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HYDROCARBON HABITAT OF THE N.W. PALAWAN BASIN, PHILIPPINES

D.M. Branson*
P.J. Newman*
M. Scherer*
P.J. Stalder*
R.G. Villafuerte*

ABSTRACT

The N.W. Palawan Basin is located offshore Palawan Island, Philippines, in water depths ranging from less than 100m to in excess of 1000m. Exploration of the basin commenced in the 1970's with the drilling of build-ups of the Nido Limestone Formation located in the shallow water Nido Shelf part of the basin. This initial exploration phase resulted in a number of small oil discoveries (e.g. Nido, Matinloc) which have since been produced. In contrast to the oil-prone Nido Shelf, exploration wells in deeper water to the west of the Nido Shelf (1982-1994) have discovered mostly gas, notably in the Malampaya/Camago accumulation which is estimated to contain 3.4 Tcf gas. With the exception of Malampaya/Camago, exploration results away from the Nido Shelf have been disappointing and have resulted in few potentially economic discoveries.

Few source rocks have been penetrated in the basin. In the absence of source rock samples, oil geochemistry has been used to deduce source rock types. Typing of oils in the N.W. Palawan Basin based on biomarkers, sulphur content and carbon isotopes has identified three separate oil families. The majority of hydrocarbons encountered appear to have been derived from a carbonate or marl source rock deposited in a marine environment. Ages of the source rocks are estimated to be Eocene to Lower Miocene. It is interpreted that source rocks have been deposited within restricted rift half grabens and/or isolated restricted intrashelf basins in the Post-Rift carbonate sequence which overlies the grabens.

Within the area of Malampaya/Camago charge is derived primarily from a deep half graben located between the accumulation and the Nido Shelf to the east. Estimates of thermal maturity suggest that source rocks in this graben are mature for both oil and gas. Geometry of seismic events in this graben suggests that migration from shallower (more oil-prone) intervals is predominantly towards the Nido Shelf to the east, whilst migration from deeper (more gas prone) intervals is mostly westwards towards Malampaya/Camago, providing a possible explanation for the oil vs. gas discovery pattern made in the area.

INTRODUCTION

The N.W. Palawan Basin, Philippines, is located offshore Palawan Island, Philippines, in water depths ranging from less than 100m to in excess of 2000m (Fig. 1).

Of the 51 exploration wells drilled in the basin to date, 13 have discovered commercial or potentially commercial accumulations, whilst a further 13 wells have encountered non-commercial accumulations. Initial exploration drilling in the late 1970's and early 1980's along the inboard Nido Shelf, where water depth is less than 100m, resulted in the discovery of a number of oil accumulations in build-ups of the Nido Limestone Formation. Whilst the majority of these accumulations have limited remaining potential, the Matinloc and Nido complexes are still being produced cyclically and have produced a cumulative total of 11 MMbbl over a 15 year period and 17 MMbbl in 18 years respectively.

Following a lull in activity during the mid 1980's,

* Shell - Philippines

exploration has focused on the outboard section of the basin. To date, drilling results away from the Nido Shelf have been generally disappointing and have resulted in few potentially economic discoveries (e.g. West Linapacan A). In contrast to the oil-prone Nido Shelf, exploration wells in Shell/Occidental Service Contract 38 (SC38) have discovered mostly gas, notably in the Malampaya/Camago accumulation (Figs. 2, 3) which is currently estimated to contain recoverable reserves of 3.4 Tcf. The feasibility of obtaining commercial production from the 65m oil rim in the field is currently under investigation.

GEOLOGICAL SETTING & STRATIGRAPHY

The N.W. Palawan Basin is located upon the North Palawan Block which has been interpreted by Holloway (1982) as a continental fragment which rifted away from southern China during the opening of the South China Sea (Fig. 4). Rifting during Palaeocene-Eocene times resulted in a northeast-southwest structural grain which is evident throughout SC38 and N.W. Palawan (Fig. 5). Rift faults are commonly offset by northwest-southeast trending transform faults.

