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Chasing channel sands in South East Asia

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Abstract: With technical advances in surface seismic and downhole electrical imaging techniques, it is now possible to not only map the distribution of reservoir sandstones in the subsurface, but to more accurately define the orientation of productive fairways, or "sweet-spots", within the sequence.

This paper will summarize the results of four case studies of how channel sands, laid down in different depositional settings, have been recognized with borehole electrical imaging. From sedimentary features and palaeocurrent directions within the sands it has been possible to determine their orientation. These channel sands frequently have favorable reservoir characteristics; having often been laid down in higher energy settings, they commonly have coarser and better sorted grains, less clay and improved poro-perm characteristics. However, they often have limited lateral extent and shoe-string geometries which makes them more difficult to predict in the subsurface. The ability to locate wells along prospective trends can result in the drilling of thicker pay zones, and in significantly improving the ratio of good producers to dry or poorly producing wells.

DEVELOPING AN EXPLORATION CONCEPT IN DEEP WATER SEDIMENTS

The first case study shows how electrical borehole images (Ekstrom *et al.*, 1987; Lloyd *et al.*, 1986) were used to orient the direction of channel levee deposits in a mid fan, deep water setting, of the Miocene, Mount Messenger Formation in New Zealand. The results were confirmed by core analysis and outcrop study as part of a multidisciplinary effort to better map such sequences in the subsurface (Spang *et al.*, 1997).

The individual channel units have a sharp erosive scoured base which is commonly lined with a basal deposit comprised of clay rip-up clasts. Typically the underlying sediments are finer grained and more highly bioturbated. The channel is filled with coarser sediment with steeper dips in the lower section. The decrease in dip as one moves up the section reflects the channel fill. From the change in dip angle it is possible to orient the channel axis; the dips along bedding surfaces point to the channel center (NW), and the axial trend is at right angles (interpreted as SW-NE). Note on the images the sharp erosive base of light coloured (more resistive) sands over the darker (more conductive) shales.

There is also a basal channel lag of conductive clayey rip up clasts, as well as a sharp change in dip direction at the basal scour surfaces (Fig. 1).

Being able to recognize such finely inter-bedded sequences and the orientation of channels will help in the evaluation of deep water sands as they become increasingly more important exploration and development targets in S.E. Asia.

APPRAISAL WELLS IN DELTA FRONT SANDS

The second study is an example from a Miocene delta front setting off the Sunda Shelf in the South Sumatra Basin of Indonesia. Here palaeocurrent analysis of distributary front sands resulted in a thicker sequence of distributary channel sands being encountered in an appraisal well drilled in a more proximal (up current) location (DesAutels and Lloyd, 1997).

No wireline logs were available in the discovery well, but dip and image data were acquired for the next two appraisal wells. The images show a typical distal deltaic setting with lots of shales, and some 5–15 feet thick sandier units with a coarsening up grain size motif and thin silty laminations and low

