SEG Applied Research Workshop: Geophysical challenges in southeast Asia exploration

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The 2008 SEG Applied Research Workshop, in Kuala Lumpur, Malaysia on 7–10 April 2008, was the first such event to focus on regional challenges rather than on a specific technical topic. This is a premier example of how SEG is exploring for new ways to reach out and encourage more interaction with its global membership base. The workshop attracted 64 attendees, with regional representation from Malaysia, Thailand, Indonesia, and India; attendees from outside the region represented North America, Europe, and Australia. The participants covered the full spectrum of business interests: international oil companies, national oil companies, independent oil companies, research institutes, and geophysical service providers. The workshop was sponsored by Hess Corporation, ExxonMobil, and National GeoConsultant of Indonesia.

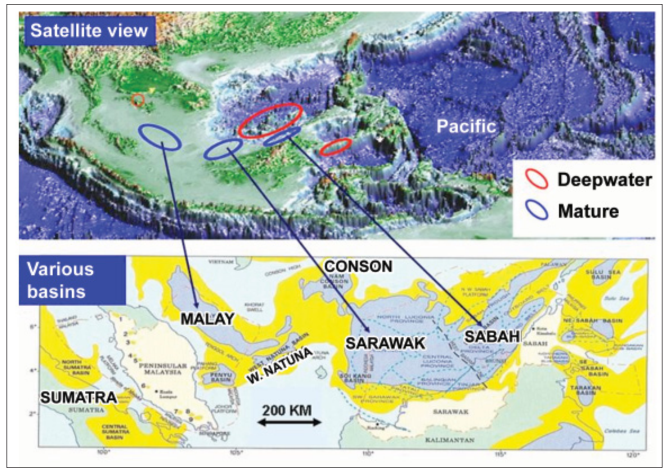

Figure 1. Basins in SE Asia. (Figures 1–4 are courtesy of Deva Ghosh, PETRONAS Research.)

Setting the stage

The keynote speech on the first day, by Deva Ghosh of PETRONAS Research, focused on the history and challenges in the Malay and adjacent Borneo (Sarawak and Sabah) basins (Figure 1). He defined the main challenges in these basins as being improved imaging of: the deep (including fractured) basement, highly sinusoidal channel systems, and thin sands, along with imaging beneath gas clouds (Figure 2). In addition, he felt that we need improved understanding of wave propagation in effective media and of related anisotropy as well as (1) improved quantitative interpretation of thin-bed AVO and coal-bed interference, (2) better discrimination of pore fill, (3) reduced ambiguity in seismic inversion, and (4) more accurate determination of pressure and fluid saturation from time-lapse data.

He concluded by defining the following metrics for success:

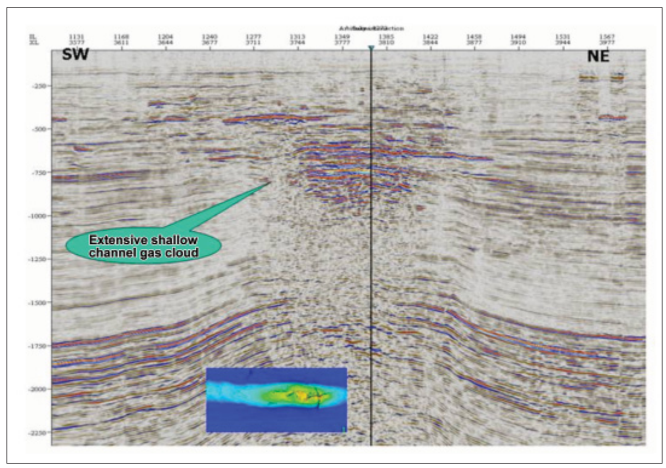

Figure 2. A shallow-gas "wipeout" in Malay Basin.

- better exploration success from risk reduction (Figure 3),
- better imaging of complex, deep high-temperature, and high-pressure reservoirs,
- better productivity (improved recovery factors) from declining fields (Figure 4)

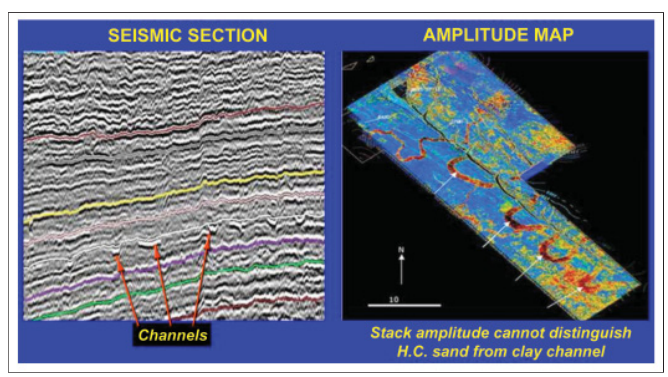

Figure 3. Exploration pitfall: abandoned clay channel.

"Ujung Pangkah field seismic acquisition challenges and solutions" by David Jessup of Hess Indonesia described a complex OBC and transition zone 3D seismic acquisition effort in the Java Sea that utilized three different source/receiver configurations. Jessup focused on the design, planning, HSE, and social issues encountered during the execution of this survey. Input from the local community was a key to successful acquisition of these data in an area of high-density fish farming. Additional challenging geophysical issues included working with tidal variations and an active prograding delta, which induced both severe statics and near-wipeout zones beneath very soft mud (Figure 5a), and delineation of the carbonate reef edge in this oil-rim carbonate reservoir (Figure 5b).

"Sadewa, a Kutei Basin deepwater gas field: Geophysi-

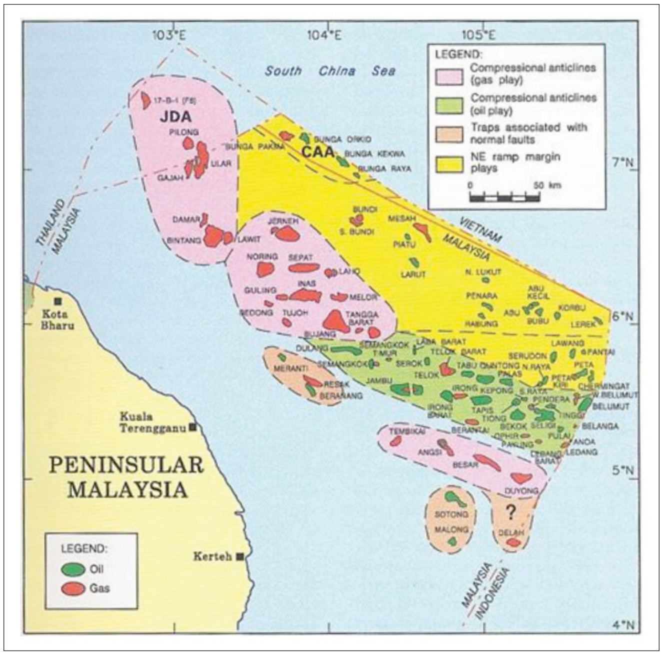

Figure 4. *Oil and gas fields in Malaysia.*

cal challenges from exploration to plan of development" by Paul Thompson of Chevron discussed the geophysical history of the field, which is 5 km off the basin shelf edge (Figure 6). The limitations of the 1997 exploration data set and the design criteria for the acquisition in 2004 of a longer cable, high-resolution development data set were highlighted, and progress in meeting the processing challenges of different acquisition azimuths, multiples, limited bandwidth, low signal-to-noise ratio, high water-bottom dip, and rugosity were discussed (Figure 6). The seismic evaluation challenges of identification and quantitative reservoir characterization, specifically the estimation of the lateral extent of the hydrocarbon-bearing channels were also described. Data examples that illustrated the application of leading-edge solutions to all these geophysical challenges were shown.

