Lithofacies characteristics and depositional processes in fore-arc basin of Andaman deep water - A case history.

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Keywords

Turbidite, Wackestone, Petrography, SEM and XRD.

Summary

The present work is an integrated and comprehensive approach to bring out the new laboratory studies carried out on the latest drilled deep water well ANDW#F in the fore-arc area of Andaman basin. It has nicely brought out the deep water reservoir facies, depositional environment and processes involved like deep water turbidite and debris flow etc.

Introduction

Andaman Basin is a part of Island Arc System where exploratory drilling for hydrocarbons started during the year 1980 with the well AN-a (DD 3734m) in the fore-arch basin. Exploratory drilling of NELP Blocks in the deep water started under the ANDWN-series and so far 07 deep water wells have been completed. The well ANDW# F (Fig. 1) was drilled in the fore-arc area of Andaman Basin in NELP Block AN-DWN-2003/1 and located further south of the deep wells ANDW-A, B, C, D and drilled to a depth of 4922m (Uppal et al. 2014). Integrated sedimentological and biostratigraphic studies have been carried out to know the lithofacies, reservoir characteristics, age and paleo-environment of the Tertiary sediments.

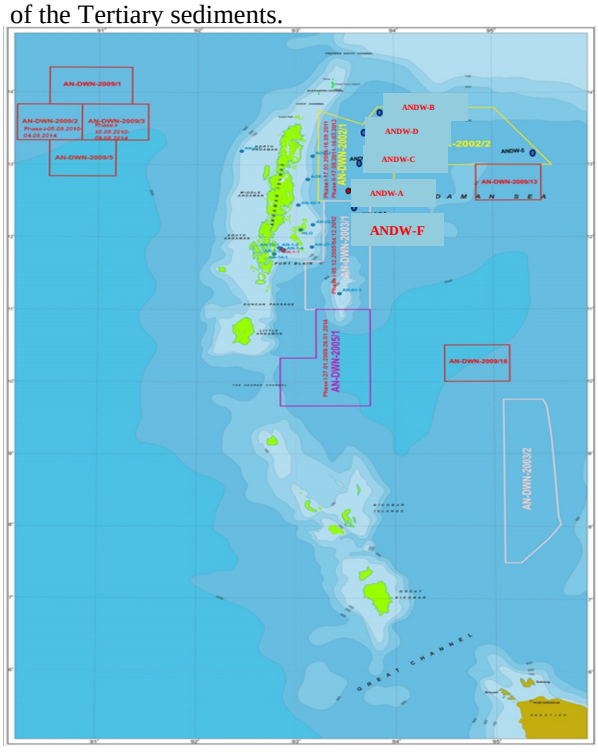

Fig.1:Location Map in study area showing drilled wells

Based on the integrated sedimentological studies, and Biostratigraphic studies, broadly four litho-units ranging in age from Early Pliocene to Early Miocene (Blow, W H, 1969, Jenkins, D.G. and Murray, J.W. 1989 and Kennett, J.P. and Srinivasan. 1983) have been identified mainly consisting of marlstone, limestone, sandstone with minor claystone and altered basalt.

The lithofacies of the upper unit is mainly represented by marlstone, sandstone interlaminations with minor claystone. The sand-marl-claystone sequences, like massive graded very fine sandstone, laminated marl-claystone indicates as fine-grained turbidities and bottom current re-working of these sediments. The fine grained sandstone in this turbidite sequence can act as a good reservoir. The limestone is mainly wackestone to foram-algal wackestone (Maurice E. Tucker, 2001) having few larger forams and algae embedded in micritic ground mass which at places is sparitized and selectively dolomitized giving rise to secondary porosity are seems to be deposited in inner to outer shelf environment and can act as a promising reservoir rock. Minor altered basalt are also observed (Mackenzie W. S. at el. 1998).