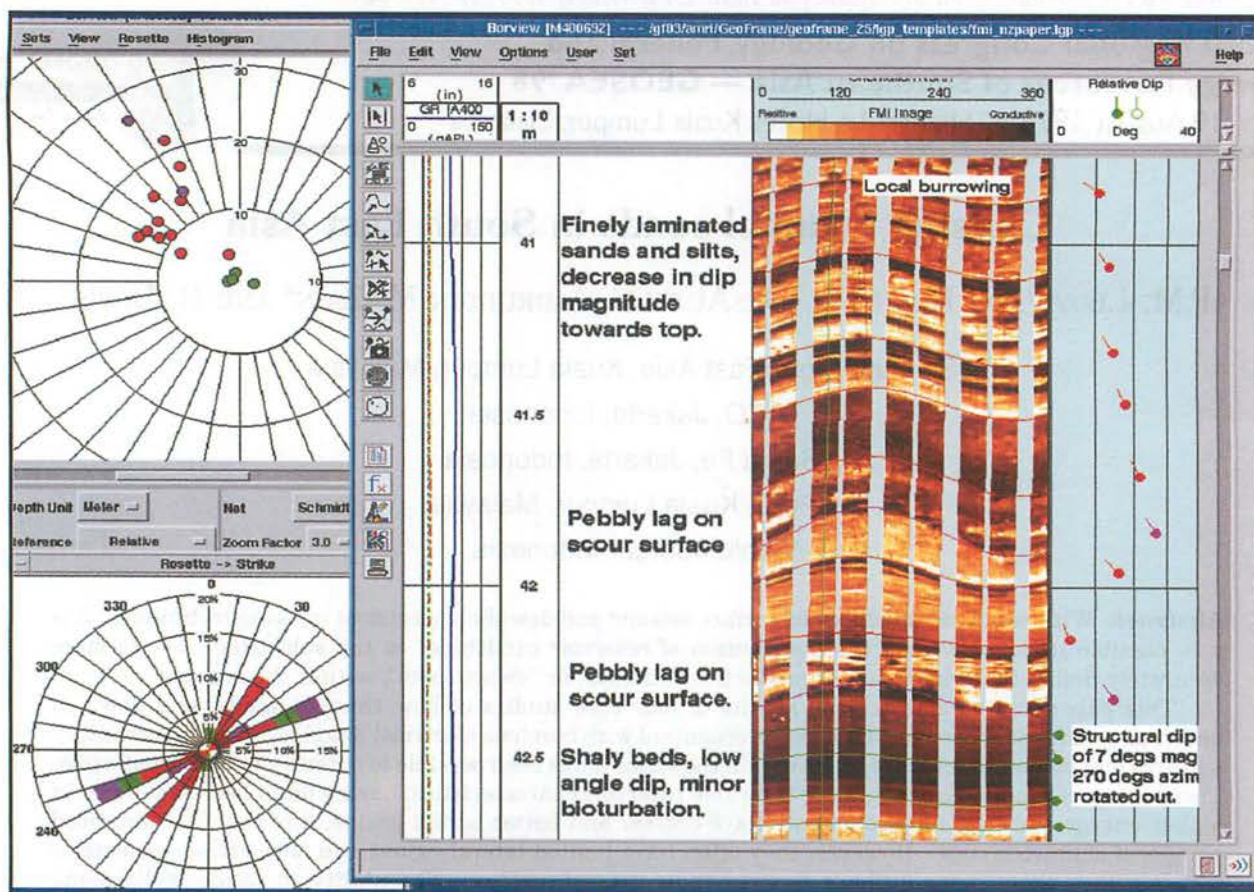


Figure 1. Images across base of a deep sea channel sand.

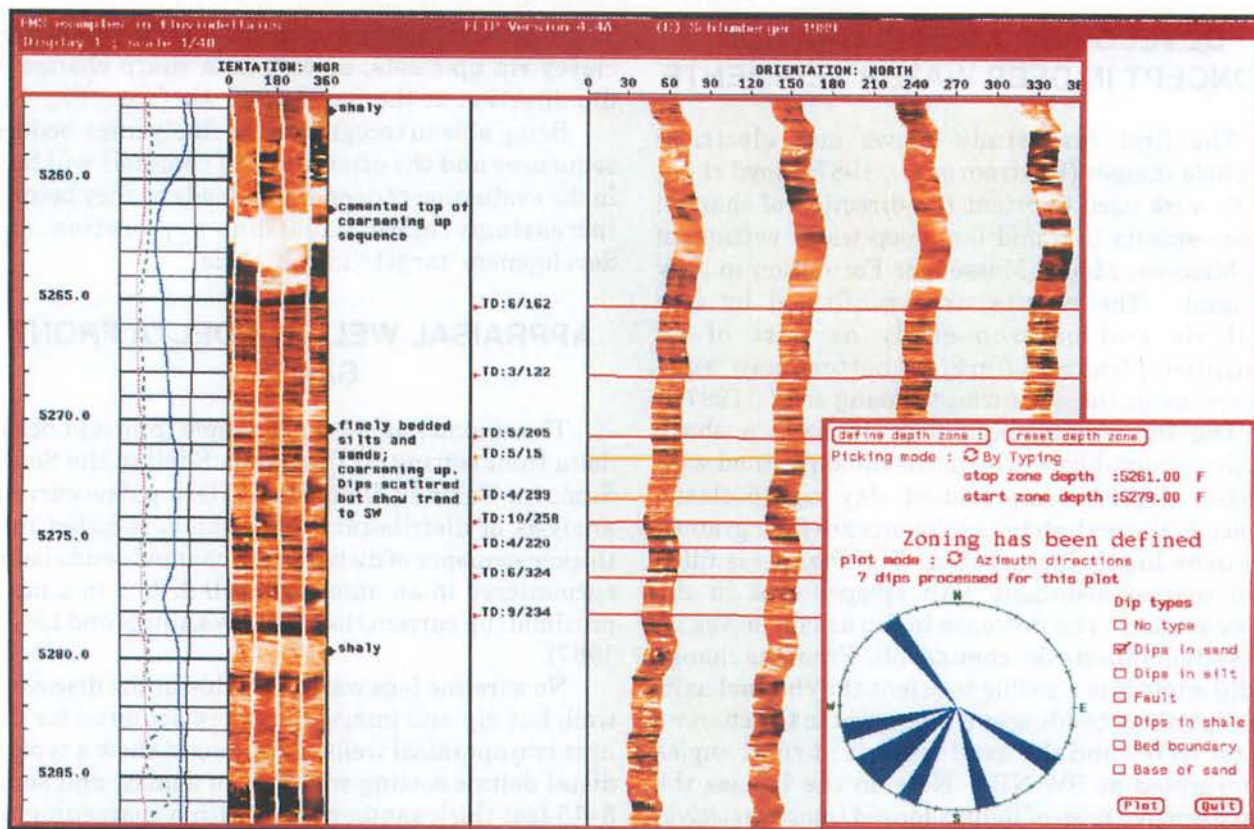


Figure 2. Images in a delta front distal setting.