In "3D AVO volume visualization in identifying HC leads in offshore Sarawak," M. Firdaus Halim, PETRONAS Research, described a quantitative 3D AVO study of a 400 km^2 area of West Baram delta that employed advanced visualization tools and a Class III DHI workflow (Figure 7). The primary objective was to predict the presence of deep prospects within or below the overpressure regime in the area. As a result, four deep prospects in the overpressure regime were identified.

"Tight reservoirs rock property estimation in peninsular Malaysia" by Yeshpal Singh, PETRONAS Carigali, described an investigation to determine the best set of AVO attributes for discrimination of hydrocarbon-bearing sands from wet sands, shale, and coal in the study area. The foundation of that was the compilation of rock physics trends for the basin (Figure 8). Simultaneous inversion (Figure 9), in conjunction with principal component analysis (Figure 10), compared well-log-based attributes and attributes based on AVO inversion of the seismic data. Primary observations from this study were that well-log-based

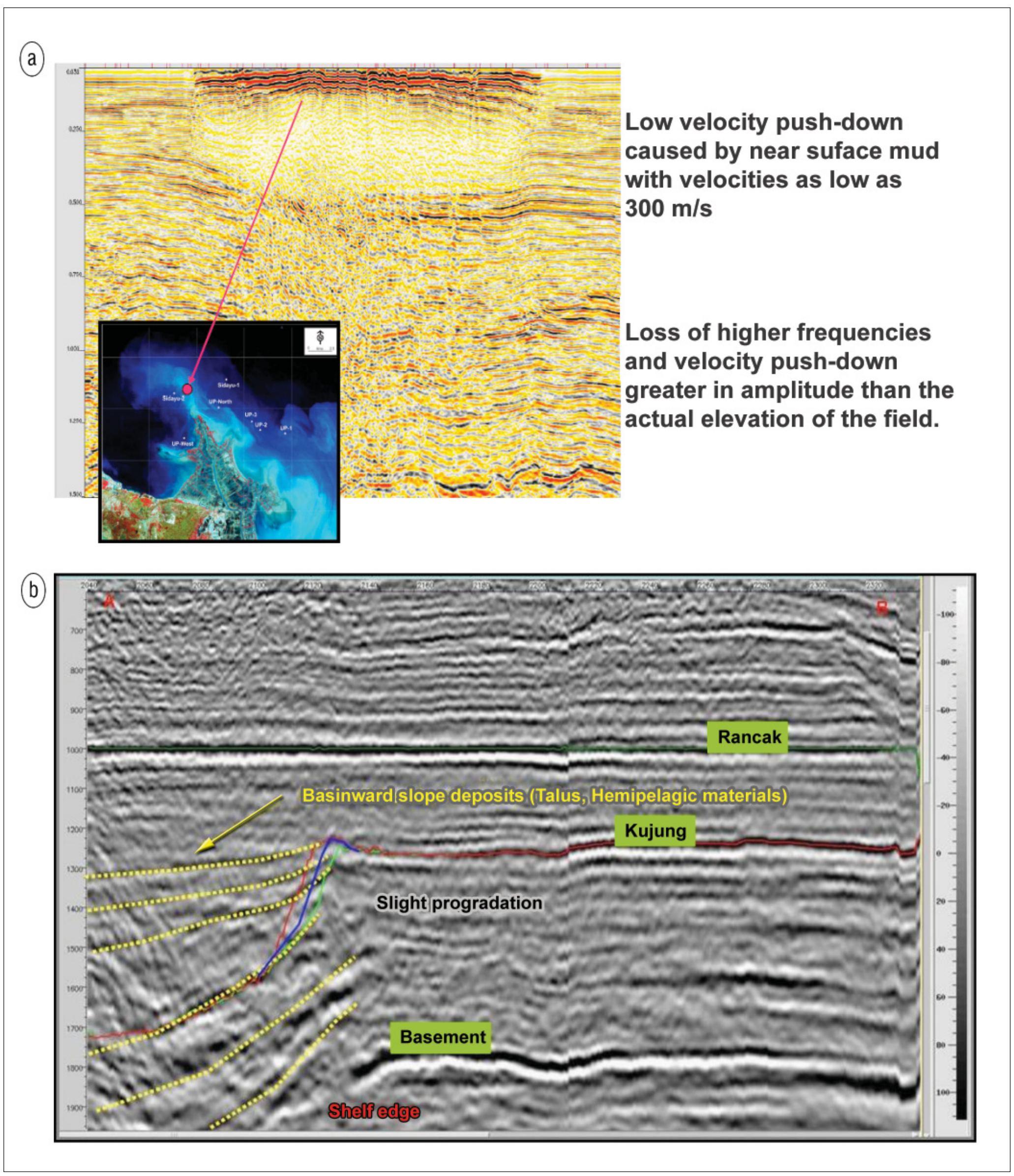

Figure 5. *(a) Near-surface static challenges in Indonesia's Ujung Pangkah Field. (b) Delineation of the carbonate shelf edge (seismic flattened on the Rancak) in Ujung Pangkah. (Courtesy of D. Jessup, Hess.)*

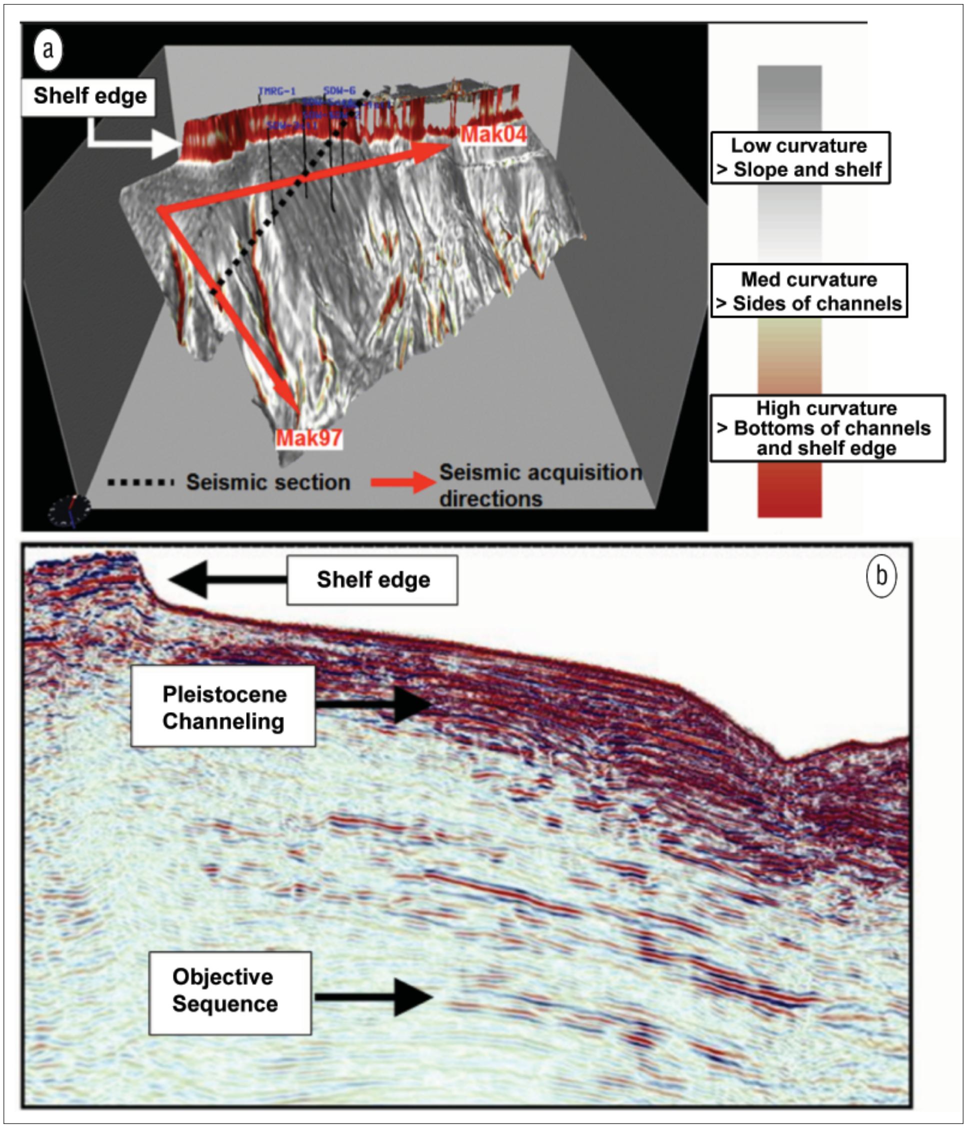

Figure 6. *Deepwater gas field in Kutei Basin, Indonesia. (a) Seismic bathymetry with curvature overlay. (b) Seismic time section. (Courtesy of Paul Thompson, Chevron.)*

attributes by themselves do not give a true representation of the geology and that conventional well wireline data do not adequately measure hydrocarbon saturation in either the primary reservoirs or the overburden.

