PROCEEDINGS, JAKARTA2006 INTERNATIONAL GEOSCIENCES
CONFERENCE AND EXHIBITION
Jakarta, August 14 – 16, 2006

DEVELOPMENT OF HIGH RESOLUTION BIOSTRATIGRAPHIC FRAMEWORK FOR KUTEI BASIN

Robert J. Morley*
John Decker**
Harsanti P. Morley*
Sherman Smith**

SUMMARY

Unocal Indonesia (now Chevron IndoAsia) undertook Indonesia's biggest deep-water hydrocarbon exploration program to date in the Makassar Straits between 1996 and 2005, drilling over 100 exploration wells between 2000' and 7500' water depth.

Biostratigraphic analysis was undertaken on all exploration wells, but initially provided little constraint to regional seismic interpretations because:

1. common reworking made it difficult to confidently place 'last appearance datums' and hence make reliable zonal interpretations
2. existing zonations were of insufficient resolution to differentiate reservoir intervals
3. thick intervals of deep water shales frequently proved to be virtually barren of age-diagnostic microfossils and
4. biostratigraphic data generated from different labs and different operators were commonly inconsistent

Following a critical basin-wide re-evaluation, biostratigraphic constraints on stratigraphic correlations were greatly improved, mainly due to the following:

1. Development of substantially improved biostratigraphic zonations, tested with seismic mapping and log correlations.
2. Development of a biostratigrapically controlled sequence framework within which the reliability of index fossils could be independently assessed. Altogether 28 sequences were differentiated through the Pleistocene to Middle Miocene and served as the basis of chronostratigraphic mapping in the basin.
3. Incorporation of palynology into the biostratigraphic work flow.
4. Eleven regional chronostratigraphic seismic horizons ('KR' markers) were calibrated against the sequence biostratigraphic framework and shown to reflect transgressive surfaces.

Prior to 2001-2002, results did not support the cost of the program since they did not provide meaningful correlations. With a slightly increased budget, the program evolved to become the cornerstone of the basin-wide chronostratigraphic mapping program and to provide detailed reservoir-scale correlations.

From 1999 – 2005, the number of chronostratigraphic datums identified in the basin increased by over 100%. One key finding from the increased resolution is that the majority of hydrocarbon accumulations occur within a single Late Miocene sequence, between 7 and 8 million years before present.

INTRODUCTION

Unocal Indonesia (now Chevron IndoAsia) undertook Indonesia's biggest deep-water hydrocarbon exploration program to date in the Makassar Straits between 1996 and 2005, drilling over 100 exploration wells starting with upper slope

* **Palynova and P.T. Eksindo Pratama**
** **Chevron IndoAsia**

targets such as Merah Besar and West Seno at 2000-3000' water depth, and culminating with wells in the deepest part of the basin such as Pangkal-1 at greater than 7500' water depth (Figure 1).

As a prelude to this program, Unocal Indonesia undertook two regional studies in the 1990's (1993, EKRS, = East Kalimantan Regional Study, and 1996, BARS, = Balikpapan Area Regional Study) which established a chronostratigraphic framework based on foraminifera (using the zonation scheme of Blow, 1969, 1979) and nannofossils (using the zonation scheme of Okada and Bukry, 1980) which it was hoped would provide the necessary stratigraphic control to help guide the drilling program. When deep water drilling commenced, numerous issues developed which made it difficult to utilise biostratigraphic interpretations. The main issues were 1) the presence of common reworking made it difficult to be confident in the placement of 'last appearance datums' and hence the reliability of zonal interpretations; 2) existing zonations were often of insufficient resolution to differentiate the reservoir intervals (for instance the main West Seno reservoirs fell entirely within a single nannofossil zone, from the position of the first cuttings sample to TD); 3) thick intervals of deep water shales frequently proved to be virtually barren of age-diagnostic microfossils; and 4) biostratigraphic data generated from different labs and different operators were commonly inconsistent.

