Borehole Images:
Present and Future Applications

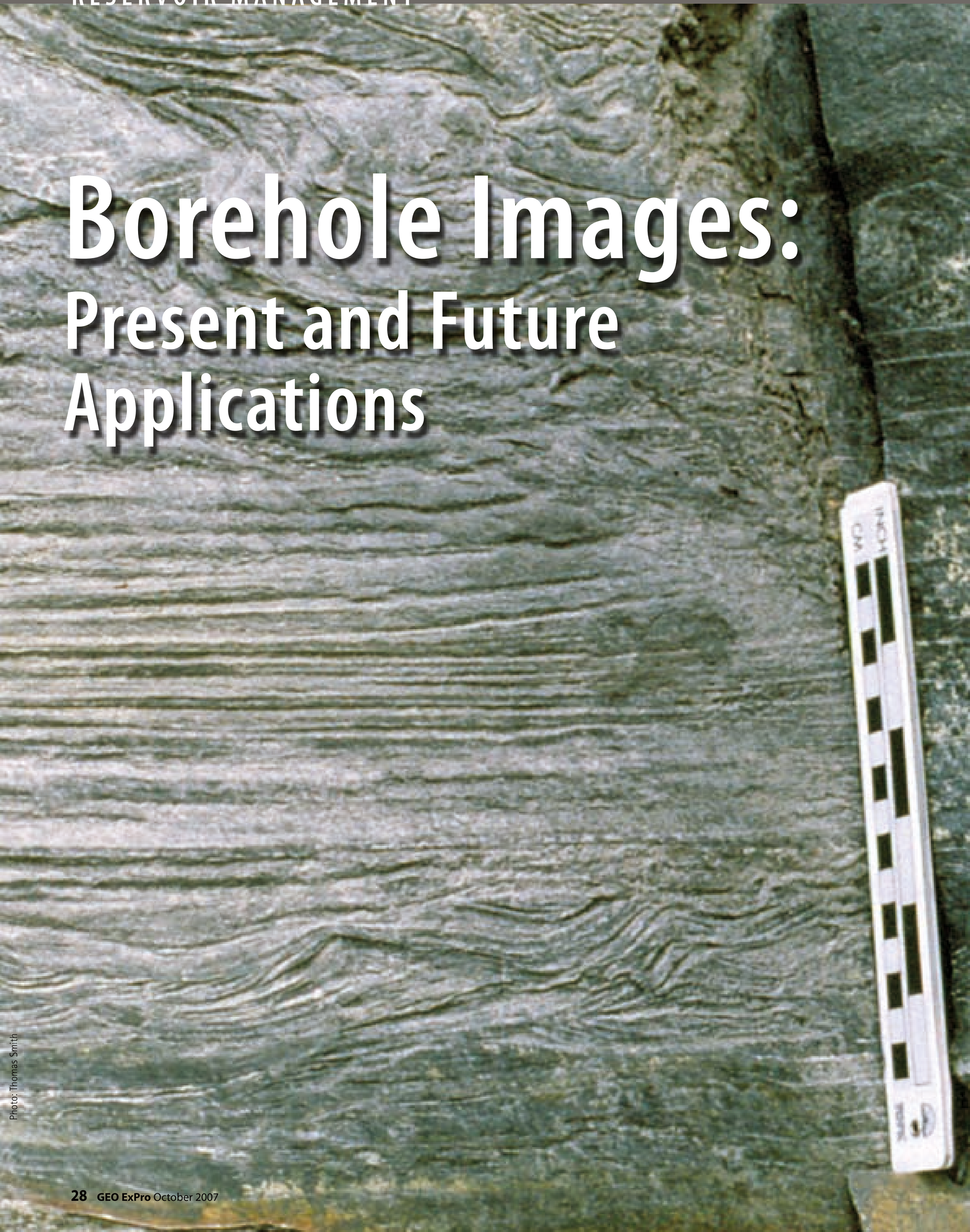

Photo: Thomas Smith

High-resolution, while-drilling electrical imaging provides a 360 degree map of the borehole wall in its most pristine state, before significant mud invasion and borehole degradation. This real-time information provides an instant look at the geology, essential to reservoir navigation and, for the first time, offers the definition needed for live geomechanical modeling.

