Geol. Soc. Malaysia, Bulletin 47, December 2003; pp. 85-94

The Pink Fan: a classic deep-marine canyon-fill complex, Block G, NW Sabah

COLIN J. GRANT

EPD-XDW
Sarawak Shell Berhad
98009, Lutong, Miri
Sarawak

Abstract: Key risks for exploration in deep-water Neogene basins are reservoir development, hydrocarbon charge and trap retention. Over the last two years SMEP's deep water asset team, EPD-XDW, has made a concerted effort to de-risk the NW Sabah deep water prospect portfolio through large-scale 3D seismic acquisition, integrated basin analysis studies, green-field exploration and deep-water field appraisal. This evaluation allows the main Miocene turbidite fan systems of the Sabah trough to be slowly unraveled and will establish NW Sabah as a classic area for the study of active margin deep-water sedimentation.

The NW Sabah basin has a surprisingly rich sand fairway, with at least four fan depositional cycles being recognised within the Upper Miocene stratigraphy between 12.1 and 6.7 Tertiary boundaries, TB2.6-TB3.3. The thickest and best known fans are those of the Kebabangan, Kinarut and Kamunsu, all named after the wells which discovered them.

The Pink fan is the last of the sand-prone Upper Miocene fans deposited in the Kamunsu basin and was deposited the furthest outboard, partly in response to the progradation of the shelf edge across the Sabah margin and partly due to local tectonics which strongly influenced the contemporaneous sea-floor profile. The older fan units within this basin are all disconnected from their slope feeders by faulting and erosion. In the past, this hindered reservoir prediction and the generation of viable palaeogeographical reconstructions. The Pink fan is still connected to its feeder canyon and, best of all, has been drilled twice in recent years. This well data in combination with detailed seismic evaluation has enabled the unraveling of this confined fan unit to a degree not yet achievable within the older fans.

INTRODUCTION

NW Sabah is rapidly becoming a classic area for studying active margin deep marine sedimentation. Not only are there fine outcrop examples of submarine fans exposed along road cuts through the Crocker mountains near Kota Kinabalu, but recent exploration offshore has found a surprisingly rich Miocene deep marine sand fairway extending from beneath the shelf into the NW Sabah deep water basin (Fig. 1). With the help of high-density 3D seismic data and a cluster of deep water wells, Shell Malaysia-EP has began unraveling the complex submarine fan stratigraphy of this compressional active margin.

Four deep-water fan units have been recognised to date within the Upper Miocene between TB2.6 (12.1 Ma) and 3.3 (6.7 Ma) Tertiary boundaries (Fig. 2). The controlling influences on deep-water sedimentation and some simple models explaining fan deposition and reservoir distribution have been described previously by Casson *et al.* (1999).

The older fan units in this basin are detached from their feeder systems by faulting, erosion or deformation along the inboard margin. Deep burial beneath the main delta slug also prevents mapping of penecontemporaneous upper slope feeder systems further inboard. These factors make accurate palaeogeographic reconstruction difficult and the construction of fan reservoir models problematic — if you don't know where the sands are coming from it is difficult to predict their internal architecture and spatial distribution.

The Pink Fan is the last of the major Upper Miocene fans deposited in the Kamunsu-Kebabangan sub-basin, in the northern part of Shell-operated Block G (Fig. 1). This fan system was deposited during the highstand preceding the TB3.3 Tertiary boundary. In contrast with the older fans, the Pink fan is largely post-kinematic and can be mapped as a discrete sedimentary feature along its entire length. It originated from a feeder that has been be mapped inboard as far as the west flank of the Gaya Harimau ridge (Fig. 3).

Paper presented at GSM Petroleum Geology Conference & Exhibition 2002

From here it followed the existing seafloor topography in a terraced slope setting, meandering its way across a series of ponded mini-basins situated on top of an allochthonous thrust sheet, referred to locally as the Upper Miocene Allochthon. Finally it spilled over this thrust sheet and into the Kamunsu sub-basin. After crossing this sub-basin, it spilled over into the Ubah sub-basin where it open out finally into a channelised fan lobe towards the outer boundary of Block G (Fig. 4a and b). The internal anatomy of this fan is the subject of this case study.

GEOLOGICAL SETTING

The tectonic style of the NW Sabah deepwater basin is mainly compressional and comprises a series of NE-SW oriented toe-thrust ridges and intervening basins lying in water depths ranging from 200–2,000 m. Reservoirs comprise both unconfined and ponded deepwater turbidite sands trapped in high-relief anticlines or stratigraphically enhanced along the flanks of major highs. A number of shelf-edge or upper slope canyon features that might have delivered sands into the deepwater during the TB3.1 low stand are known from the Bunbury-St. Joseph and South Furious ridges, and from the western flank of the Labuan-Paisley syncline. These canyon systems evolved in response to rivers dumping their sediment load at the shelf edge following the "big drop" in sea level coincident with the TB3.1 boundary. In contrast, canyon systems are virtually unknown within the TB3.2 sequence. During this time interval, sands reworked by uplift and erosion inboard were cleaned up on a narrow shelf by long-shore currents before cascading over the shelf edge and out into deep water as a series of (coalescing) fan aprons (Fig. 3).