MAIN STEPS IN DEVELOPING THE PROGRAM

Developing Data Compatibility Between Labs

A critical basin-wide re-evaluation of the biostratigraphic database was undertaken during 2001-2002. Also, with the forthcoming drilling program for 2003-2005, subsequent work was split more or less equally between two service company labs, Lemigas and CoreLab, since it was understood that with the number of wells planned, a single contractor would be unable to handle the workflow alone. It was therefore essential to ensure that work from the two laboratories was compatible. This was achieved by working closely with both laboratories, to ensure that, even if using slightly different methods to reach the same goal, results would be consistent, with the same diagnostic taxa being identified. The aim was to determine the number and diversity of foraminifera in 50 g of wet cuttings, and of nannofossils within a fixed number of traverses of a microscope slide using a standard processing technique. During this process, numerous anomalies in methodologies and protocol were discovered, which significantly affected the eventual success of a sequence biostratigraphic interpretation. Analysts were initially unaware of the implications of these, but the issues were quickly corrected and incorporated into their respective protocols.

Development Of A Biostratigraphically-Defined Sequence Succession, An Independent Yardstick For Testing The Reliability Of Index Fossils

Reworking of index fossils initially created innumerable problems in the attribution of biostratigraphic zones. Three types of reworking were particularly prominent: 1) reworking from sediments being eroded from the hinterland, mainly present as a consistent background noise; 2) reworking from the underwater erosion of toe thrusts, which generally occurs in short-lived pulses; and 3) reworking of the previous highstand into the subsequent lowstand by downslope transportation in turbidites. Reworking of material from older highstands could be relatively easily recognised by examining microfossil distributions within a sequence biostratigraphic perspective. Mainly using foraminifera, a model was constructed to characterise and differentiate the lowstands and condensed sections in slope and basin floor sediments by comparing overall foraminiferal abundance with the percentage of foraminifera clearly derived from the shelf. Intervals with foraminiferal abundance maxima but minima of transported shelf taxa were interpreted as condensed sections, whereas intervals with more common transported shelf fauna, irrespective of foraminiferal abundance, were interpreted as due to transportation in turbidites and therefore as lowstands (Figure 2).

Using this approach a total of 28 biostratigraphically defined sequences were differentiated between the Early Pleistocene and Middle Miocene (Figure 3A). Each of these were then characterised, or 'fingerprinted' by an association of index nannofossils and foraminifera. For nannofossils, reference was made to the zonation scheme of Martini (1971), with modifications to the ranges of specific nannofossil species according to Perch-Neilsen (1985), Berggren et al. (1995) Young (1998) and unpublished data. For foraminifera, although interpretations of zones followed Blow (1969, 1979), most emphasis was placed on the identification of specific datums, mainly following Berggren et al (1995), either as first or last appearances, or coiling ratio changes. Third order sequences were attributed a name after the initial letters of the nannofossil species which became extinct following the condensed section, with, for instance, the Late Pliocene including sequences DB (after the *Discoaster brouweri* extinction at end NN18), DS (after the *Discoaster surculus* extinction at end NN16) and DT (after the intra NN16 *Discoaster tamalis* extinction). Fourth order sequences were then differentiated numerically (eg DT1, DT2). This approach was originally introduced for the Gulf of Mexico by TGS Calibre (unpublished), and subsequently applied in the Niger Delta (Morley and Rosen 1996; Morley 2000) and Natuna Sea (Morley et al 2003). Once the scheme was established, the 'extinction' level of any index fossil could be tested against the predicted succession. A 'top' would be immediately suspect if it occurred out of succession, or in an interval with common transported shelf foraminifera.

Increasing The Resolution Of The Biostratigraphic Zonation

Increasing biostratigraphic resolution was principally applied to the subdivision of nannofossil zone NN11, which spans the time interval from 5.56 – 8.5 Ma (using timescale of Berggren et al 1995). This time period contained most reservoir intervals in the basin, and for most wells from West Seno field, the first cuttings samples below the 13 3/8'' casing point and the deepest sample at TD fell within this zone! Working closely with service company analysts, and utilising experience gained in other Tertiary deltas, such as the Gulf of Mexico and Niger Delta and with help from an independent consultant, this interval was subdivided into seven subzones (Figure 3A), five of which could be picked with some degree of reliability. Since the scheme was devised, a similar (although less rigorous) zonation scheme has been published for the Gulf of Mexico by Wei (2003).