The session also featured a talk by N. van de Coevering, CGGVeritas, titled "Bayesian seismic inversion and lithology prediction in a stratigraphic grid." He presented a geostatistical stochastic inversion method that operates in a stratigraphic grid defined in the time domain and showed results from a deepwater field from west Africa where the reservoir is a faulted anticline comprising turbidite channels and lobe complexes. Multiple realizations of compressional and shear impedance were generated for use in uncertainty analysis and cascaded stochastic simulation of petrophysical reservoir properties.

Imaging below gas/imaging

The keynote speech for the second day, by Joseph M. Reilly of ExxonMobil, was "Amplitude and frequency-band recovery under gas zones using Kirchhoff prestack depth Q-migration." Reilly first described the problem in terms of (1) the severity of the imaging challenge, (2) the selection of geophysical technology options, and (3) the need to consider the economic realities of the target asset. This was followed by a summary of the current physical understanding of Q (rock quality) by various factions of the geophysical community. The limitations of statistics-based amplitude/phase correction were described. Two workflows were then presented: a poststack viscoacoustic migration algorithm and implementation of a full 3D prestack model-building and viscoacoustic migration approach. Two case histories were shown. In the first example, a 3D model-building and poststack migration workflow was applied in a production environment to an area in the Malay Basin with low structural complexity but including multiple pay zones (Figure 11). The second example, from an exploration setting with high structural complexity, employed a full 3D prestack model-building and migration approach. In this case, both "coupled" and "uncoupled" relations between Q and velocity were observed. The fundamental conclusion from this paper is that including attenuation in the imaging algorithm represents "better physics" and therefore generates higher confidence in our ability to perform quantitative analysis of the output data.

"3D tomographic amplitude inversion for compensating amplitude attenuation due to shallow gas" by Stephen Kefing Xin, CGGVeritas, demonstrated an inversion method based upon postmigration common-image-gather tomography to correct transmission anomalies within the overburden. Both synthetic and real field data were presented. The examples show that the method can mitigate amplitude attenuation caused by transmission anomalies (Figure 12) and should be considered for amplitude-preserving processing, particularly when AVO analysis is considered.

"Seismic imaging through gas clouds: A data-driven imaging strategy" by A. R. Ghazali, PETRONAS, showed how to mitigate overburden gas effects via the common focus point (CFP) method. This method does not require a macrovelocity model for the focusing part, but only for the time-to-depth conversion. Application to a synthetic data set appeared to improve overall resolution, reflection continuity, and recovered amplitudes. Furthermore, encouraging results were obtained for field data offshore Malaysia with a gascloud problem. It was observed that reflection energy is present beneath the gas clouds, but due to the complex propagation effects it was not possible to fully recover the image using available seismic migration techniques.

"Improving the image across shallow gas channel areas using prestack depth migration (PSDM); (offshore Sarawak)" by Bruno Virlouvet, CGGVeritas, proposed a new methodology based upon multilayer tomographic velocity updates to solve the imaging problem associated with shallow gas. In an example from offshore Sarawak (Malaysia) where shallow gas accumulations are observed in numerous locations, the proposed methodology produced a clearer and less distorted image of the structure below the shallow gas.

"Imaging of fractures and faults inside granite basement using controlled beam migration" by Jason Sun, CGGVeritas, illustrated how the latest processing technologies improved seismic imaging in a granite basement reservoir offshore Vietnam. A high-fidelity controlled beam migration, combined with stack sweep velocity updating, produced results that are superior to those obtained using Kirchhoff migration. This method clearly imaged the top of and fractures within the basement in the study area (Figure 13).

M.S. Sams of Fugro-Jason ("Reservoir characterization beneath shallow gas disturbances") demonstrated that, if appropriate procedures are followed, very detailed geostatistical inversion models can be generated, even below shallow gas. However, the reduced bandwidth results in higher uncertainty. The keys to providing quantitative estimates of the reservoir properties within the limits of the data are the ability to (1) estimate and use wavelets that vary in amplitude, phase and bandwidth spatially, temporally, and with offset/angle; (2) apply inversion algorithms that

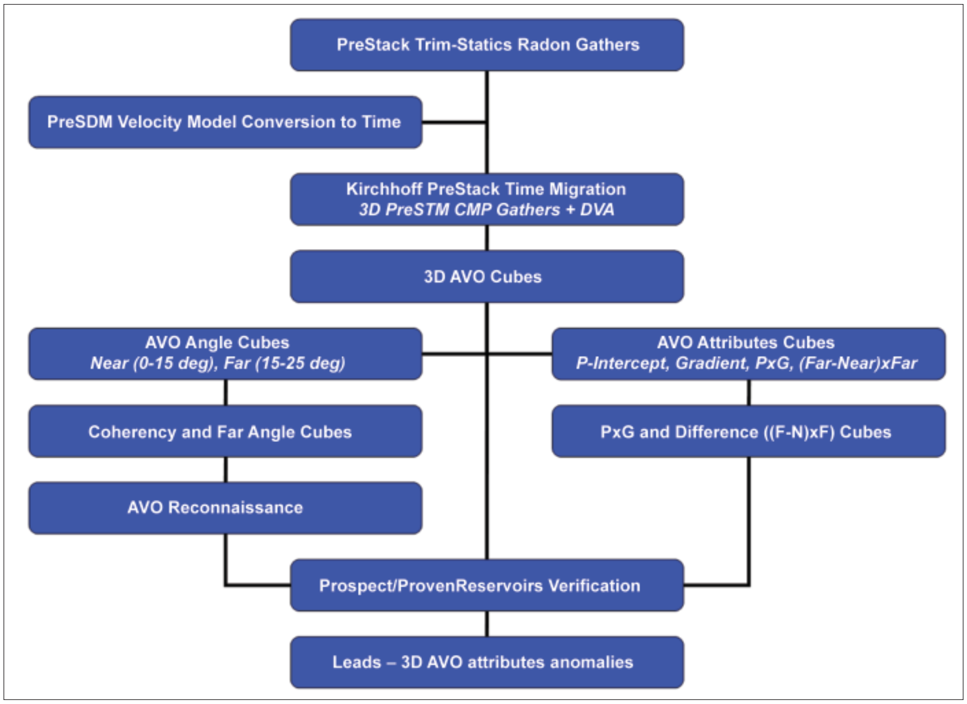

Figure 7. 3D AVO workflow for offshore Sarawak. (Courtesy of M. Firdaus Halim, PETRONAS Research.)