A number of compressive phases have overprinted the extensional structures created during rifting. During Early to Middle Miocene times collision of the North Palawan Block with the Cagayan Ridge resulted in the transpressional reactivation of rift faults and the commencement of uplift of Palawan Island. This uplift intensified during docking of the North Palawan Block with the Philippine Island Arc system. As a consequence of these compressional phases, parts of the N.W. Palawan Basin have been uplifted by in excess of 1000m, and wrench-induced 'pop-up' features are common adjacent to major rift transforms.

The stratigraphy of the Pre-Rift section in the N.W. Palawan Basin is highly variable with Palaeozoic and Mesozoic carbonates and clastics, metamorphic and igneous rocks having been encountered. It is currently interpreted that N.W. Palawan was located in a relatively distal position such that rifting occurred in a predominantly marine environment. Recent evidence from Malampaya/Camago indicates the oldest section of the Nido Limestone Formation to have an Eocene age and to be a Syn-Rift sequence (Fig. 6). Incipient Syn-Rift highs are interpreted to have been the site of shallow marine carbonate deposition whilst open marine conditions prevailed in Rift half-grabens.

A major Intra-Oligocene ("break-up") unconformity, which can be recognised throughout SC38 and much of N.W. Palawan, marks the onset of stabilised drifting. Well data, supported by seismic facies analysis indicate that during the Post-Rift phase the main areas where shallow marine carbonates of the Nido Limestone Formation continued to be deposited became increasingly restricted along fault block crests. Outside of these areas, deposition was predominantly in deeper marine conditions and is characterised by the pelagic marls, calcareous siltstones and fine-grained sandstones of the Linapacan Formation. Thin calcarenite beds and carbonate conglomerates are indicative of episodic turbidite deposition.

An abrupt sea-level rise at the Oligocene/Miocene boundary reduced the influence of carbonate sedimentation and resulted in the vertical aggradation of the main build-ups such as Malampaya/Camago, and the deposition of the laterally equivalent deep marine Pagasa Formation.

HYDROCARBON HABITAT

Source Rocks

Despite numerous hydrocarbon occurrences in the N.W. Palawan Basin, source rocks have been rarely penetrated. With little information on source rock distribution, thickness and maturity, access to hydrocarbon charge and oil/gas mix have represented a major uncertainty in the evaluation of exploration prospects in the basin.

In an attempt to constrain charge predictions, Shell Research analysed 20 oil samples and 6 gas samples and demonstrated the existence of three distinct oil families based on differences in carbon isotope ratios, sulphur content, pristane/phytane ratios, and the saturate/aromatic fraction. In contrast to an interpretation of Williams et al. (1992), which suggested that source rocks for the Palawan oils were deposited in lacustrine conditions, the presence in all samples of minor amounts of propylcholestane biomarkers (produced by the action of marine algae) and high sulphur contents strongly suggest that source rocks have been deposited in a marine environment. However, the abundant presence of angiosperm derived biomarkers in all studied oils indicates a

strong land-plant imprint, and that their sources are of Tertiary age. Variations in carbon isotope composition of the oil families have been used to constrain ages of the related source rocks.

Characteristics of the three identified oil families (which are labelled according to their interpreted age and lithology) are summarised in Table 1.

The majority of oil accumulations in the N.W. Palawan Basin are interpreted to have been derived from a source rock deposited in a marine environment of Late Oligocene age developed in either a carbonate or marl facies (28C and 28M oil families, Fig. 7), with some land-plant derived contributions.

The strong carbonate signature of the 28C source rock is interpreted to be related to the increase in carbonate production following the termination of rifting in the N.W. Palawan area, with source rock deposition located in isolated deeper water restricted intra-shelf basins which separated the main areas of shallow water carbonate deposition, as described by Fulthorpe and Schlanger (1989). In support of this interpretation, well Linapacan A-1A has encountered potential source intervals within the Late Oligocene Linapacan Formation, with Total Organic Carbon values of up to 7.5% recorded.

The 28M marly source rock, which forms the source for the oil in Malampaya/Camago and the majority of oil accumulations on the Nido Shelf, is interpreted to be slightly older that the 28C source, and to have been deposited in restricted early Oligocene Syn-Rift half-grabens.

