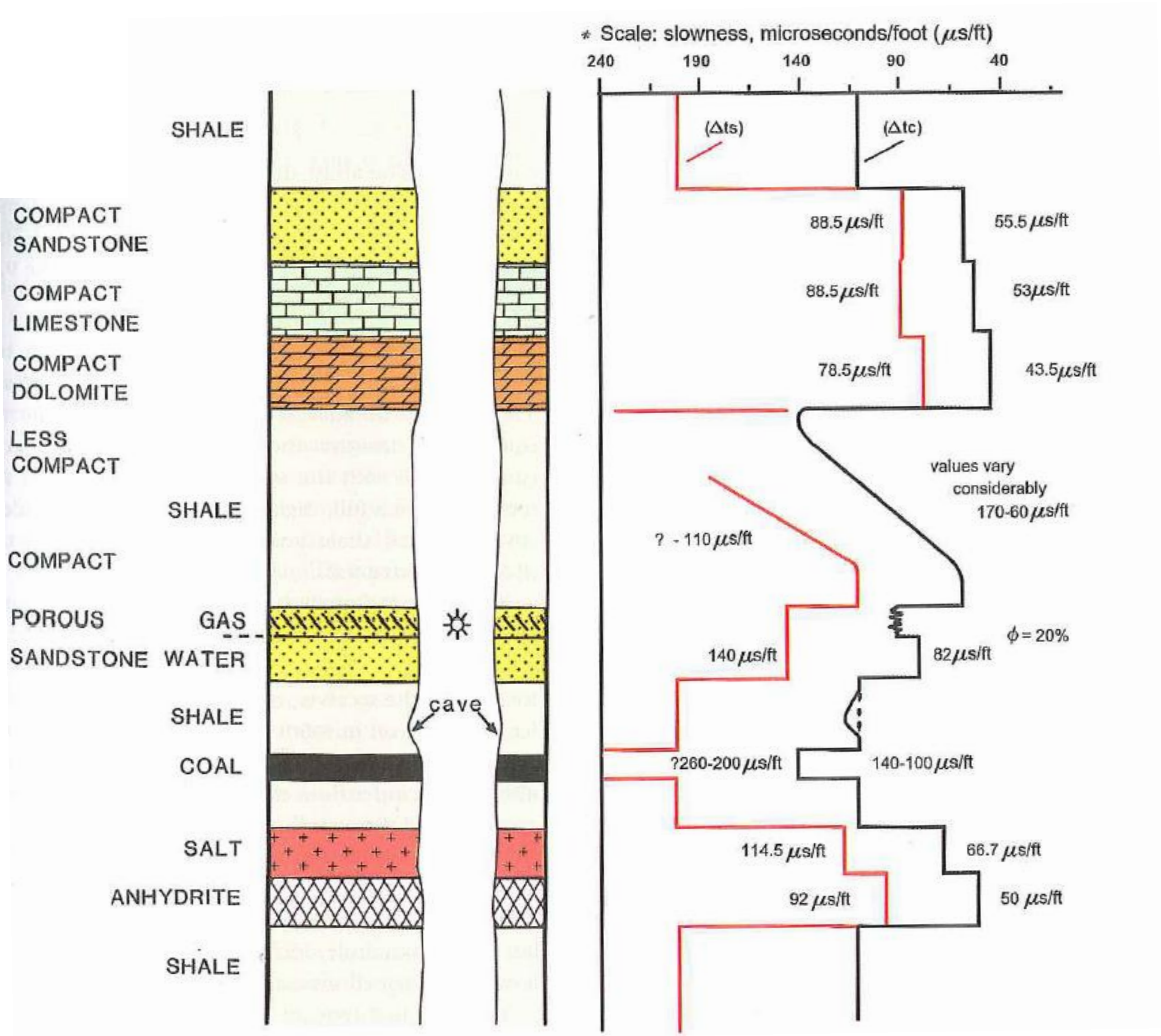


- acoustic signal is emitted by an acoustic transmitter and detected after passing through formation by two receivers
- tool measures runtime and amplitude of the waves
- determination of travel time / acoustic velocity vp, vs (m/s)
- sensitive to cavings / bad borehole conditions
- vertical resolution ~ 20 cm



Ellis, 1987

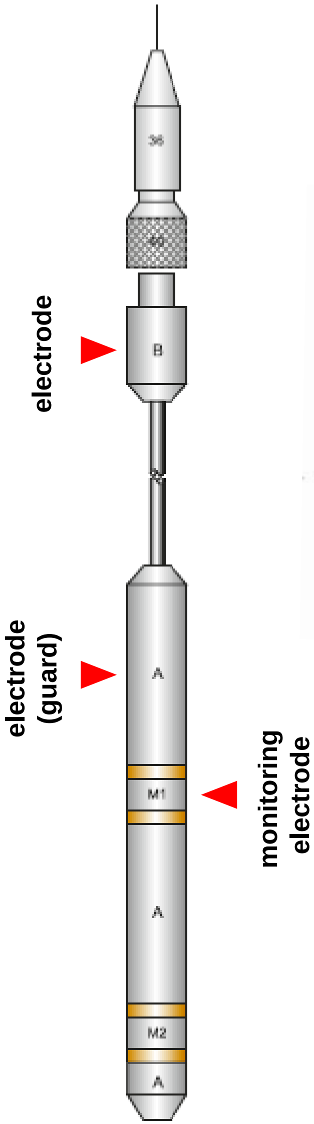
Sonic - typical log response

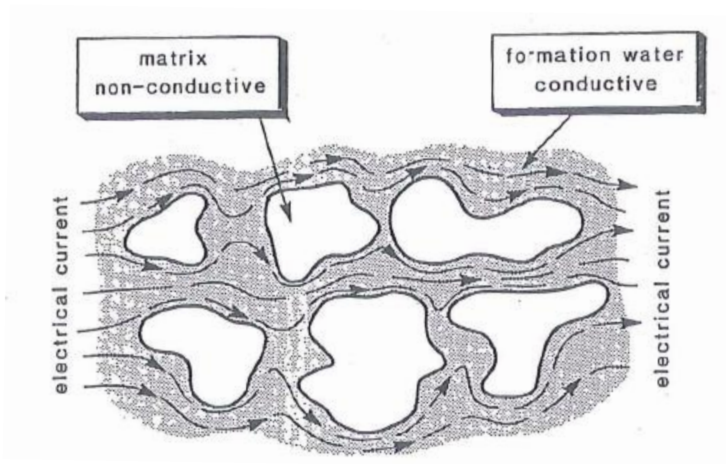


Rider & Kennedy, 2011

- velocity depend on lithology but overlapping value ranges
- compaction of sediments / rocks affects acoustic characteristics strongly
- general increasing velocity with greater depth (porosity reduced)