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Starting from single-button, wireline-deployed pads on an articulated arm measuring SP or micro-electrical responses, borehole imagers have evolved a great deal over the past 30 years to full coverage circumferentially and longitudinally measuring devices. Each successive evolution has a more refined resolution. Their value for the detection and interpretation of geological features, both structural and sedimentological, is well established. Now, high-resolution electrical imaging is possible while drilling

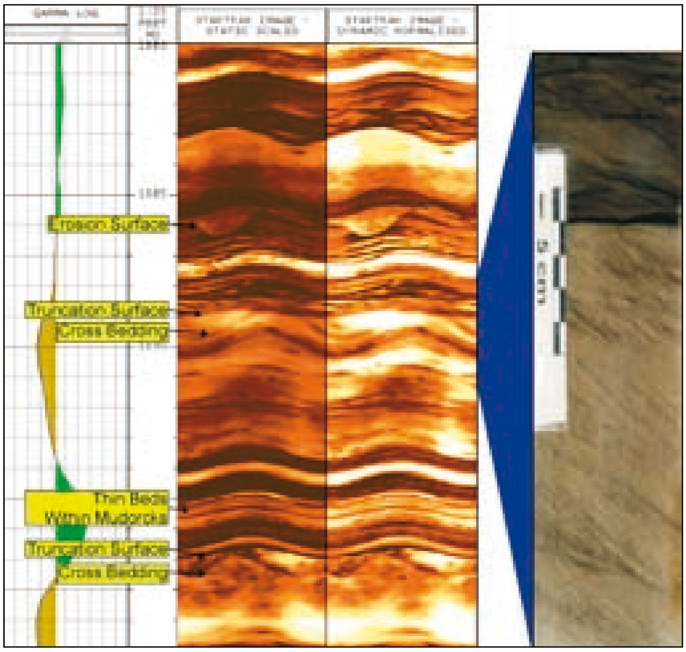
Comparison to Wireline

High-resolution LWD electrical imaging provides several important advantages over similar wireline imaging.

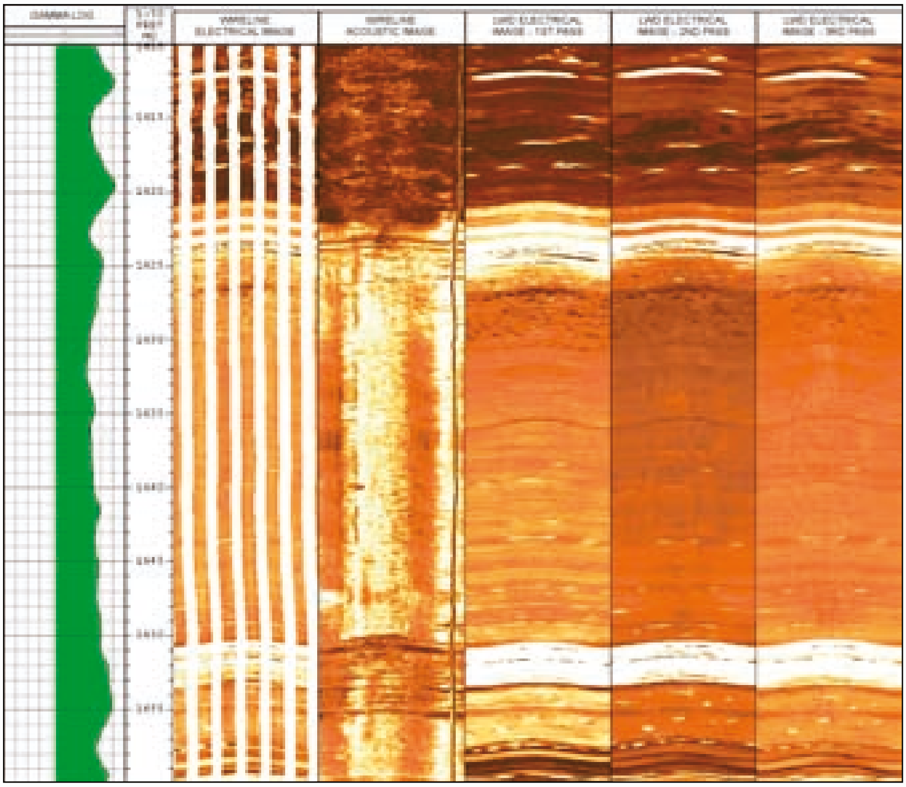
The LWD electrical imaging device can be placed 2 to 3 m behind the bit of a rotary steerable, bottom-hole assembly (BHA). The image can then be obtained in nearly virgin formation soon after penetration. Also, borehole wall images are obtained before significant mud invasion. Image quality is also affected less by the artifacts related to caving, wash-outs, mudcake or other borehole shape irregularities.