Oil from the older Palaeocene/Eocene 45S oil family, which is interpreted based on pristane/phytane ratios to have been deposited in a shaley facies, has only been encountered in the Octon. and Calauit discoveries. Artificial maturation experiments also indicate the possibility that Malampaya/Camago has a component from the 45S source in addition to the younger source intervals.

Hydrocarbon Kitchens and Migration

The interpretation that source rocks for the hydrocarbon accumulations in N.W. Palawan are developed within Syn-Rift half grabens and isolated restricted basins in the immediate Post-Rift carbonate depositional system allows potential kitchen areas to be defined on the basis of isopachs of the Syn-Rift and Post-Rift Linapacan sections. On the basis of the distribution of hydrocarbon occurrences a cut-off in interval thickness has been applied to define potential kitchen areas with source rocks assumed to have been deposited only in the thicker intervals. An additional constraint in the determination of potential kitchen areas is the degree of restriction suggested by the isopachs, with kitchen areas most likely to be developed in areas where isopachs indicate the liklihood of a closed basin having been present.

On this basis, the main kitchen area for N.W. Palawan, including Malampaya/Camago, is interpreted to be developed in, and to directly overlie, a major Syn-Rift half-graben which extends from the Nido area in the south to Calauit in the north (Fig. 7), and separates the Malampaya/Camago trend from the Nido Shelf to the east.

In order to estimate thermal maturities of source rocks within this half-graben, a simple, empirically derived relationship between overburden thickness and measured Vitrinite Reflectance has been derived. The reliability of this relationship has been verified by time/temperature trends. Maturities estimated in this manner are supported by well results with the potential source interval mature for predominantly gas generation in the area of Malampaya/Camago. Elsewhere, the half-graben is mature for oil generation only, notably adjacent to the Nido, West Linapacan and Galoc oil discoveries.

Furthermore, the geometry of seismic events within the half-graben indicates that migration at the base of the potential source interval (i.e. from the most mature source rocks) is predominantly towards the Malampaya/Camago Trend to the west, whereas migration at the top of the interval is practically all to the east (Fig. 2). It can therefore be proposed that migration from the least mature, more oil-prone source intervals is towards the Nido Shelf area where well results indicate predominantly oil. By contrast, migration of gas from more mature source rocks towards the west may have flushed any oil which migrated in this direction such that the majority of the outboard Malampaya/Camago Trend is interpreted to be gas-prone.

Reservoirs

The Nido Limestone Formation and Linapacan Formation are the shallow marine and deeper water time equivalent sequences of a widespread Eocene-Miocene carbonate depositional system. Consequently, a range of depositional environments and lithofacies are present in the N.W. Palawan Basin.

Inner Shelf foraminiferal and red algal dominated packstones and grainstones which characterise Nido build-ups have the best reservoir potential with porosities commonly averaging 15-20%. Porosities are considerably higher on the Malampaya/Camago trend (mean 22%) than on the Nido Shelf (mean 13%). Eocene-Early Oligocene mud-supported platform carbonates, deposited in an open marine environment, have a considerably lower porosity (4-11%) in Malampaya/Camago.

The Linapacan Formation comprises Slope and Deep Marine components of the carbonate system and is characterised by marls, siltstones and fine-grained sandstones with calciturbidite deposition adjacent to shallow water areas. Porosities commonly average around 6%, whilst core data indicate that background pelagic sedimentation within the Linapacan Formation comprises waste zones with permeabilities in the order of 0.01mD.

Not unexpectedly, diagenesis, notably recrystallisation, cementation and leaching, plays an important role in the porosity development of the Nido Limestone and the Linapacan Formation. A number of diagenetic phases have been observed to have modified the initial Nido reservoir in Malampaya/Camago. During deposition of the reservoir, marine calcite cementation led to a significant reduction in porosity in open marine lithofacies. In contrast, protected lagoonal environments, where marine and meteoric waters mixed, experienced early leaching which generated biomouldic porosity. Subsequent meteoric calcite cementation is interpreted to be related to periods of subaerial exposure during relative lowering of sealevel. Finally, extensive burial fracturing of the build-up has resulted in additional leaching and the creation of poorly connected mouldic porosity. Well data clearly show the influence of depositional environment on early diagenetic events which, in turn, determine reservoir potential.