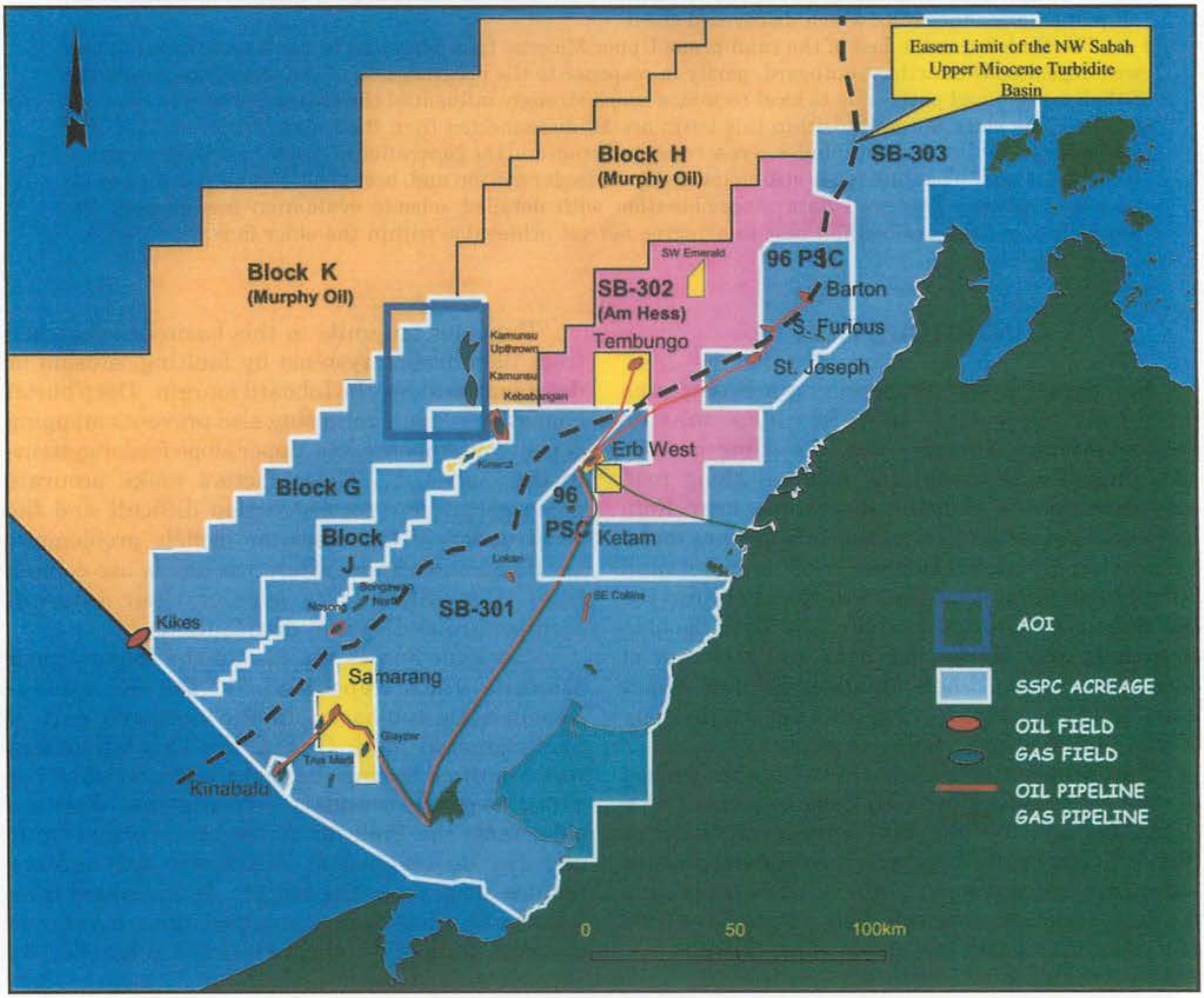

Figure 1. NW Borneo Structural Provinces and Area of Interest.

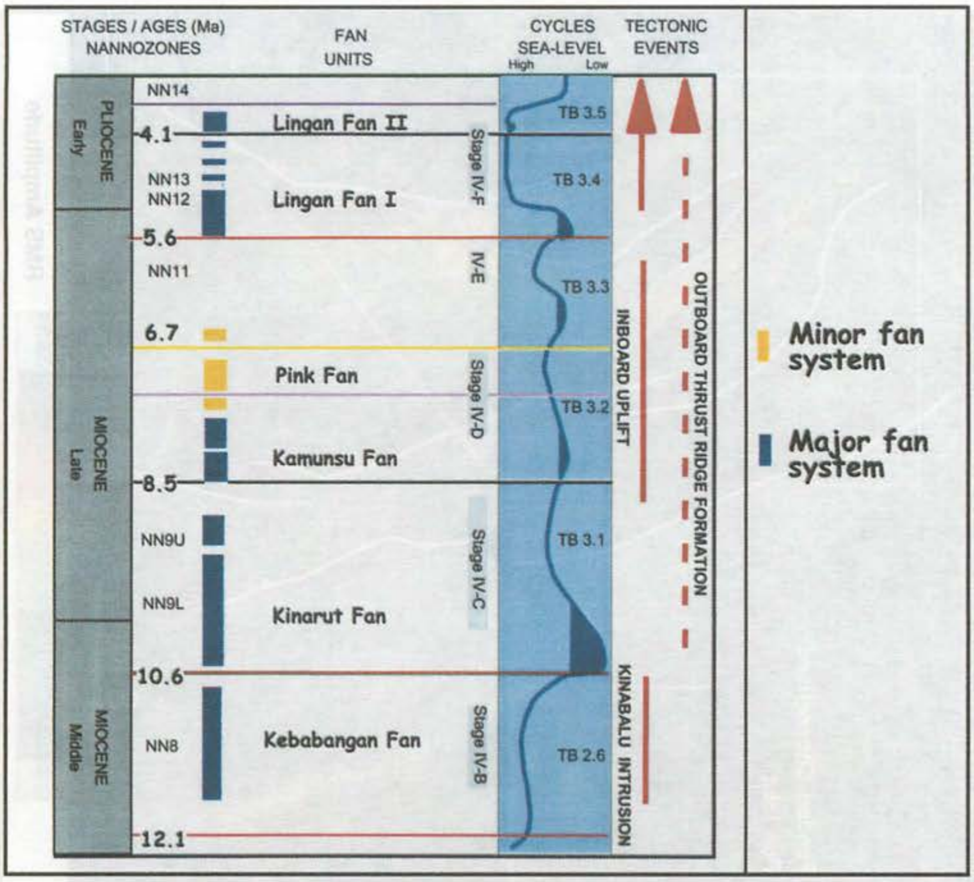

Figure 2. Neogene seismostratigraphic framework, West Sabah.

