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Author **DEBASHIS CHAKRAVORTY , ONGC , India**

Co-Authors **Dr. N. G. Das, Dr. K. K. Bandyopadhyay, C. Chaudhury, Ms. N. Parwin, S. Gangopadhyay & A. K. Seth**

Andaman Accretionary Prism…New Frontier for Hydrocarbon Exploration

Abstract: Accretionary Prisms, throughout the world are often associated with hydrocarbon bearing fields. Andaman Accretionary Prism (AAP) is a structurally complex frontier basin south of producing Myanmar Accretionary Prism which is having over 6 Tcf of gas reserves. Existence of large hydrocarbon reserves in AAP has been a matter of intensive research. The shallow offshore area west of Andaman Island remains largely underexplored with only two exploration wells to date.

Present paper evaluates elements of the petroleum system for the area with the aid of key hydrocarbon indicator i.e. Mud Volcano (MV). Thermogenic hydrocarbon emissions through MVs suggest presence of petroleum source rocks beneath. Revaluation of geological data based on recent geological field investigations and integration of the same with existing geochemical, MV and drilling data has been carried out for identifying areas for future hydrocarbon exploration. δ13C values of gases emitted from MVs of Andaman & Little Andaman Islands indicate Thermogenic origin. 1D Petroleum System Modelling (PSM) studies indicate deepest source rock at a depth below 5 Km during its peak generation at around 15 Ma when all other entrapment conditions were already in place. Being part of the same Island-arc system, located suitably between hydrocarbon producing basins of Myanmar and Sumatra along with oil & gas emitting MVs and oil/gas indication in one of the two wells drilled, makes shallow water west of Andaman Island, an ideal area for future hydrocarbon exploration.

Introduction: Nearly 10% of the world's hydrocarbon discoveries are encountered in Accretionary Prism set up. Prevalence of hydrocarbon generation in Accretionary Prisms is due to constant input of sediments carrying new Organic Carbon into the subduction zone.

Recent deepwater discovery of Shwe Field & Rakhine Basin in Myanmar in the northand gas indications in Sumatra and oil & gas fields in Timor Accretionary Prism in south of Andaman Basin indicate huge hydrocarbon potential in Accretionary Prisms around SE Asia (Fig: 1). Andaman Accretionary Prism located between 6° N and 14° N latitudes in Indian Ocean, formed as a result of the northward oblique subduction of Indian Plate below the Burmese Microplate along the Andaman-Java Trench (Fig: 2). This interaction of