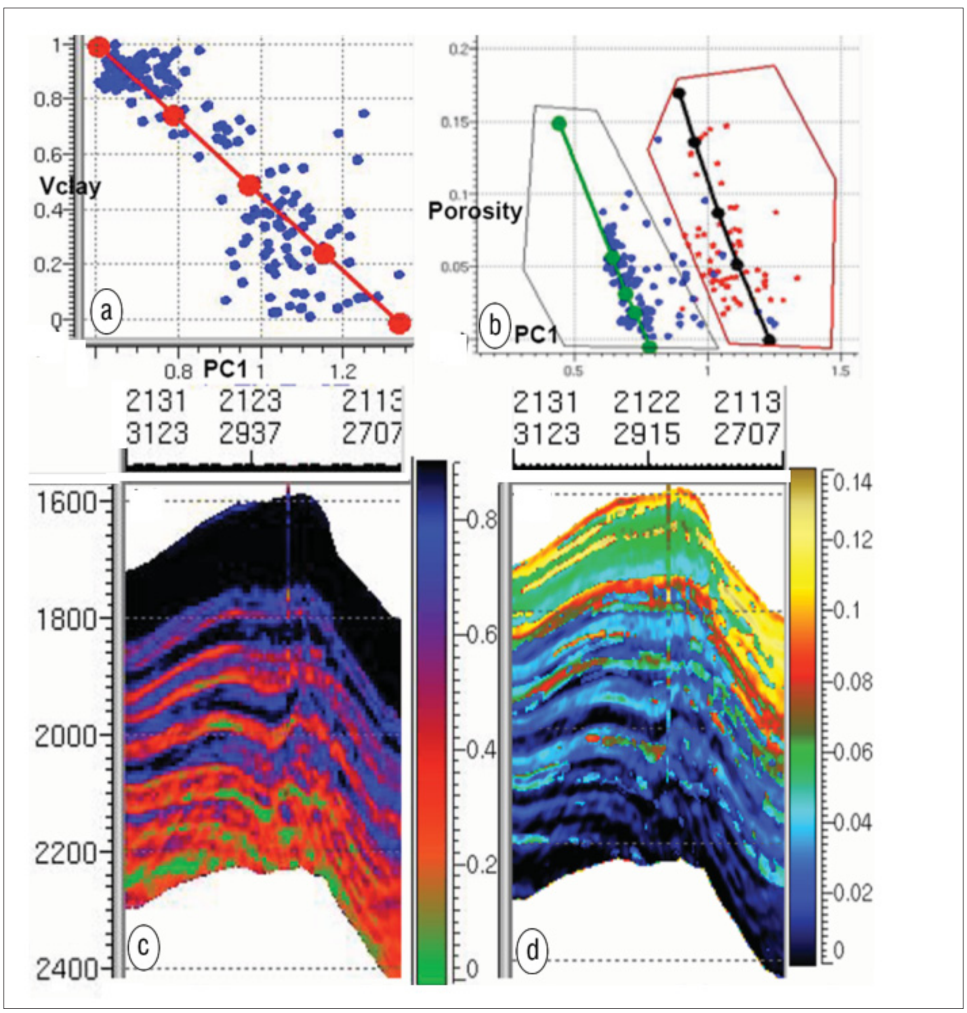

Figure 8. Rock physics trends in Malaysia. (a) Vclay versus PC1. (b) Porosity versus PC1 (blue = shale and red = sand). (c) Vclay predicted based on regression in (a). (d) Porosity predicted from shale-sand regression curves in (b). (Figures 8–10 courtesy of Y. Singh, PETRONAS Carigali.)

deal with spatially and temporally varying signal-to-noise levels; and (3) quality control the results.

Jim Keggin of BP ("Multi-azimuth and wide-azimuth 3D seismic for imaging beneath complex overburdens") discussed three novel wide-azimuth marine acquisition techniques to improve data quality in deepwater areas with complex overburden geometry. Data from the Gulf of Mexico, Egyptian Nile Delta, Caspian Sea, and UK Shetlands showed improved illumination, multiple attenuation, and lateral resolution.

Lynn Comeaux of PGS ("Beam migration images in complex structural settings") used data from the North Sea Norway, Bay of Bengal, and Beaufort Sea Canada to produce beam-migrated images that have excellent accuracy and quality, especially in areas of poor signal-to-noise ratio and steep dip. Comeaux emphasized that the beam migration algorithm and workflow was designed to be a highly efficient interactive process for testing various geologic models. Alternate implementations, given differing operational values, could be considered to produce an "ultimate resolution" seismic depth image. These data examples demonstrate the simplicity, economy, flexibility, and future development possibilities of beam migration.

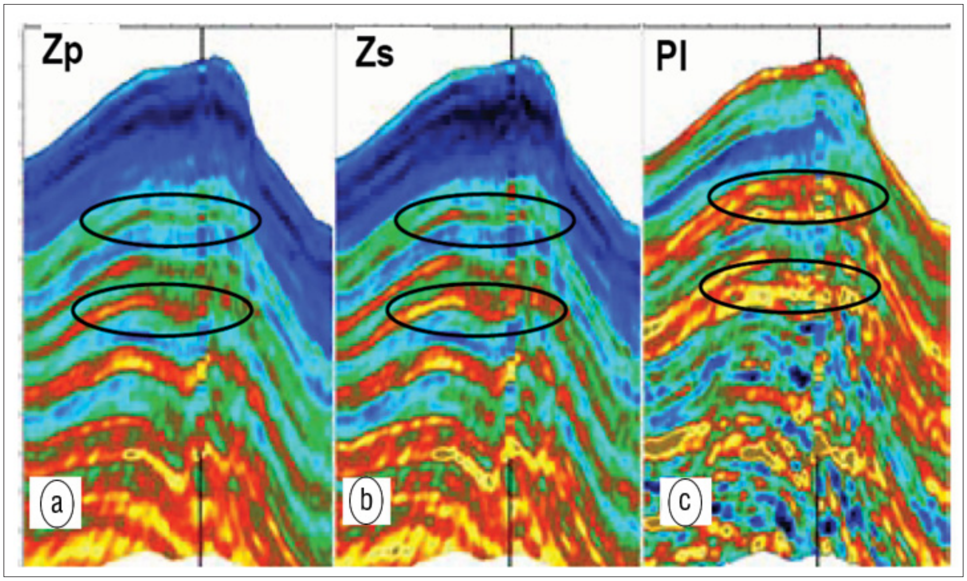

Figure 9. Output of simultaneous inversion in Malaysia. (a) Zp, (b) Zs, and (c) PI. The log curves have been inserted at the well location, and the match with the inversion results is good. The circled flat spots indicate that reservoirs are observed at two levels.

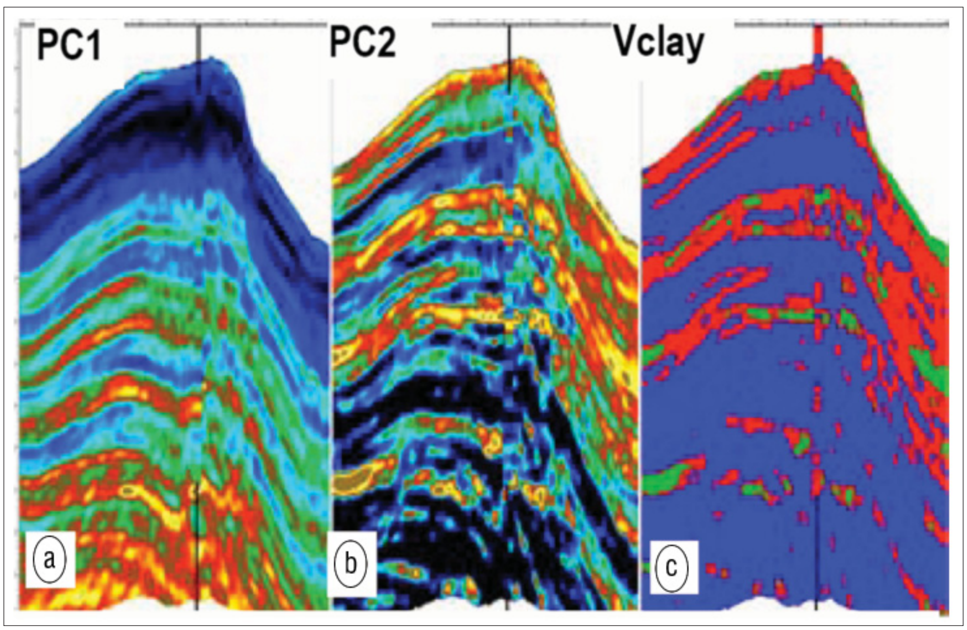

Figure 10. Principal component attributes and lithology in Malaysia. Section view of (a) PC1 and (b) PC2 attributes derived from Zp-Zs combination after simultaneous inversion. Flat spots are more obvious on PC2 section. (c) Lithology derived from PC2 attributes.

