Borehole Geophysics

Electrical resistivity imaging – RAB and FMS

Electrical resistivity can not only be used to quantify pore-fluid filling and the amount of hydrocarbon (e.g. free gas or gas hydrate) through standard Archie-analyses, but also to get structural information about the stratigraphy.

There are two main tools:

RAB – resistivity-at-bit is a LWD (logging-while-drilling) device

FMS – Formation-Micro-Scanner is a wire-line deployed tool

RAB tools provide complete 360 degree borehole images, but to a lesser resolution (1-2 inch). FMS tools do not cover the entire borehole wall but give very fine-scale information (1 cm or less).

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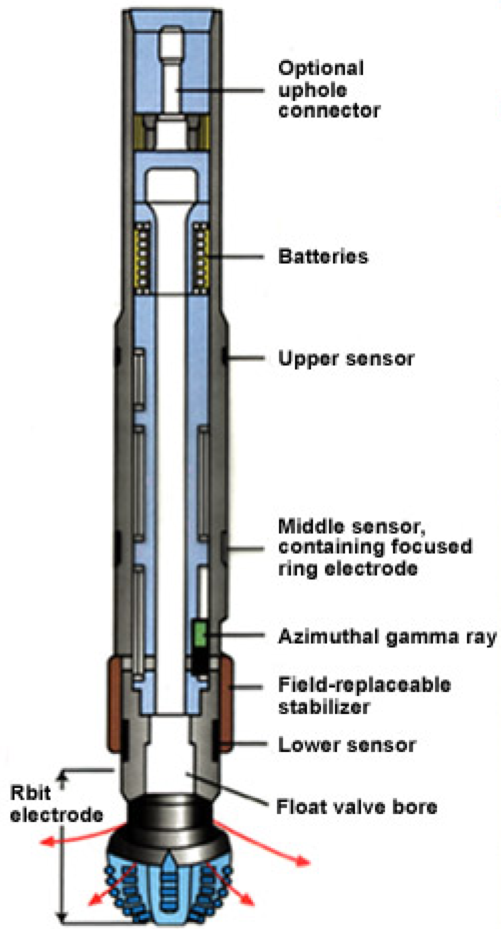
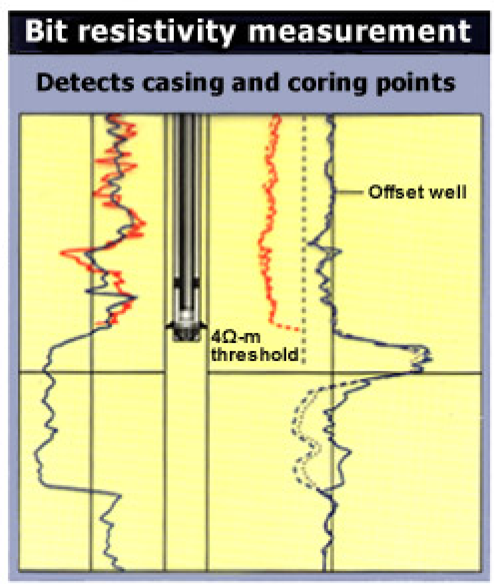
Resistivity-at-the-Bit

- Built into a near-bit stabilizer (for rotary BHAs)
- Earliest possible resistivity measurement while drilling ← **!! Safety!!**
- Data sent to MWD by tool bus or by EMAG telemetry, up to 150 ft





Source:

LDEO http://www.ldeo.columbia.edu/BRG/ODP/LOGGING/MANUAL/Pages/lwd_rab.html

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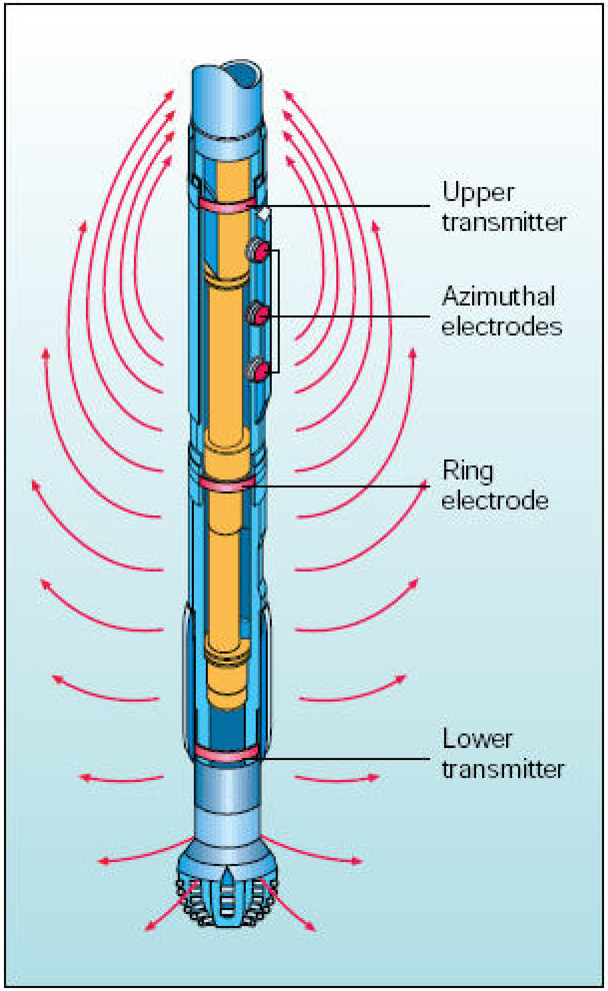

Illustration of current flow.

Induced at the bit, the current is measured at various electrodes mounted across the tool in addition to the bit-electrode itself.

Various electrodes are used to also investigate the depth-penetration effect of the resistivity (shallow, medium, deep).

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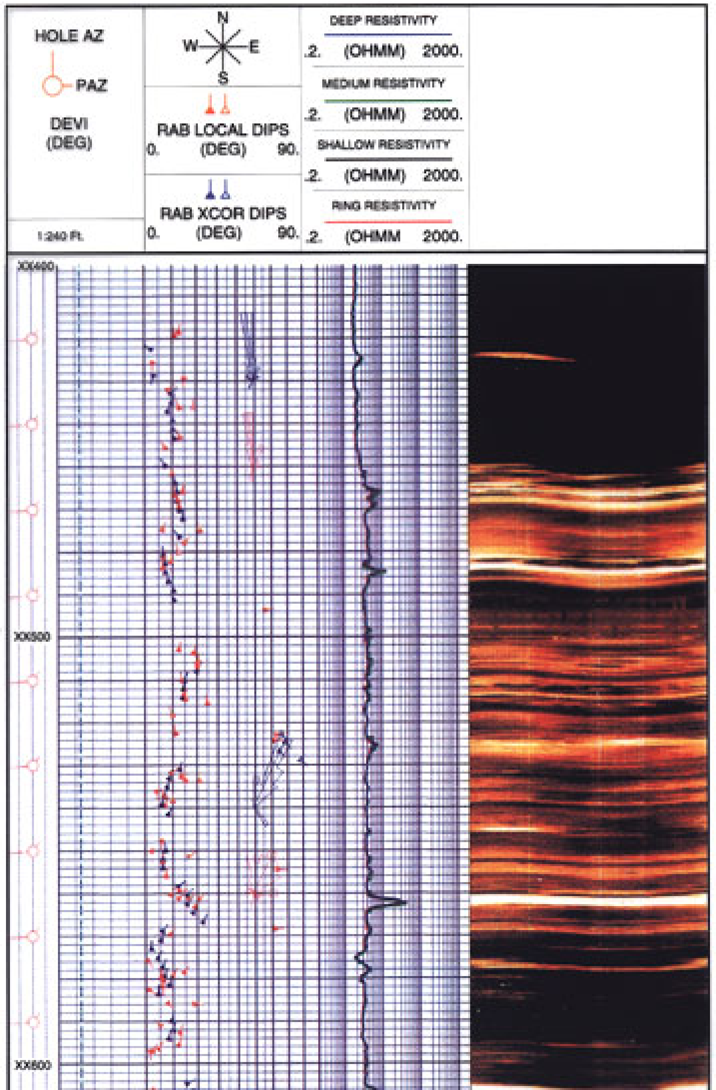
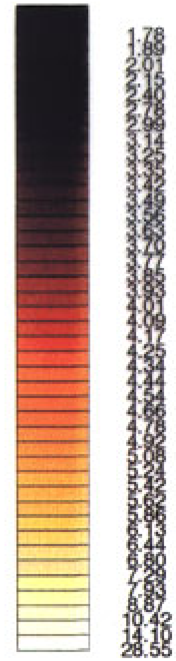




Standard output of the RAB tool.

Resistivity is measured 360 degrees around the borehole and the values of measured resistivity are color-coded such that highly resistive material appears in white/yellow colors, conductive material is set to black/brown.

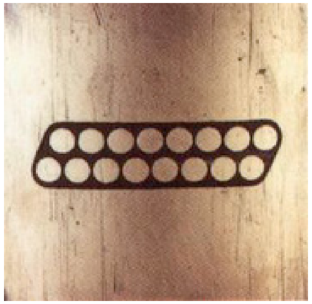
Source:

LDEO http://www.ldeo.columbia.edu/BRG/ODP/LOGGING/MANUAL/Pages/lwd_rab.html

Borehole Geophysics

Formation micro-scanner (**FMS**), sometimes also called FMI: formation micro-imager is a wire-line deployed tool, thus it yields information AFTER the borehole was drilled.