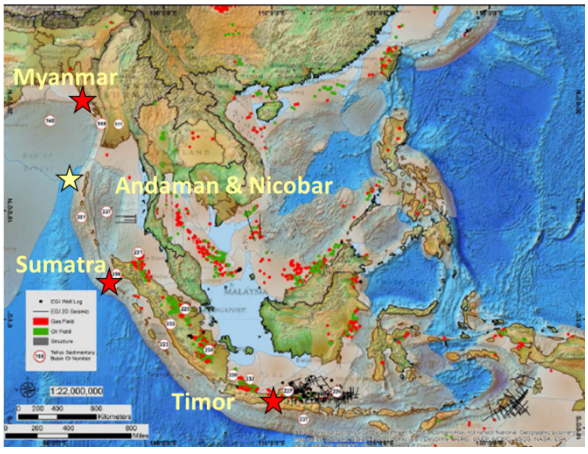


Fig: 1 Hydrocarbon Province of SE Asia

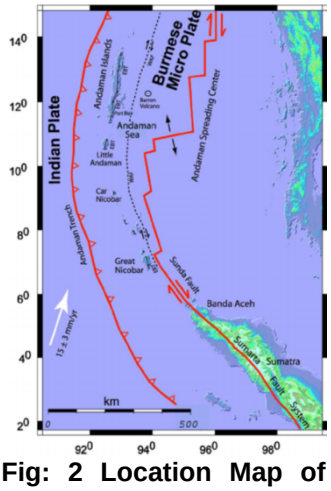


Fig: 2 Location Map of A & N

plates is envisaged to have caused the pre-requisite condition for constant supply of source rocks, adequate maturation & generation and finally migration of hydrocarbon into multiple reservoirs. Primary world-wide hydrocarbon indicator in Accretionary Prism being, existence of numerous aerial & subaerial Mud Volcanoes (MVs). Throughout the world, active thermogenic hydrocarbon emitting MVs are often associated with hydrocarbon occurrences beneath, as observed in Myanmar, Timor, Trinidad & Barbados and many other Accretionary Prisms. As a corollary, a thorough investigation in Andaman Accretionary Prism could reveal large hydrocarbon reserves.

A systematic revaluation of geological data based on recent geological field investigations and integration of the same with existing geochemical, MV and drilling data indicates possible existence of hydrocarbon accumulations in Andaman Accretionary prism area of over 11,000 Km^2 (up to 300m bathymetry).

Tectono-Stratigraphy and Structural Style: Andaman–Nicobar Ridge is an imbricate stack of thrust slices consisting of segments of Late Cretaceous Ophiolite suit with pelagic sediments and Paleogene–Neogene deep and shallow water both siliciclastics and carbonate sediments. The Andaman Island arc continues northward as mountains of Arakan-Yoma and finally abuts against Himalayan arc along Indo-Burma border. Towards south it includes Mentwai Island of Sumatra basin and submarine ridge on the land ward side of Java Trench. Major tectonic elements of Andaman basin from west to east transect are; Andaman-Java Trench, Accretionary Prism, Fore Arc, Magmatic/Volcanic Arc and Back Arc (Fig: 3). A major tectonic element Jarwa Thrust is mapped all along South and Middle Andaman Islands, not exposed in North Andaman, where it probably continues offshore.

The stratigraphy of the Andaman and Nicobar Islands is generally classified into four groups: the Late Cretaceous Ophiolite Group, Cretaceous-Eocene Baratang Formation (with five members), Oligocene Port Blair Formation and Miocene Archipelago Group (Fig: 4).

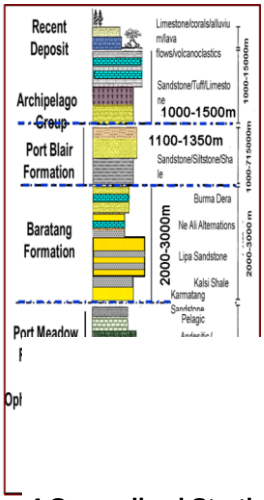


Fig: 3 Tectonic elements of Andaman Basin

Fig: 4 Generalized Stratigraphy

Methodology and Approach: Integration and analysis of enormous field geological data with drilled wells, Mud volcano data and recent geological field input along with Petroleum System Modelling study to assess the hydrocarbon prospectivity of Accretionary Prism for future exploration in present Open Acreage Licensing Policy (OALP) regime.

Exploratory Efforts and Recent Geological Field Work inputs: Geological field work on these Islands was initiated way back in 1840. ONGC & GSI had taken up geological mapping since early sixties, followed by Gravity-Magnetic, Geochemical Sniffer Survey and 2D/3D Seismic. Present study is triggered after two field trips in Islands of Andaman in a span of last 12 months.

Source Rock Potential…….A Re look: Presently, dark grey Kalsi Shale member within Baratang Formation is identified as only source rock based on TOC. However, during recent field trips, similar dark grey shales were observed within other members of Baratang Formation (Fig: 5). Hence, a shale percentage analysis was made for each member. Results indicate 40% & 80% grey shales present in Burma Dera & Neali Alternations respectively (Fig: 6). Organic Carbon % of these shale indicate values in the range of 0.45-1.15, which matches well with TOC range in Prism set up. Other than shales, limestones present at different levels in the Baratang Formation are also envisaged as potential source rock.