Resistivity



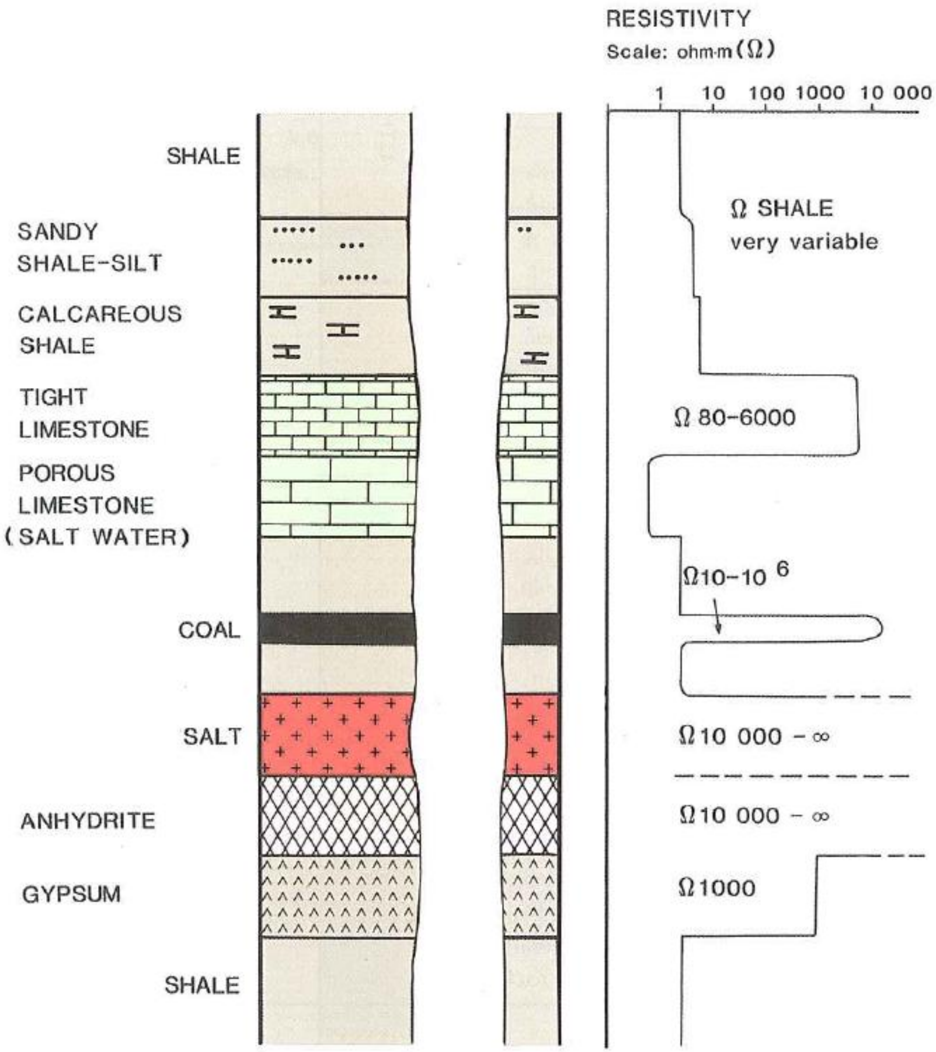


- Dual Laterolog tool (DLL): dual focused electrical current passes through formation
- voltage drop is measured in two depth of investigations:

1) shallow – close to the borehole wall,
2) deep – at a distance of 30 – 100 cm from the borehole

- vertical resolution ~ 10 – 15 cm
- majoritiy of minerals have very high resitivities (Ω*m), except clay minerals (negatively-charged surface layers)
- conduction mainly by fluids

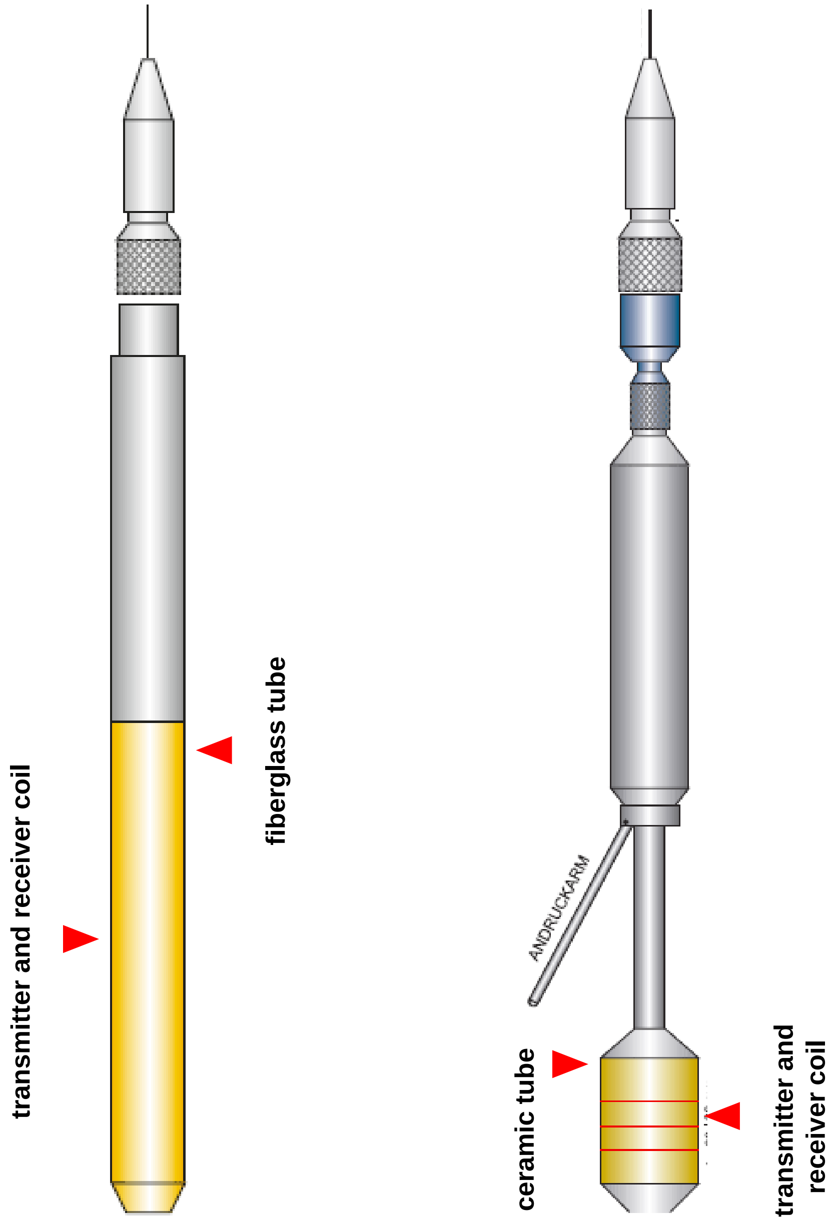
Resistivity – typical log response



Rider & Kennedy, 2011

- **typical lithological resistivity values / ranges (log-scale!)**
- **mainly controlled by texture: grain size, sorting,…**
- **can be used to detect slight texture changes in sedimentary facies**

Magnetic susceptibility



- electromagnetic method; electromagnetic field of a frequency of 1 kHz is induced
- measure of the magnetisability of rocks / sediments