The FMS tool consists of four orthogonal imaging pads each containing 16 microelectrodes which are in direct contact with the borehole wall during the recording. The button current intensity is sampled every 0.1 in (2.5 mm). The tool works by emitting a focused current from the four pads into the formation. The current intensity variations are measured by the array of buttons on each of the pads.

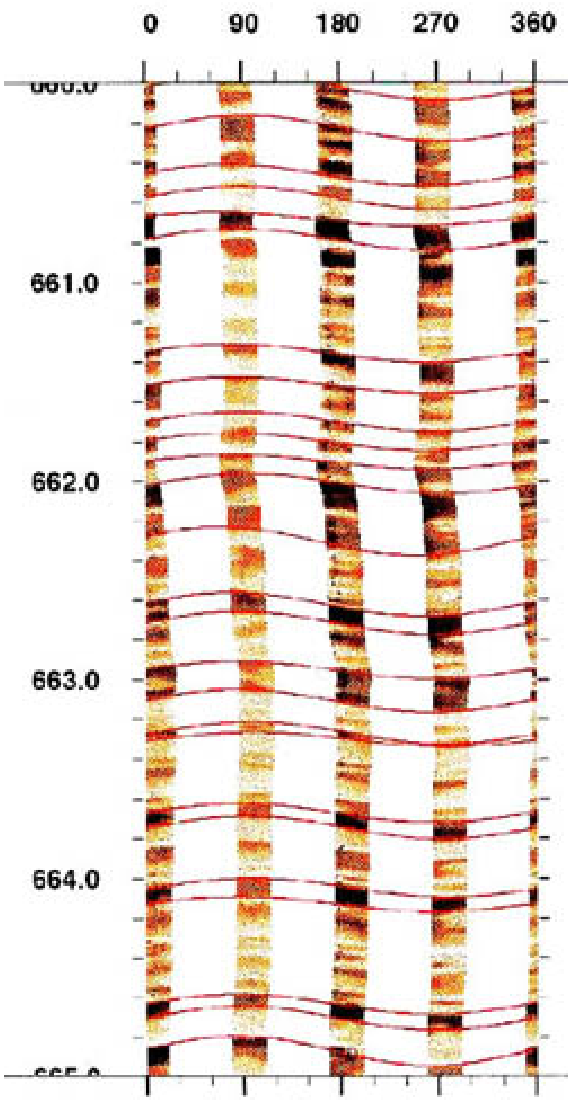


FMS pad with 16 micro-electrodes

Source:

Schlumberger, http://www.slb.com/content/services/evaluation/geology/fmi.asp?

Borehole Geophysics



Standard output of the FMS tool.

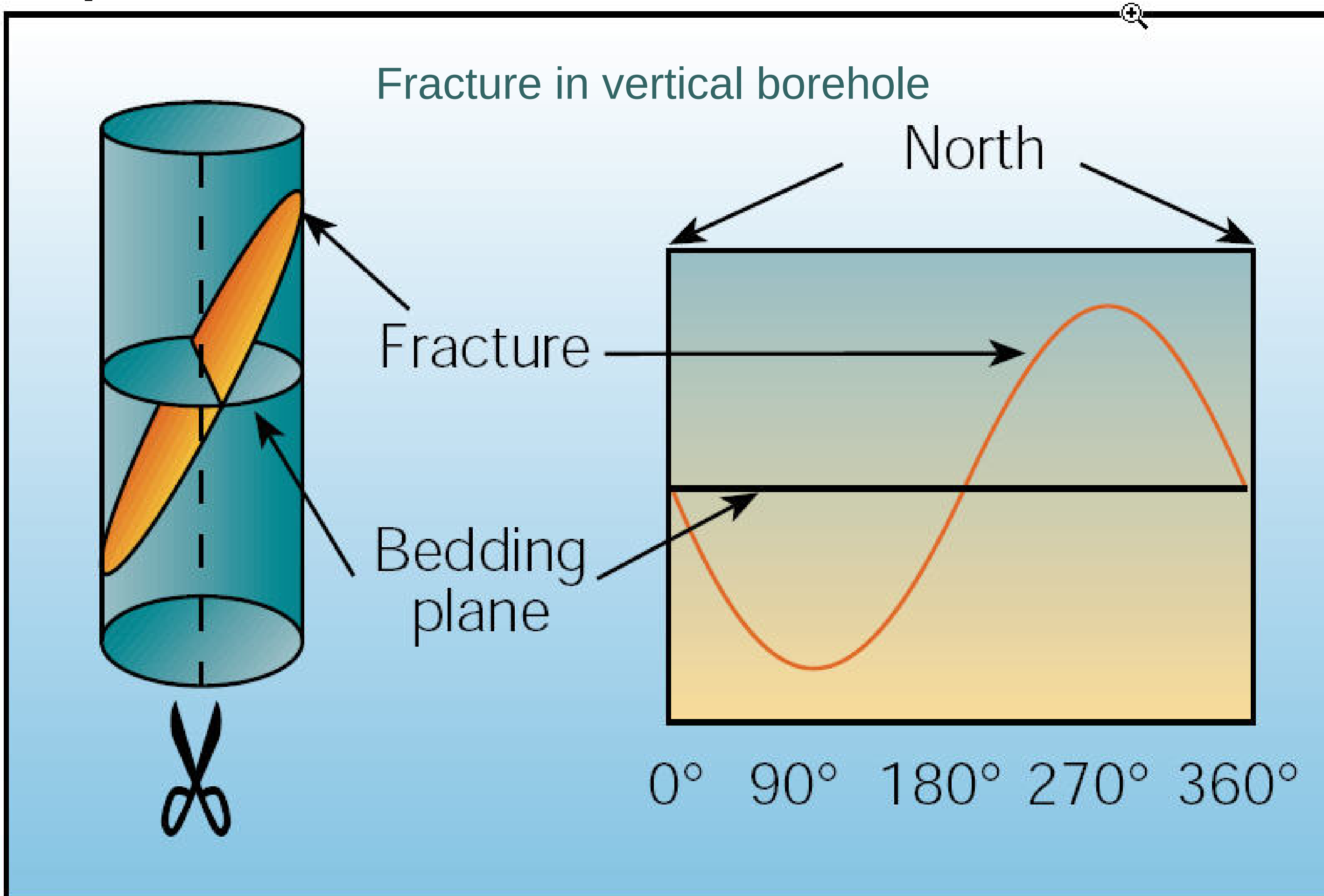
Resistivity is measured not entirely around the borehole, hence the gaps in the image to the left. The values of measured resistivity are again color-coded such that highly resistive material appears in white/yellow colors, conductive material is set to black/brown.

Source:

LDEO http://iodp.ldeo.columbia.edu/TOOLS_LABS/FMS/fms_mest.html

Borehole Geophysics

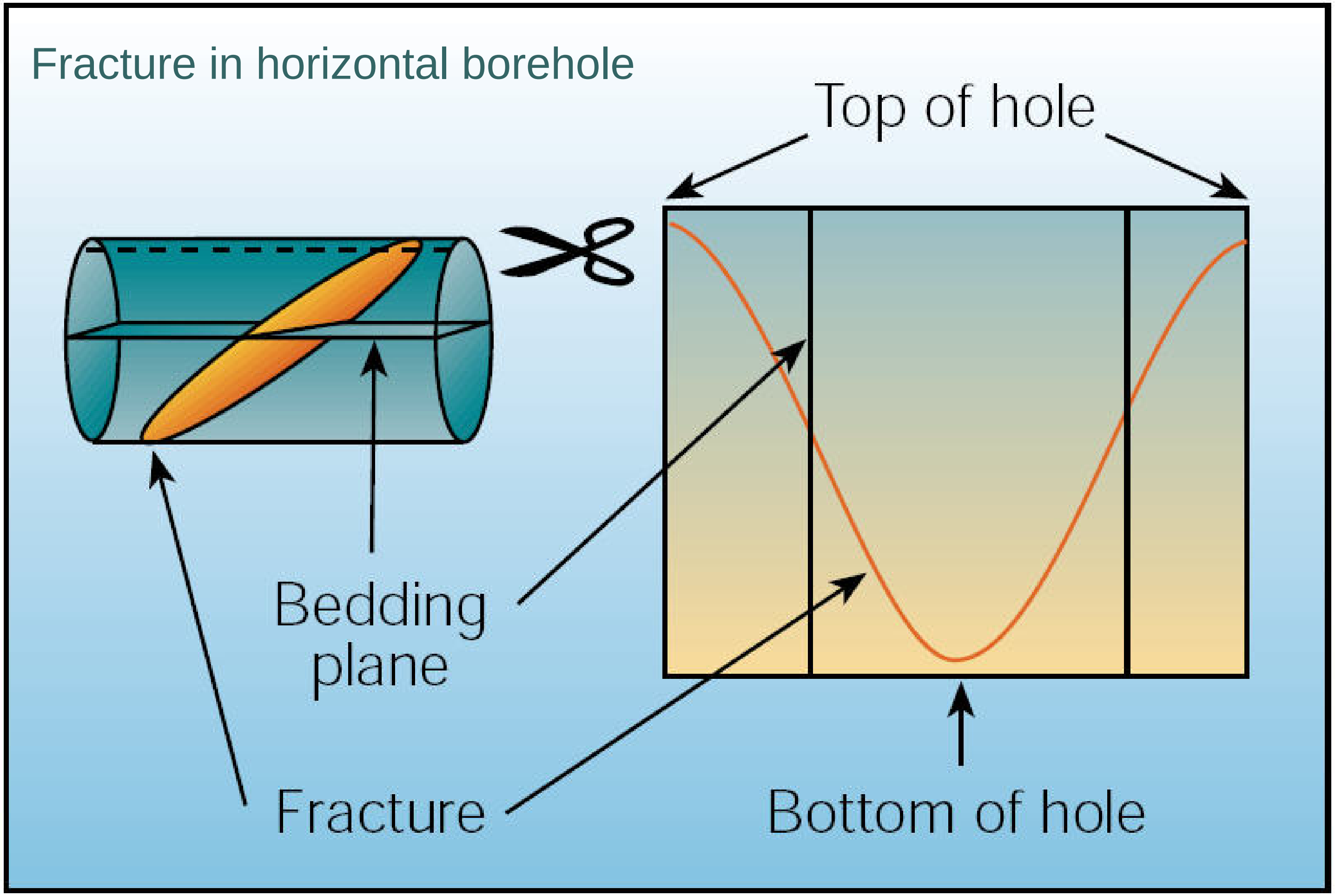
How to interpret the RAB, FMS/FMI images?