Resolving The Issue Of Deep Water Shales Lacking Index Fossils

As exploration moved from the upper/mid slope to the lower slope, thick sections of mudstone were encountered which were very poor in microfossils or just yielded non age-specific arenaceous fauna. This was shown to be due to dissolution caused by acidic bottom conditions resulting from a combination of cold corrosive bottom waters and the presence of high concentrations of organic matter, raising bottom sediment acidity. Palynological analysis was used to help understand dissolution issues since pollen and spores are unaffected by this kind of dissolution. Mangrove pollen acmes coincide with periods of sea level rise and transgressive systems tracts (Morley 1996), and being easily recognisable in the deepest parts of the basin, provided a guide as to the location of the condensed sections in the absence of calcareous microfossils. One of the main realisations was that in 'dissolution' settings, calcareous fossils, including acmes of planktonics and nannofossils, could be preserved when rapidly buried in turbidites, but could be entirely absent from the condensed section that contained only arenaceous fauna, thus planktonic acmes reflect condensed sections in normal settings but may correlate with lowstands in 'dissolution' settings. Again, a model was constructed to facilitate systems tract interpretation in dissolution facies, and in the absence of any index fossils, realistic interpretations of sequences could be made by counting sequence packages from higher, or lower intervals of known age.

Carbonate dissolution was greatest in intervals with the highest sedimentation rates on the mid and lower slope, and in West Seno, it extended into the upper slope during intervals of particularly high sedimentation. It became less marked on the basin floor, especially in the most distal wells drilled, although in most wells, some dissolution is discernible in most intervals, indicated by the increased percentage of arenaceous fauna in condensed sections relative to lowstands. Today, there is virtually no carbonate dissolution taking place at depth in the Makassar Straits (Morley et al 2004)

CALIBRATION OF REGIONAL SEISMIC HORIZONS

Using the sequence biostratigraphic framework as a reference, previous seismic picks (the z/x scheme of the EKRS and BARS studies) were recalibrated and found to vary widely with time across the region (Figure 3B), These were replaced with eleven regional chronostratigraphic seismic horizons, termed 'KR' (Kutei Regional) markers, which, from comparison with the sequence biostratigraphic framework were shown to equate with transgressive surfaces (Figure 3A). KR markers are nearly time-synchronous chronostratigraphic surfaces numbered approximately in millions of years X10, picked near the top of major sand packages.

DISCUSSION

Prior to 2001-2002, the results received from Unocal's investment in biostratigraphy were not supporting the cost of the program. "Routine biostrat" was not providing meaningful regional or reservoir scale correlations. With only a slight increase in budget and a passionate attention to every detail, the program evolved to become the cornerstone of the basin-wide chronostratigraphic mapping program and to provide detailed reservoir-scale correlations.

Over the period 1999 – 2005, there was a more than 100% increase in the identification of chronostratigraphic datums in the basin, and also in the reliability with which datums could be positioned (Figure 4). One key finding from the increased resolution is that the majority of hydrocarbon accumulations, from shelf to basin occur within a single chronostratigraphic sequence of the Late Miocene. There are other zones that also contain hydrocarbons, within the basal Pliocene and basal Late Miocene, but the main prospective zone basin-wide is the large lowstand progradation (the 'DL' sequence) between 7 and 8 million years before present.

ACKNOWLEDGEMENTS

The authors wish to thank Wantoro, Sukarno and Yuliana Pane from Corelab, and Nur Hasjim and Eko Budi Lelono from Lemigas, and Alaa Baky from Eksindo Pratama for analyses, tolerance and discussions, and to Chevron IndoAsia for permission to publish this paper. Art Saller and Achmad Nurhono were responsible for the KR surface mapping across the basin.

REFERENCES

Berggren, W.A., Kent, V.D., Swisher III, C. C. and Aubrey, M. -P., 1995. A revised Cenozoic geochronology and chronostratigraphy. In: Time scales and global stratigraphic correlation, SEPM special Publication 54 p129-212.