angle foresets (Fig. 2). These sands are invariably well cemented and bioturbated at the top, and are interpreted as distributary front deposits; the distal edge of a prograding delta lobe. Another facies is developed in close association; units are 10 feet thick, have a sharp erosive base, and a massive lower section overlain by finely interbedded silty sands. They correlate with the distributary front facies in the nearby wells, and are interpreted as representing storm deposits. The palaeo-current direction in these various distal sand units varies from SSW to NNW, showing a dominant WNW trend.

This palaeocurrent data from the dips in the distal sands was used to locate the next appraisal well approximately 3 km to the E, towards the more proximal part of the delta where thicker sands could be expected. This fourth well on the structure was successful, with the sand/shale ratio close to 50% across the prospective interval, and with improved reservoir quality. 25–55 feet thick distributary channel sands were penetrated at several of the levels confirming the progradational deltaic model. They are characterized on the oriented wrap-around images by a sharp base and have well developed current bedding from which the palaeocurrent direction (and by inference the direction of the axis of the channel) can be determined, in this case to the WNW (Fig. 3). Note that planarity along the individual bedding surfaces is poor and the dips are quite scattered (Fig. 4); characteristic of trough cross sets and indicative of a high energy flow regime. The fining up grain size motif at the top of the sand represents a channel abandonment facies.

With this additional image data in this fourth well, it has been possible to develop palaeogeographic and thickness maps of the sand bodies as they develop across the field.

INFILL DRILLING IN FLUVIAL DELTA TOP SANDS

The third study shows how the integration of image, log and seismic attribute data in Miocene delta top channel sands in the Kutai Basin of E. Kalimantan, resulted in drilling 4 successful oil producing wells. In previous drilling efforts (before the integrated study) stratigraphic complexity resulted in other oil bearing channel sands being missed in 6 out of 7 offset wells on an otherwise straightforward plunging anticlinal feature (Koch *et al.*, 1997).

Interpretation of image data from wells across the field indicated stratigraphically complex, often compartmentalized deltaic reservoirs; those with

the best poroperm being delta top stacked fluvial channel sands sometimes exceeding 100 feet. A pilot study was initiated using hires 2D seismic. Seismic horizons were picked and carefully tied to geological markers in the wells. For the E314 reservoir interval (the prime target of the study) 25 different seismic attributes were extracted and presented as maps. However, the physical significance of an attribute map, and how it might relate to sand thickness and hydrocarbon column thickness is never immediately obvious.

Where wells intersect the seismic lines a match can be made between the seismic attribute and the petrophysical parameters (Fig. 5). In fact 2,760 combinations of various attributes and different log properties (such as net/gross, net pay thickness, porosity etc.) were statistically compared in order to find attributes with good dynamic range which correlated well with reservoir properties. Having identified good matches (Fig. 6), it is possible to calibrate the attribute, and with the depositional setting interpreted from the images, develop a geological model including thickness variation, stratigraphic pinchouts and palaeocurrent direction (Fig. 7).

The next step was to pick well locations and drill. All 4 proposed wells encountered 100 feet oil columns, with net and gross thicknesses within 5% of prediction. Imagery was again used to better understand and fine tune the model. The images show a sharp base to the channels, well developed sets of stacked foreset beds (typically with planar bedding surfaces and low dip scatter, and so interpreted as tabular sets), and a consistent palaeoflow to the ESE (Fig. 8).

FIELD DEVELOPMENT PROGRAM IN TIDAL CHANNEL SANDS

The fourth study reviews the recognition of channel features in a tidal and lower coastal plain setting in the Miocene of the Malay Basin, and how this is helping delineate the orientation of gas sandstone reservoirs. The channel sands are interesting targets because when deposited by higher energy currents they are moderately to well sorted and typically less subjected to bioturbation which can be very intense in (for example) bar sands, where sedimentation rates may be lower. This bioturbation can result in grains and pore throats being coated by clays, and for capillary bound water to be correspondingly high and permeabilities low. However, the shoestring geometry (and subsequent restricted areal extent) of the channel sands makes it important that they be mapped accurately in the subsurface and so