Source: Bonner et al., 1996

Borehole Geophysics

How to interpret the RAB, FMS/FMI images?



Source: Bonner et al., 1996

Borehole Geophysics

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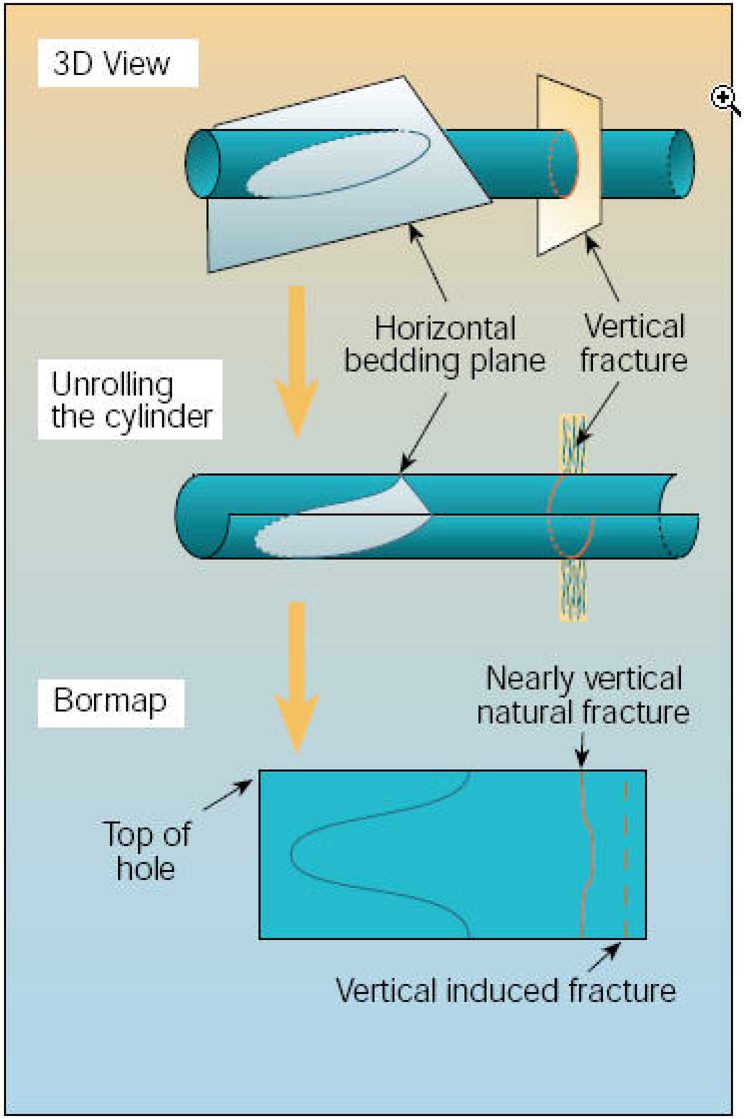

Source: Bonner et al., 1996

Borehole Geophysics

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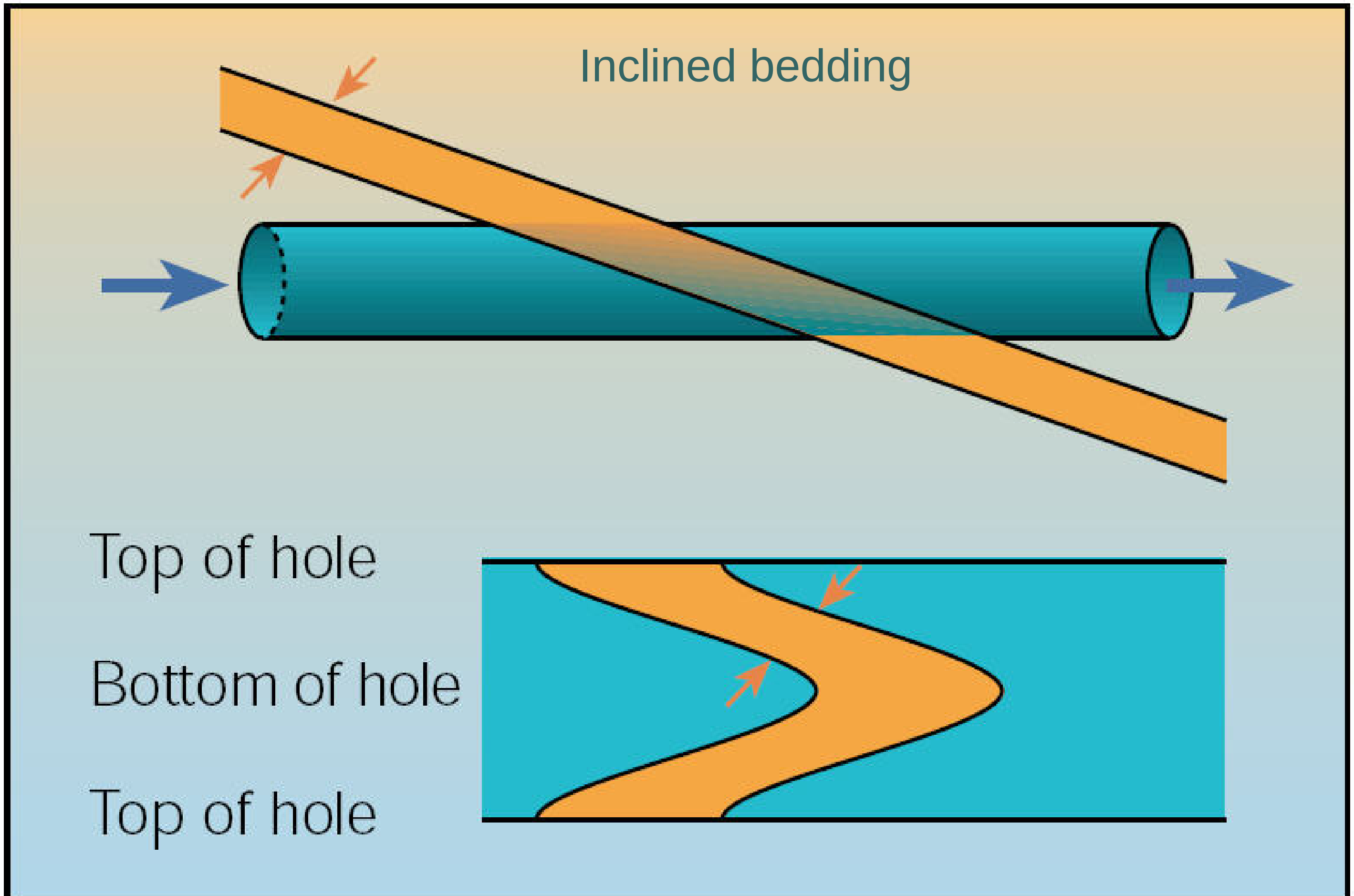
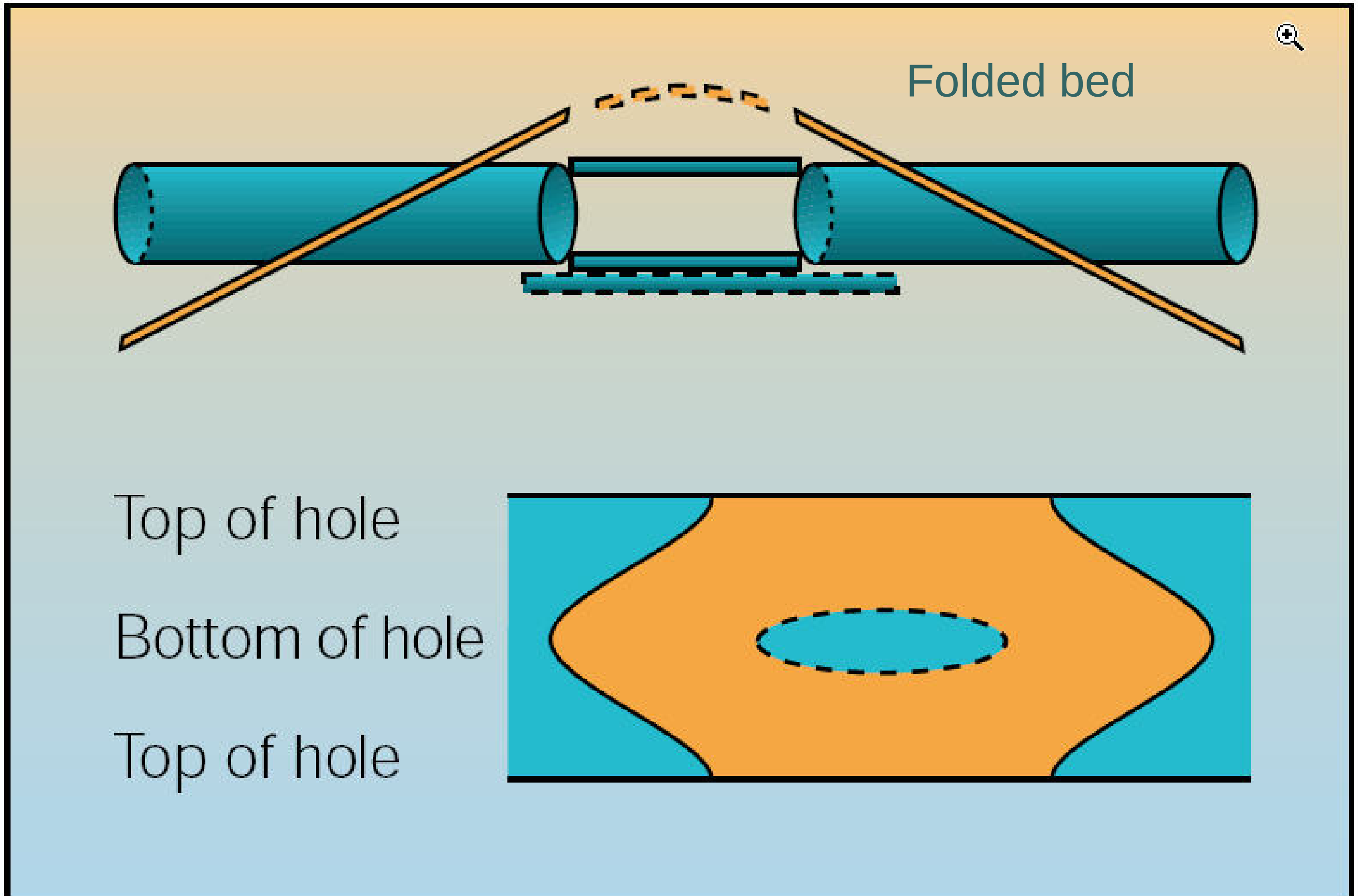


