U.S. Department of the Interior
U.S. Geological Survey

U.S. Geological Survey Bulletin 2208-D

Text version for 508 compliancy

Sylhet-Kopili/Barail-Tipam Composite Total Petroleum System, Assam Geologic Province, India

By C.J. Wandrey

Petroleum Systems and Related Geologic Studies in Region 8, South Asia

Edited by **Craig J. Wandrey**

Contents

Figures

Table

Foreword

This report describing the petroleum resources within the Sylhet-Kopili/Barail-Tipam Composite Total Petroleum System in India was prepared as part of the World Energy Assessment Project of the U.S. Geological Survey. For this project, the world was divided into 8 regions and 937 geologic provinces,

which were then ranked according to the discovered oil and gas volumes within each (Klett and others, 1997). Of these, 76 "priority" geologic provinces (exclusive of the United States and chosen for their high ranking) and 52 "boutique" geologic provinces (exclusive of the United States and chosen for their anticipated petroleum richness or special regional economic importance) were selected for assessment of undiscovered oil and gas resources. The petroleum geology of these priority and boutique geologic provinces is described in this series of reports.

The purpose of the World Energy Project is to assess the quantities of oil, gas, and natural gas liquids that have the potential to be added to reserves within the next 30 years. These volumes either reside in undiscovered fields whose sizes exceed the stated minimum-field-size cutoff value for the assessment unit (variable, but must be at least 1 million barrels of oil equivalent) or occur as reserve growth of fields already discovered.

The total petroleum system constitutes the basic geologic unit of the oil and gas assessment. The total petroleum system includes all genetically related petroleum that occurs in shows and accumulations (discovered and undiscovered) that (1) has been generated by a pod or by closely related pods of mature source rock, and (2) exists within a limited mappable geologic space, along with the other essential mappable geologic elements (reservoir, seal, and overburden rocks) that control the fundamental processes of generation, expulsion, migration, entrapment, and preservation of petroleum. The minimum petroleum system is that part of a total petroleum system encompassing discovered shows and accumulations along with the geologic space in which the various essential elements have been proved by these discoveries.

An assessment unit is a mappable part of a total petroleum system in which discovered and undiscovered fields constitute a single, relatively homogeneous population such that the chosen methodology of resource assessment based on estimation of the number and sizes of undiscovered fields is applicable. A total petroleum system may equate to a single assessment unit, or it may be subdivided into two or more assessment units if each unit is sufficiently homogeneous in terms of geology, exploration considerations, and risk to assess individually.

A graphical depiction of the elements of a total petroleum system is provided in the form of an event chart that shows the times of (1) deposition of essential rock units; (2) trap formation; (3) generation, migration, and accumulation of hydrocarbons; and (4) preservation of hydrocarbons.

A numeric code identifies each region, geologic province, total petroleum system, and assessment unit; these codes are uniform throughout the project and will identify the same type of entity in any of the publications. The code is as follows:

The codes for the regions and provinces are listed in Klett and others (1997). Oil and gas reserves quoted in this report are derived from Petroconsultant's Petroleum Exploration and Production database (Petroconsultants, 1996) and other area reports from Petroconsultants, Inc., unless otherwise noted. Figure(s) in this report that show boundaries of the total petroleum system(s), assessment units, and pods of active source rocks were compiled using geographic information system (GIS) software. Political boundaries and cartographic representations were taken, with permission, from Environmental Systems Research Institute's ArcWorld 1:3 million digital coverage (1992), have no political significance, and are displayed for general reference only. Oil and gas field centerpoints, shown in these figures, are reproduced, with permission, from Petroconsultants (1996).