Retention

Seal for Nido Limestone prospects is commonly provided by pelagic shales of the Pagasa Formation which have a considerable thickness in the N.W. Palawan Basin. However, the failure to encounter significant hydrocarbons in a number of prospects can be demonstrated to be due to the fact that the carbonate reservoir section is in contact, at or near the structural culmination, with coarse clastic (turbiditic) non-sealing sequences which act as thief-beds. Retention is therefore at risk in such situations where such thief-beds have lateral continuity. However, coarser clastics abut the Malampaya/Camago reservoir, yet the seal for the accumulation has remained intact.

CONCLUSIONS

In contrast to early exploration successes in the N.W. Palawan Basin which discovered primarily small oil accumulations along the inboard Nido Shelf, exploration of the deeper water Malampaya/Camago trend indicates that substantial gas reserves are also present in the N.W. Palawan Basin. A detailed geochemical analysis of oil and gas samples, supported by regional geological interpretation, suggests that source rocks for the majority of hydrocarbons encountered in the Basin to date have been deposited in a marine environment, either in a carbonate or marl facies within Syn-Rift half-grabens, or in isolated restricted intra-shelf basins in the Post-Rift sequence (Fig. 8).

The main interpreted hydrocarbon kitchen half-graben in N.W. Palawan is mostly mature for oil generation, with gas generation restricted to the area of Malampaya/Camago. Whereas the oil accumulations of the Nido Shelf and the gas in Malampaya/Camago are interpreted to be derived from the same half-graben, geometry of seismic events in the half-graben suggests that the difference in hydrocarbon type may be related to differential migration of the different maturity products.

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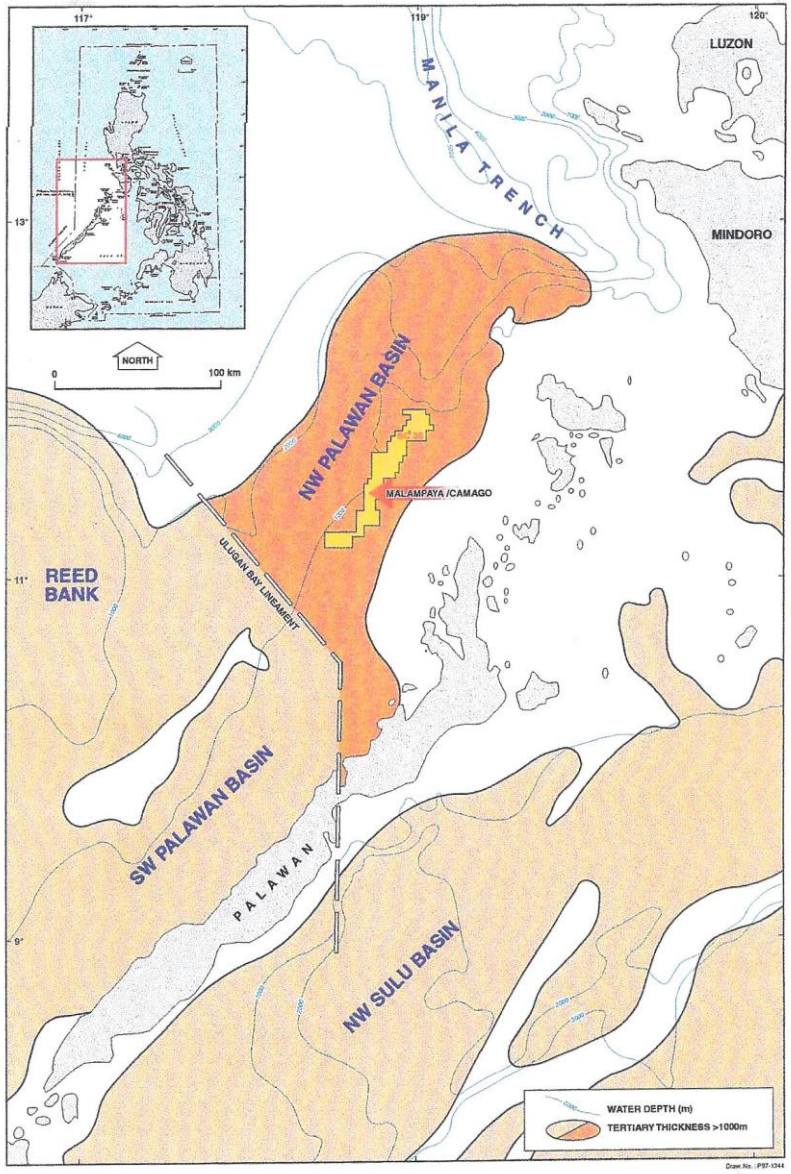