Franck Pichard of Paradigm ("Advances in fracture network system identification") described an integrated geoscience and reservoir modeling fracture workflow for detecting fracture systems. It includes a system map that describes the various seismic data classes and analysis techniques that may be utilized in fracture network characterization. The conclusion was that, depending on the available data, different approaches should be considered to better understand the impact of fractures on production and optimize recovery.

New geophysical methods /case studies

The keynote speaker for the third day, Frank A Maao of EMGS, discussed "Seabed logging: a marine EM exploration tool." He began with a historical perspective of CSEM logging for hydrocarbon exploration, reviewed the physical principles of seabed logging, and presented applications in marine exploration. Acquisition designs were described for three different applications: prospect verification, regional scanning, and 3D imaging (Figure 14). He emphasized that interpreted results, whether from inversion or attribute analysis, should be followed up by iterative modeling and/or inversion to check the interpretation against actual measurements. Several examples were shown in which seabed logging contributed to exploration success, including a discovery offshore Borneo (Figure 15).

"A comprehensive approach to CSEM 3D model building: Calibration and application in DW NW Borneo Basin" by Chester Young, Sarawak Shell, described the success of CSEM

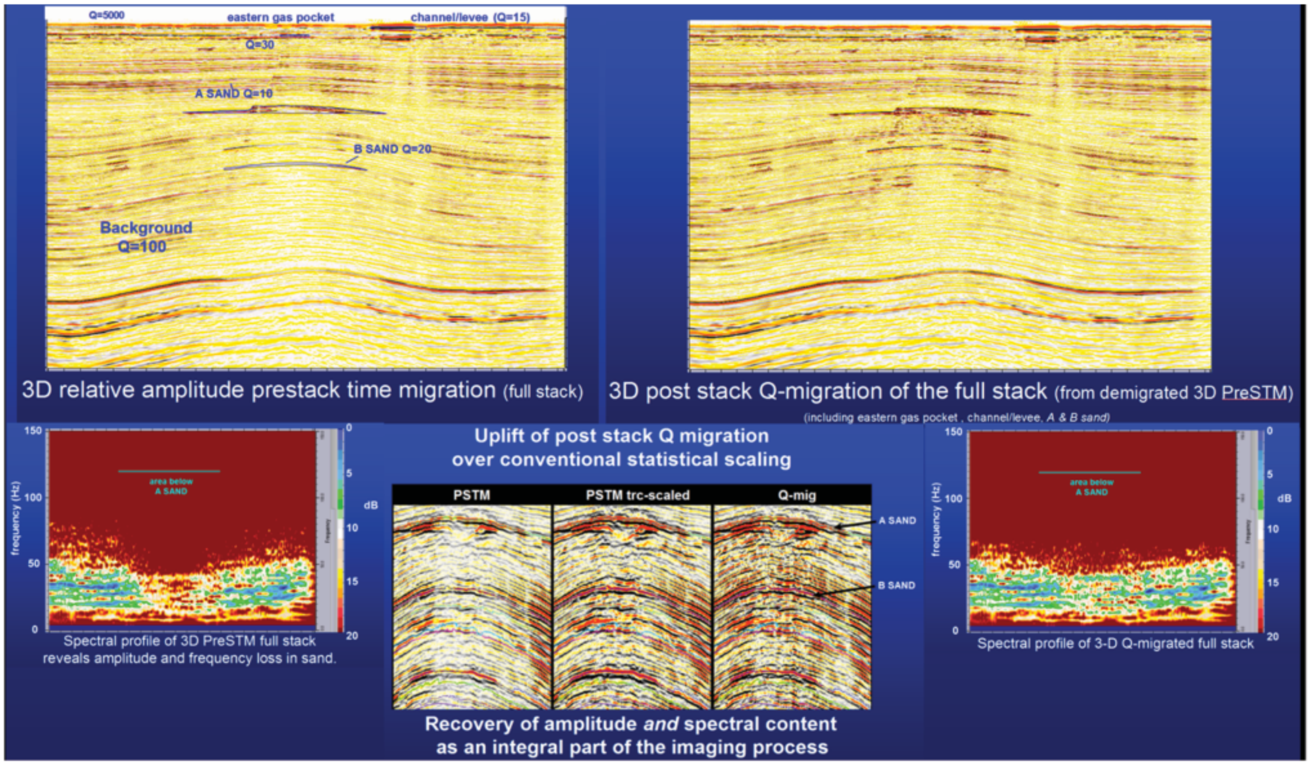

Figure 11. *Q migration for compensation of attenuation of stacked pays in Malay Basin. (Courtesy of J. M. Reilly, ExxonMobil.)*

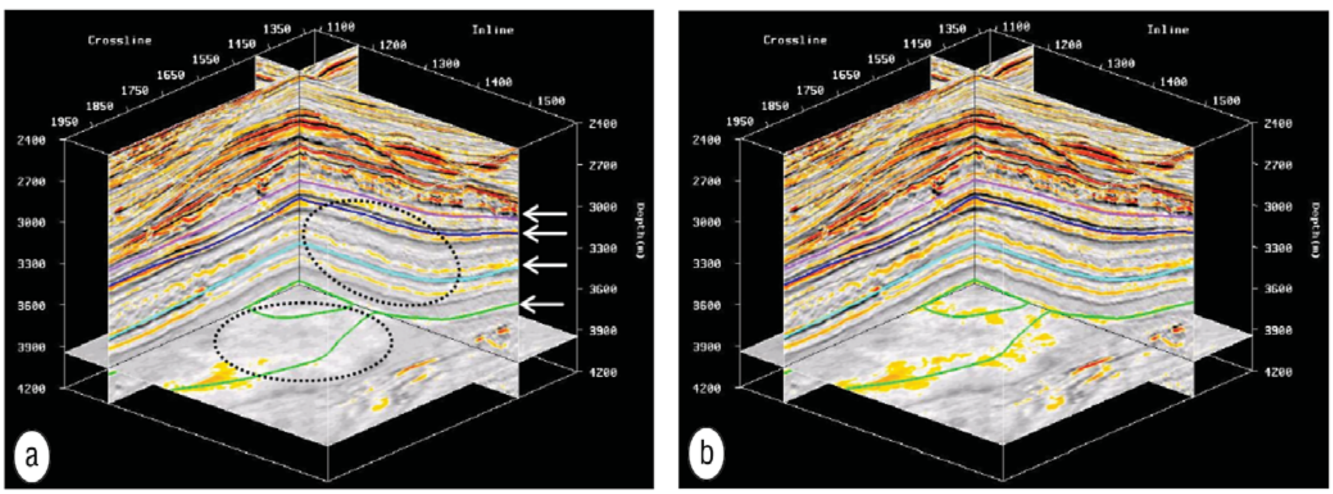

Figure 12. *3D tomographic amplitude inversion for compensating attenuation due to shallow gas. (a) Migrated stack volume showing amplitude-dimming areas (arrows) picked for inversion. (b) The same data after application of the amplitude tomography method. The amplitudes are now restored in the dimming areas. (Courtesy of Stephan Kefeng Xin, CGGVeritas. Data courtesy of OMV.)*

in the Sabah region in evaluating prospects obscured by shallow diffuse gas anomalies, and disappointments as prospects lower in the drilling seriatim were tested. He presented a new "best practice" CSEM workflow to address the negative test results caused by near-surface hydrate layers. Critical aspects of this validation process include high-frequency data (6.75 Hz), shallow coring and wireline logging of the hydrate layers, and mapping hydrate amplitude anomalies and bottom-simulating reflectors. The workflow demonstrates the importance of integrating all available regional and local resistivity information to establish the best nonreservoir background model. Iterative 3D modeling was recommended as optimal for resolving background effects. Young emphasized the need to (1) evaluate the background resistivity in detail prior to attempting prospect modeling and (2) fully scrutinize the raw field data for validity, including such factors as clock drift on the receivers.