A sensor attached to an instrumented drill collar rotates and scans the entire borehole wall. The resulting LWD image is of the full (360°) borehole wall without the typical white bands observed from wireline image logs.

The information generated can be made available to the surface through telemetry. Real-time images (albeit less resolved) provide instant access to the geology and help in guiding reservoir navigation. In addition, the high-resolution image is stored in a solid state memory on the BHA and downloaded when the tool is tripped out to the surface.



Near core quality images can be obtained by logging-while-drilling (LWD) high-resolution electrical devices. Here cross bedding and set-bounding surfaces are clearly seen over a 2 m interval. The core is from an offset well.



Excellent repeatability of sedimentological features over a 10 m interval imaged by the LWD device is at least equivalent to the wireline measurements. In general, there is very good comparison between wireline and images while drilling in respect to image sharpness and resolution. Borehole coverage while drilling is clearly advantageous.

Thin lamination, cross-lamination, fractures, faults, vugs, and mudclasts/pebbles can now be determined from high resolution electrical borehole images.

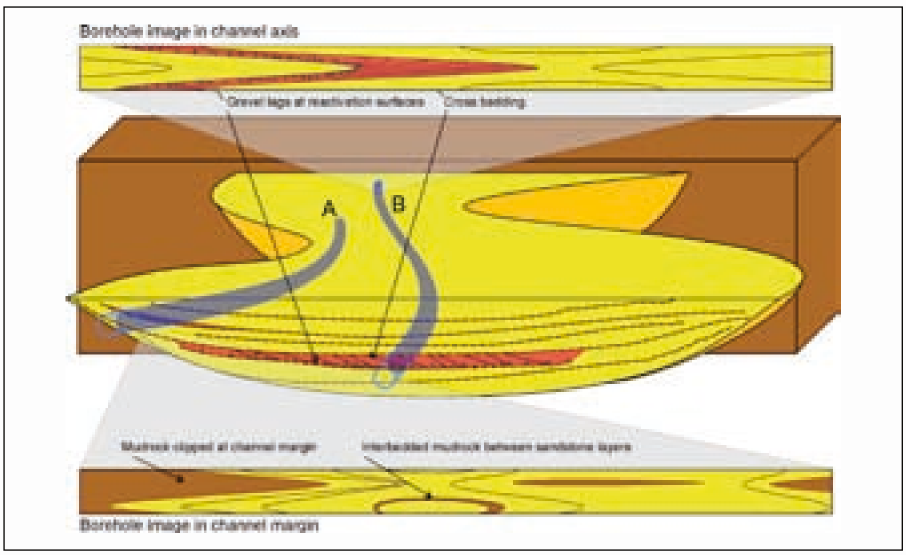
Real-Time Resolution While Drilling

Sedimentary steering and wellbore stability management become more a reality with less "guess work" and reduced uncertainty using images sent to the surface while drilling. Currently resolution is less than full memory stored data. Data compression techniques, however, are designed to retain the essential features of an image that allows for interpretation at the surface. Thin lamination, cross-lamination, fractures, faults, vugs, and mudclasts/pebbles can be determined from these images. These features were previously only possible after retrieving the memory data. Soon, memory resolution images while-drilling will be possible using new technologies such as wired pipe communication lines and high speed telemetry systems.

Real-time images at a resolution of 32 sectors are adequate in detail to show faults, where there is a distinct offset between bedding and juxtaposition of different lithologies. Higher real-time image resolution may be needed in order to identify and distinguish different fracture types. The example shown here indicates that individual pebbles on bed bases (rounded, highly resistive features) can be resolved and even counted.

'Sedimentary Steering'

Hitting the 'sweet spot', the channelized sandstone or a high porosity interval in a particular reservoir, is a goal of accurate reservoir navigation. Often, geosteering within a sand body is limited until a lithological boundary is detected often to the detriment of maximizing the 'sweet spot' in the reservoir. Using high-resolution real-time images will effectively reduce the uncertainties by allowing the interpretation of the sandbody internal geometry, thereby providing information earlier before exiting of the desired part of the reservoir.