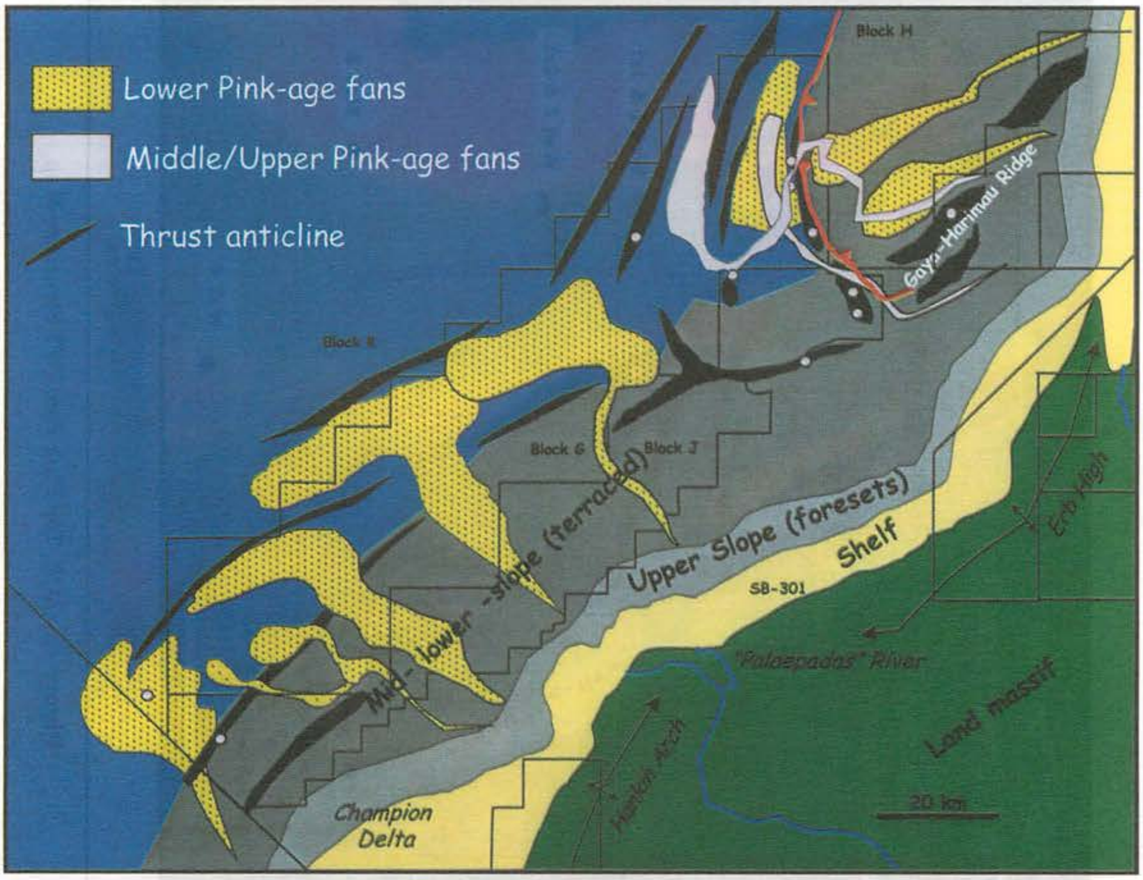

Figure 3. Schematic Upper Miocene Palaeogeography of the Pink Fan (Upper TB3.2), West Sabah.

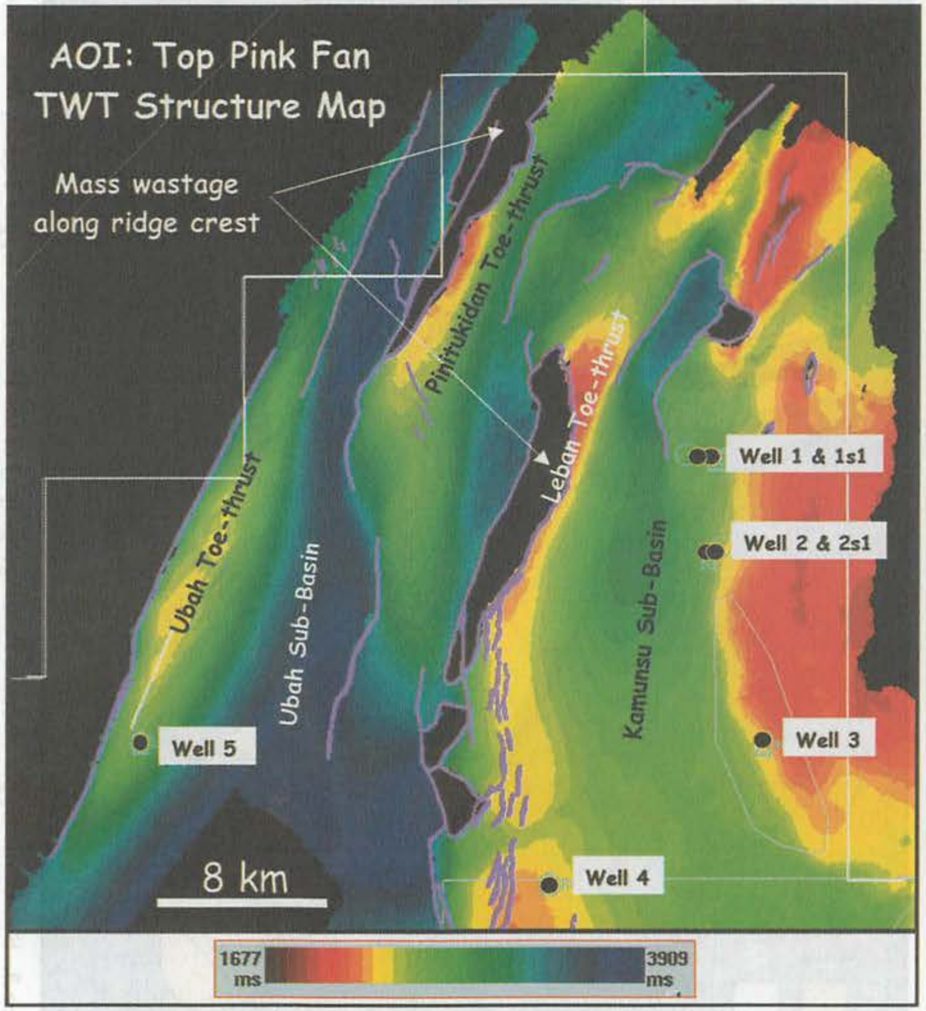

Figure 4a. AOI: Top Pink Fan TWT Structure Map.