Abstract

The Sylhet-Kopili/Barail-Tipam Composite total petroleum system (TPS) (803401) is located in the Assam Province in northeasternmost India and includes the Assam Shelf south of the Brahmaputra River. The area is primarily a southeast-dipping shelf overthrust by the Naga Hills on the southeast and the Himalaya Mountain range to the north. The rocks that compose this TPS are those of the Sylhet-Kopili/Barail-Tipam composite petroleum system. These rocks are those of the Eocene-Oligocene Jaintia Group Sylhet and Kopili Formations, the Oligocene Barail Group, the Oligocene-Miocene Surma and Tipam Groups. These groups include platform carbonates, shallow marine shales and sandstones, and the sandstones, siltstones, shales, and coals of deltaic and lagoonal facies.

Source rocks include the Sylhet and Kopili Formation shales, Barail Group coals and shales, and in the south the Surma Group shales. Total organic content is generally low, averaging from 0.5 to 1.8 percent; it is as high as 9 percent in the Barail Coal Shales.

Maturities are generally low, from R_o 0.45 to 0.7 percent where sampled. Maturity increases to the southeast near the Naga thrust fault and can be expected to be higher in the subthrust. Generation began in early Pliocene. Migration is primarily updip to the northwest (< 5 to 15 kilometers) along the northeast-trending slope of the Assam Shelf, and vertical migration occurs through reactivated basement-rooted faults associated with the plate collisions.

Reservoir rocks are carbonates of the Sylhet Formation, interbedded sandstones of the Kopili Formation and sandstones of the Barail, Surma, and Tipam Groups. Permeability ranges from less than 8 mD (millidarcies) to as high as 800 mD in the Tipam Group. Porosity ranges from less than 7 percent to 30 percent.

Traps are primarily anticlines and faulted anticlines with a few subtle stratigraphic traps. There is also a likelihood of anticlinal traps in the subthrust. Seals include interbedded Oligocene and Miocene shales and clays, and the thick clays of the Pliocene Gurjan Group.

Introduction

Among the 76 priority provinces identified by the U.S. Geological Survey World Energy Assessment Team (2000) was the Assam geologic province. Located in northeastern India, Assam geologic province is an onshore province covering approximately 74,000 km^2 (figs. 1 and 2). The geologic province is bounded on the north and west by the Brahmaputra River, and on the south and east by the Indo-Burman Ranges and the Central Burma Basin (fig. 3). Major features within the Assam geologic province include the Assam Shelf, Brahmaputra River valley, Shillong Plateau, Mirkir Hills, and a foreland portion of the Indian Shield. The Assam Shelf consists of a portion of the Paleocene to Eocene continental shelf of the Indian plate which became emergent and which is being overthrust by the Himalayas on the northwest and by the Burma micro-plate on the southeast.

Figure 1. Location of Assam geologic province shown in green (8034); other assessed provinces in region 8 shown in yellow.

Figure 2. Himalaya mountain range at top of picture (north), Brahmaputra River flowing east to west, and Assam Shelf (NASA, 1998).

Figure 3. Generalized geologic map of Assam geologic province (Wandrey and Law, 1999).

Structurally, the Assam geologic province consists of two primary, subparallel features trending southwest to northeast, which developed just prior to, and as a result of plate collision. The northernmost structural feature is the Assam Shelf, which is presently being subducted beneath both the Eurasian plate to the north and the Burma plate to the southeast. The southernmost feature consists of en-echelon folds of the Naga Hills overthrust belt and northernmost Indo-Burman Ranges, which are continually developing as the shelf is subducted. At present, most hydrocarbon production is northwest of, and parallel to, the Naga thrust fault.

Figure 2 shows Brahmaputra River flowing from east (right) to west (left) and tributaries flowing from the Himalayan ranges at the top of the view (north) and from the Naga Hills in the bottom of the view (south). The producing area lies south of the Brahmaputra River.

Acknowledgments

Insight into the geology and data presented in this report were provided by scientists of the Oil and Natural Gas Corporation (ONGC), Dehra Dun, India.