Blow, W.H., 1969. Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. Proc. 1st International conference on planktonic microfossils, Geneva 1967 1, p199-422.

Blow, W.H., 1979. The Cainozoic Globigerinida: a study of the morphology, taxonomy, evolutionary relationships and stratigraphical distribution of some Globigerinida (mainly Globigerinacea), 3 Vols. E.J.Brill, Leiden, 1413 pp.

Decker, John, Teas, Philip A., Schneider, Rhys D., Saller, Arthur H., and Orange, Daniel L., 2004, Modern deep sea sedimentation in the Makassar Strait: Insights from high-resolution multibeam bathymetry and backscatter, sub-bottom profiles, and USBL-navigated cores. In: Noble, Ron. A., Argenton, Antonio, and Caughey, Charles A. (eds.) Deepwater and Frontier Exploration in Asia & Australasia; Proceedings of the International Geoscience Conference; Indonesian Petroleum Association, p377-388.

Haq, B.U., Hardenbol, 5., Vail, P.R. and Baum, G.R., 1988. Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. In: Wilgus, C.K.

Hastings, B.S., Posamentier, H and Van Wagoner, 5. (Eds), Sea Level Change: an integrated approach. Society of Economic Palaeontologists and Mineralogists special Publication 42, p71-108.

Martini, E., 1971. Standard Tertiary and Quaternary nannofossil zonations. In: Farinacci, A. (ed) Proceedings II Planktonic Conference, Roma, 1970, p739-785

Morley, R.J., 1996, Biostratigraphic characterisation of systems tracts in Tertiary sedimentary basins, Proc. International Symposium on Sequence Stratigraphy in SE Asia, IPA Jakarta 1996, p49-71.

Morley, R.J., and Rosen, R.S., 1996, High resolution biostratigraphic zonation for the offshore Niger Delta region, IX International Palynology Congress, Houston, June 1996, (Abstract).

Morley, R.J., 2000, Origin and Evolution of Tropical Rain Forests, Wiley & Sons, London, 362pp.

Morley, R.J., Morley, H.P. and Restrepo-Pace, P. 2003. Unravelling the tectonically controlled stratigraphy of the West Natuna Basin by means of palaeo-derived Mid Tertiary climate changes. Proceedings of 29th IPA Convention, Jakarta 2003, v1, p561-584

Morley, R.J., and Morley, H.P., Wonders, A.A.H.W., Sukarno and Van Der Kaars, S., 2004, Biostratigraphy of Modern (Holocene and Late

Pleistocene) Sediment Cores from Makassar Straits, Proceedings of IPA Deepwater and Frontier Exploration in Asia & Australasia Symposium, Jakarta, December 2004.

Okada, H. and Bukry, D., 1980. Supplementary modification and introduction of code numbers to the low latitude coccolith zonation (Bukry 1973; 1975). Marine Micropalaeontology 5 (3) p321-325.

Perch-Nielsen, K., 1985. Cenozoic calcareous nannofossils. In : Bolli, H.M., Saunders, J.B. and Perch-Nielsen, K. Plankton Stratigraphy I p427-554. Cambridge University Press.

Wei, W., 2003. Upper Miocene nannofossil biostratigraphy and taxonomy of Exxon core CH30-43-2 from the Gulf of Mexico. Journal of Nannoplankton Research, 25, p17-23.

Young, J.R. 1998. Neogene. In Bown, P. (ed), Calcareous nannofossil biostratigraphy, pp 255-266. British Micropalaeontological Society Publications series, Kluwer Academic Publishers.