General Geology and tectonic set up of the basin

The Andaman-Nicobar basin, located in the southeastern part of the Bay of Bengal, occupies an area of 47,000 sq. km including deep waters. This basin forms a part of Island Arc System which extends from Myanmar in the north to Indonesia in the south (Fig.2a). The Andaman-Nicobar basin represents a typical Island arc system. The basin came into existence as a result of the northward movement and anticlockwise rotation of the Island Plate and its under thrusting under the Asian plate in the Cretaceous time. As subduction progressed, the Outer High Arc complex started rising steeply,

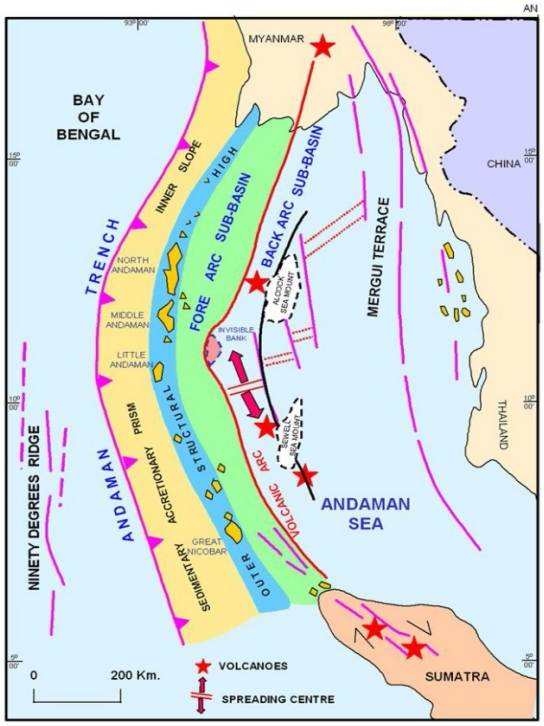

Fig.2A:Tectonic Map of the Andaman Basin
(Source DGH)

thereby creating a depression or a Fore Arc basin between Volcanic Arc and the Outer High Arc. Continued thrusting caused uplift and formation of the Andaman Nicobar Ridge as a chain of Islands. The Andaman chain of islands forms a part of geotectonic regime; "The Great Indonesian Island Arc System" of the East Indies and it extends upto Burmese Arc i.e. Arakan Yoma fold belt. It is more than 5000 km in length.

The Andaman-Nicobar Basin has evolved through a complex history of tectonics associated with the convergent plate boundaries between Indian plate and west Burmese plate. The Andaman-Nicobar basin was initiated with northward drift of Indian Plate with respect to Asia. The collision of Indian/Eurasian plates initiated along the irregular boundary and occurred at the same time as the oceanic subduction beneath the southern Eurasia. The continental collision slowed down the oceanic spreading rates in the Indian Ocean and slowed down the subduction velocity along the Sunda Arc system. It resulted in a phase of extension in the adjacent Fore-Arc and Back-Arc areas (Fig.2b).

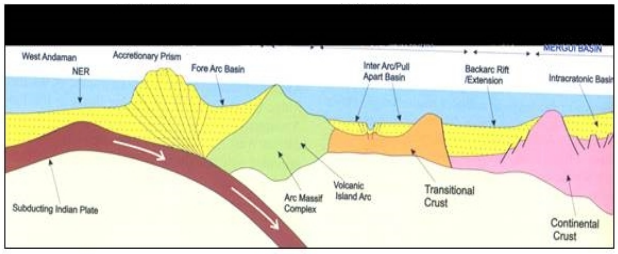

Fig.2B: Schematic Diagram from West to East showing the different tectonic elements of Andaman Subduction Complex.

Methodology

Megascopic and thin section petrographic studies were carried out to identify and infer microfacies, mineral association and type of matrix/cement. SEM/XRD analysis of representative samples from the reservoir facies were carried out to understand reservoir properties, associated clay in pore spaces and mineralogy.

Case studies

Based on lithofacies analysis of sediments encountered in the well ANDW-F, four units (Unit I to IV) have been identified and detail of each unit is discussed below.

Unit-I (2915-3265m)

Early Pliocene age has been assigned to this unit on the basis of *Globorotalia plesiotumida* and *Sphaeroidinellopsis paenedehiscens*. Based on the log signature and litho-association this section represented as fine-grained turbidities (Fig.3) and is further subdivided into three litho-units i.e., upper, middle and lower units.