<u>conventional SUSZ:</u>

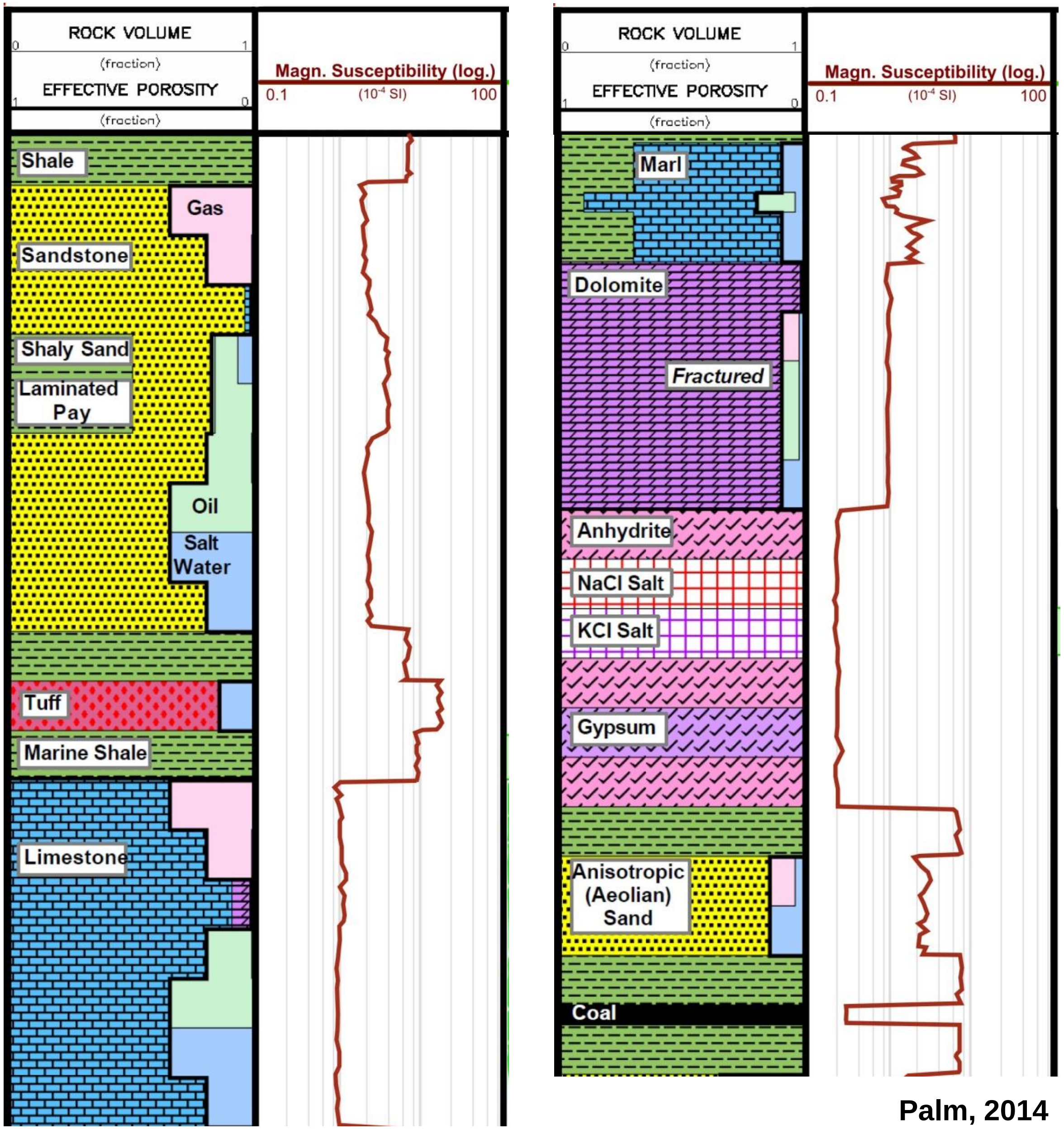
vertical resolution of ~ 20 cm

<u>micro SUSZ:</u>

vertical resolution of ~ 2 cm

small depth of investigation

SUSZ - typical log response

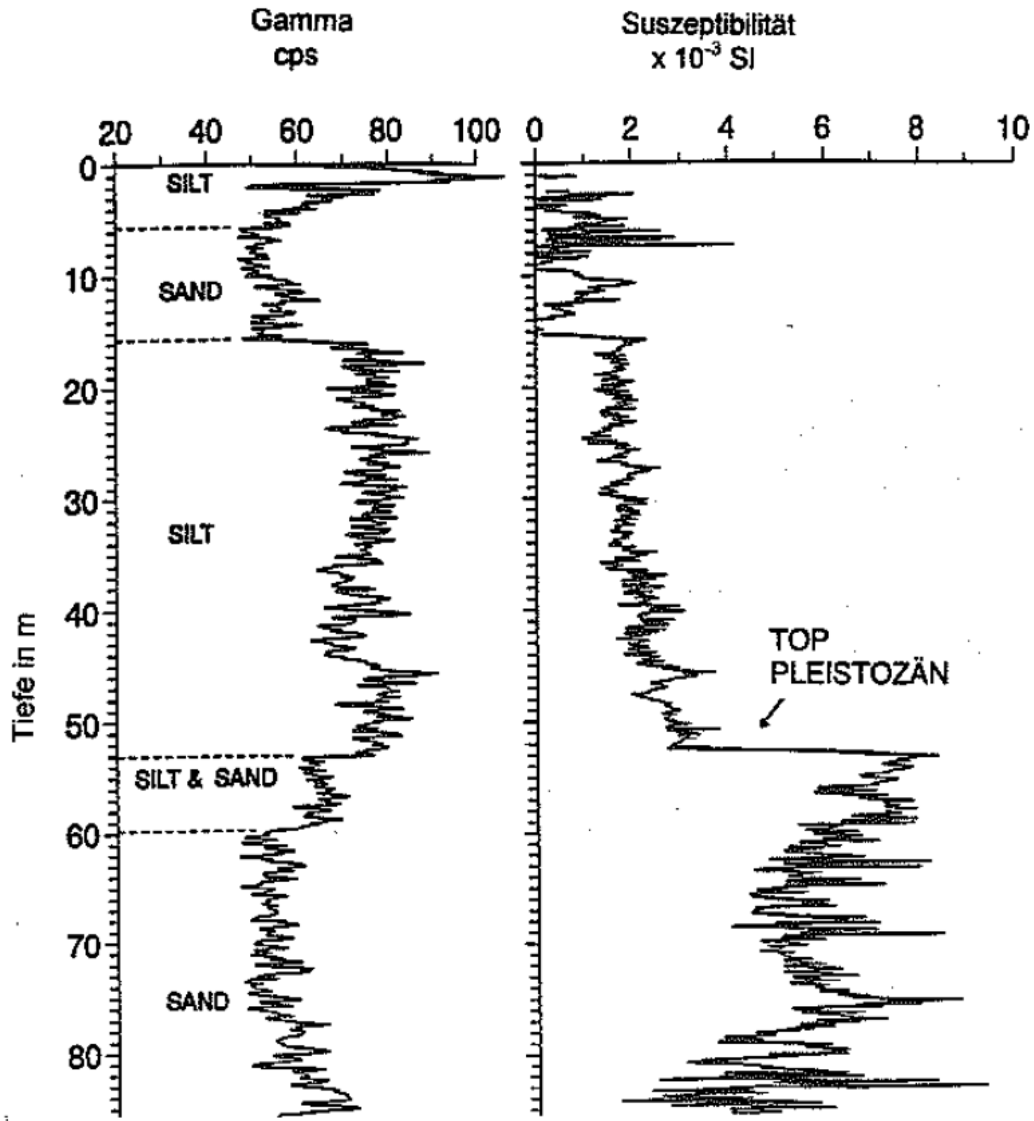


Palm, 2014

sediments:

- mainly controlled by occurrence of ferrimagnetic minerals (Fe-oxides)
- smaller effect from paramagnetic (e.g. biotite) and diamagnetic minerals ($CaCO_3$)
- depend on sediment composition, e.g. occurence of volcanogenic material
- grain size: magnetite occur mostly in clay fraction
- detrital input: sea level / lake level changes, surface runoff

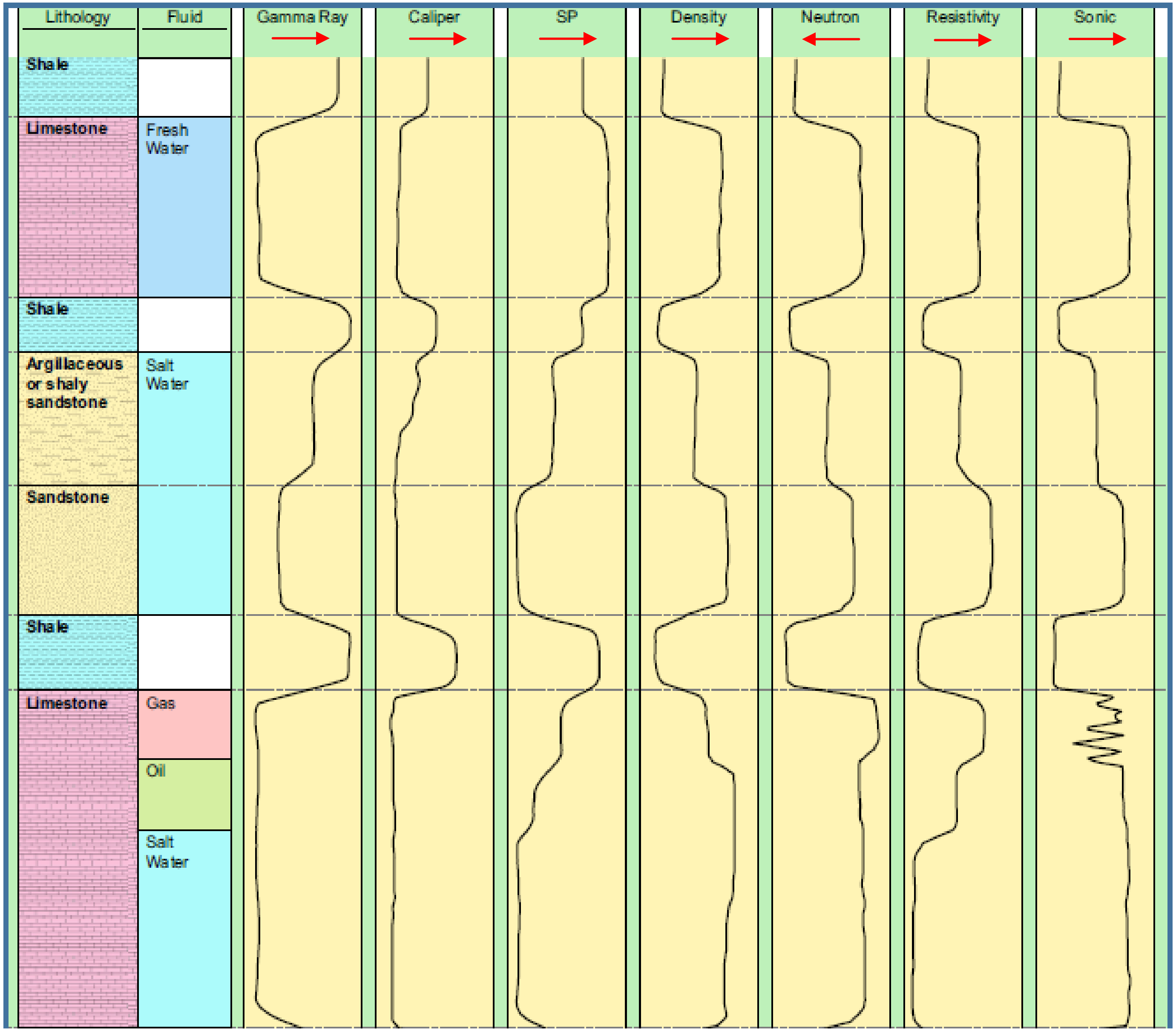
SUSZ – stratigraphic boundary



Mc Neil et al., 1996

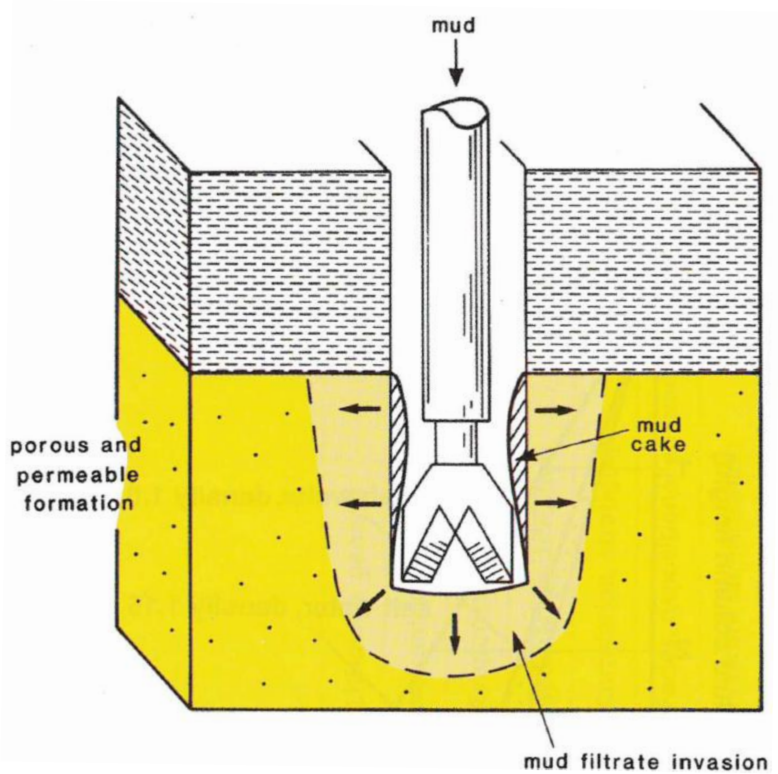
- susceptibility log from Fraser river delta (Canada)
- strong change at stratigraphic boundary in SUSC, little contrast in gamma ray
- logs can support stratigraphic classification e.g. Pleistocene-Holocene-boundary