FIGURE 1 - N.W. Palawan Basin Location Map

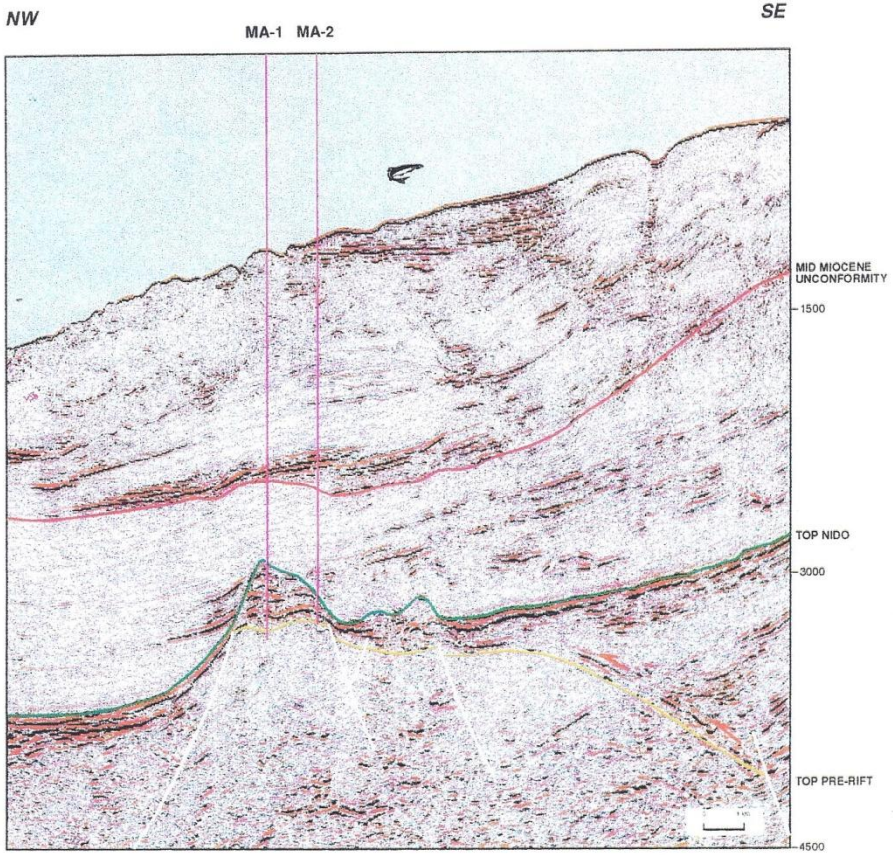

FIGURE 2 - 2D Seismic Line through Malampaya/Camago. Gas charge for the accumulation is interpreted to be derived from the deeper part of the half-graben to the SE of the accumulation (←).