"Role of seismic data in redevelopment of complex carbonate reservoir—the case of Mumbai High" by M. Pratap, ONGC, described reprocessing 1997–98 2-C OBC data using relative-amplitude prestack time migration and prestack depth migration to improve imaging in a mature production setting (Figure 16). The challenge in this mature field is defining the value of seismic data where the well control density averages 1 km^2. Pratap used static seismic attributes to help identify areas of bypassed (fracture) permeability. He also

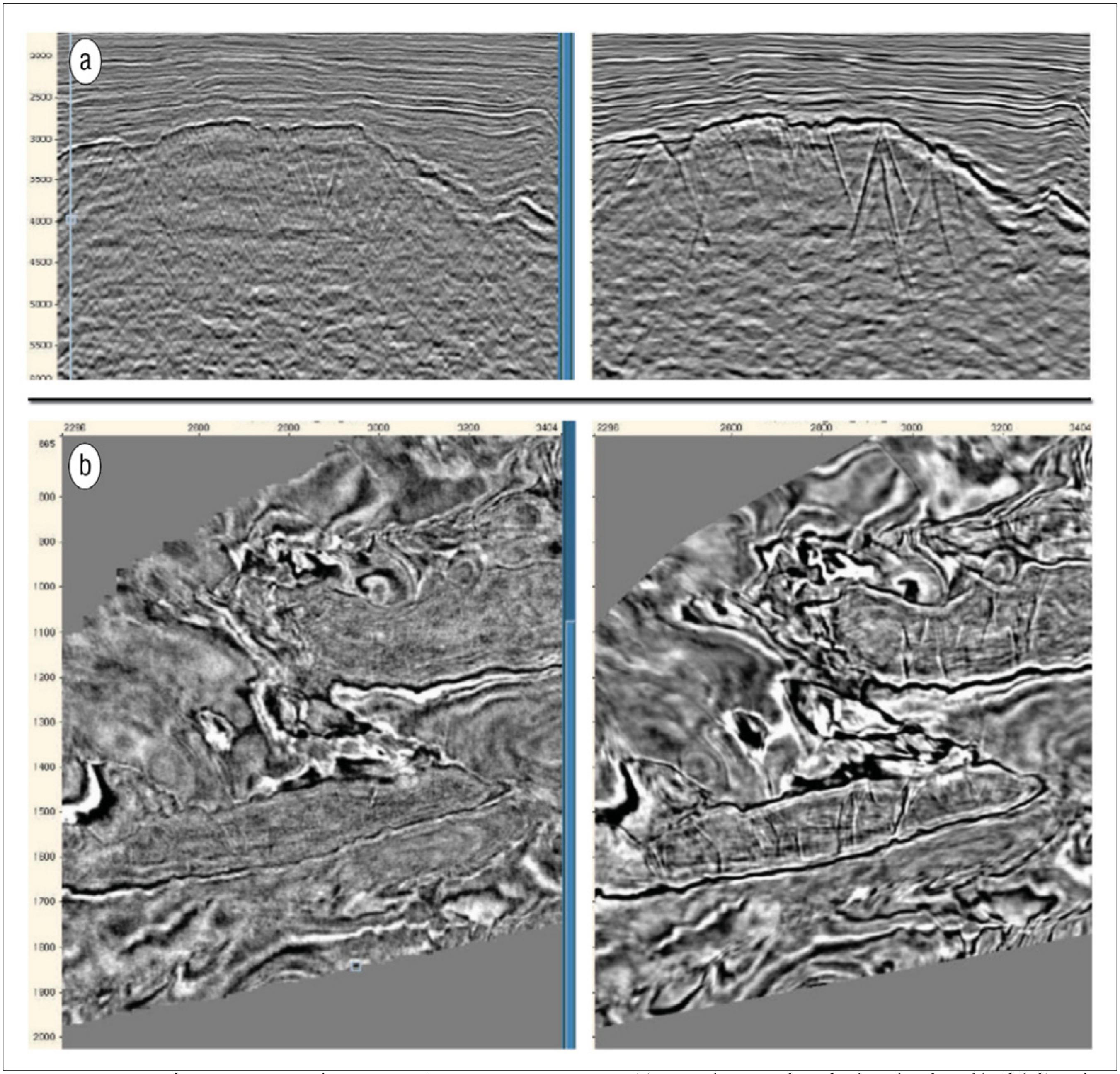

__Figure 13.__ Imaging fractures in granite basement in Cuu Long Basin, Vietnam. (a) Vertical sections from final results of Kirchhoff (left) and beam migration. (b) Depth slice comparison of Kirchhoff (left) and beam migration. (Courtesy of J. Sun, CGGVeritas.)

showed examples of successfully using seismic data to control the horizontal drilling program.

"Exploring a stratigraphic play beyond seismic resolution—a case study of Thung Yai-A01 exploration well, S1 Concession, Phitsanulok Basin, onshore Thailand" by Farid Saifuddin, PTTEP Siam Limited, was a case history of a 2007 exploration well that was drilled after a detailed study of seismic inversion and attributes. The well proved valuable in understanding the seismic character and depositional system of the target reservoir. Saifuddin also described the remaining exploration potential in the region and the fundamental challenge of detecting stratigraphically trapped thin-bed sand reservoirs embedded in hard shales with a soft-shale overburden (Figure 17).

Folke Engelmark, PGS EM ("High resolution multitransient EM for reservoir characterization and monitoring"), reviewed the MTEM methodology, and described advantages over conventional CSEM. MTEM is the only modern galvanic EM technology applicable to land, transition zone, and marine environments allowing the fastest buildup of S/N noise through a combination of a PRBS source signal in conjunction with deconvolution to recover the Earth's impulse response. The acquired data are constantly monitored and the S/N buildup at target depth is estimated in real time. The bandwidth of the source is always matched to the offset being currently recorded, allowing a resistivity-depth profile to be built up from surface/mudline to target depth. This provides excellent depth control of subsurface resistors. Engelmark concludes that the technique should complement, not replace, seismic in many characterization issues. He noted that