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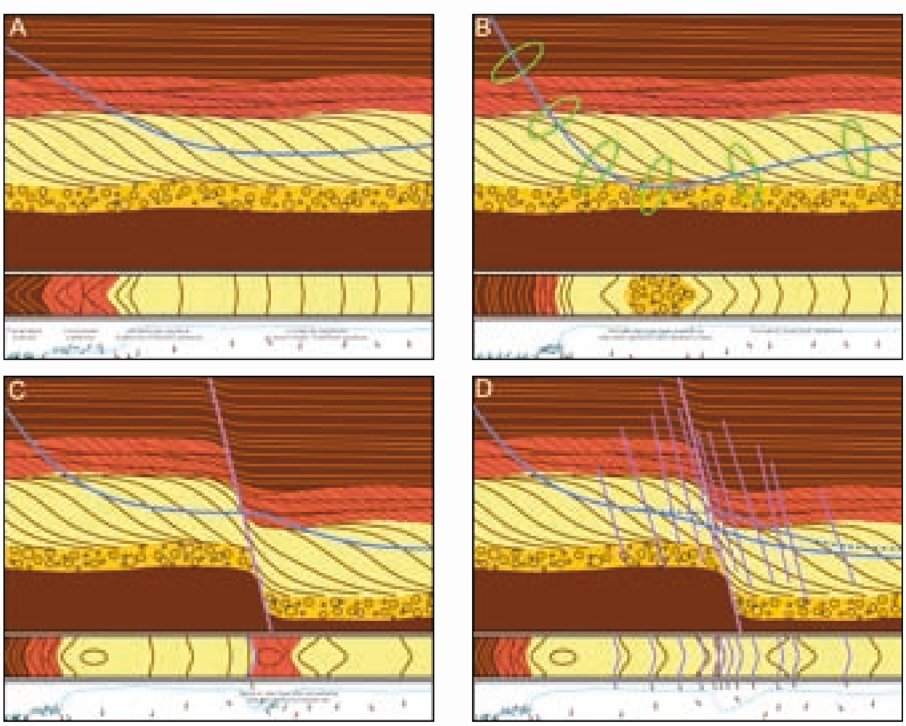
Lateral steering is illustrated in a similar sand body that was used for vertical positioning. The borehole can be positioned in this meandering channel-fill reservoir by recognizing facies changes across the unit; A. The borehole penetrates the channel margin and internal mudrock layers; B. The borehole stays in the reservoir intersecting cross bedded units and internal lags.



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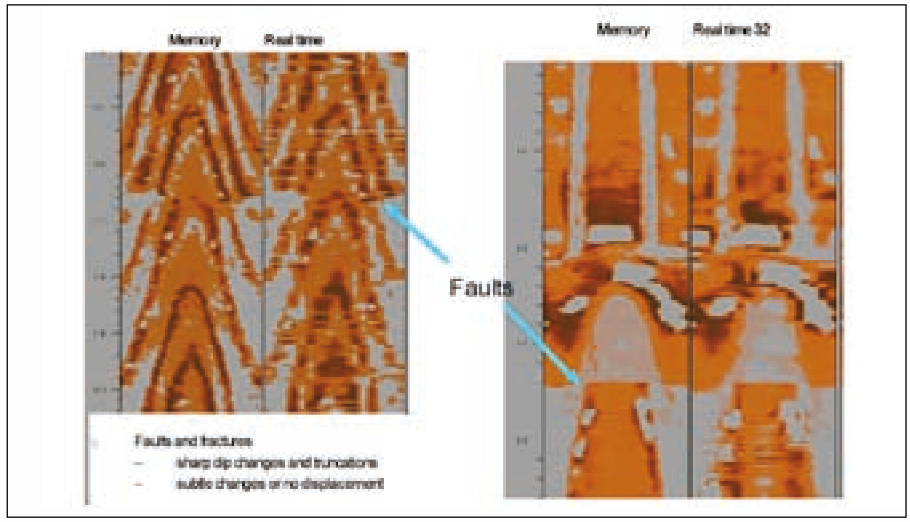
Vertical positioning is demonstrated by these 4 models. The sand body comprises an upper cross bedded unit, a middle sandstone with clinoforms (large-scale, inclined sedimentary surfaces) and a lower pebbly unit; A. The borehole enters the sand body at high inclination and is steered into the middle of the sandstone unit containing dipping clinoforms, staying in the 'sweet spot'; B. A steeper inclination well entered the same sand body and intersects the orange (pebbly) unit at the base. The borehole is consequently steered back into the sandstone; C. The borehole intersects a simple fault into the overlying unit and corrective decision to steer downwards can be made; D. Similar to C but with fractures surrounding the fault. Having seen the fracture density increase in real-time, a proactive decision can be made to steer downwards to keep the borehole in the middle sandstone.