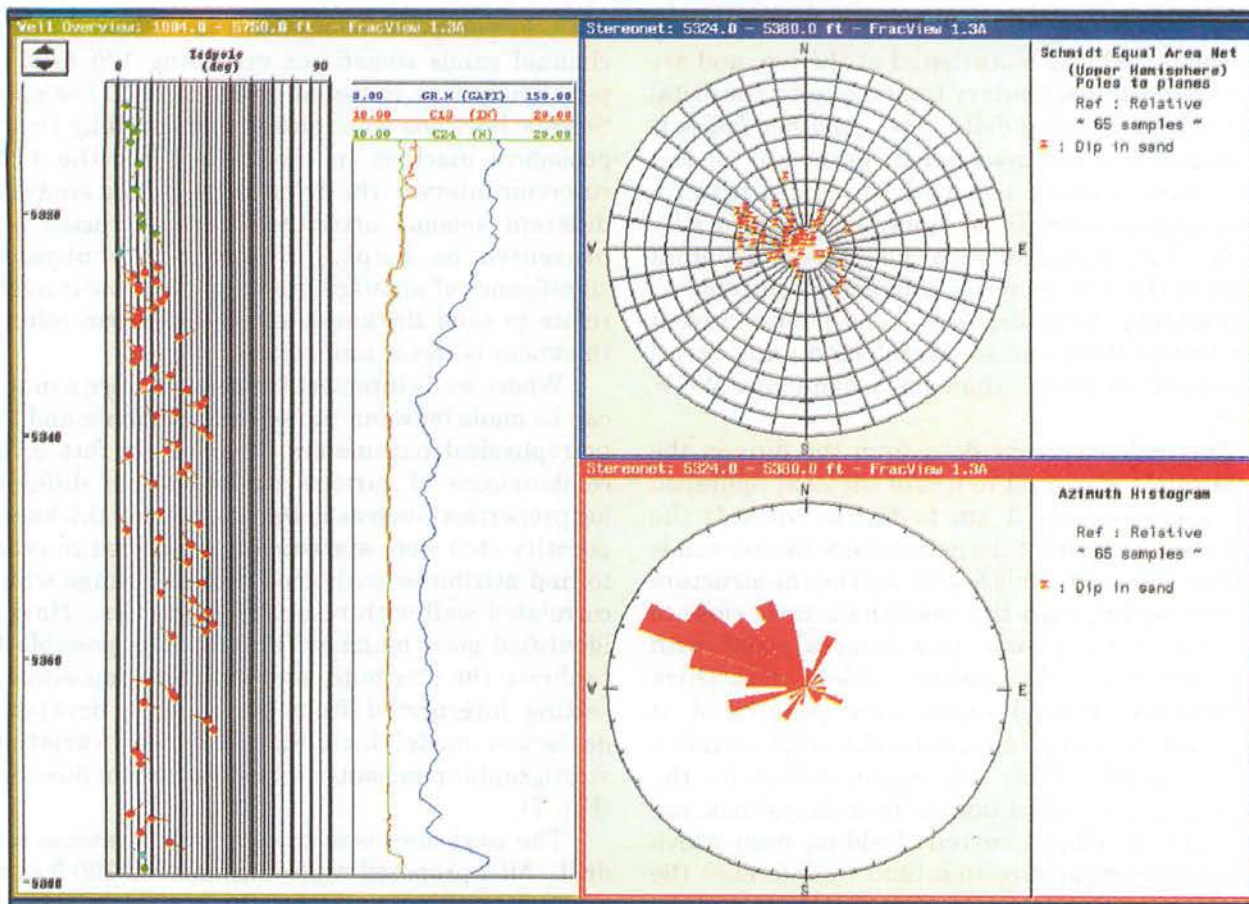


Figure 3. Dips across a distributary channel sand.