Regional Geologic History

The Sylhet-Kopili/Barail-Tipam Composite Total Petroleum System (TPS) and Assessment Unit (AU) of the same name (fig. 4) acquired their primary structural and stratigraphic features from events associated with plate movements that occurred from latest Paleozoic to the present.

Figure 4. Sylhet-Kopili/Barail-Tipam Composite Total Petroleum System (803401).

From Permian through Middle Jurassic time, the Indian plate was located in the southern hemisphere between the African, Antarctic, and Australian plates, and constituted part of southern Gondwana (fig. 5). The Lower Permian tillites on the northwestern part (Shah, 1977) and other basal Permian glacial deposits on the southern Indian plate are indicative of a much cooler paleoclimate. The area that is today the Indus Basin and northern India was a shallow continental shelf on which carbonates, sandstones, and shales were accumulating. These depositional conditions persisted at least intermittently on the western and northern parts of the shelf through Late Jurassic. Jurassic carbonates have not been reported in the area of the Assam geologic province or in the eastern Gondwana basins of Damodar and Krishna Godovari (fig. 1). The Jurassic was generally a period of nondeposition (Datta and others, 1983). During the Late Jurassic the Indian, Australian, and Antarctic plates began to break away from Africa, forming the Somali Rift basin (figs. 5, 6). Late Jurassic rifting also initiated separation of Australia and Antarctica from India (Scotese and others, 1988).

Figure 5. Middle Jurassic (approximately 166 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

Figure 6. Early Cretaceous (approximately 130 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

During Early Cretaceous time, the Indian plate drifted northward entering warmer latitudes (fig. 6). Along the northeastern portion of the Indian plate, volcanic activity occurred as the northeast corner of the Indian plate passed over the Kerguelen hot spot (fig. 7); this resulted in the expulsion and deposition of the Rajmohal Trap volcanics. Through the Late Cretaceous, the Indian plate continued drifting northward toward the Asian plate and the seafloor of the Bengal Basin began to form. As the northward movement of the Indian plate continued, a transform fault became active along the Ninety East Ridge (figs. 7, 8). In the Assam area, block faulting and a southeasterly dipping shelf developed. Late Cretaceous rifting between Madagascar and the western part of the Indian plate initiated formation of Mascarene Basin. Counterclockwise rotation of the Indian plate began, and the Seychelles portion of the Indian plate started to break away (Waples and Hegarty, 1999) (fig. 8). The Indian plate continued to move northward at an accelerated rate of 15–20 cm/yr. The east edge of the plate passed over the Kerguelen hot spot forming a line of islands near long 90° E. (fig. 9). The Sino-Burman Ranges first emerged, and flysch was deposited in the area that is now the Central Burma Basin. The Assam Shelf began to tilt farther toward the southeast, and block faulting was reactivated.

Figure 7. Late Cretaceous (approximately 94 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

Figure 8. Latest Cretaceous (approximately 69 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

Figure 9. Middle Eocene (approximately 50 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

Continued northward movement and counterclockwise rotation of the Indian plate slowly closed the Tethyan Sea, and along the northwest edge of the plate, the Sulaiman-Kirthar fold belt (fig. 1) began to develop. Uplift on the Eurasian plate created a new primary sediment source, and the prevailing sediment transport direction of south to north was reversed. Carbonate platform build-up continued intermittently from the Eocene through middle Miocene time on the shelves surrounding much of the Indian plate. A trench formed along the subduction zone as the Indian plate began to slip beneath the Eurasian plates (fig. 10).

Figure 10. Late Oligocene (approximately 27 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

As subduction continued, the Eurasian plates shed sediments into the trench. Terrestrial sediment influx from the rapidly rising Himalayan, Sino-Burman, and Indo-Burman Ranges exceeded carbonate accumulation on late Miocene platforms (Roychoudhury and Deshpande, 1982), and smothered the carbonate reefs in the shelf areas. The shelf areas along these collision zones were either subducted or became emergent fluvial-deltaic environments.