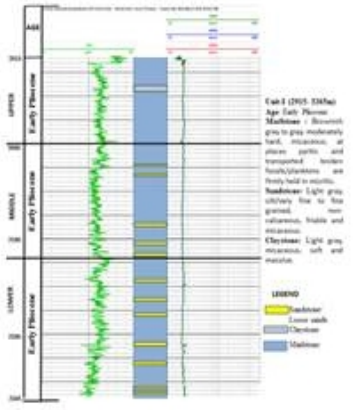

Fig.3: Log signature showing (serrated pattern) typical fine grained tubidite sequence.

Upper Unit (2915-3000m)

The lithofacies in this unit mainly consists of marlstone with minor claystone. The marlstone is brownish gray to gray, moderately hard, micaceous and pyritic at places. Broken fossils/planktons are observed in micritic matrix which appears to be transported in nature. Claystone is light gray, micaceous, soft and massive.

Petrographically, marlstone consists of micrite lime mud matrix, broken smaller forams and detrital quartz (Figs.4A).

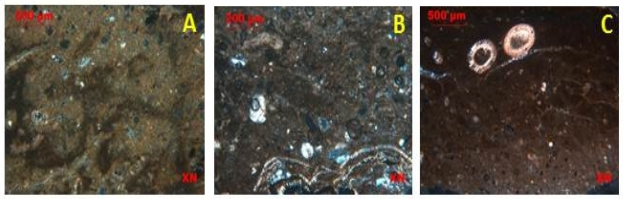

Fig.4: Photomicrographs Marlstone showing broken smaller forams, detrital quartz, wavy laminations (A), broken unidentified fossils, planktons with rim structure (B) and radiating spartized rims arround the planktons and lime mud matrix (C).

Middle Unit (3000-3120m)

This unit is mainly consisting of marlstone with minor intercalation of sandstone. The marlstone is brownish gray to light gray, micaceous, at places pyritic and occasionally broken fossils are embedded in matrix. Sandstone is light gray, very fine to fine grained, non-calcareous, good visual porosity, friable and micaceous.

Lower Unit (3120-3265m)

Lithologically, the lower unit is represented by marlstone with interlaminated thin sandstone beds. The marlstone is gray to light gray, micaceous, at places pyritic and massive. Sandstone is light gray, very fine to occasionally very coarse grained, non-calcareous, friable and micaceous.

Microfacies study indicates marlstone consisting of broken unidentified fossils, planktons with diagenetically formed rim structure, detrital quartz grains embedded in lime mud/micritic matrix (Fig.4B). XRD analysis shows that marlstone mainly contain clay type as montmorillonite (48.24%), illite (27.73%) and kaolinite (30.43%) (Fig.5).

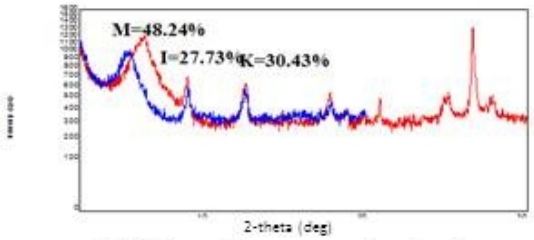

Fig.5: X-ray diffractogram showing clay mineralogy in marlstone

The marlstone/claystone with thin fine grained sandstone lamine could act as good reservoir.

Based on the faunal assemblage, Outer shelf to upper Bathyal environment has been interpreted.

Unit-II (3265-3640m)

The sediments deposited in this unit have been dated as Late Miocene age on the basis of *Neogloboquadrina continuosa*, *Globorotalia merotumida* and *Gl. Paralenguaensis*. The Late Miocene section has further been subdivided into three subunits based on lithology as upper, middle and lower units.

Upper Unit (3265-3350m)

The unit is represented mainly by marlstone with occasional thin bands of sandstone/loose sand. The marlstone is brownish gray to gray, moderately hard, micaceous, at places oozy. Loose sand is coarse to very coarse grained and occasionally of granule size.

Middle Unit (3350-3464m)

This unit is characterized by marlstone with interlaminated sandstone/loose sand bands. Marlstone is gray, moderately hard, micaceous, having tiny clasts of limestone embedded in the matrix as transported debries. Loose sand/sandstone is light gray, silt size to fine grained, at times very coarse to granule sized, non-calcareous.

Thin section studies reveal that marlstone comprises disseminated silt grade quartz, lime mud matrix and diagenitically formed radiating sparitized rims arround the fossils (Fig. 4C).