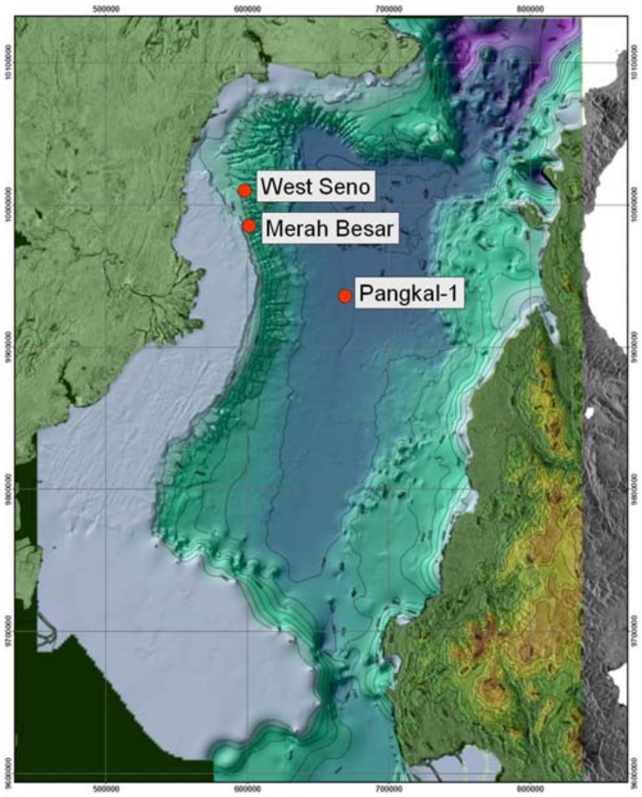

Figure 1 - Makassar Straits location map (from Decker et al 2004).

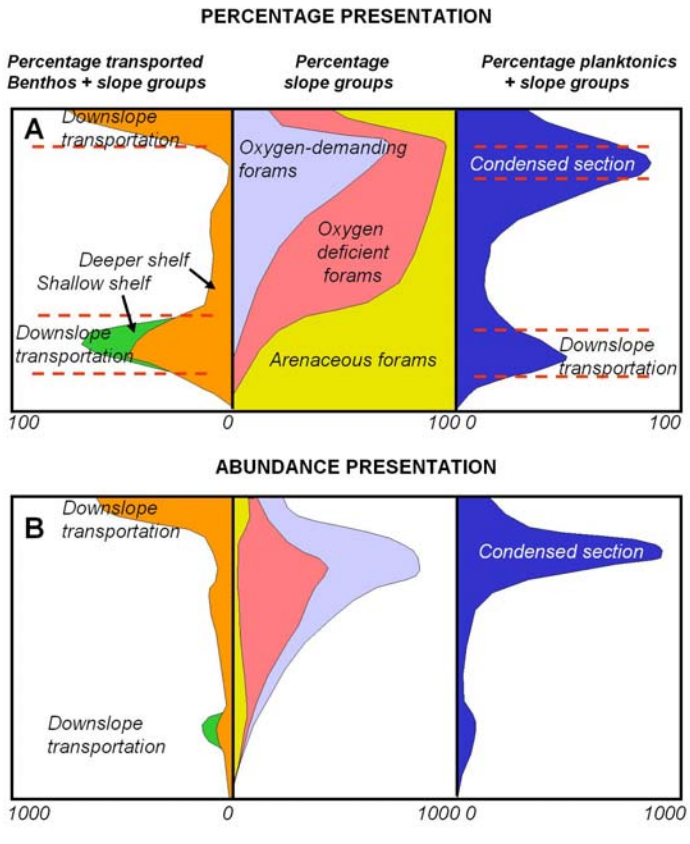

Figure 2 - Scheme for differentiation of systems tracts in slope and basin floor settings through the statistical analysis of foraminiferal assemblages.