The proto Indus, Narmada, Ganges, Brahmaputra, Megna, Chindwin, and Irrawaddy Rivers developed extensive deltas as the Himalayan and other ranges continued to shed sediments at a high rate. Today, uplift of the Himalayas and subduction of the Indian plate continue, and the growth rate of the Indus, Ganges-Brahmaputra (Megna), and Irrawaddy deltas remains high.

The present-day Assam geologic province, a cratonic margin, reflects three distinct tectonic phases. The earliest was Late Cretaceous to Eocene block faulting and development of a southeasterly dipping shelf. During the second phase, in Oligocene time, uplift and erosion occurred north of the Dukai fault (fig. 3); many basement faults were reactivated; and many basement-controlled structures became prominent (Naidu and Panda, 1997). Oligocene uplift and erosion were followed by late Miocene through Pliocene extensive alluvial deposition. The resultant sedimentary column is as much as 7,000 m thick (fig. 11). The thickest section is along the Naga thrust fault and in the Dhansiri Valley where it is greater than 4,500 m. The thinnest section lies along the axis of the central basement ridge, where it is less than 2,000 m thick.

Figure 11. Generalized cross section showing development of the Assam Shelf (modified from Murty, 1983; and Naidu and Panda, 1997).

Stratigraphy

The oldest sedimentary rocks reported near the Assam geologic province are thin Cretaceous limestones to the south, in eastern Manipur (fig. 3). Within the Assam geologic province, the oldest sedimentary rocks are the continental to lagoonal sandstones and interbedded shales of the Upper Cretaceous and Paleocene Dergaon and Disang Formations (fig. 12). More than 5,300 m of shales and sandstones of the Upper Cretaceous and Paleocene Disang Formation were deposited in the Manipur and Mizoram areas (fig. 3), and on the Assam Shelf more than 500 m of sandstones and shales of Upper Cretaceous Dergaon Formation were deposited. The top of the Dergaon and Disang is marked by an unconformity and overlain by the medium-grained massive sandstones of the Paleocene and Eocene Jaintia Group Tura and Langpar Formations. More than 250 m of the Tura and Langpar were deposited in a fluvial to marginal marine environment. The overlying Eocene Sylhet Formation was deposited in a range of environments and is subdivided into members generally representing these different depositional environments. More than 350 m of thin sandstones and interbedded shales and coals of the basal part of the lower Lakadong member were deposited in a lagoonal environment. The middle part of the Lakadong member typically consists of the thick sands of strand plain or barrier-bar environments. The upper part of the Lakadong member is a calcareous sandstone of a restricted shallow-water platform (Mathur and others, 2001). The overlying Narputh member consists of claystones and siltstones of a shelf environment. The upper member of the Sylhet, the Prang member, is a shelf carbonate with interbedded siltstones and clay. Within the Assam geologic province, the Sylhet Formation is depositionally thicker from northwest to southeast due to contemporaneous platform tilting and basement-sourced block faulting. The top of the Sylhet is marked by a regional unconformity on which as much as 500 m of the shallow marine to lagoonal shales and interbedded limestones of the Eocene Kopili Formation accumulated.

Figure 12. Generalized stratigraphy of Assam Shelf (modified from Mathur and others 2001; Murty, 1983; and Petroconsultants. 1996).

On the partly unconformable top of the Kopili more than 3,000 m of the upper Eocene and Oligocene Barail Group rocks were deposited. The Barail Group is divided into the Barail Lower Arenaceous Unit, also referred to as the Tinali Formation in some places and the Upper Barail Group Coal-Shale Unit (also called the Rudrasagar Formation). The primarily delta front Barail Lower Arenaceous Unit consists of the Main Pay Sand, Main Lower Sand, and minor shales with a combined thickness of as much as 900 m. The Upper Barail Group Coal-Shale Unit consists of as much as 1,200 m of interbedded coals, shales, and discontinuous sandstone reservoirs deposited in a delta-plain environment. The Barail Group strata are truncated by an unconformity north of the Dukai fault. This unconformity is probably associated with uplift caused by crustal shortening. In the Dhansiri Valley (fig. 3), erosion completely removed the Barail Group and Kopili Formation from the southeastern portion of the Mirkir Hills at the end of the Oligocene.