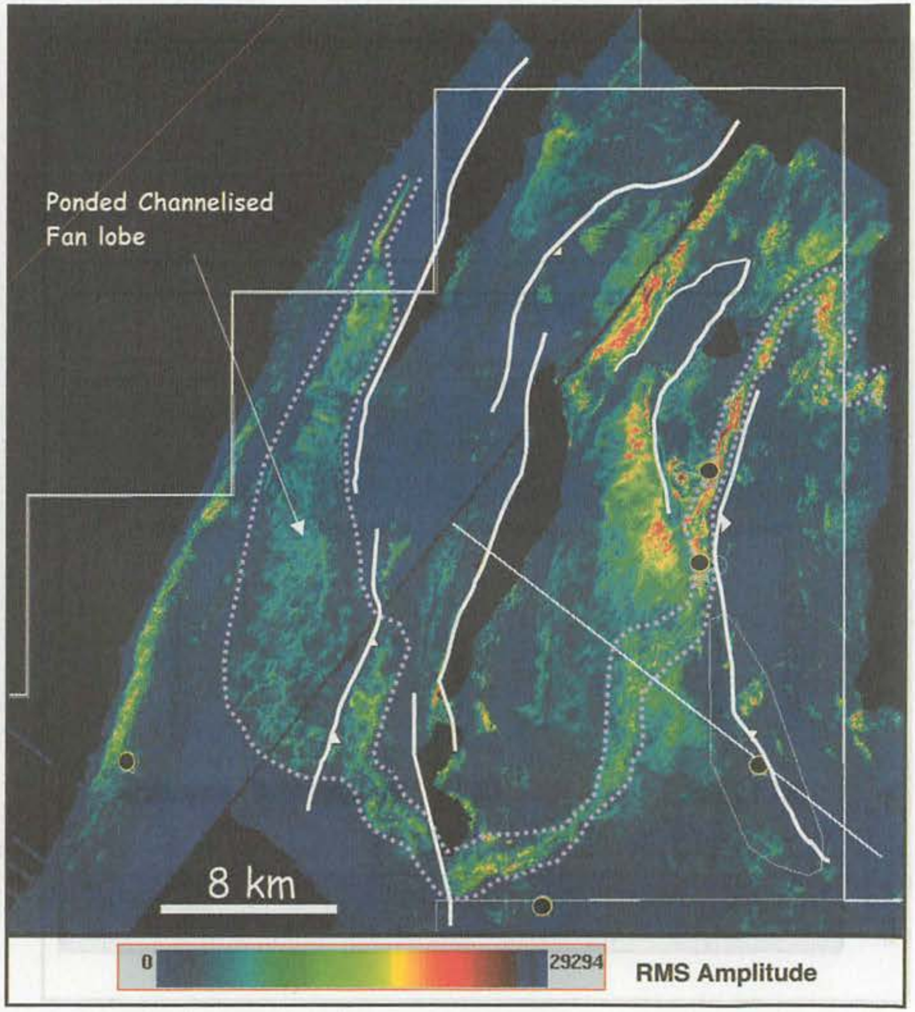

Figure 4b. Intra-Pink Fan: RMS amplitude extraction in window +50+125 ms below top of fan.

STRATIGRAPHY OF THE PINK FAN

SM-EP has drilled two exploration wells and two deviated exploratory sidetracks through the Pink Fan (Figs. 4b and 5). Three of these holes penetrate the centre of the canyon, with one drilling into the canyon margin. The centre of the canyon comprises massive amalgamated sand bodies as well as interbedded overbank shales. Net-to-gross and sand bed thickness is highly variable over short distances and decreases rapidly away from the thalweg.

The Pink Fan has been separated into three component members, Lower, Middle and Upper. The Lower Pink comprises a ponded sequence of turbidite sands up to 500' thick. These reservoirs are regarded as amalgamated sheets that infilled a ponded basin formed behind the emerging Leban toe-thrust ridge (Fig. 5a). They were sourced from feeders originating from the NE (Fig. 3). Eroded deep into this ponded sequence is the Middle Pink Canyon. This feature was excavated by high-energy flows emerging from a canyon head situated where the Pink feeder system plunged over the frontal thrust-ridge of the Upper Tertiary Allochthon. The flows that formed the trough spilled over the proto-Leban ridge and out into the Ubah sub-basin (Fig. 5a) where they deposited a channelised fan lobe (Fig. 5b) in the ponded basin that was evolving behind the Ubah thrust ridge. The feeder canyon was later back-filled by amalgamated channel complexes that remained confined within the canyon feature. The Upper Pink fan comprises minor amalgamated channel and sheet sandstones that represent the waning stages of fan deposition within the canyon and contiguous Kamunsu basin shortly before sand supply was shut off by a TB3.3 flooding event.

SEISMIC CHARACTER IN PROFILE AND MAP VIEW

The seismic character of the Pink Canyon is captured in profile and in map view in Figures 6 and 7. Key characteristics in profile are its highly discordant basal character, its mounded form, arising from compactional drape (this results in the canyon fill having a convex shape in areas of sand thicks), and the discontinuous nature of the high amplitude seismic events that form the canyon fill. These high-energy events originate from point bar high-porosity sand bodies within the thalweg. In map view the canyon has fairly low external sinuosity but individual channel forms have fairly high internal sinusosity. The channels visibly acrete laterally and amalgamate in a braided relationship without levee development. This canyon form is consistent with a feature scoured out by high-energy turbulent flows and later back-filled by lower energy sand-rich turbidity currents.

ATTRIBUTE MAPPING, VOLUME INTERPRETATION AND ILLUMINATION

Amplitude extractions (Fig. 5b) and horizon-consistent coherency slices (Fig. 7b) are used to illustrate the detailed internal character of the canyon fill. 3D-volume interpretation is used to assess internal connectivity of individual sand bodies. The Upper Pink sands show fairly good to excellent connectivity along the canyon axis and appear to be connected to sheet sands within the basin (Fig. 8). In contrast, voxel mapping shows that sands belonging to the Middle Pink fan, although locally much thicker, have less connectivity along the canyon, probably as a result of multiple phases of cut and fill, but are connected to sheet sands within the Lower Pink interval.