Several geological criteria are necessary for successful sedimentary steering and the example here is for steering a highly deviated well through the same sand body using a geological model constructed from existing nearby wells. First, it is helpful to correlate between wells. Commonly mudrock layers are used but other features such as distinctive bed boundaries and changes in dips or image facies can be also be correlated. For steering within a channel sandbody, correlatable image facies associations (IFAs) form the main criteria. These can be internal structure of various sedimentary units such as lamination and bedding structures. Dip patterns, particularly abrupt changes in magnitude at lithological boundaries, are useful. Cross-lamination, a useful correlative IFA, and the geometry of cross-lamination, can be used to interpret bedform morphology and sediment dispersal directions. These are essential for the interpretation of overall paleotransport and sandbody orientation. Finally, the structural dip must be removed for restoring true sedimentary dip patterns.



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Real-time images compare favorably to the higher resolution image allowing instant identification of faults and fractures at the surface. Additionally, enough detail is transmitted for accurate dip information and to clearly see thin beds and individual clasts within beds.

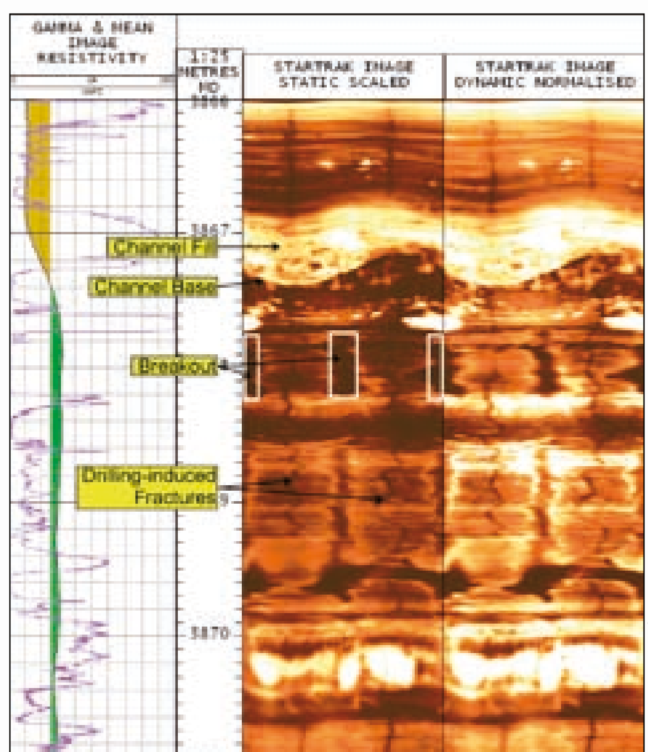
Photo: Halfdan Carstens

Jeremy Lofts is a Chartered Geologist with a PhD from Leicester, UK in 1993. He has worked as an image interpretation specialist and is author of more than 25 papers on geological and petrophysical oilfield applications. He is SPWLA 2007 Distinguished Speaker. Jeremy is currently Director for Formation Evaluation Product Lines at INTEQ.

Wellbore Management

Extended reach drilling, high pressure, and complex well design all push well design boundaries that require sophisticated wellbore stability management and geomechanical interpretation. Using real-time information from LWD high resolution images, geomechanical hazards such as drilling-induced tension fractures and breakout can be identified, and wellbore stability can be managed that will reduce risks in challenging well conditions.

A pre-well model for such a well incorporates information from offset wells, seismic models, and core data to identify potential drilling hazards. A well logging program then can be designed to deliver sufficient real-time data, including images, to identify geological hazards and borehole integrity issues. Borehole stability features can be seen on real-time electrical images shown on the illustration below.



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Breakout and drilling-induced tension fractures are seen in real-time from a vertical wellbore. The proximity of these features indicates a narrow mud weight stability window at this depth. This real-time information can be used to help make decisions, in this case to change the mud weight to maintain borehole integrity, for improved and safer drilling performance.