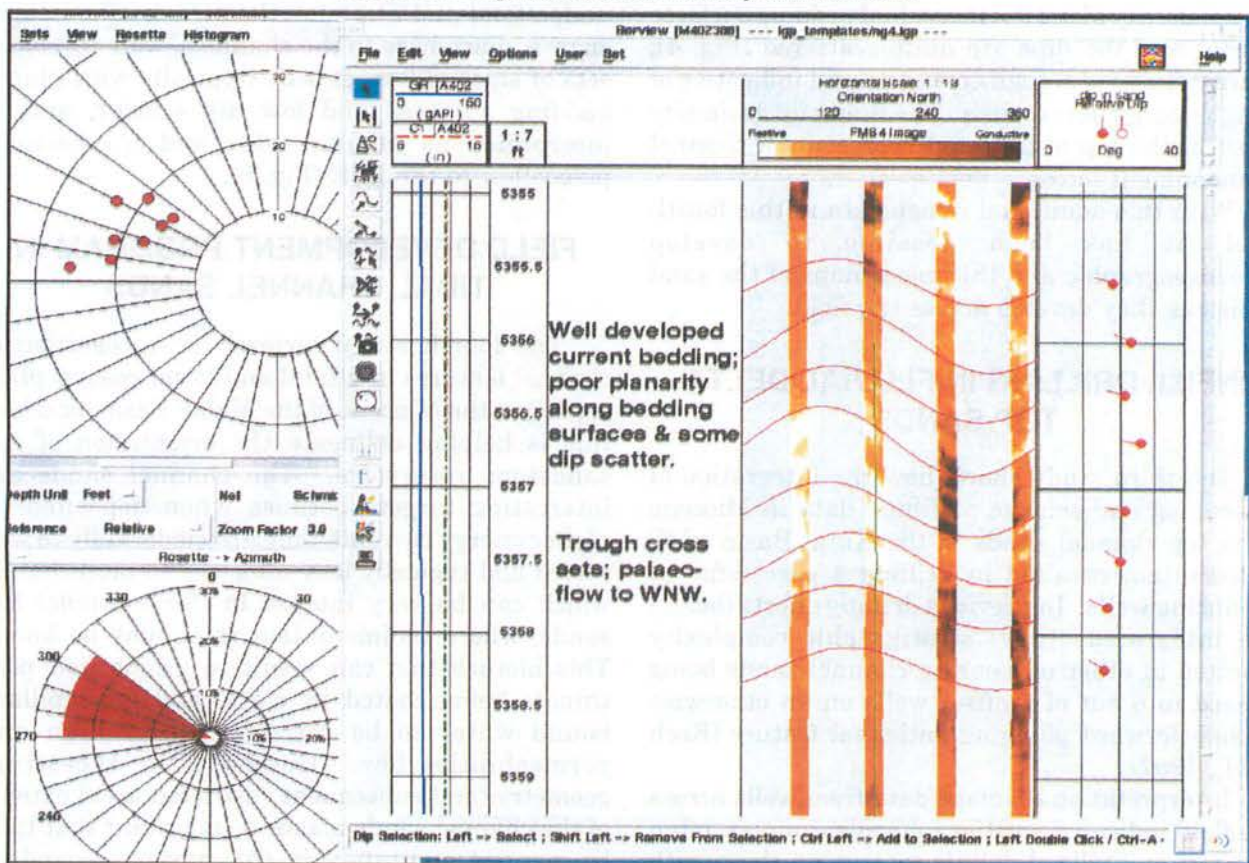


Figure 4. Images across a distributary channel sand.