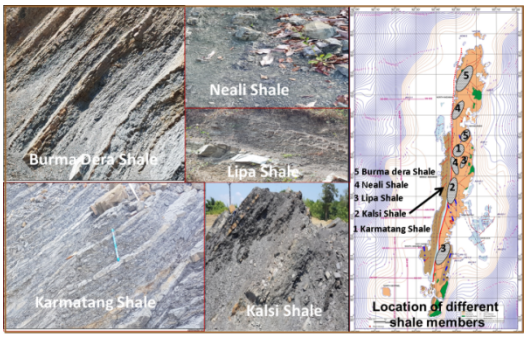


Fig: 5 Location of carbonaceous shale in Baratang Fm

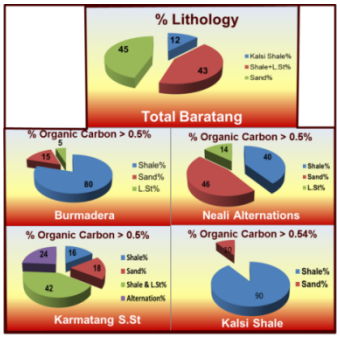
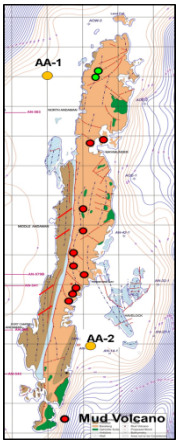


Fig: 6 Carbonaceous shale % in different Members in Baratang Fm

Drilling Results: Out of 21 wells drilled in this basin till date, only two wells fall in Prism set up. Well AA-1, drilled around 4000+ m indicated oil & gas shows during drilling below 3000m from Paleogene section, another well AA-2 drilled east of island produced about 2 lac cubic meter of biogenic gas from Miocene section (Fig: 7).



Studies of shale samples of the well AA-1 indicate; good source rock potential having average organic carbon of 0.62% in Archipelago group between 1300-2200m. Maturation level corresponding to beginning of significant generation of hydrocarbons (R_O=0.5%) is delineated below 4000m in Baratang formation. Ratio of pyritic iron to organic carbon indicates all sediments are inferred to be deposited under transitional to brackish environment. Cross plot of Bitumen Percentage (B %) & Organic Carbon % content indicate Archipelago Group & parts of Baratang has organic matter richness for hydrocarbon generation for Biogenic & Thermogenic gas and oil. Cross plot of Vro & H.I. indicates dominantly Type-III Kerogen (Fig: 8-15).

Fig 7: Location map of Mud Volcanoes & few drilled wells

Presence of Mud Volcano…The key Hydrocarbon Indicator: Global data from 140 onshore Mud Volcanoes (MVs) from 12 countries show, 76% of the gas emitted from MVs is Thermogenic, 20% are mixed & only 4% are Biogenic. More than 21 active MVs have been reported from Andaman, Little Andaman and Car Nicobar Islands since eighteenth century; many subaerial MVs are also envisaged based on limited seismic data on either side of Island (Fig: 16 & 17).