Lower Unit (3464-3640m)

It is mainly represented by alternations of marlstone, limestone and sandstone with minor claystone. Marlstone is gray, moderately hard, micaceous, with tiny limestone clasts as transported debries. Loose sand/sandstone is light gray, silt size to fine grained, non-calcareous, friable and micaceous. The loose sand is very coarse to granule sized and non-

calcareous. Limestone is white, massive occasionally pyritic. Claystone is light gray, micaceous, soft and massive.

SEM analysis carried out on the selected sample shows tight nature of reservoir with some polymodal quartz grains and isolated matrix porosity (Fig. 6A). Enlarge view indicating alteration of feldspar giving rise to formation of authigenic smectite (Fig. 6B).

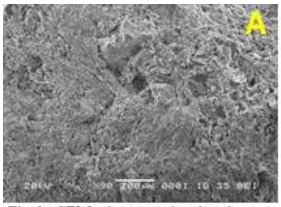

Fig.6 : SEM photographs showing polymodal quartz grains and matrix porosity (moderate reservoir condition)

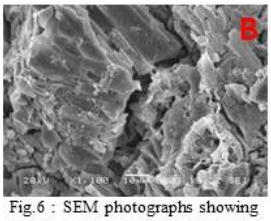

Fig.6 : SEM photographs showing diagenetically formed authigenic smectite clay formed from alternation feldspar.

These finely laminated sandstone of silt size to fine grained as a turbidite sequence can be a reservoir facies.

Based on the faunal assemblage, upper part of the section (3265-3440m) is deposited in upper Bathyal-Middle Bathyal conditions whereas the lower part (3440-3640m) is deposited in outer shelf to upper Bathyal marine condition.

Unit-III (3640-4190m)

This unit has been assigned Middle Miocene age based on the diagnostic fauna *Globorotalia peripheroronda*. Based on the litho-association, the Middle Miocene section is further subdivided into two broad sub-units i.e., upper and lower.

Upper Unit (3640-3948m)

The lithofacies in this unit comprises dominantly marlstone, sandstone/siltstone, limestone along with minor altered basalt. Marlstone is gray, moderately hard, micaceous and massive. Sandstone is light gray, silt to very fine grained, non-calcareous, friable and micaceous. Limestone is milky white, massive, hard with slickenslide surface which might be due to faulting effect. Altered basalt is melanocratic, massive, hard and feebly-calacreous.

Micro-facies study altered Basalt consists of tiny threads of plagioclase and augite (pyroxene) embedded in vocanic clayey ground mass (Fig. 7A).

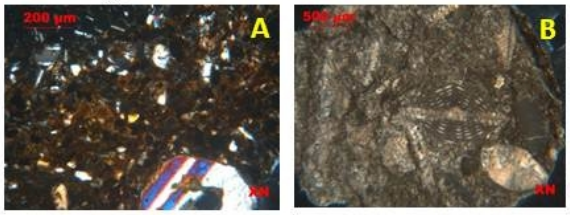

Fig.7: Photomicrographs Altered Basalt exhibiting tiny threads of plagioclase , augite grain (pyroxene) embedded in vocanic clayey ground mass (A) and Foram algal wackestone having larger forams (chambers sparitized), algae amid lime mud/micrite.(B)

Lower Unit (3948-4190m)

The lithofacies in this unit comprises dominantly marlstone with few bands of sandstone/siltstone and minor limestone. Marlstone is gray, moderately hard, micaceous and massive. Limestone is milky white, massive and hard.

Resevoir facies in this unit is sandstone/siltstone laminations as turbidite.

Based on the faunal assemblages, Outer shelf to upper Bathyal condition of deposition has been interpreted.

Unit-IV (4190-4922m)

Unit-IV belongs to Early Miocene age on the basis of *Globorotalia birnageae*, *Gl.* cf. *birnageae*. The Early Miocene section has further been subdivided into two subunits based on lithology i.e., upper, and lower units.

Upper Unit (4190-4758m)

The unit is represented mainly by limestone. Limestone is milky white to off white, massive, hard, at places sparitized and fossiliferous. Two SWC have also been taken which are mainly limestones.

SEM analysis carried out in this unit shows generally tight nature of reservoir, however, at places, moderate intercrystalline and vugy porosity is observed (Fig. 8A).