Sands within the Pink fan display classic hard shale-soft sand AvO behaviour, with amplitudes increasing (softening) with offset. As a result, AvO difference imaging in the far minus near domain provides a quick means of assessing sand distribution within the fan system as a whole (Fig. 9). This technique shows that much of the early sand deposition took place within the channelised lobe setting in the Ubah sub-basin (Fig. 10) with only relic sand patches preserved within the lower part of the canyon feeder.

DISCUSSION

Slope canyon-channel systems are one of the key emerging plays in deep water basins. When sand-rich, they are easy to identify seismically, but their reservoir architecture is notoriously heterogeneous. Well correlations within canyon systems are difficult and predicting production performance based on assumptions concerning connectivity is problematic. Part of this problem stems from the large expense involved in collecting high-quality reservoir production data during exploration, especially in deep water settings, and part stems from the variability in deep-marine sedimentation processes within topographically influenced channel systems. Outcrop analogues and facies models can be used to help predict reservoir architecture away from the well bore and used as statistical input into stochastic modeling software. The latter allows the generation of multi-equiprobable reservoir scenarios. But the most appropriate analogue is not always available.

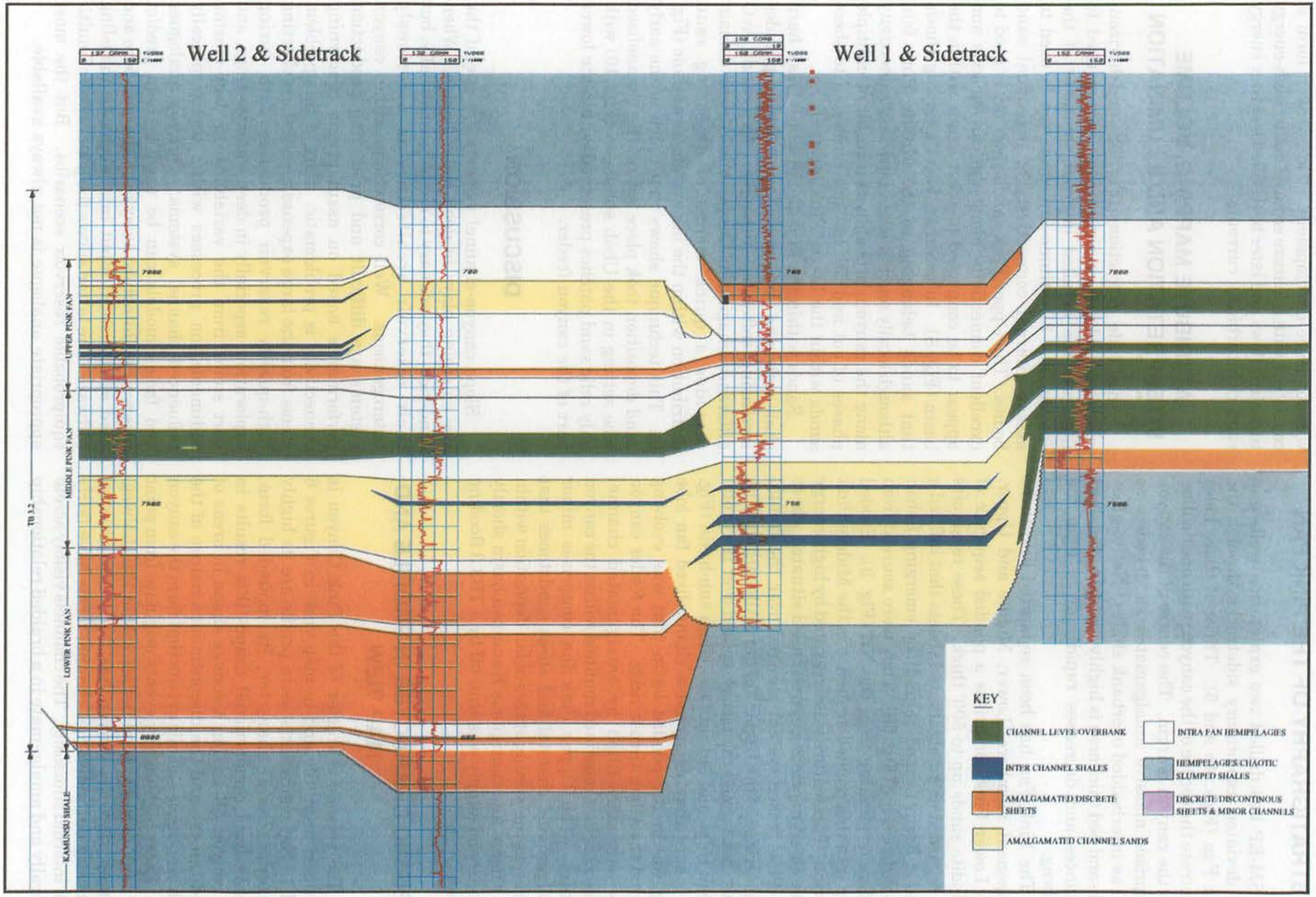

Figure 5. Stratigraphy of the Pink Fan from well correlation. The Pink fan is divided into two components members, a lower sand-rich member that thins abruptly onto the basin margins, and an upper/middle sand-rich channel complex infilling a deeply excised canyon trough.