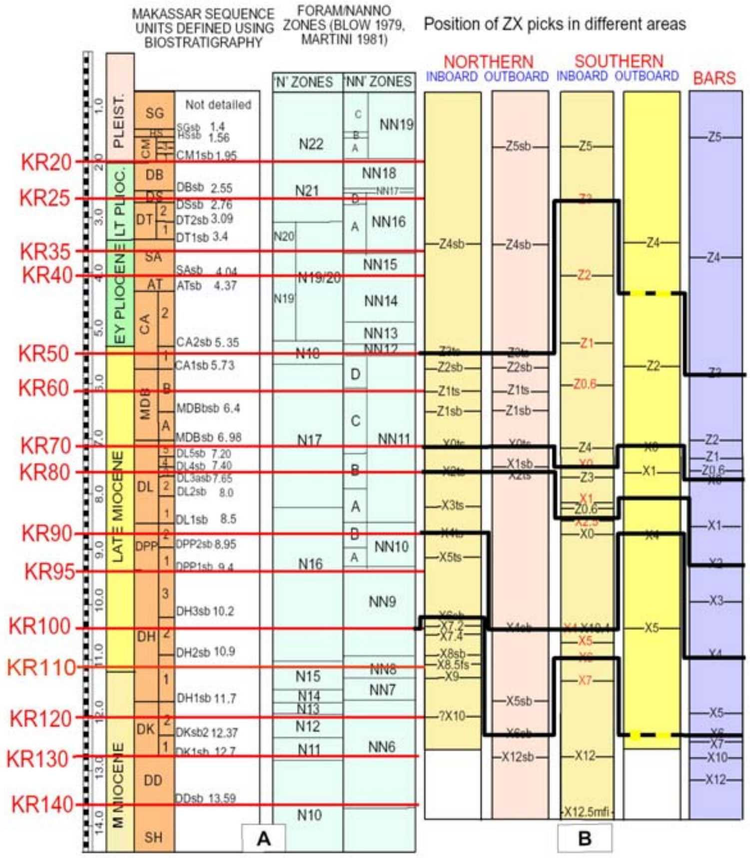

Figure 3 - A Sequence biostratigraphic succession for the Kutei Basin and correlation with N and NN zones; 3B chronostratigraphic position of major seismic horizons prior to this evaluation.

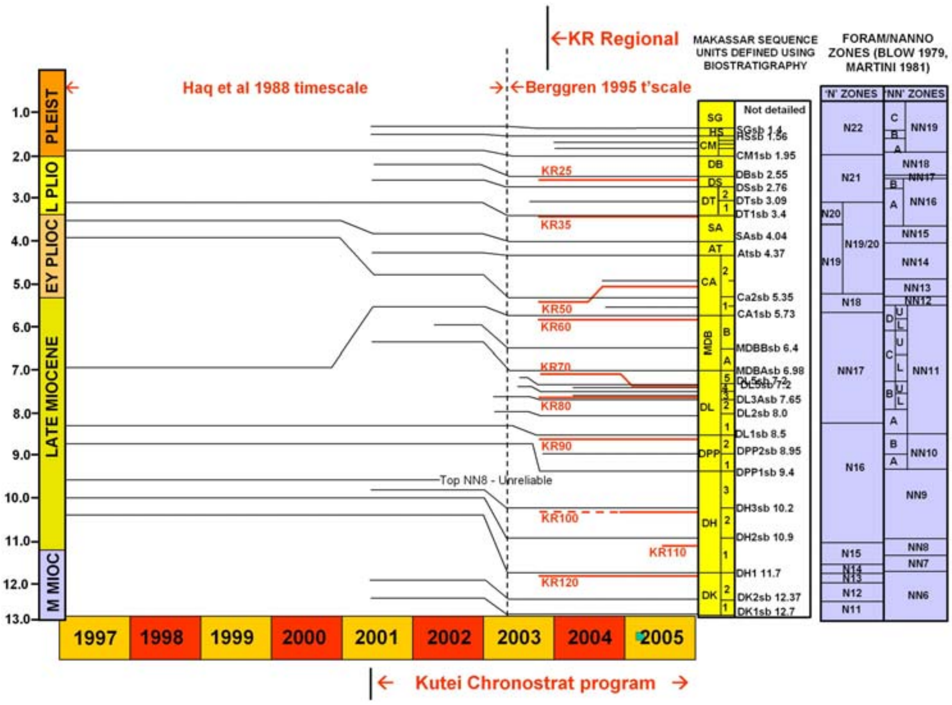

Figure 4 - Increasing stratigraphic resolution with ongoing Kutei chronostrat program. The sequence biostratigraphic scheme was introduced mid 2001, the timescale used was changed from Haq et al 1988 to Berggren et al 1995 in early 2003, KR regional markers were introduced late 2003.