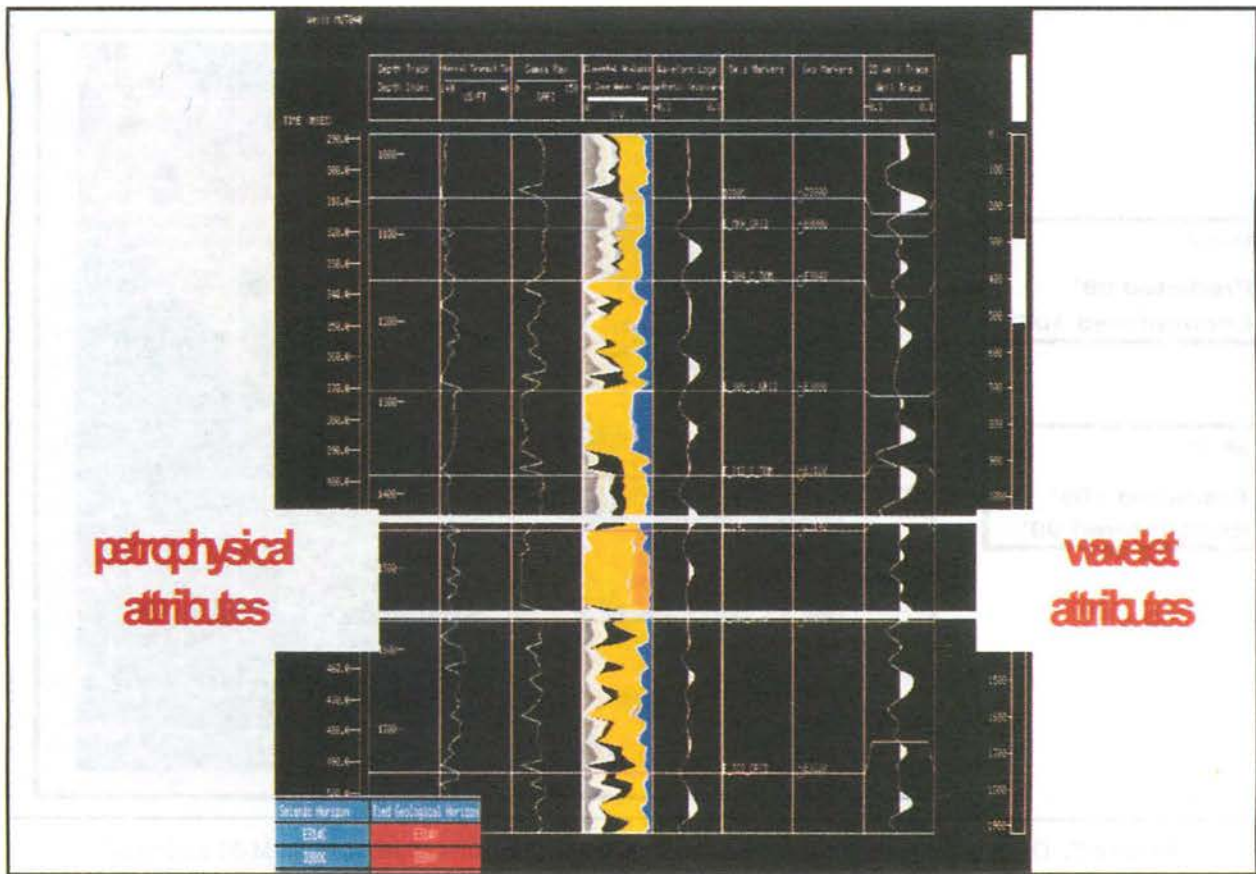


Figure 5. Matching petrophysical attributes in the depth domain with seismic attributes in the time domain.

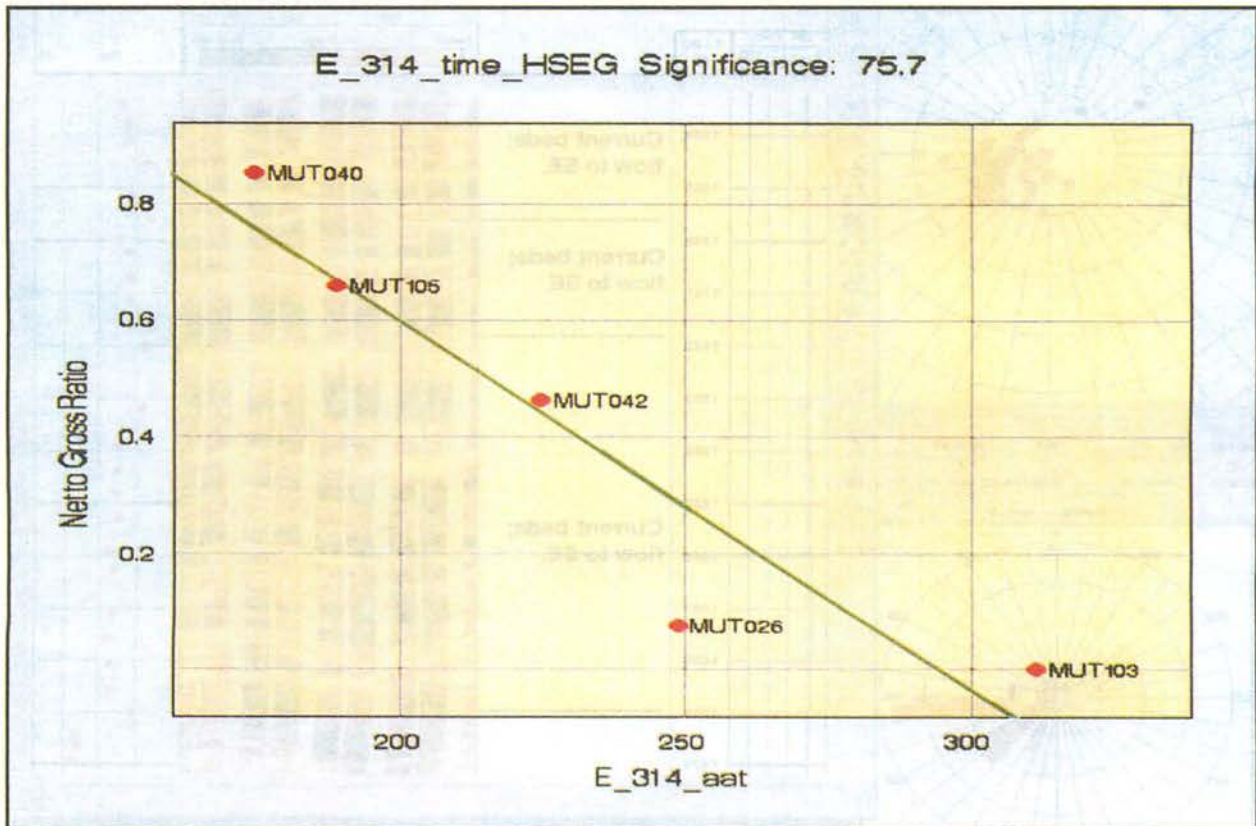


Figure 6. Calibrating the seismic attributes against the petrophysical properties.