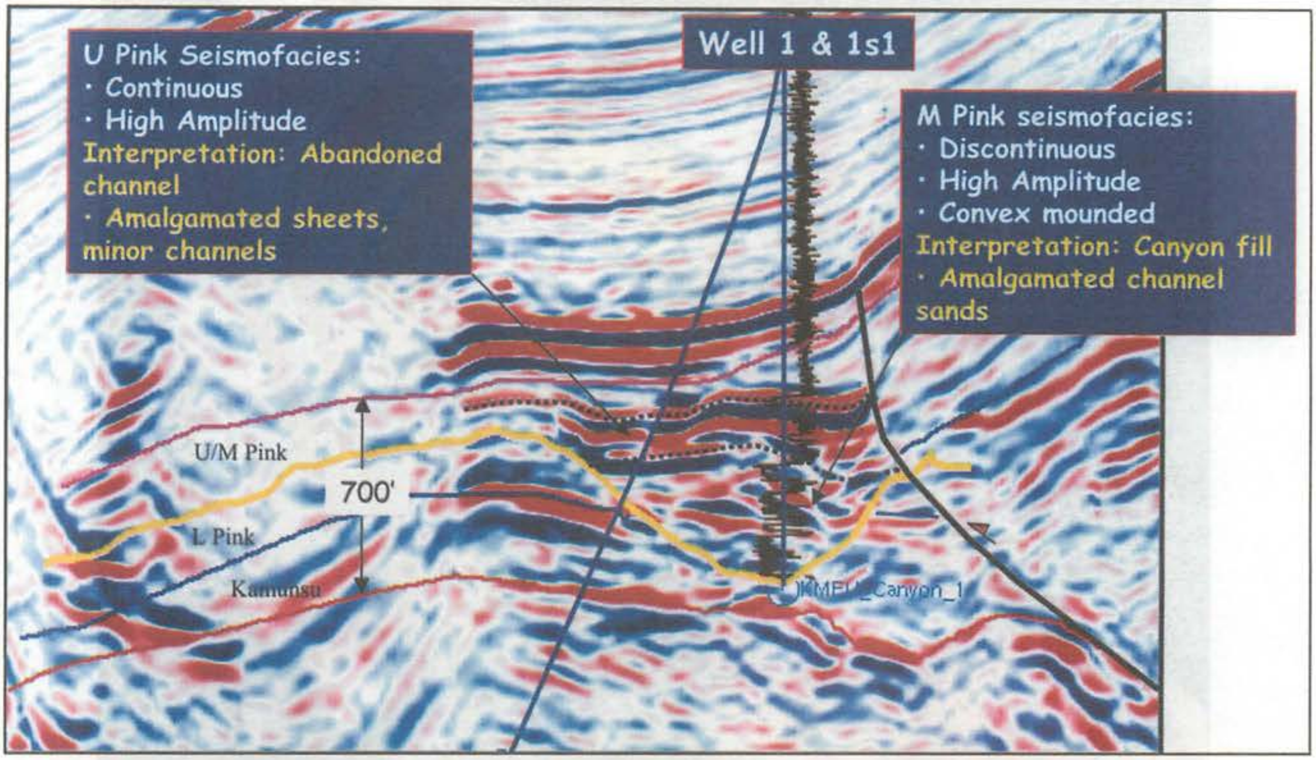

Figure 6. Seismic profile (fullstack reflectivity volume) through well 1 and sidetrack.

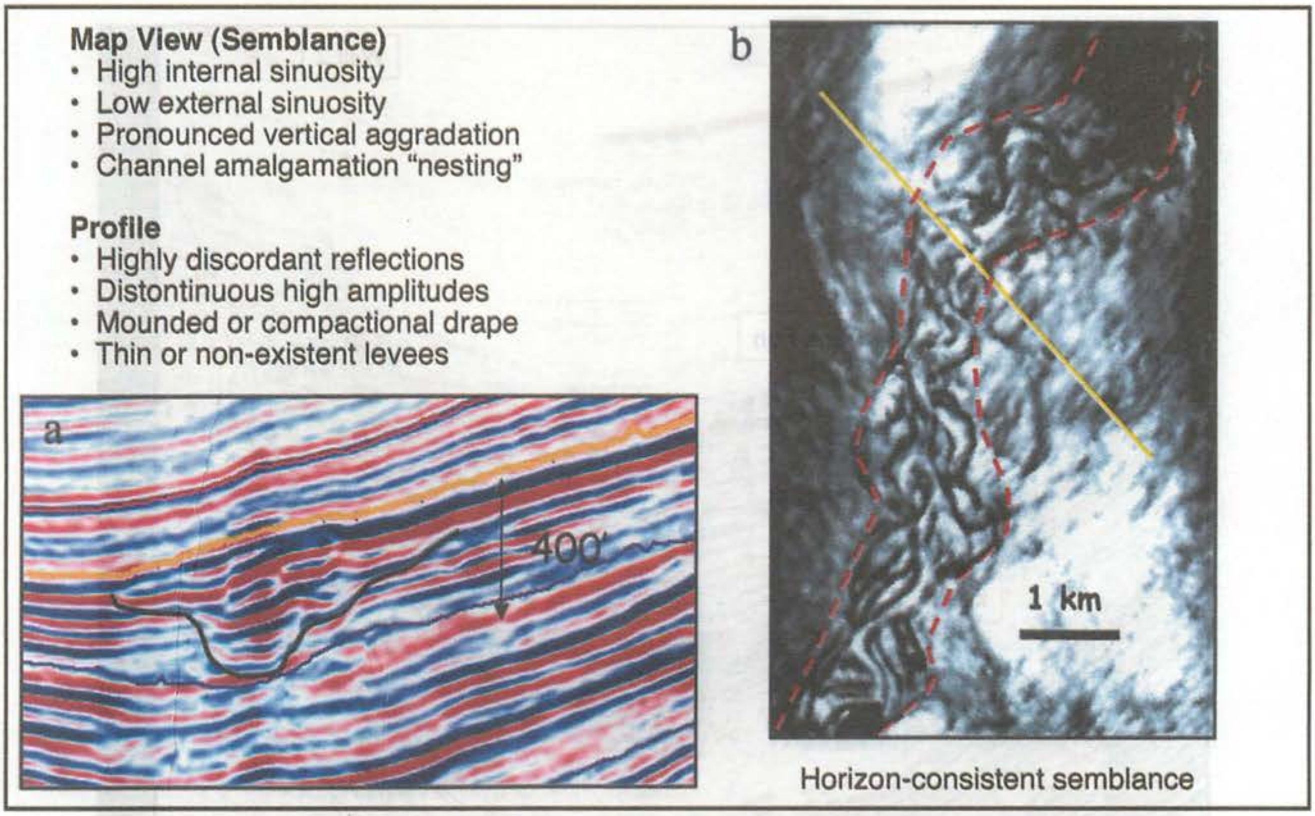

Figure 7. Internal seismic character of sand-prone amalgamated channel infill.