Source: Bonner et al., 1996

Borehole Geophysics

How to interpret the RAB, FMS/FMI images?



Source: Bonner et al., 1996

Examples of FMI images

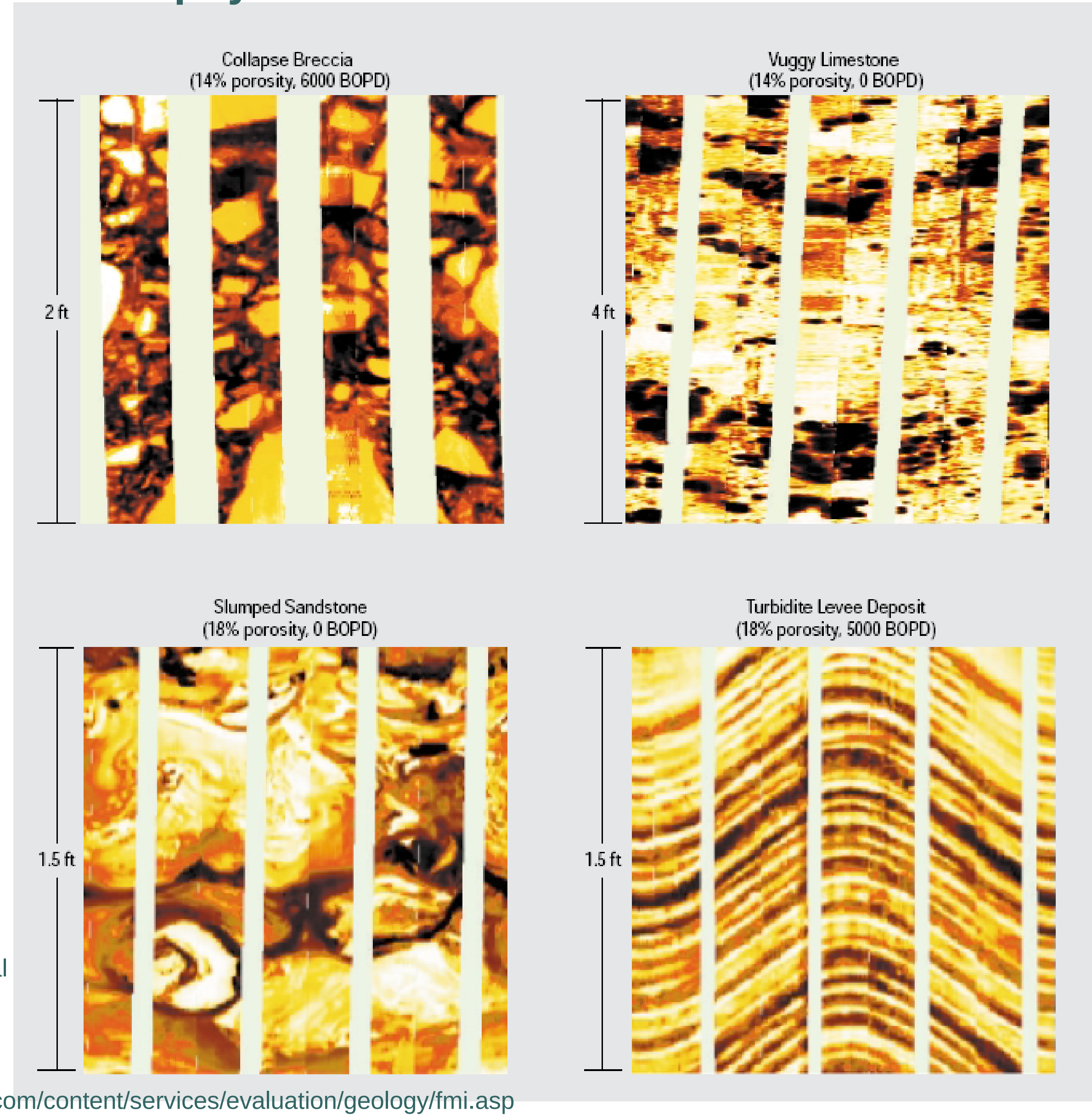
Top left: collapsed Breccia

Top right: Vuggy limestone

Bottom left: slumped sandstone

Bottom right: turbidite levee deposits

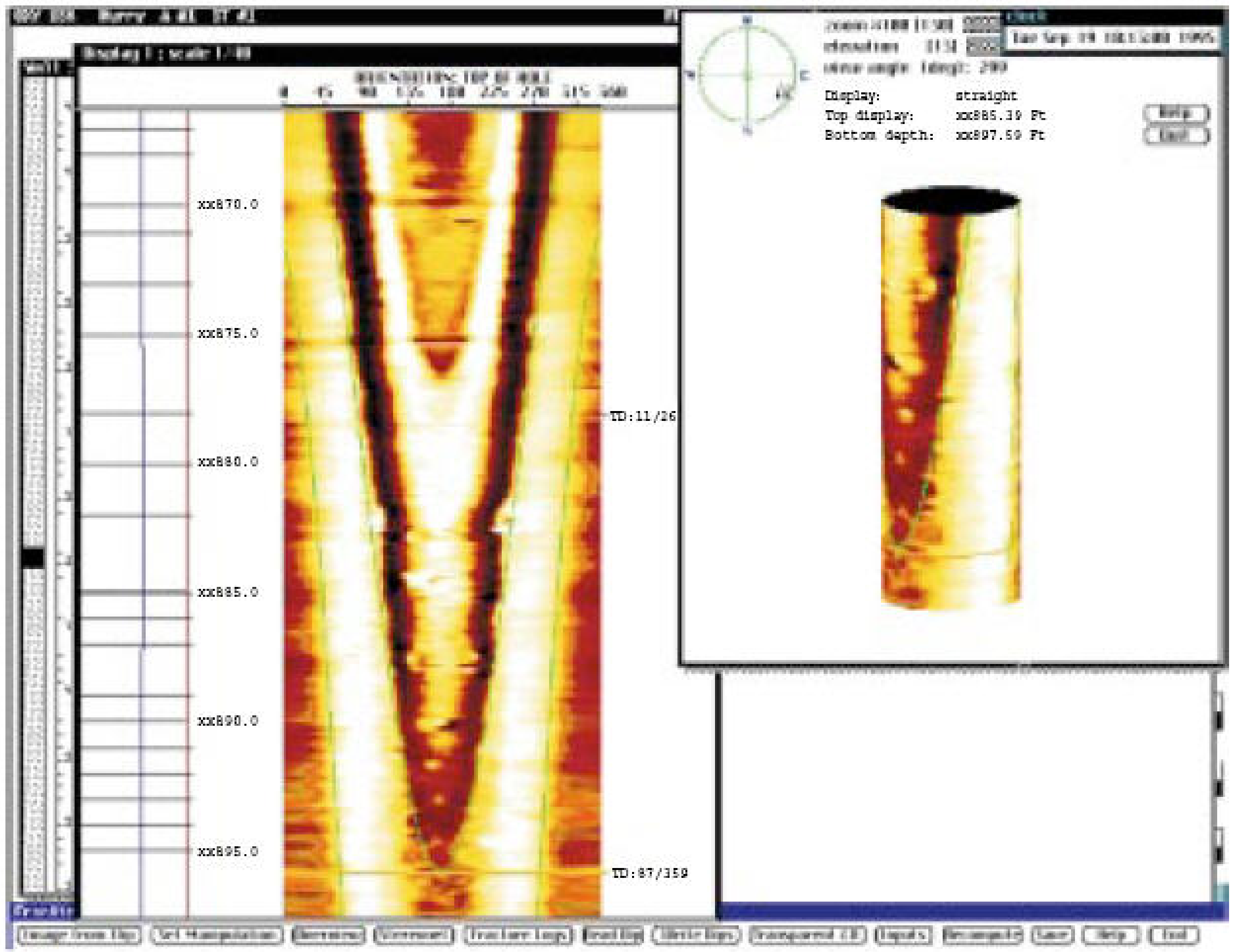
Vug: A cavity, void or large pore in a rock that is commonly lined with mineral precipitates.



Source: Schlumberger, http://www.slb.com/content/services/evaluation/geology/fmi.asp