Well Log Response Chart

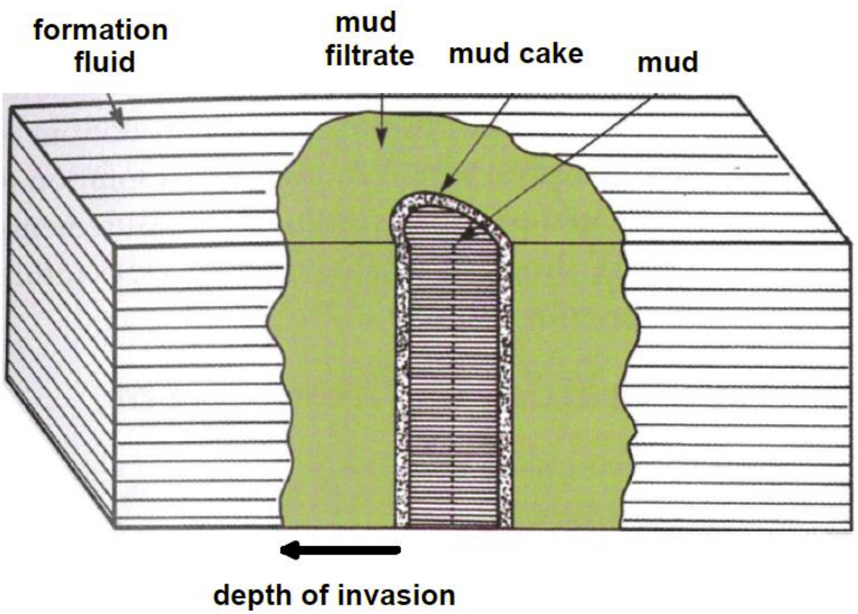


ARM Geophysics, 2013

Logging environment

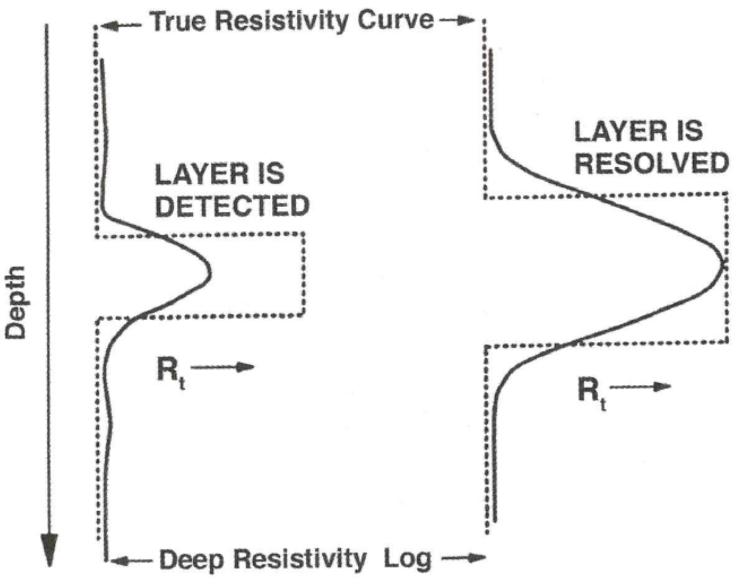


- mud invasion close to borehole wall
- disturbance due to drilling (cavings, washouts)
- depth of investigation range from cm to m-scale

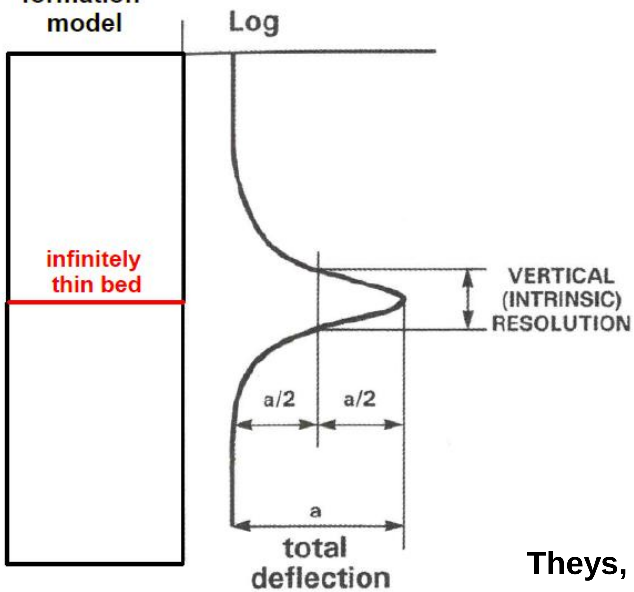


Rider & Kennedy, 2011

Vertical resolution



Worthington, 2000



Theys, 1991

<u>minimum bed resolution</u>

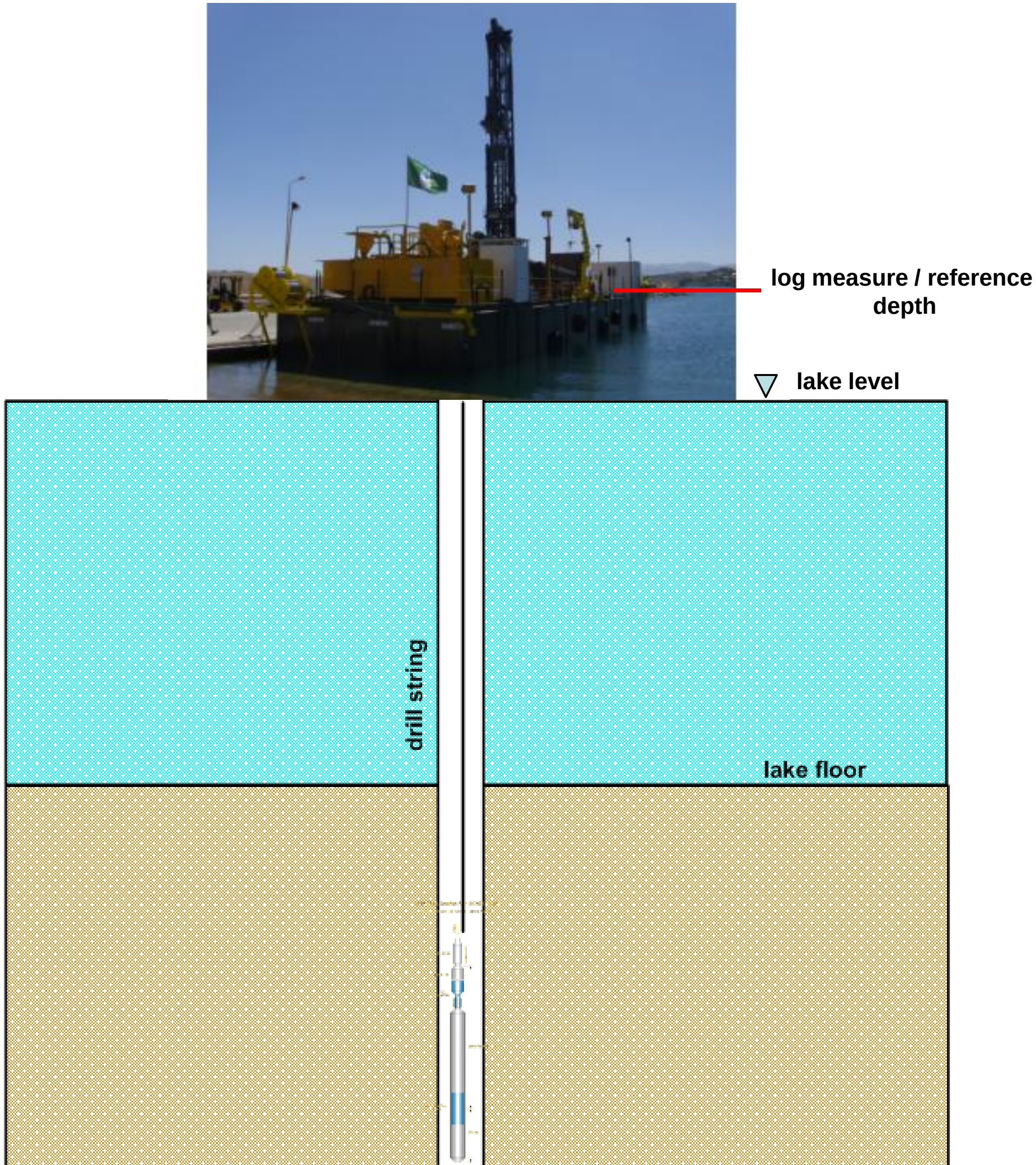
sampling rate: 3 mm - 5 cm

vertical resolution: 2 - 20 cm

- depend on tool dimensions,
  e.g. detector to receiver distance

- depth and thickness of bed
  might be affected by limited
  vertical resolution