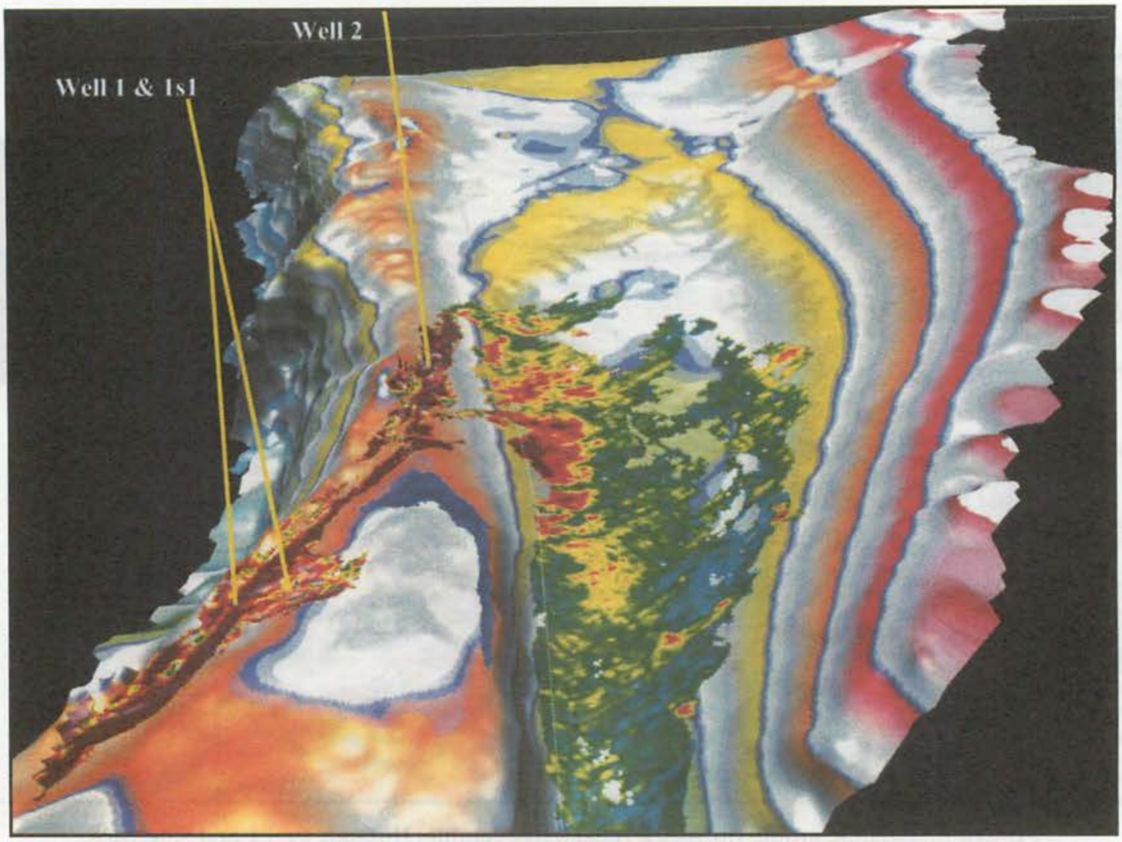

Figure 8. 3D image of an intra-upper Pink voxel pick and amplitude extraction draped over Lower Pink time structure looking towards the SE.

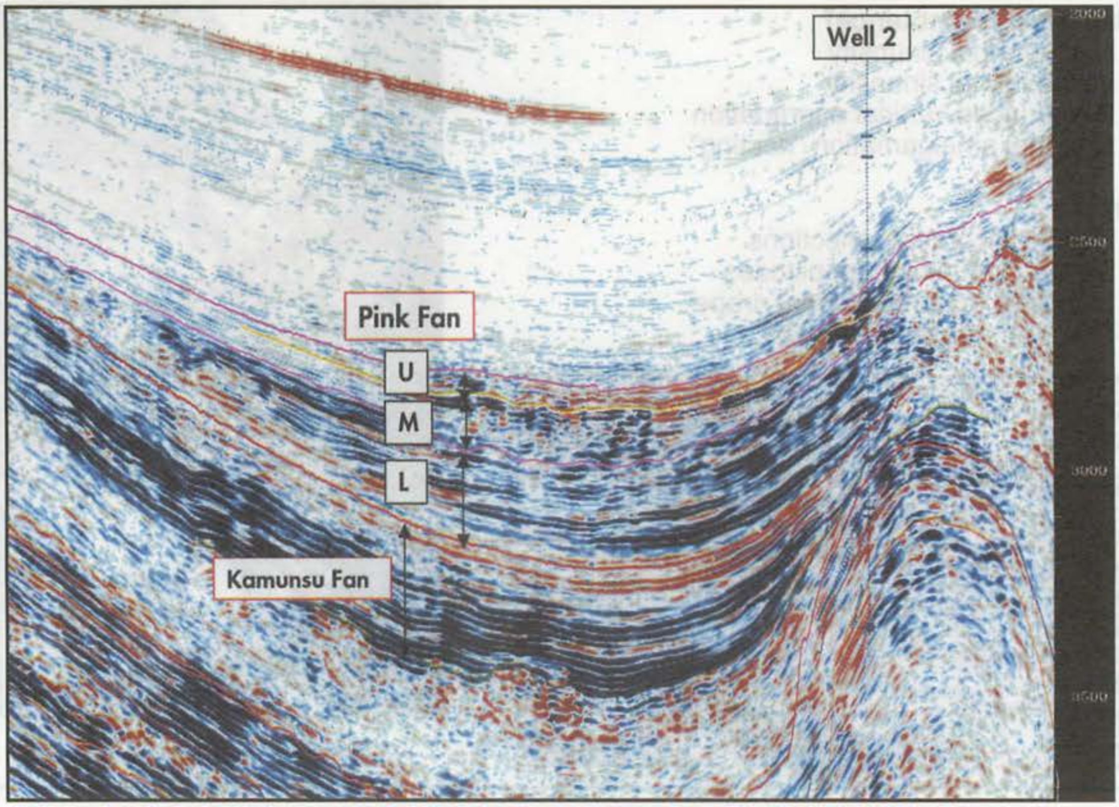

Figure 9. Seismic profile (absolute AvO difference volume) through well 2 showing sand distribution within the Kamunsu basin.