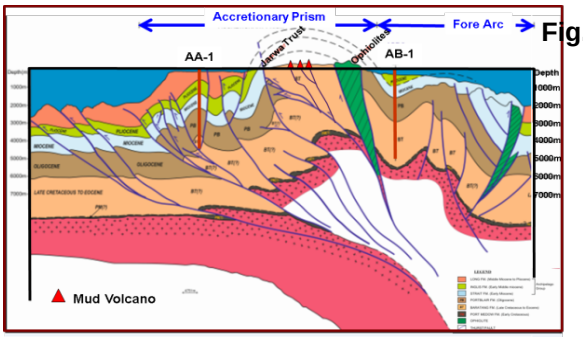


Fig. 16 Seismo-geological section showing well A -1 & MVs

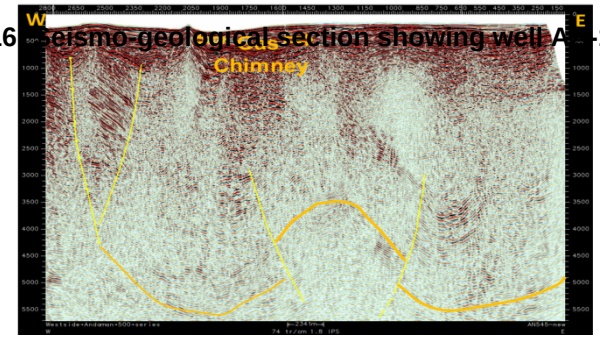


Fig. 17

Geological–Geochemical Peculiarities of Mud Volcanoes

Mud volcanoes are mostly located along the anticlinal crests or fault zones and all hydrocarbon shows are confined to Baratang terrain. Emanating gases contain 90-95% Methane with perceptible traces of Ethane & Propane, 0.4% O2, 1.4% CO2, 3.1% N2. MVs of Middle Andaman are located along N-S & NW-SE fault zones and emit Gas only. MVs of North Andaman emit traces of crude oil along with gas and located along NNE-SSW & NE-SW fault zones. Analyses of MV oil traces indicate, Aromatics 55.7%, Cycloalkane 41%, Alkenes 4.25% & gas having 95% CH_4.

The NE-SW aligned faults are part of the imbricate thrust sheets that dip eastward, parallel to trench axis of the subduction zone. The diapiric ascent of fine sediments pierced through these faults is believed from compressional forces resulting from overthrusting. These faults are envisaged to provide the pathways for the materials in the Accretionary Wedge to come up as mud volcanoes either through diapirism or along newly created faults/conduits. Andaman mud volcanoes eject sediments from the Port Meadow, Baratang & Port Blair formations.

It is observed that MVs along NW-SE faults in Middle Andaman emit gas whereas MVs along NE-SW faults in North Andaman emits oil. The main point of interest remains, area west of Jarwa Thrust is traversed by many NE-SW faults. As most part of the area is inaccessible, presence of oil emitting MVs in the area though highly possible remains a matter of debate

Geochemistry of the Mud Volcanoes: Analysis of elemental and isotope geochemistry of the expelled gas/oil, fluids and mud breccia of MVs spread over North, Middle & Little Andaman is primarily directed towards deciphering the reasons for concentration of oil & gas emission from different locales of MVs, depth of hydrocarbon generation & probable source rocks.

δ13C from Andaman & Little Andaman MVs was found to vary from -41.8 to -48.2 ‰, δ13C of Methane in all samples is >−49‰ confirming Thermogenic origin of MV gases. Ratios of Methane to Ethane + Propane contents (C1 / (C2 + C3)) in MVs of Middle Andaman are much lower compared to that in MVs of North Andaman. Average δ13CCH4 is ~2‰ higher & C1 / (C2 + C3) is much higher (22 times) in the MVs of North Andaman, indicating probable cause of fluid difference (Fig: 18). TOC/N ratio in these samples are well within the range of values found in marine organic matter indicating that the organic matter of mud breccia represents the subducting sediments (Fig: 19). Presence of all four major types of clay minerals suggests that they come from the deep burial diagenetic environment.