Borehole Geophysics

RAB example of crossing bedding planes. Analyses show that the bed dips at 11 degrees to the NNE.



Source: Bonner et al., 1996

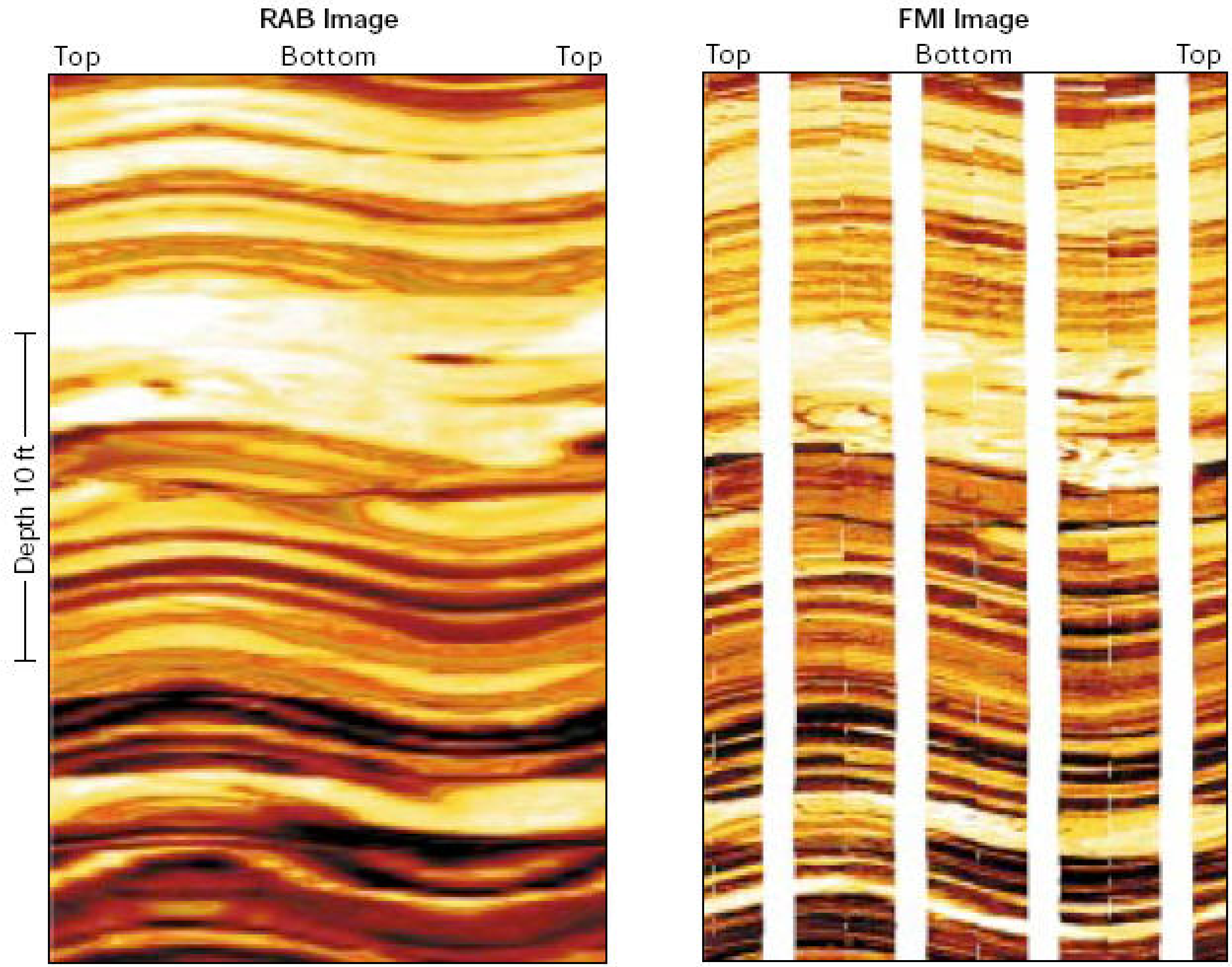
Borehole Geophysics

Comparison of RAB and FMI images from same borehole depth interval.

Left: RAB

Right: FMI

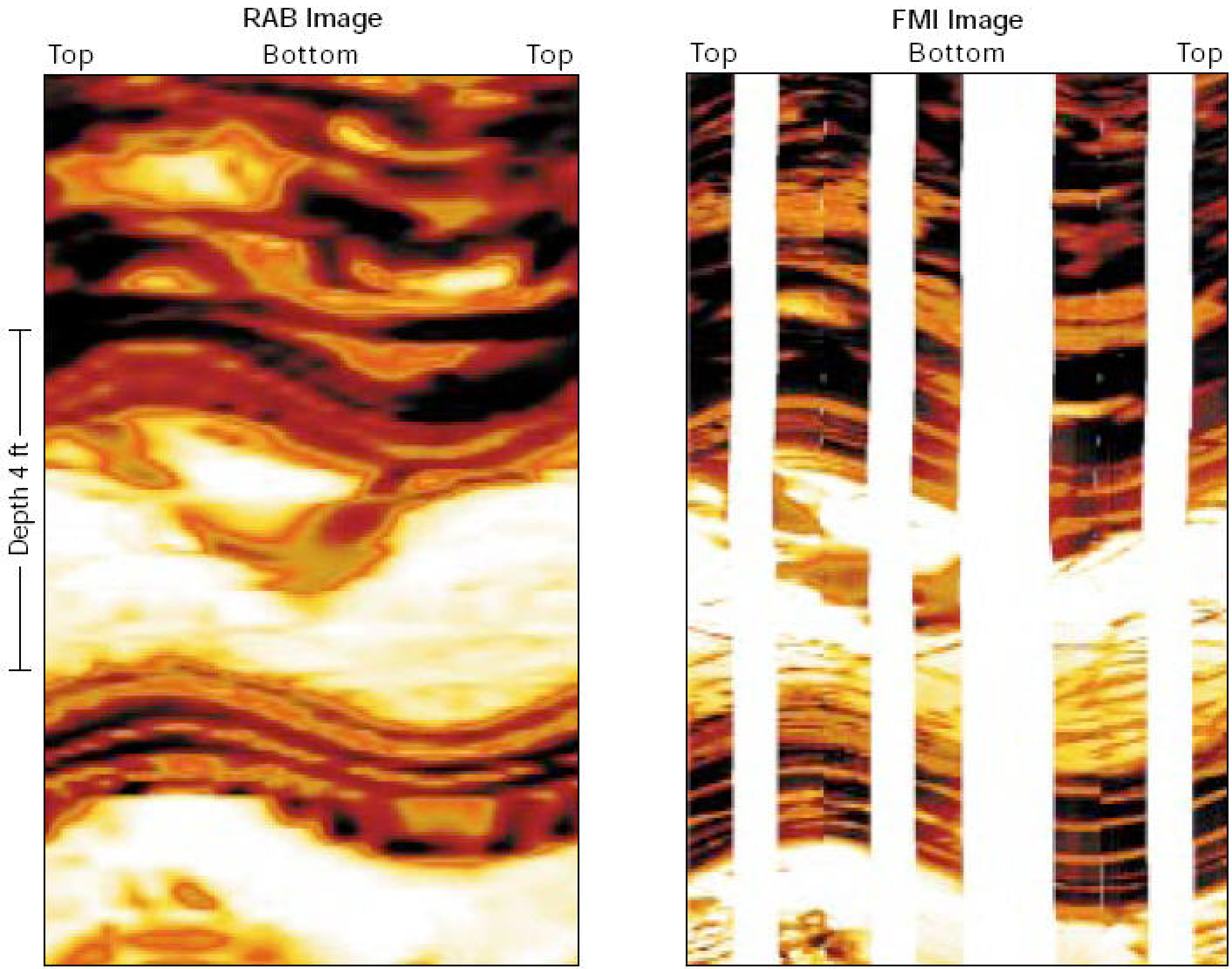
Both images show dipping beds. Note that beds less than 4 in (10 cm) thick, cannot be seen on the RAB images.