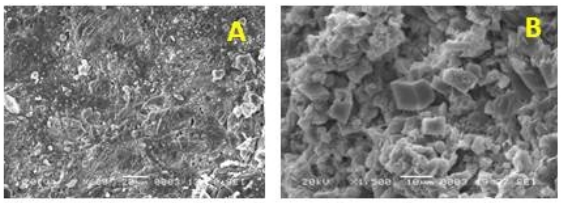

Fig.8: SEM photograph showing intercrystalline porosity and partly vugy porosity (A) and diagenetically formed dolomite crystals creating secondary porosity (B).

Lower Unit (4758-4922m)

Lithologically, this unit is represented by mainly limestone and minor marlstone, loose sand with minor claystone and altered basalt (VRF).

Limestone is milky white to off white, massive, hard, at places sparitized and fossiliferous. Marlstone is gray, moderately hard, micaceous and massive. Loose sand is of medium to coarse grained, occasionally of very fine sized. Claystone is dark gray, soft and massive. Altered basalt is melanocratic, massive and hard. Twenty two SWC have also been taken which mainly comprises limestone, volcanoclastic claystone and volcanic rock fragment (VRF). Microfacies SWC shows that limestones are wackestone to foram algal wackestone deciphering algae emmbedded in micrite/partly sparitized matrix and larger forams at places sparitized (Fig. 7B).

XRD analysis of limestone indicates calcite (74.08%) and dolomite (25.92%) (Fig.9).

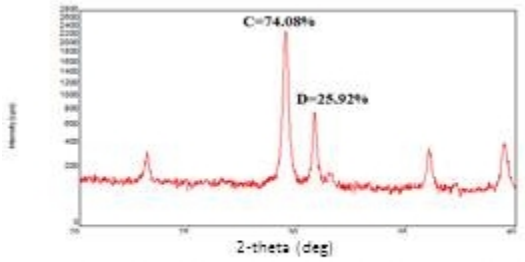

Fig.9: X-ray diffractogram showing bulk mineralogy in limestone

SEM analysis of SWC depicts good reservoir conditions, showing dolomite crystals (rhombs) creating secondary porosity (Fig.8B).

The limestones having intercrystalline and vugy porosity can act as a reservoir facies.

Interval 4590-4922m largely comprises larger and smaller benthic foraminifera and appears to be deposited under gradually shallowing conditions. Within this section foraminiferal bank type facies could be observed in the basal part gradually shallowing to chalky assemblages with similarity to restricted marine circulation between 4710-4830m. *Spiroclypeus ranjanae* is observed at two levels at 4920m and 4870m. Based on the faunal assemblage the upper interval between 4190-4590m is predominantly deposited under outer shelf conditions whereas the section 4590- 4710m may be deposited in middle-outer shelf. Sediments between 4710-4922m are deposited in very shallow marine / inner shelf condition.

CONCLUSIONS:

Based on Biostratigraphic and sedimentological studies, broadly four litho-units ranging in age from Early Pliocene to Early Miocene have been identified mainly consisting of marlstone, limestone, sandstone with minor claystone and altered basalt.

The sediments in the well in the interval 2915-4922m are dated from Early Pliocene to Early Miocene age and are deposited from inner shelf to upper bathyal palaeo-environment. The lithofacies of the upper unit sand-marl-claystone sequences, like massive graded very fine sandstone, laminated marl-claystone indicates as fine-grained turbidities and bottom current re-working of these sediments. The fine grained sandstone in this turbidite sequence can act as a good reservoir.

The overall reservoir facies of this unit in general, is tight, however at places moderate intercrystalline and vugy porosity are observed. These porous carbonate rocks show good reservoir quality.

Foram wacke to packstone and marlstone showing radiating rim cement indicates that diagenitic process have taken place in marine condition. Altered basalts are also noticed.

XRD analysis of clay indicates presence of montmorillonite (48.24%), illite (27.73%) and kaolinite (30.43%). Bulk analysis of limestone contains calcite (74.08%) and dolomite (25.92%).

Way forward: In the fore arc basin good carbonate reservoir rock should be targeted. In case of back arc area Irrawade delta sand should be targated as a promising reservoir rock.

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