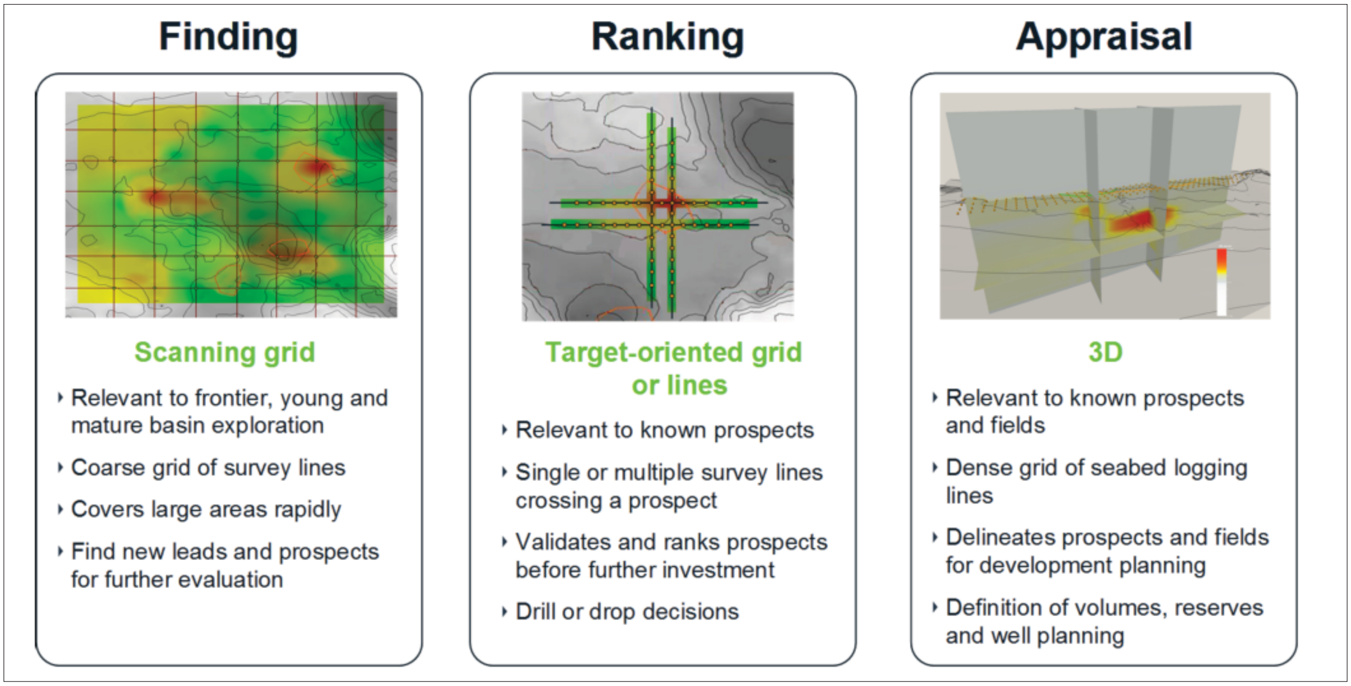

Figure 14. *Marine EM as an exploration tool. (Figures 14–15 courtesy of Frank Maao, EMGS.)*

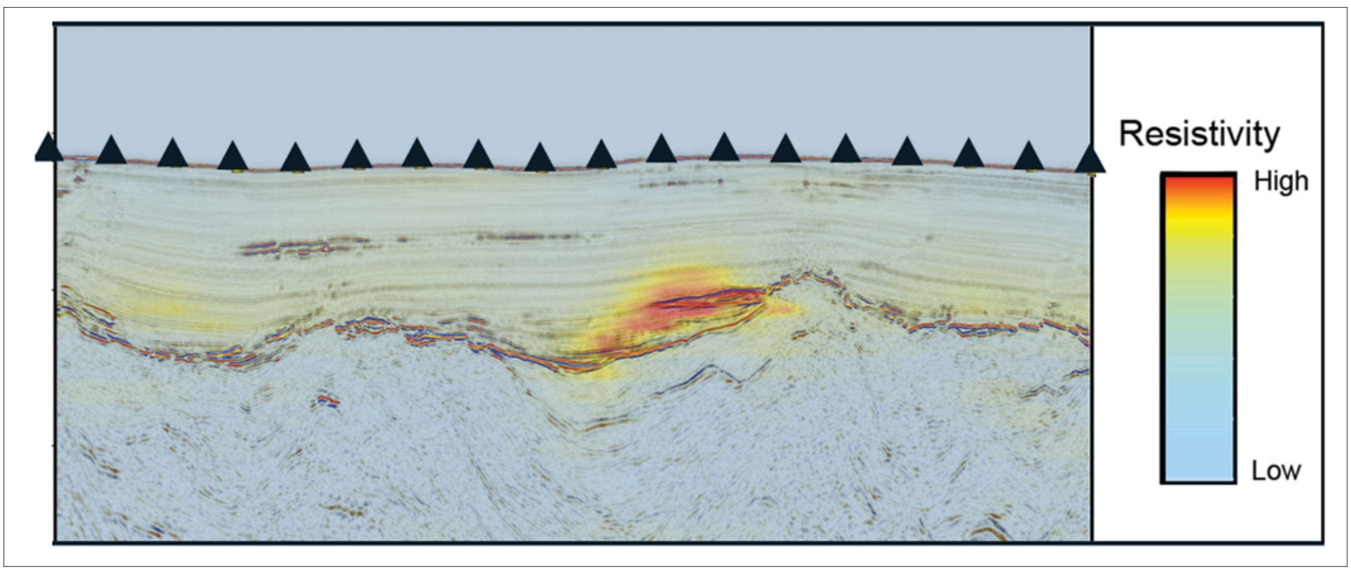

Figure 15. *Marine EM exploration offshore Borneo. Depth section with seismic and electromagnetic resistivity inversion. (Also courtesy of Murphy Sabah Oil Company.)*

half of all producing fields in the world are not amenable to seismic time-lapse monitoring, but many would be suited to EM time-lapse monitoring.

Jean-Pierre Deflandre, IFP ("Analysis and interpretation of microseismic data associated with underground gas reservoir storage fill-up") illustrated how a virgin aquifer may react to initial gas reservoir fill-up. In this study, microseismic events are associated with stress rearrangement due to the significant reservoir pressure increase when gas replaces water. Deflandre described a passive seismic method for reservoir monitoring