Source: Bonner et al., 1996

Borehole Geophysics

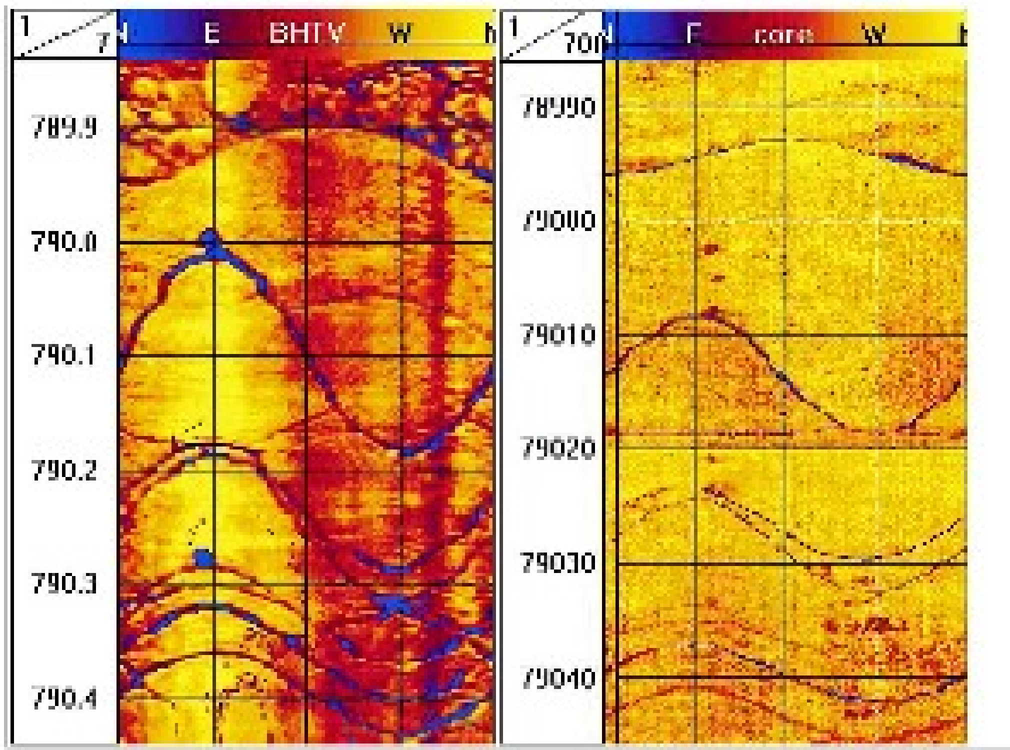
Comparisons of RAB and FMI images of fractures. Note the much finer resolution in the FMI for fine-scale fractures.



Source: Bonner et al., 1996

Borehole Geophysics

Alternative tools to image the borehole with resistivity:
BTV: Borehole Televiewer – acoustic imaging

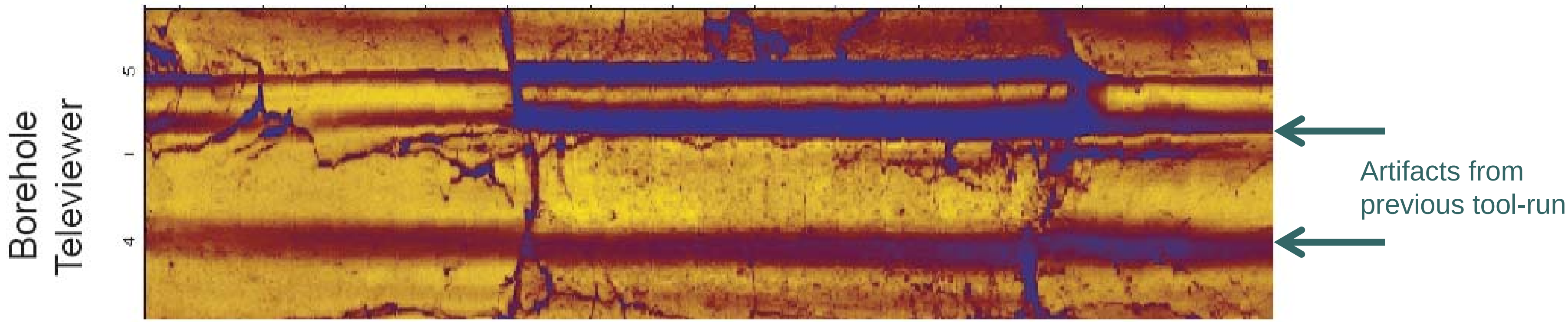


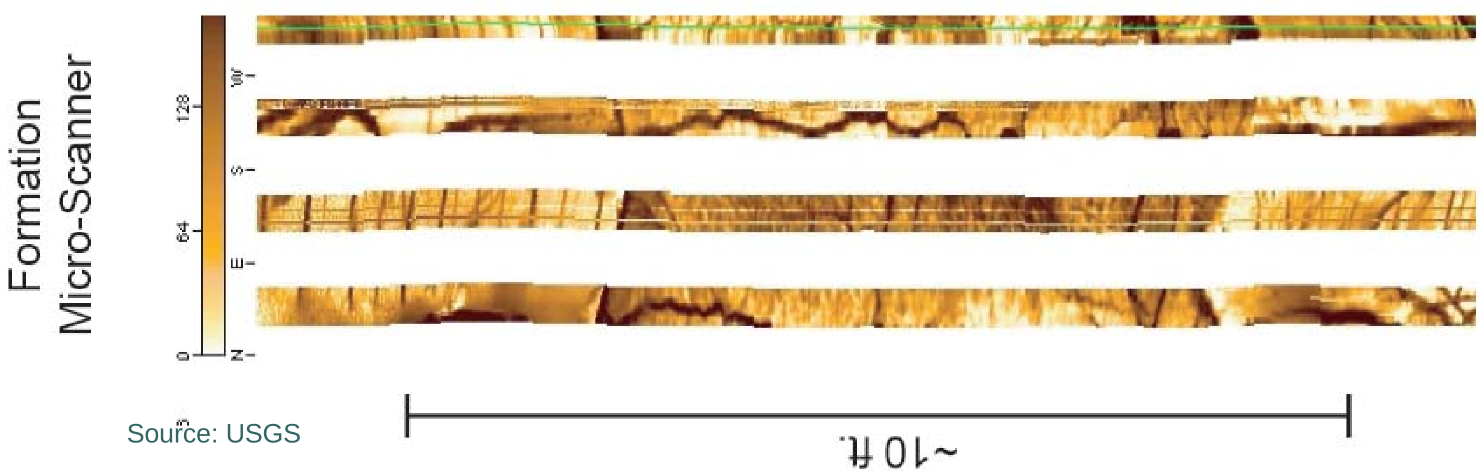
Instead of using electrical resistivity, the BTV (or ATV = Acoustic Televiewer) images the borehole wall by acoustic methods. Low velocity due to cracks filled with pore-fluid are typically color-coded in blue.