Drillers depth vs. loggers depth



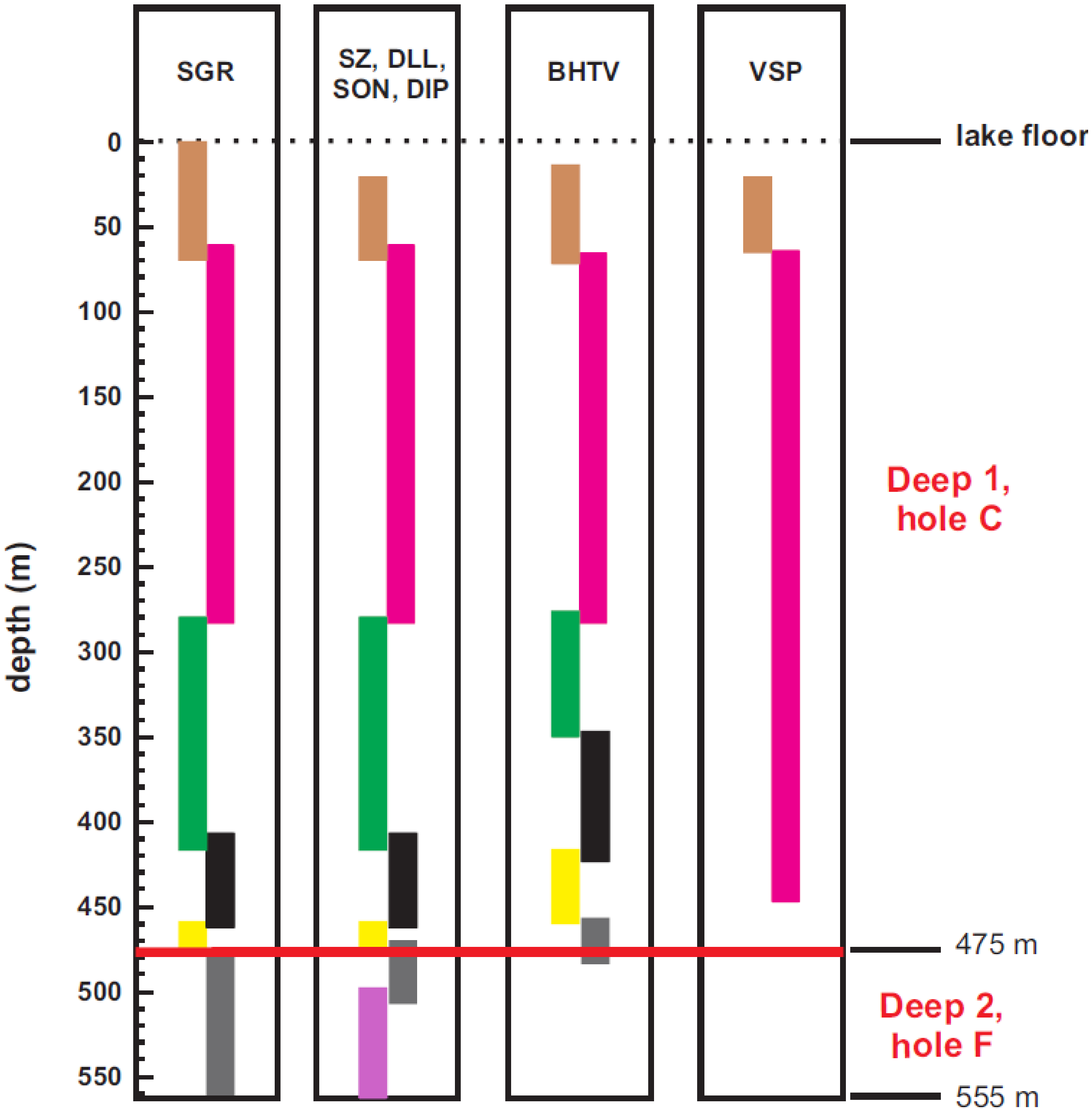
<u>drillers depth (core depths)</u>

- single length of pipes compiled
- possible errors:
  length „forgotten“, new tools with different length not accounted for, elastic pipe stretch (weight on bit)

<u>loggers depth</u>

- length of cable going down is measured
- possible errors:
  cable stretching, tool sticking, frictional forces, measuring wheel accuracy (calibration), zeroing