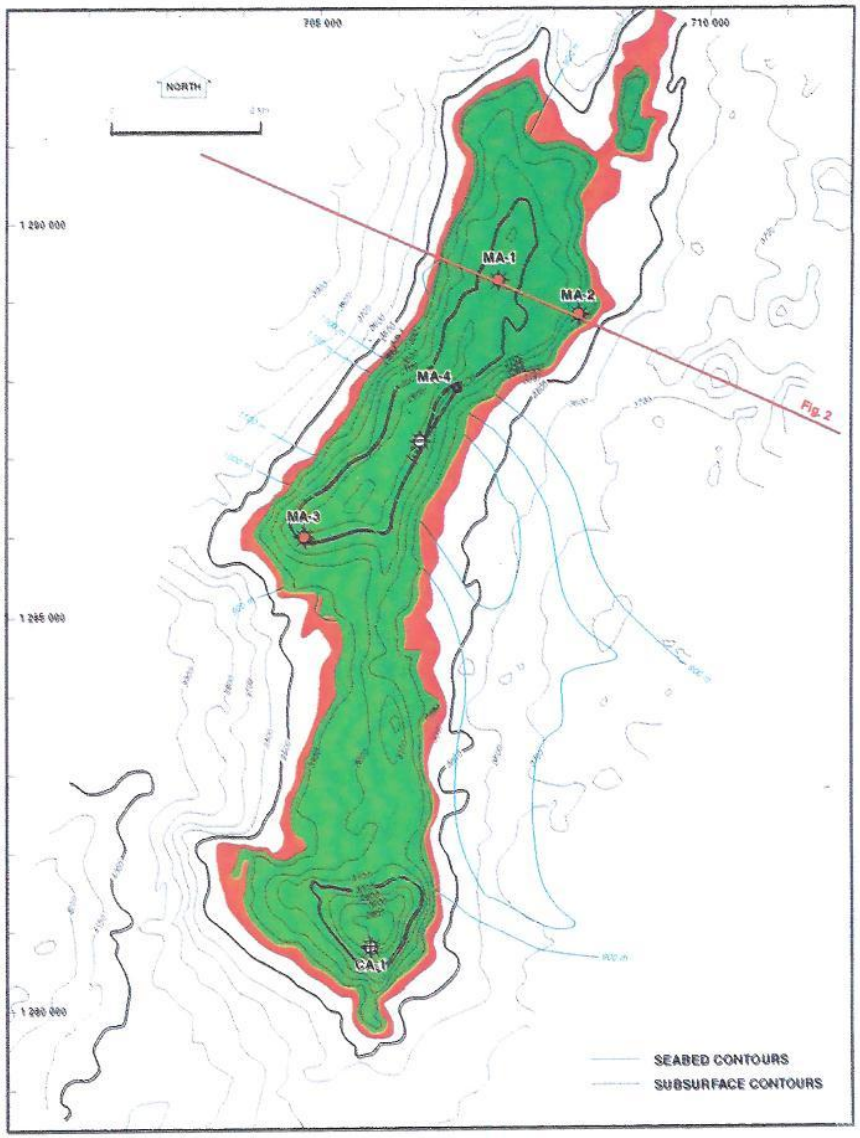

FIGURE 3 - Malampaya/Camago, Depth to Top Nido Limestone Formation based on 3D PSDM data set