Source: www.andrill.org/iceberg/blogs/julian/all.php

Borehole Geophysics

Alternative tools to image the borehole with resistivity:
BTV: Borehole Televiewer – acoustic imaging



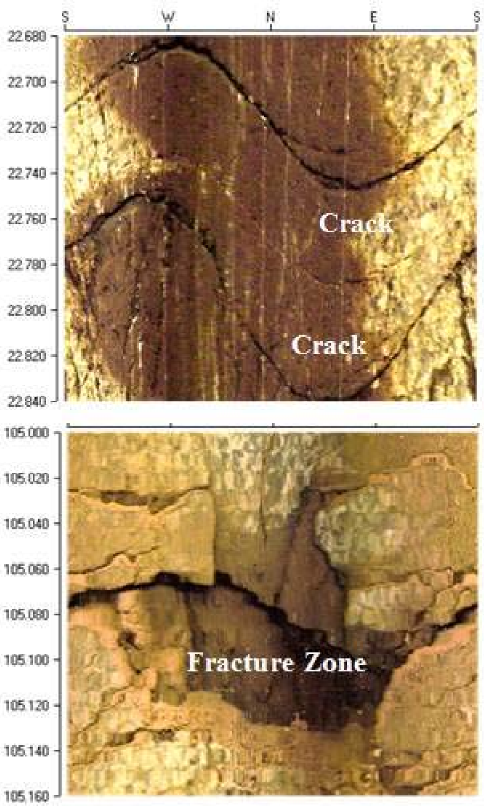


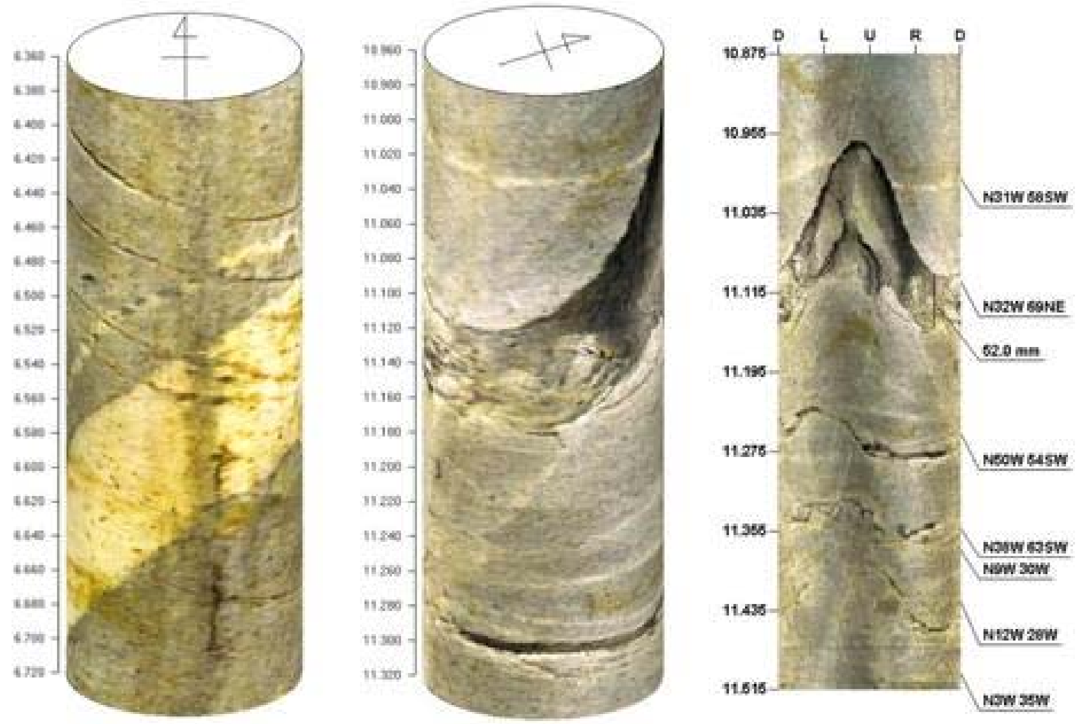
Source: USGS

Borehole Geophysics

Alternative tools to image the borehole with resistivity:

Optical methods



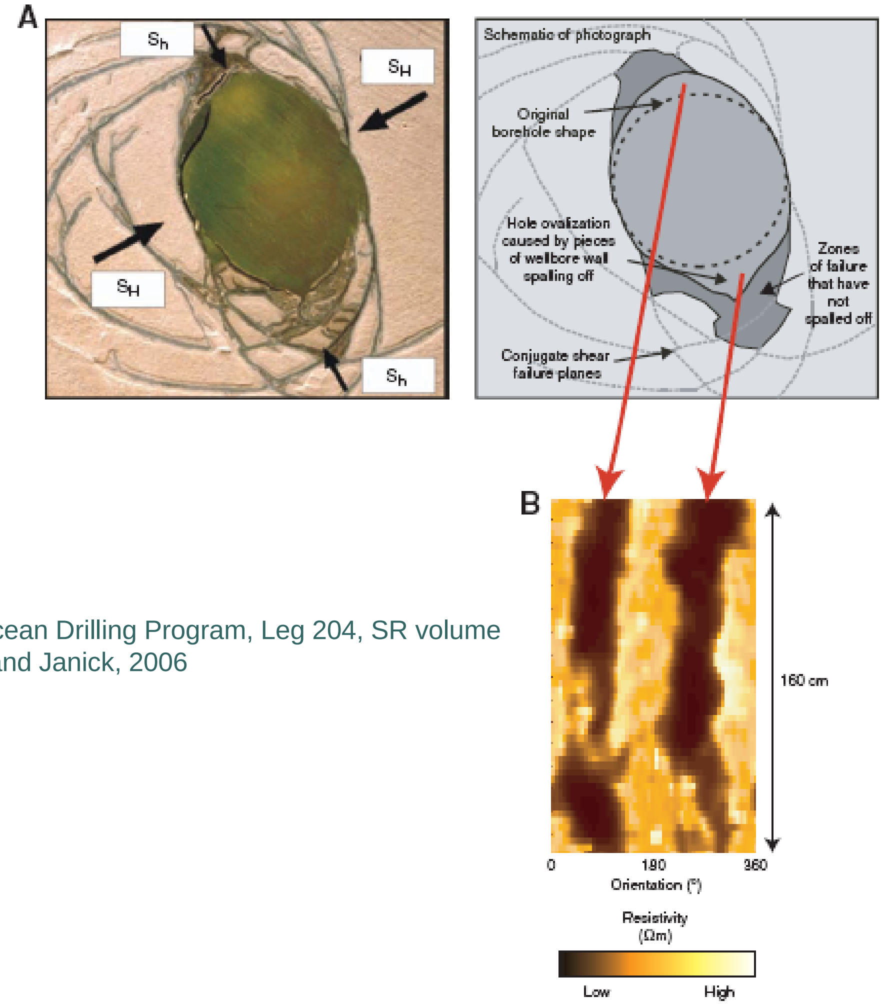


Used in open boreholes that can be drilled without borehole fluids; shallow application. Not much used in deep drilling (too high pressures!)

Source:
http://cgsweb.moeacgs.gov.tw/CGSWeb/Result/Fault/english/teaching/geophysics/Geophys_en/LOG-6.htm

Borehole Geophysics

Structural interpretation of RAB/FMI/FMS images



Source: Ocean Drilling Program, Leg 204, SR volume
Goldberg and Janick, 2006

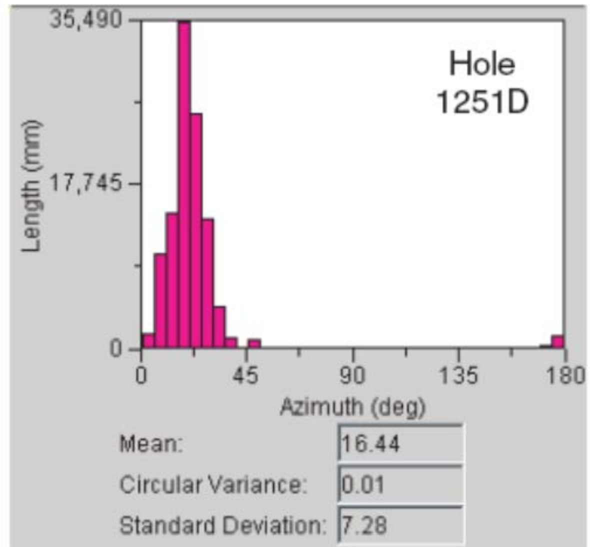
Illustration how the Resistivity-at-bit (RAB) tool sees borehole irregularities:

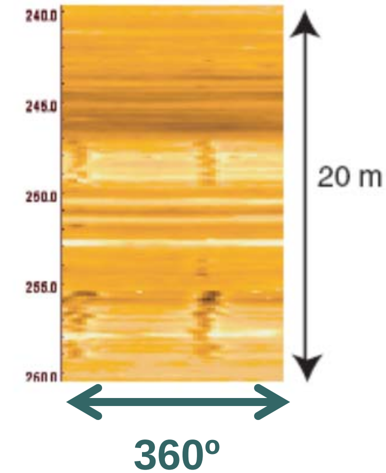
Breakouts have low resistivity compared to surrounding rock – breakout is fluid-filled, which is generally less resistive than the rock.