Logging of short sections

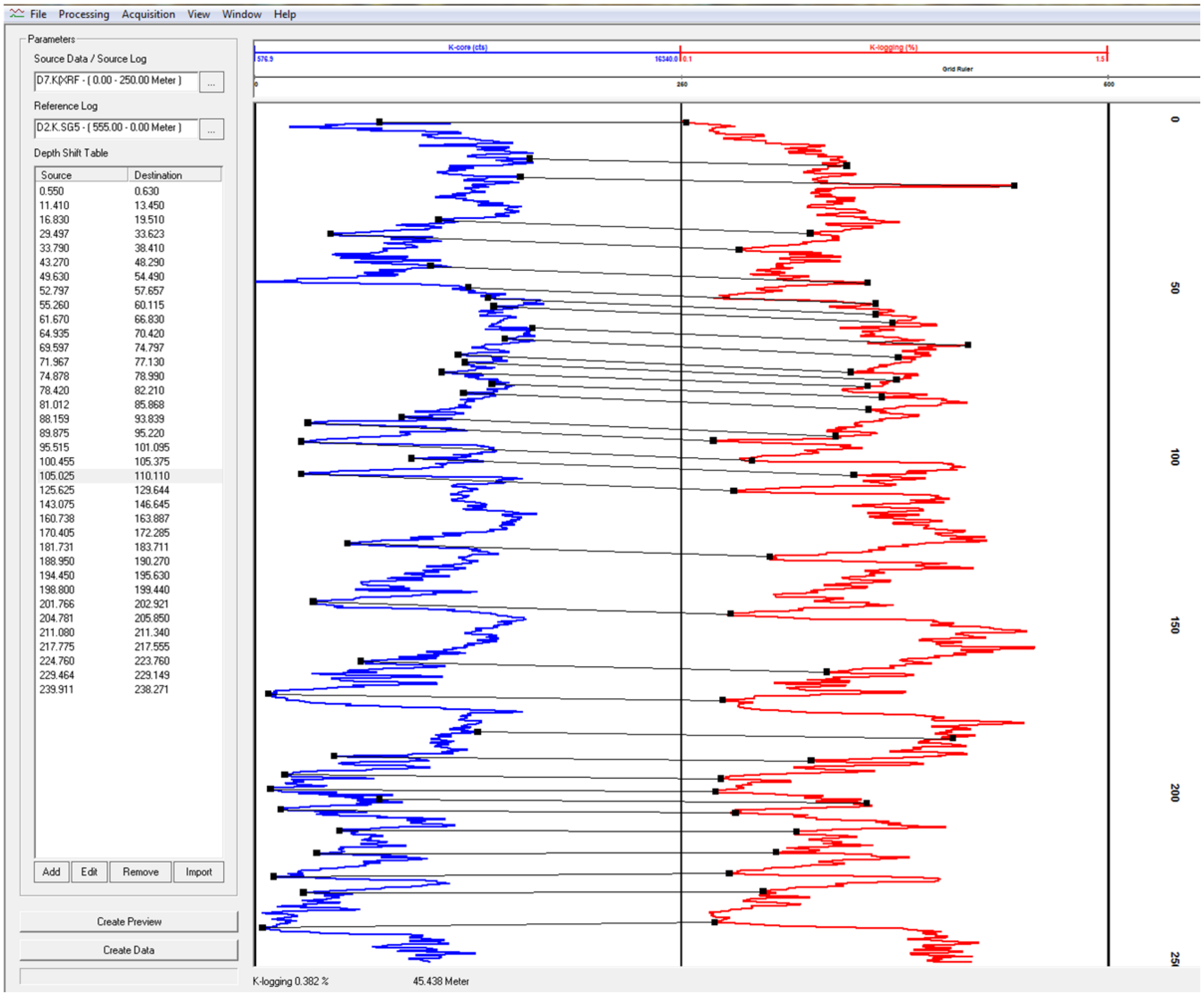


- lake sediments often unconsolidated (low borehole stability)
- tools run into the drillstring and logging of overlapping open hole sections, time-consuming!
- processing: splicing of sections to generate a continuous data file

SGR:	spectral gamma ray
SZ:	susceptibility
DLL:	resistivity
SON:	seismic velocity
DIP:	dipmeter
BHTV:	ultrasonic borehole image
VSP:	vertical seismic profile

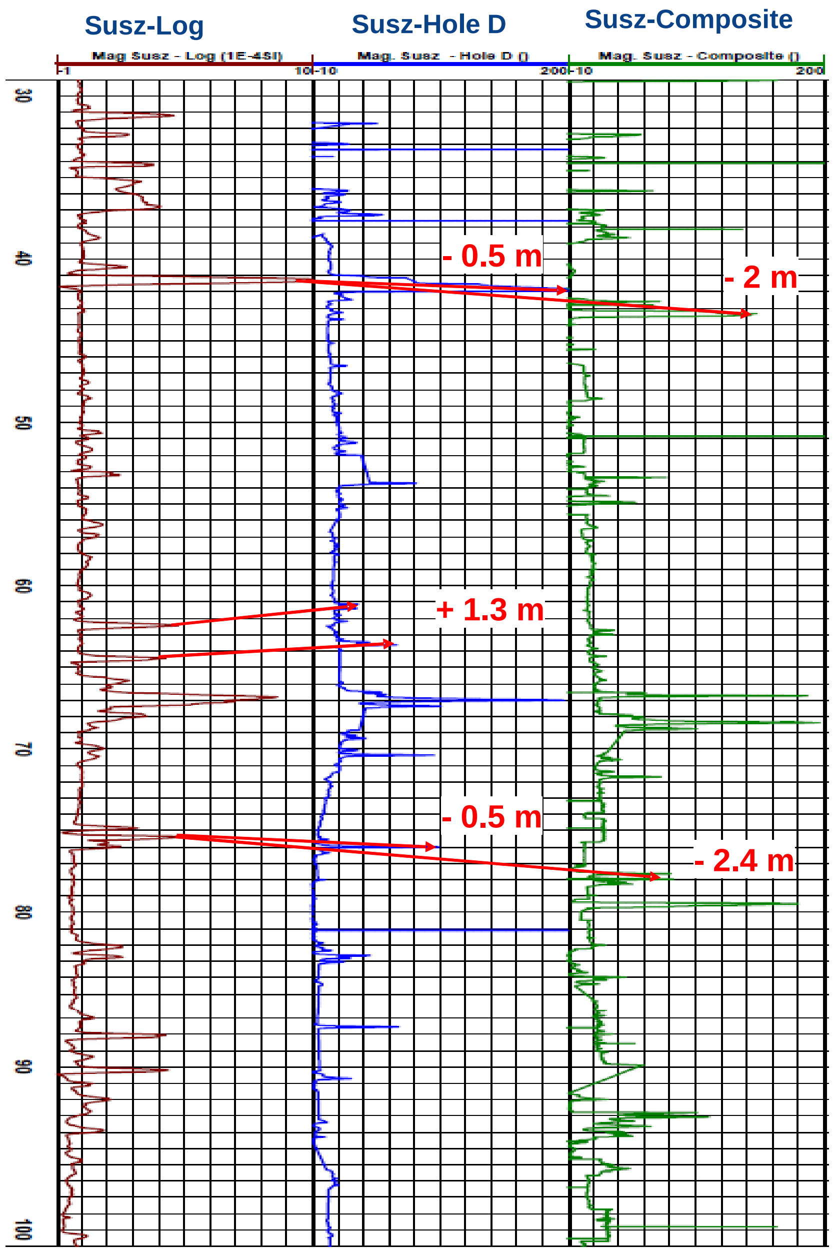
Depth matching of core and logging data: simple example

core log



- matching of K-log with K-intentities from cores)
- high core recovery, high data quality, simple to depth match
- some (minor) systematic shifts
- common / cannot be avoided due to, e.g.:
  a) gas extension (core stretching) or b) core gaps

Depth matching: difficult example



- matching of susceptibility
- depth shifts up to +/- 2.5 m (↑↓)
- difficult due to:

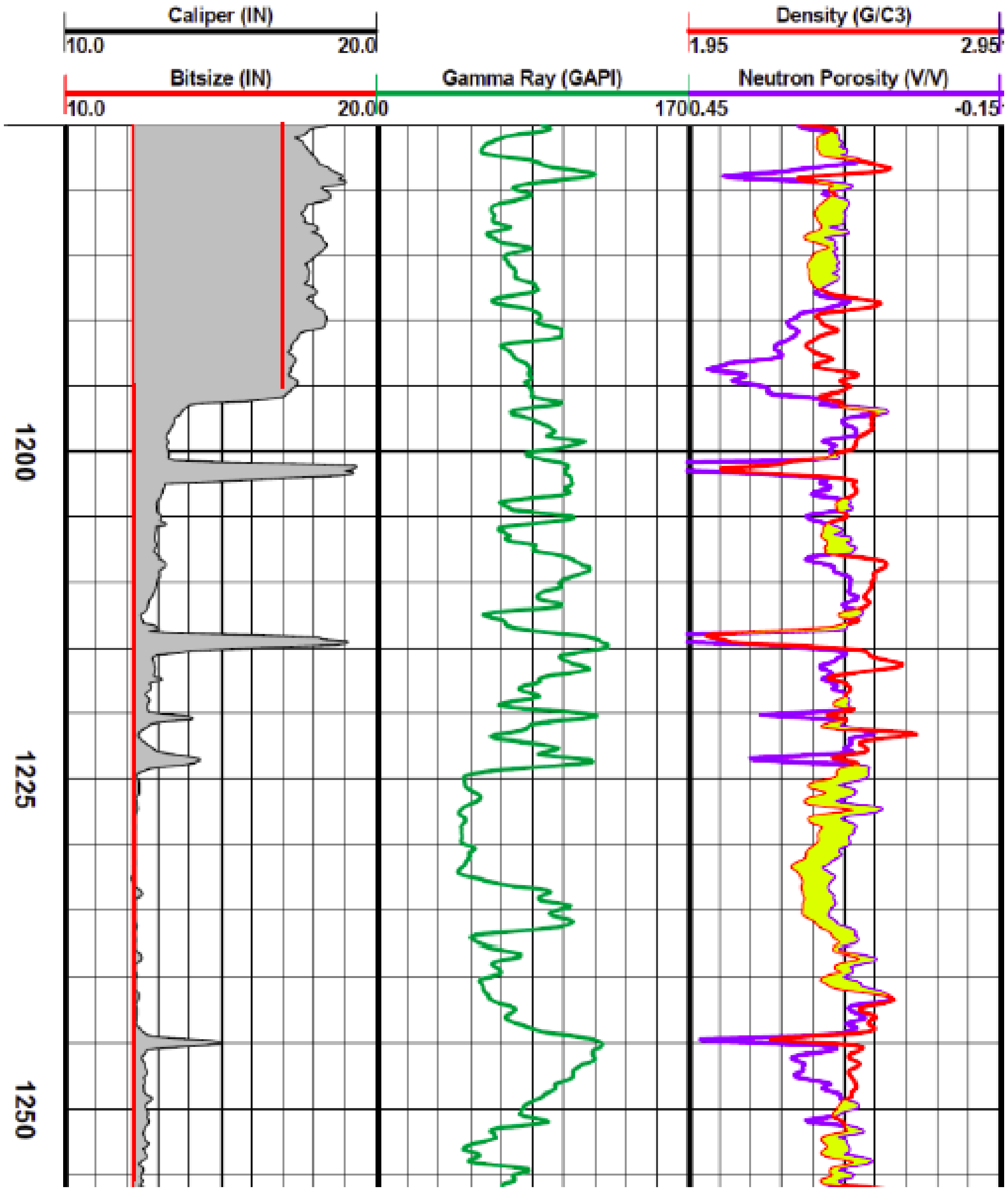
1) (partly) low core recovery (depth allocation of core segment??)

2) logging of one hole and composite profile from multiple holes (vertical depth of layers differ up to meters)

<u>agreement:</u>

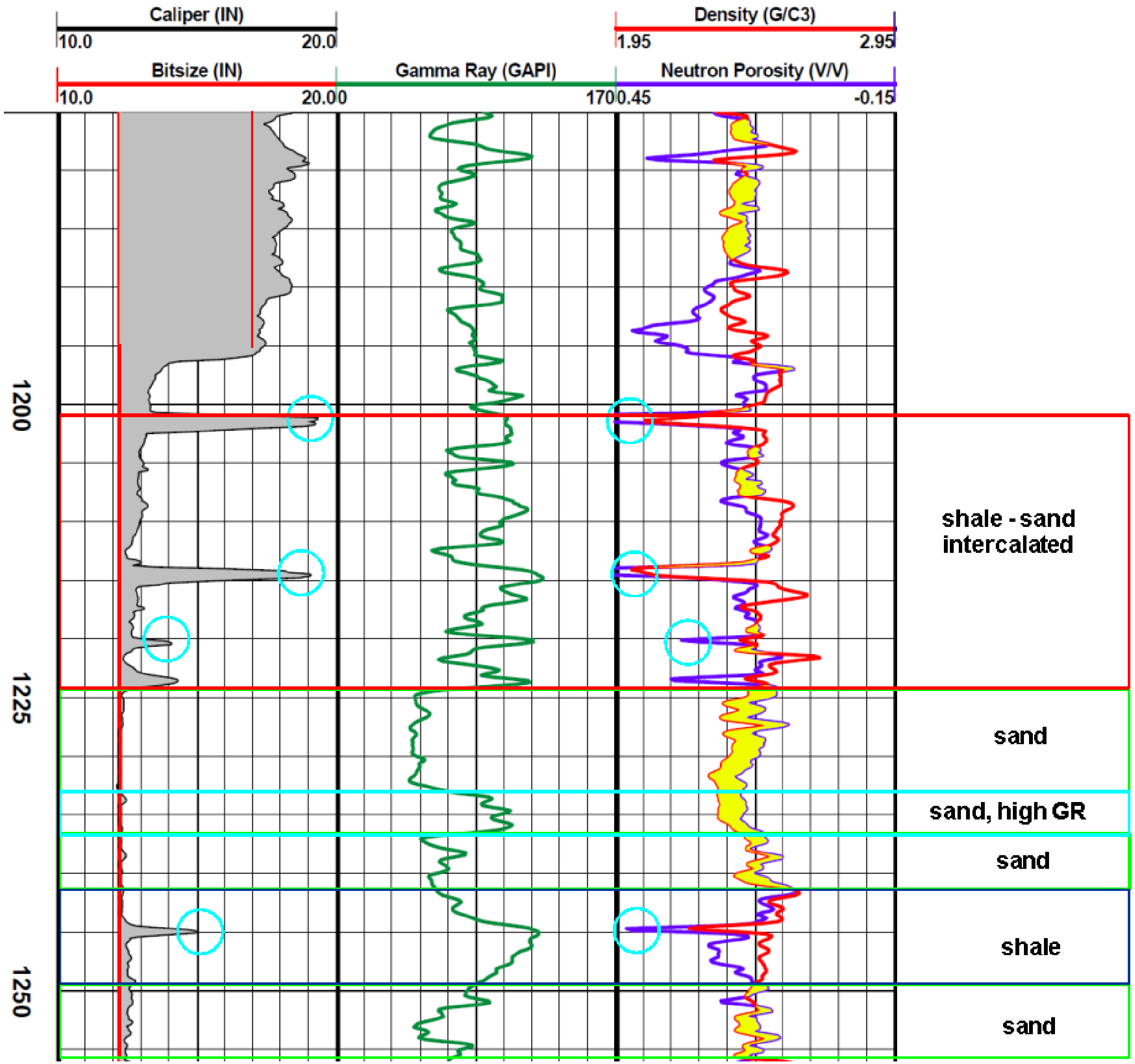
no reference depth, individual depths for datasets; integrated interpretation difficult

Excercise



- sandstone and shale (cretaceous; North German Basin)
- Caliper: borehole size (diameter)
- Caliper >> Bitsize!

Combined evaluation



- different porosity (high to low porosity sandstone)
- strong effect from washouts on density and neutron porosity
- caliper = quality control
- washouts coupled to lithology, shale = weak zones