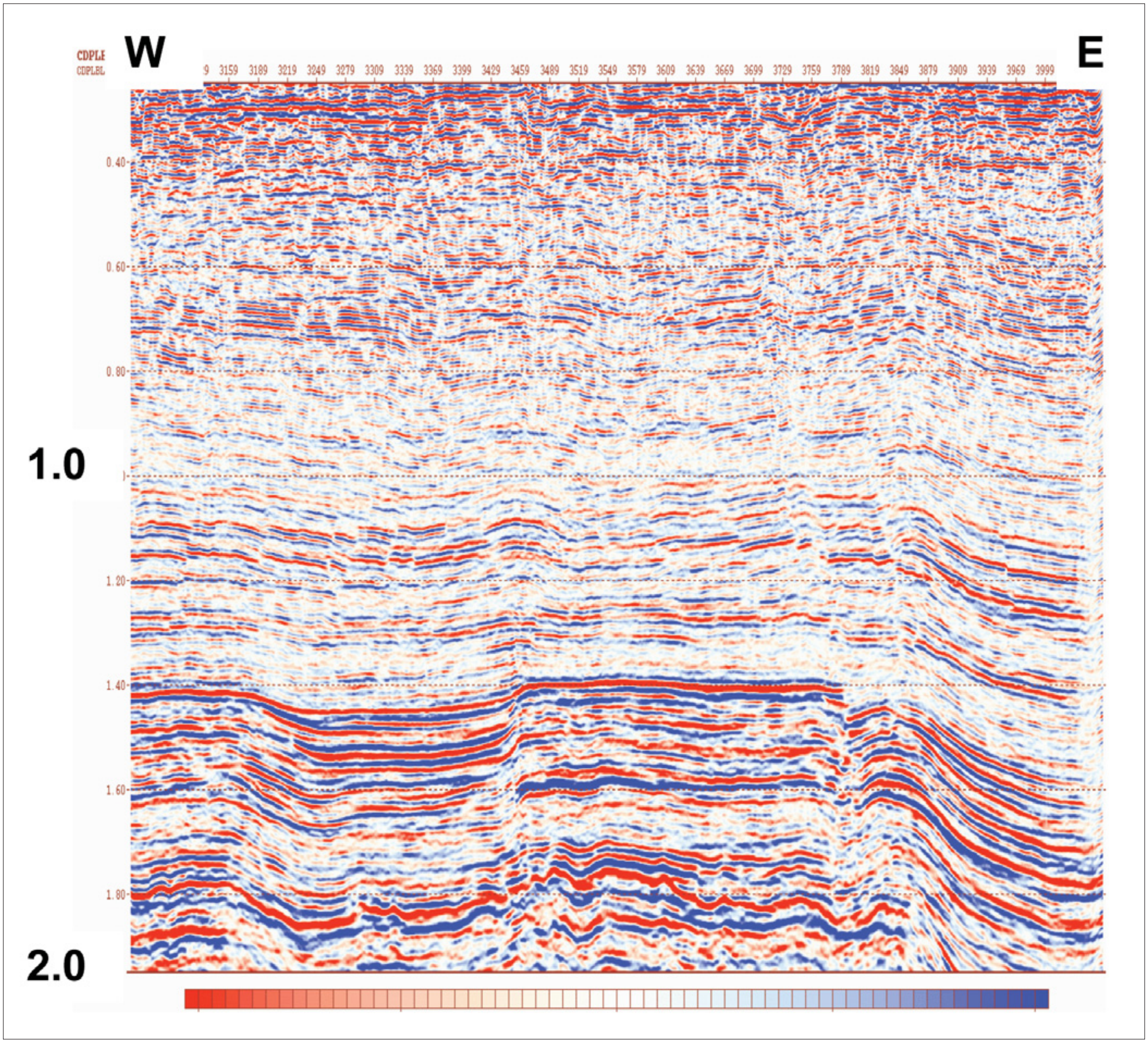

Figure 16. *Seismic cross-section across the Mumbai High, India. (Courtesy of M. Pratap, ONGC.)*

and listed the R&D challenges to improving 3D data interpretation, especially if fault and fracture networks are to be included in a coupled reservoir-geomechanical model.

Workshop discussion

During the question periods and in the wrap-up session, attendees contributed numerous insights about areas in which geoscientists within the region were practicing, or leading, in the application of "world-class" geophysics, as well as about topics they felt would benefit from leveraging global expertise.

Geophysicists within the region are clearly leading in the areas of:

- quantitative analysis of Class II, Class IIP, and Class III DHI/AVO reservoirs
- high-frequency and thin-bed analysis
- reservoir interpretation in the presence of thin coals
- acoustic inversion
- pore-pressure trends/HPHT detection
- depth imaging (in time) for quantitative analysis
- application of deepwater electromagnetic methods (including early successes and an understanding of pitfalls)
- university research in near-surface geophysics, whole Earth seismology, and tsunami prediction

Topics identified as opportunities for global leveraging or further research include:

- fully exhausting existing data
- elastic inversion
- spectral decomposition methods
- full prestack interpretation
- interpretation in depth
- imaging through shallow gas
- imaging beneath carbonate reefs
- improved compensation for attenuation, illumination, and overburden reflectivity

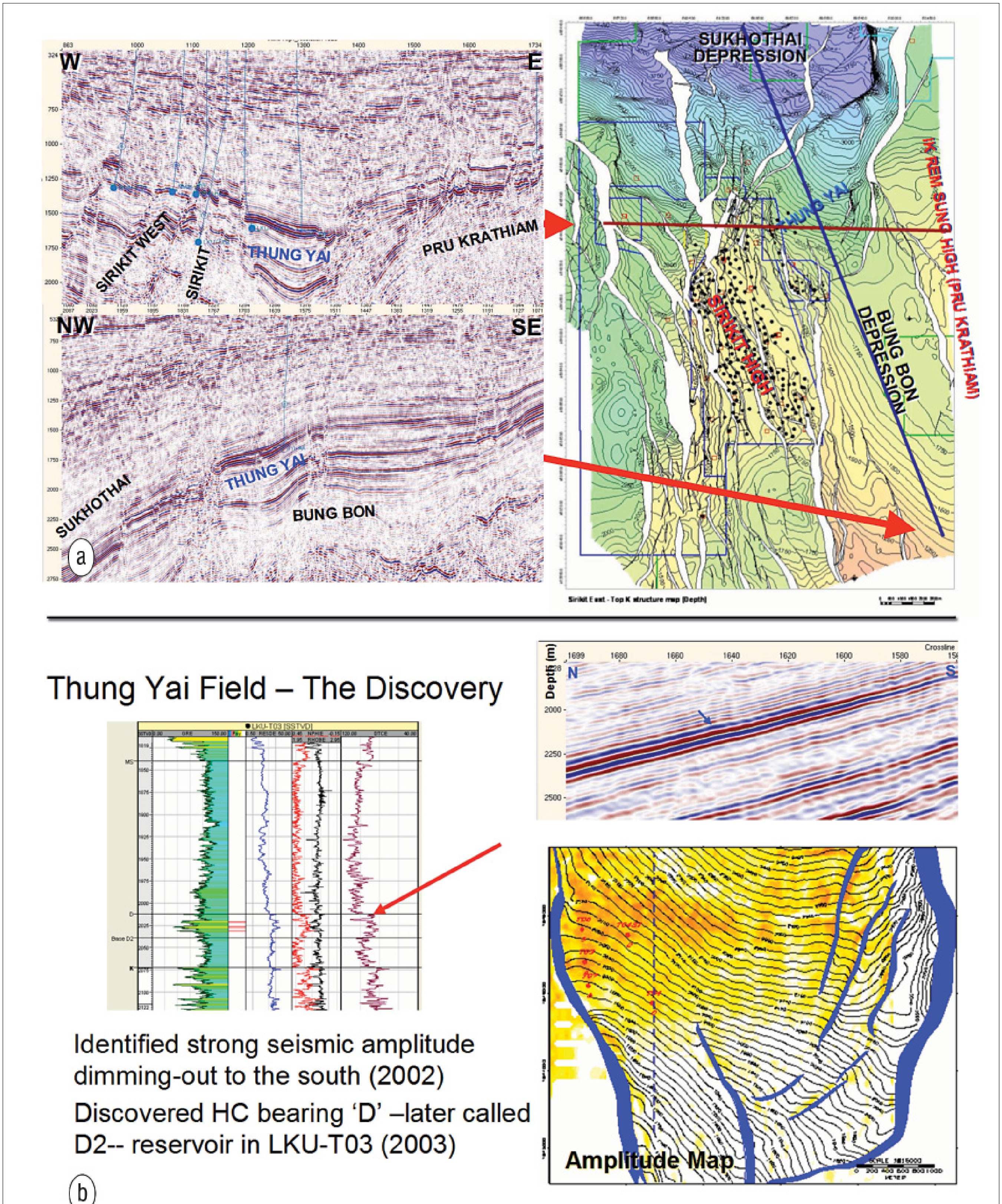

Figure 17. (a) Structural setting in Phitsanulok Basin, onshore Thailand. (b) Exploring beyond seismic resolution in Phitsanulok Basin. (Courtesy of Farid Saifuddin, PTTEP Siam Limited.)

- shallow water demultiple, free-surface (SRME) and inter-bed demultiple
- corrections to wireline logs for geophysical use
- rock physics database
- error analysis of geophysical predictions
- integration of static and dynamic measurements
- integration and cross training among geologists, petro-physicists, geomechanicists, and engineers
- utilization of emerging methods
- 4D/time lapse

- shallow-water CSEM/MTEM
- 4-C, converted-wave imaging for structure mapping and lithology prediction
- wide-azimuth/multi-azimuth acquisition and processing
- passive seismic and nonseismic methods
- methods for valuation of geophysical methods within the E/D/P cycle
- case histories defining value-of-information for enhanced geophysics
- relating field economics to geophysics options
- deepwater geophysics
- education
- enhanced access for students to industry tools and data
- more professional workshops in the region
- preparing for the next "step change"
- sharing case histories of stratigraphic traps

Conclusions

Southeast Asia presents a variety of geophysical challenges, many of which can be overcome by integrated workflows and novel and emerging technologies. The success of these approaches demonstrates the continued value of applied geophysics research, and we expect that focusing on these challenges will further improve the application of emerging geophysical technologies. The ultimate benefit of these improvements will accrue to service providers, oil companies, and host governments. TLE

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