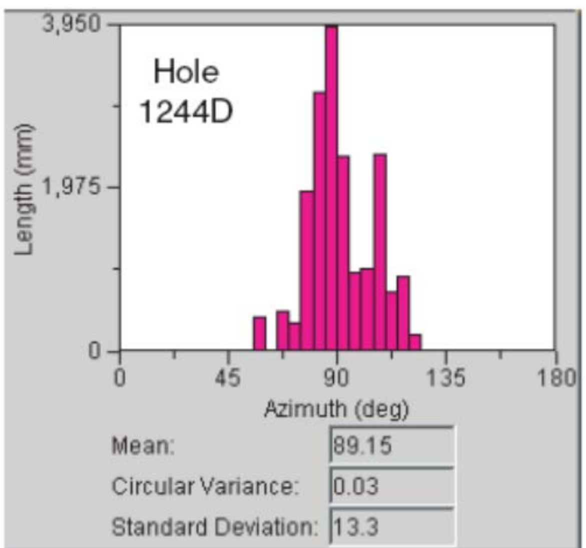
Borehole Geophysics

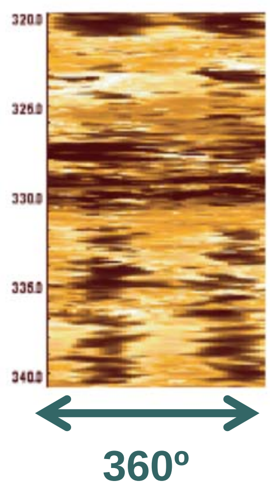
Structural interpretation of RAB/FMI/FMS images:

Using breakouts to define stress regime



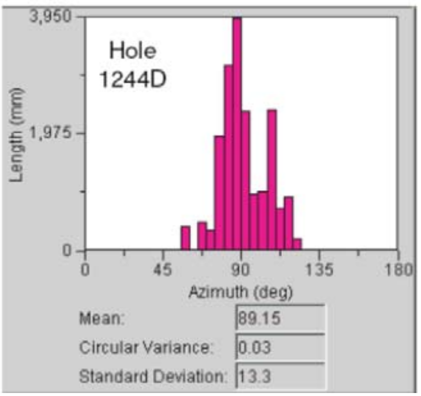


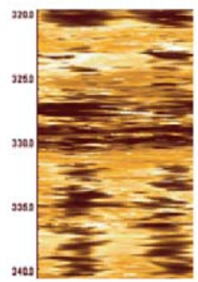


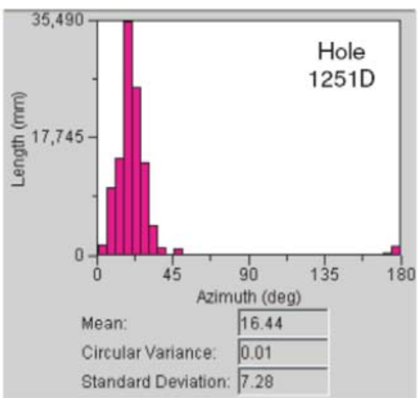


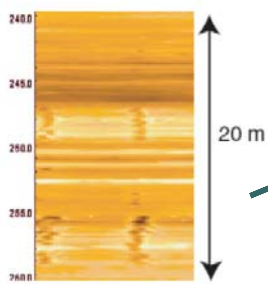
Source: Ocean Drilling Program, Leg 204, SR volume
Goldberg and Janick, 2006

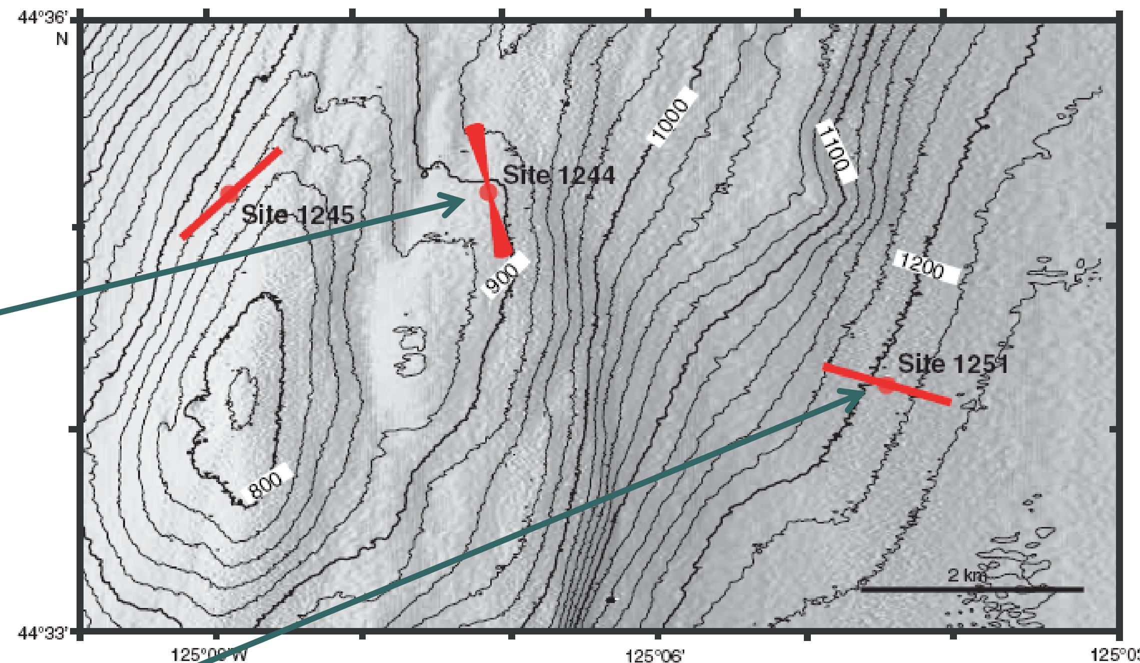
Borehole Geophysics











Source: Ocean Drilling Program, Leg 204, SR volume
Goldberg and Janick, 2006

LWD and safety

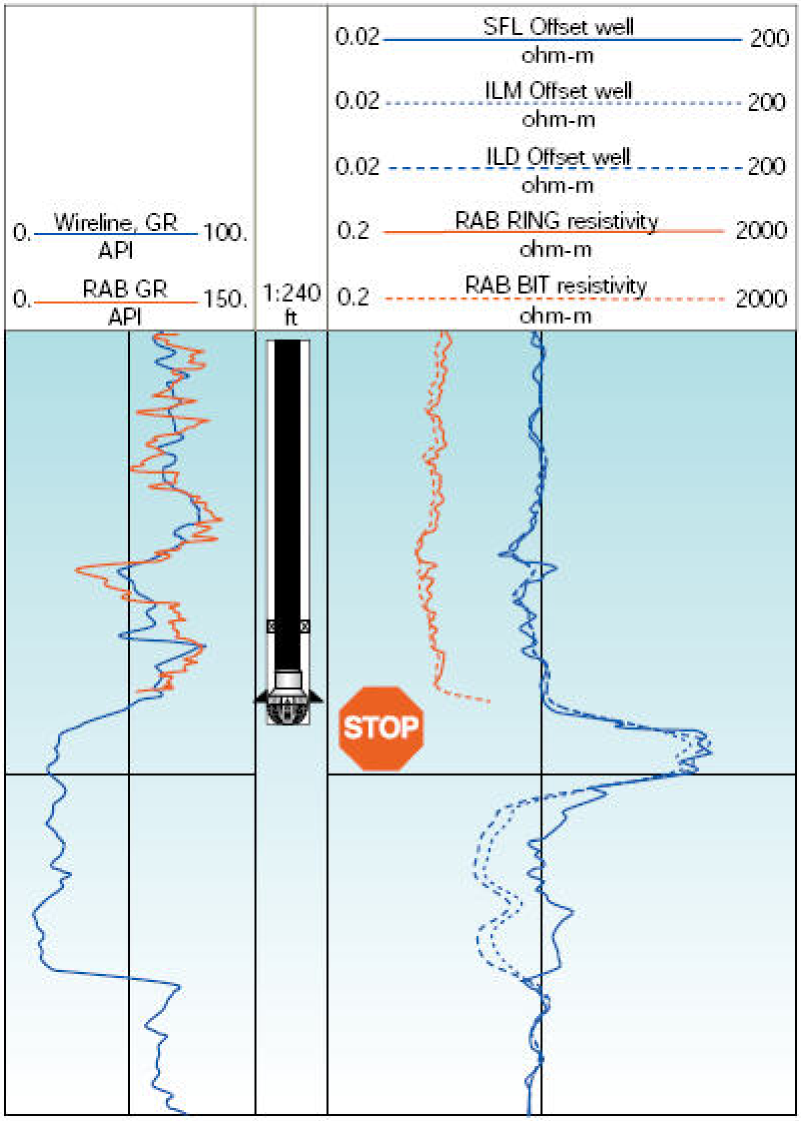
Logging-while-drilling offers a unique possibility to evaluate the safety of drilling operations as the drilling data are immediately available while the drill-bit enters the formation. The main concerns are free gas (or flowing sand) entering the borehole and borehole collapse (stuck tools). Free gas can result in a blow-out if the borehole cannot be plugged in time. Flowing sand are also a concern as the sand (water or gas-bearing) will spill out at the seafloor.

Typically the LWD data are transmitted back to the ship via the MWD tool (measurement-while-drilling), which consists of a special transmission unit to maintain communication with the drill-ship.

There are three important tools used to evaluate safety:

- Pressure response
- Resistivity at the bit (RAB)
- Acoustic coherence

Borehole Geophysics



Entering a zone of high resistivity (potentially free gas).

If resistivity values go above a pre-defined threshold, drilling is stopped.

Pressure response is evaluated (is free gas flowing?). If no flow is detected, drilling will resume.

Borehole Geophysics

Image showing (raw, not depth-shifted) results from IODP X311 LWD deployment.

Shown are pressure variation (hydrostatic trend taken out) on the left panel and acoustic coherence on right panel.

Note the drop in pressure and loss of coherence below the hydrate-related BSR. Here some free gas had entered the formation, but since pressure did not continuously drop, drilling was resumed.