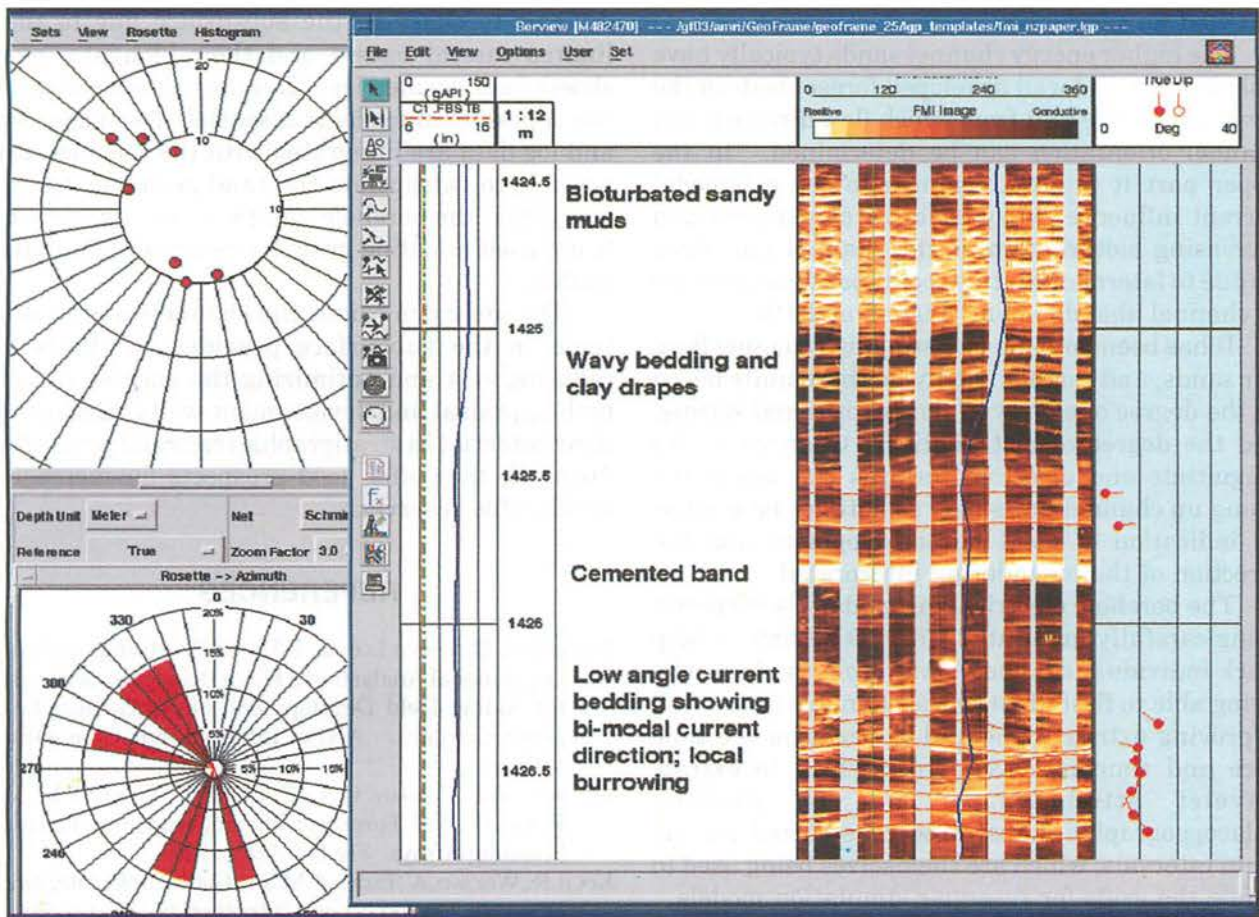


Figure 9. Images across top of tidal channel sand.