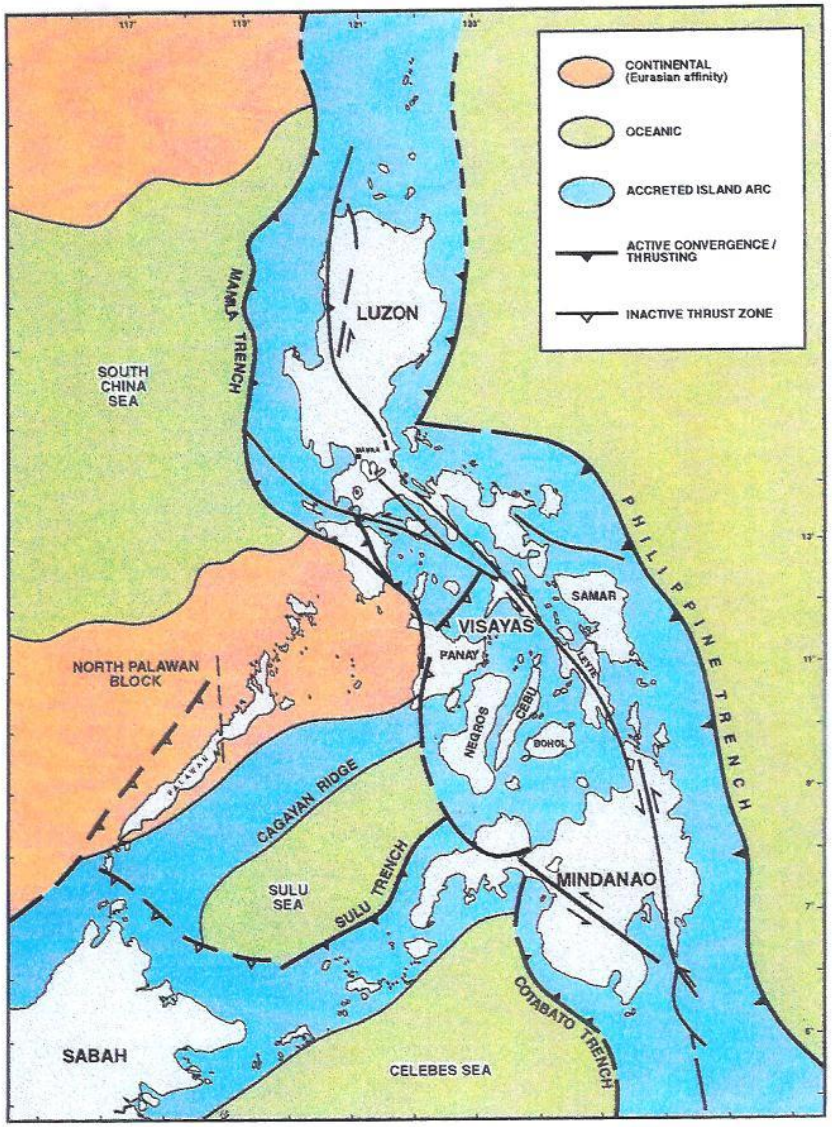

FIGURE 4 - Philippines Simplified Crustal Elements

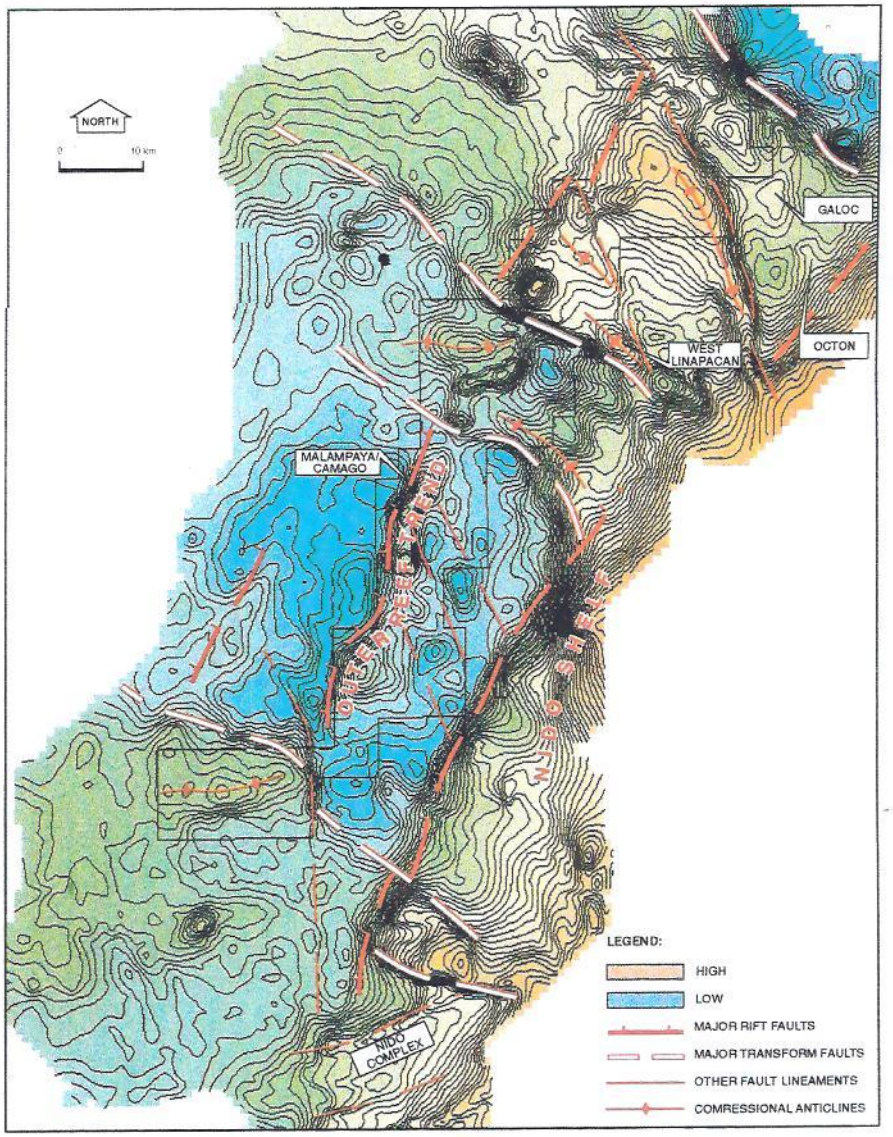

FIGURE 5 - Block SC38, Structural Elements at Top Nido Limestone. Note NE-SW rift trends and NW-SE transform faults.