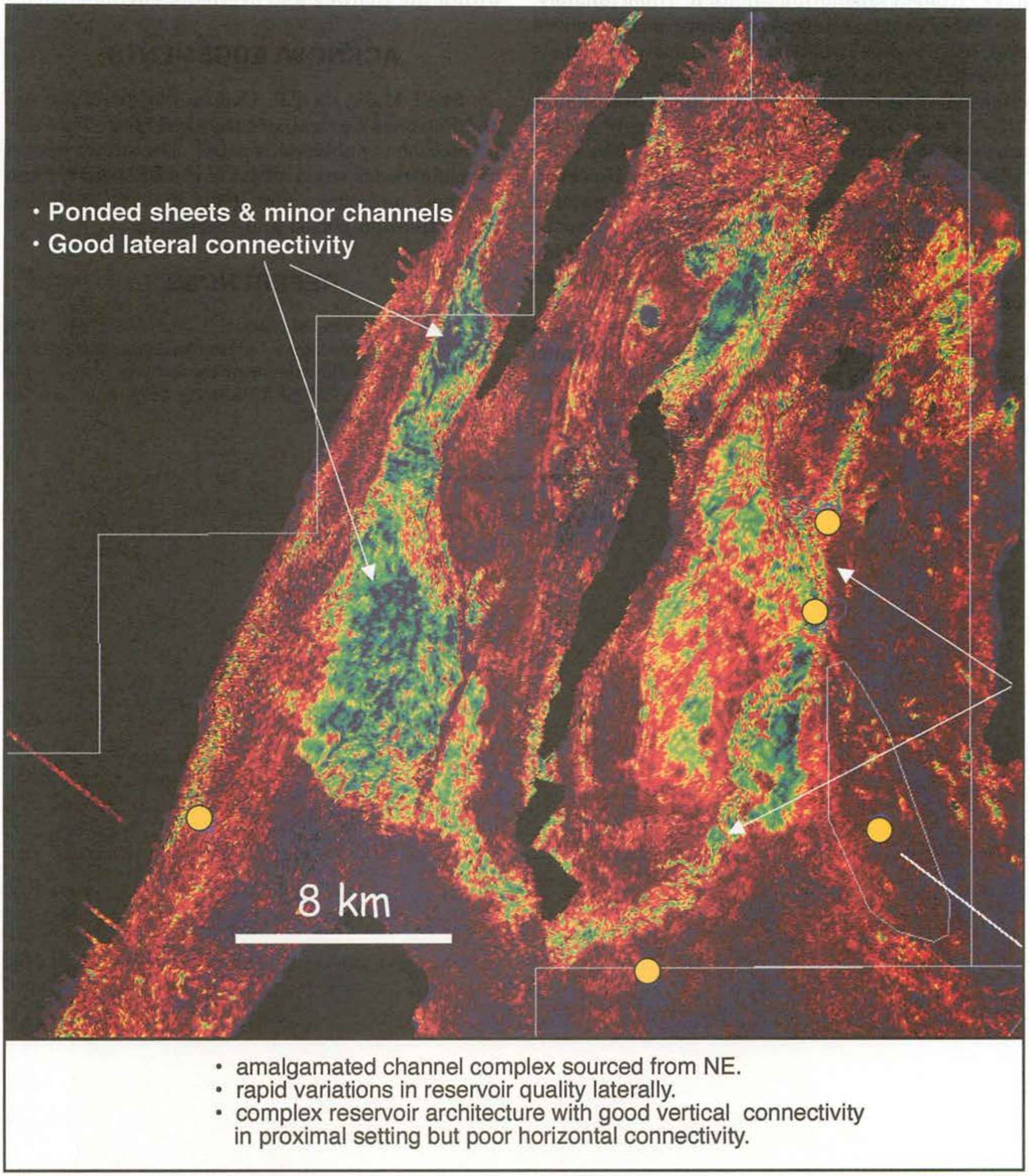

Figure 10. Middle Pink Fan: maximum amplitude extraction AvO difference cube in gated window of 50 ms, 80 ms below top Pink Fan marker.

High-resolution 3D seismic data offers seismic interpreters a means of examining in three dimensions deep marine reservoir features that have excellent seismic illumination. Unfortunately, the rather chaotic internal structure of channelised fans coupled with unfavourable acoustic contrasts between fan lithologies and bounding mudstones often makes seismic analysis difficult or ambiguous. This is especially true with more deeply buried fans where acoustic impedance trends often show little separation between sand and shale. However, the Pink Fan described in this study is illuminated sufficiently that individual channel forms can be measured and their continuity assessed, so helping constrain stochastic modeling input where an obvious analogue is missing.

The Pink fan is a classic example of a topographically influenced slope canyon and channel system. With the help of well data and excellent seismic illumination it is possible to appreciate the complexity of slope canyon and channel systems. Furthermore 3D volume interpretation and AvO attribute analysis have proven exemplary techniques for revealing the distribution of sand within the thalweg and overbank environments.

ACKNOWLEDGEMENTS

Shell Malaysia EP, Conoco-Philips Malaysia, and Petronas Carigali are thanked for giving their permission to publish this paper. The author wishes to acknowledge co-members of the EPD-XDW team for their assistance and lively discussion during the evaluation period and thereafter.

REFERENCES

CASSON, N., WANNIER, M., LOBAO, J. AND GEORGE, P., 1999. Modern morphology — ancient analogue: insights into deep water sedimentation on the active tectonic margin of West Sabah. GEOSEA '98 Proceedings. *Bull. Geol. Soc. Malaysia*, 43, 399–403.

Manuscript received 28 June 2003