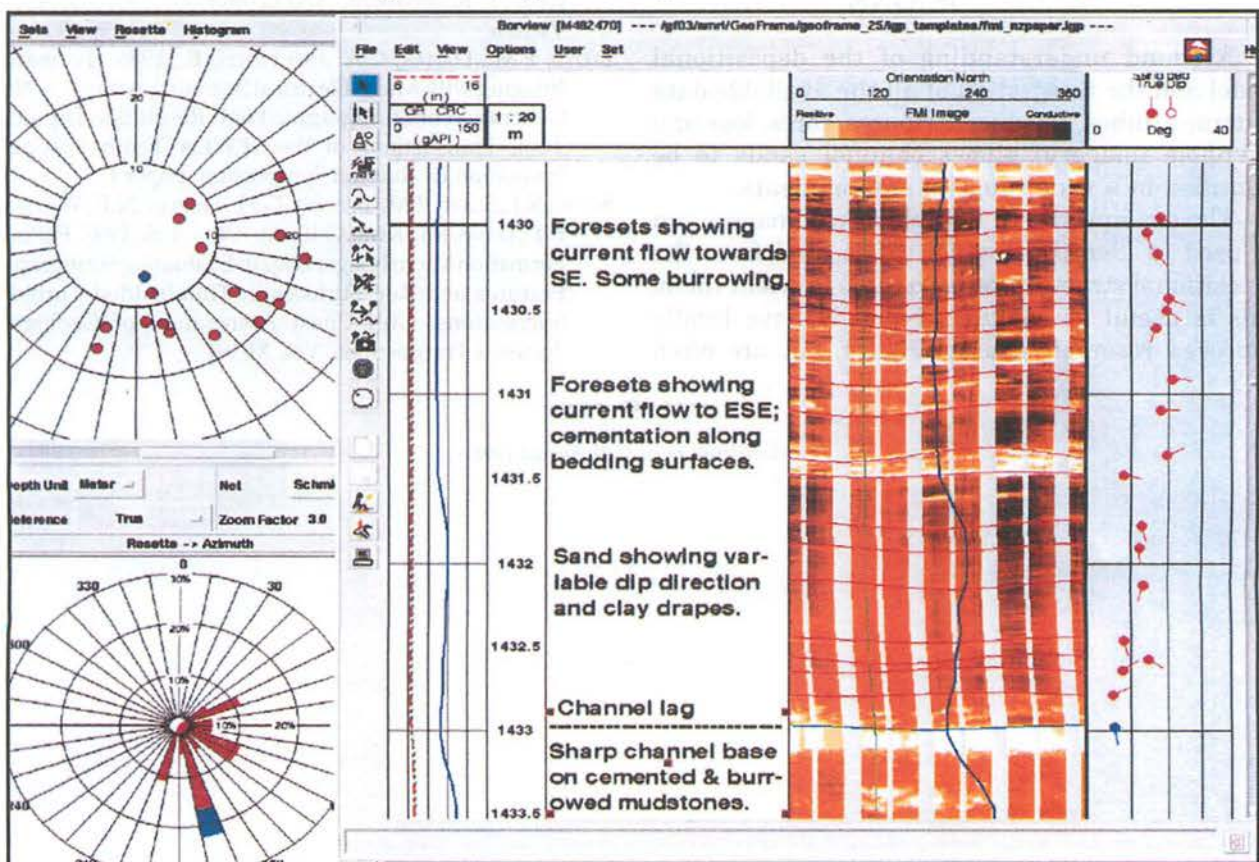


Figure 10. Images across lower part of tidal channel sand.

targeted for production.

The higher energy channel sands typically have a sharp base and well developed foreset beds in the lower part of the unit from which flow direction and channel orientation can be determined. In the upper part it is often common to see a bimodal current influence, wavy bedding, clay drapes and increasing bioturbation as the channel unit fines up due to lateral migration (point bar development) or channel abandonment (Figs. 9 and 10).

It has been possible to distinguish channel from bar sands, and further subdivide those units based on the degree of energy in the depositional setting, and the degree of bioturbation. Changes in dip magnitude and direction towards the top of the fining up channel units may sometimes be used as an indication of point bar development and the direction of the meandering interpreted.

The borehole electrical image data is currently being carefully integrated with 3D seismic to help track individual channels away from the borehole. Being able to first identify the channels in the well is proving extremely helpful in isolating the time slice and time interval across which to extract wavelet attributes. This is allowing palaeogeographic maps to be constructed for the main intervals, which are themselves being used to define the grids for reservoir simulation models.

CONCLUSIONS

A sound understanding of the depositional model and the integration of all the available data (outcrop studies, seismic attributes, cores, logs and downhole imagery) allows channel sands to be identified in a wide range of environments.

The examples show how electrical imagery can be used to identify channel sands, and from the depositional structures it is possible to orient them. This is useful as channels typically have locally improved reservoir characteristics, but are often

difficult to chase in the subsurface due to their limited lateral extent and their elongate, often shoestring, geometries. Developing a concept for the depositional model is essential. As image, core and log data are integrated with the seismics, it is possible to extrapolate the sand geometry further away from the borehole. Maps of the channels are being used to define grids for reservoir simulation models.

The ability to orient the channels and so map them in the subsurface provides the basis for reducing risk and optimizing the success ratio of both appraisal and development wells. Because of their potential as stratigraphic traps and production fairways, they offer good prospects for increasing recoverable reserves.

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