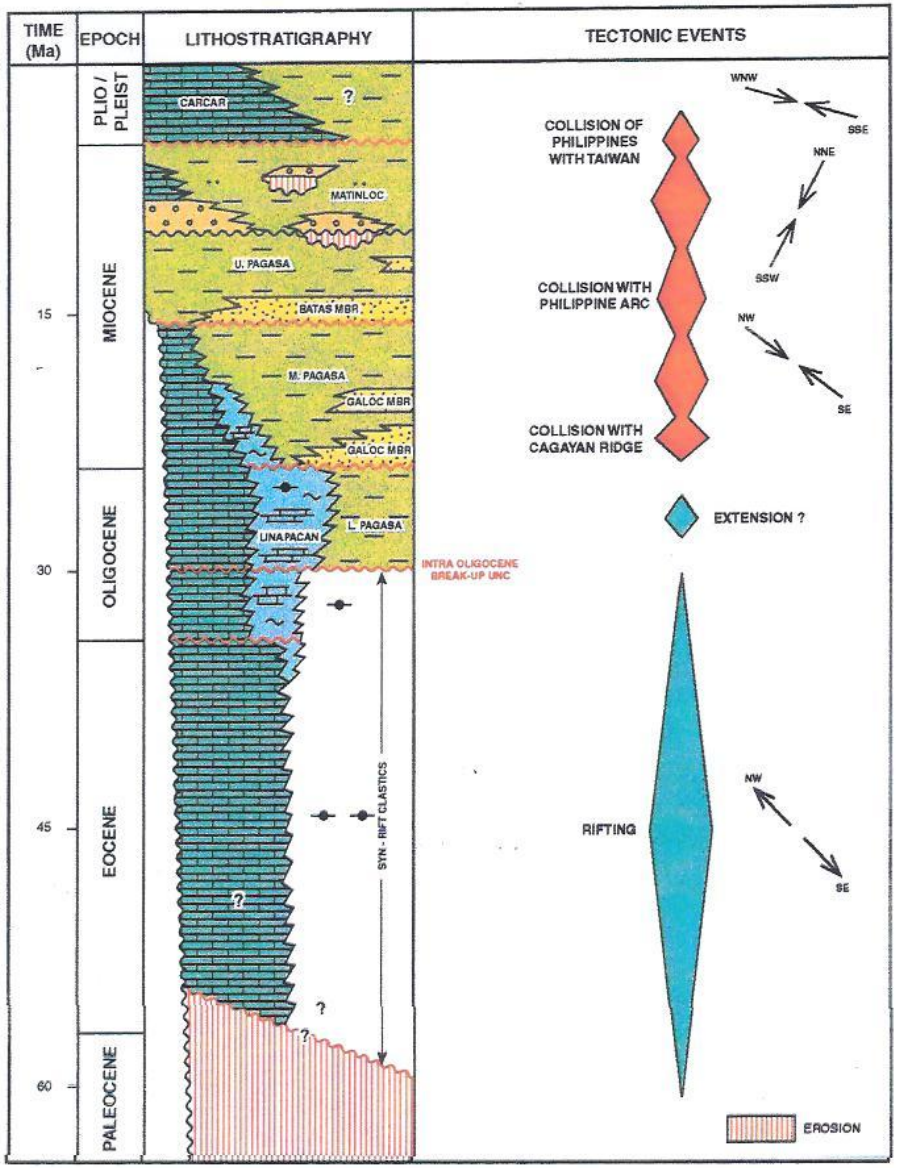

FIGURE 6 - N.W. Palawan Basin Tertiary Lithostratigraphic Column