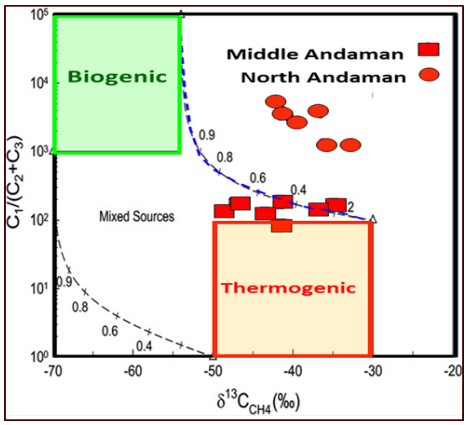


Fig. 18: C1 / (C2 + C3) ratio of MV gases of Middle & N. Andaman

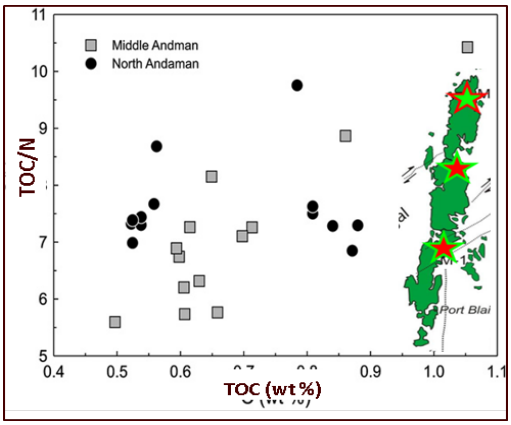
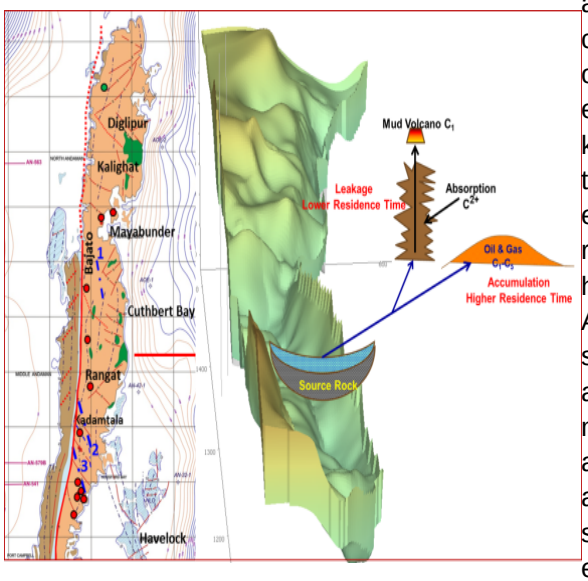


Fig. 19: TOC/N ratio of MV gases of Middle & N. Andaman

The fact that all Smectite and Kaolinite have not fully been converted to Illite and Chlorite, respectively, suggests that the region from which mud breccia has been extracted has a temperature in the range of 70 to 95 °C. Such temperatures would correspond to a depth range of 3.0 km to 4.7 km, considering average geothermal gradient of 1.5 °C/100 m and an average ground temperature of 25 °C.

Correlations between stable carbon isotope data & VRo indicate gases could have originated from a source rock with VRo of around 0.9. Extrapolation of Vitrinite maturation profile indicate, maturity value of 0.9 obtained at depths 4.5 km, probably from the Baratang Formation, similar studies of samples from Little Andamans showing VRo of around 0.4, indicating its occurrence from base of Port Blair or top of the Baratang Formation. Entire study clearly indicates adequate source rock maturation & HC generation from Port Blair/Baratang source rock below 4000m; same is confirmed by the sample analyses of well AA-1.

Unlike the reservoir gas, the MV gas has never been trapped, but it is expelled in a regular way in the atmosphere and thus has a low time of residence compared to reservoir gas. The relatively high flow of gas recorded from the mud volcanoes are expelled directly from deep source rocks (the kitchen) and are not emitted from the leakage of trapped hydrocarbons. The hydrocarbon fluids expelled from the mud volcanoes thus can be regarded as reflecting the present state of the hydrocarbons produced at depth.



All the hydrocarbons (HC) are produced from the same parent rock. A part of the HC, after dissolution and diffusion in water, takes a different pathway of migration toward mud volcanoes, whereas the oil and the residual gas move toward reservoirs for accumulation. Having undergone a process of surface adsorption, the mud volcano gas is almost essentially constituted by methane and expelled regularly in the atmosphere (low time of residence). Studies indicate existence of genetic relationships between MVs & oil and gas deposits. Nevertheless, a thorough analysis is likely to reveal exact relationships (Fig: 20).

n & Expulsion

Petroleum System & Entrapment Modelling: To ascertain the burial or thermal histories, hydrocarbon charge, and migration histories, 1D Petroleum System Modelling of one well AA-1 within the Accretionary Prism was carried out. 1D model indicates that deeper Baratang source rocks (Cretaceous-Eocene) are the main contributors for HC generation. The peak generation of the source rocks is at around 15 Ma when all other entrapment conditions have been formed, whereas that of Miocene & Oligocene are immature & the peak HC generation (>50% Transformation ratio) has not been reached yet. 1D thermal modelling showed presence of both mature Thermogenic and Biogenic system in the Accretionary Prism area, west of the Andaman Islands (Fig: 21 & 22).

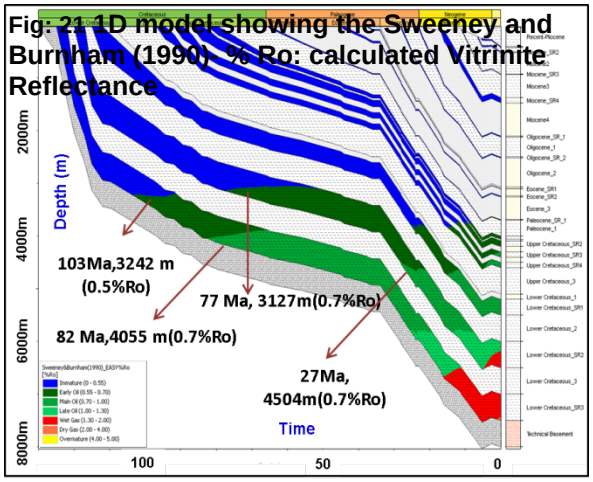


Fig: 21 1D model showing the Sweeney and Burnham (1990) % Ro: calculated Vitrinite Reflectance

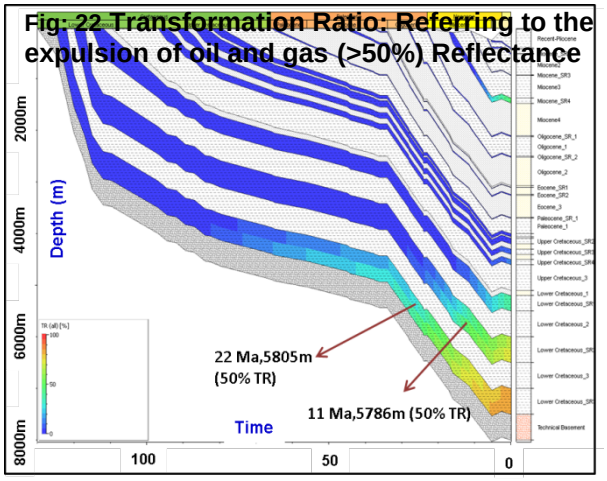


Fig: 22 Transformation Ratio: Referring to the expulsion of oil and gas (>50%) Reflectance

Conclusions: Emanating gas and oil from active Mud Volcanoes, confirm presence of hydrocarbons down below. Structures adjacent to MVs are prime exploration targets as inferred from global and local analogy. Natural gas is inferred to be dominant product with oil potential. 1D PSM study envisaged generation, migration and accumulation of hydrocarbon (both Thermogenic &

Biogenic) in Paleogene & Neogene sections within the Andaman Accretionary Prism area west of Andaman Islands. The Biogenic gas discovery and indication of Thermogenic gas & oil in wells drilled on either of Andaman Island corroborates the 1D PSM study. Identification of deeper prospects in the Baratang Formation which are close to source rocks is necessary to ensure higher success in exploration in western Andaman/ Accretionary Prism.