The Miocene-Pliocene Surma Group is missing on much of the Assam Shelf (fig. 12). However, as much as 1,400 m was deposited on an unconformable surface in the southwestern part of the Assam geologic province. The Surma Group is divided into the Bhuban Formation (>500 m thick), overlain by the Bokabil Formation (>900 m), and is typified by a series of thin siltstones, sandstones, and shales deposited in fluvial deltaic to estuarine environments.

Following further southward tilting of the Assam Shelf, an early Miocene transgression occurred, depositing tidal mudflat and minor tidal sand-flat facies (Dhar and Debashis, 1997). Several minor transgressions followed, and by middle Miocene there was widespread deposition of the fluvial Tipam Formation sandstones. The Surma, or Barail, and Jaintia Groups (where the Surma is missing) are overlain by as much as 2,200 m of massive sandstones and subordinate shales and clays of the (Nahorkatiya or Tipam Group) Tipam Sandstone Formation. The upper Nahorkatiya or Tipam Group Girujan Formation, found over most of the Assam Shelf, consists of more than 1,300 m of mottled clays containing minor sandstone lenses.

By late Miocene time the course of the Brahmaputra River east and south of the Shillong Plateau was altered, possibly by uplift along the edge of the Assam Shelf, to its present-day course around the north side of the Shillong Plateau (fig. 3) and then south to the Bay of Bengal. In the Manipur and Mizoram areas, the Nahorkatiya or Tipam Group thins to 900 m, possibly due to the uplift. During the Pliocene fluvial shales, sands, and clays were deposited in the Indus, Bengal, and Central Burma Basins and onto the Assam Shelf, where the Nahorkatiya or Tipam Group is overlain by the sandy clay and mudstones of the Duptilia and Dihing Groups.

Exploration and Production History

Oil seeps were reported in the Assam geologic province as early as 1825. In 1867 the first well was completed in the Namdang area by “mechanical” means and encountered oil at a depth of 35 m. The first reported commercial discovery in India occurred near Digboi in about 1889, in the thrust and fold belt

of the Assam Shelf (fig. 13). By 1901 a refinery had been established in Digboi and 500 barrels of oil a day were being produced (Indian Ministry of Petroleum, 1999). Between 1922 and 1932 Burma Oil Company (BOC) mapped and drilled 10 structures in the Schuppen Belt (fig. 3), with no economic successes reported (Rangaroo, 1983). BOC also conducted seismic surveys in 1937. Though further exploration was postponed until after World War II, the seismic surveys conducted in 1937 resulted in the next major discovery, the Nahorkatiya field, in 1953. According to the Petroconsultants International Oil and Gas Field Database (Petroconsultants, 1996), 38 oil fields and 1 gas field have been discovered within the Assam geologic province (fig. 13). These fields each have more than 1 million barrels of oil equivalent (MMBOE) of cumulative production and (or) proved reserves.

Figure 13. Oil and gas fields and identified prospects in the Assam geologic province (modified from Naidu and Panda, 1997 and Mallick and others, 1997).

These 39 fields contain at least 89 reservoirs that have produced oil, gas, or condensate. The largest fields are Nahorkatiya, Moran, and Lakwa discovered in 1953, 1956, and 1964, respectively (figs. 13, 14). These three fields each contain more than 500 MMBOE, discovered recoverable reserves. Until the 1974 discovery and subsequent development of the Bombay High field on the western Indian Shelf, the Assam geologic province was the largest producer of oil in India.

Figure 14. Cumulative number of new-field wildcat wells versus well completion year plot, an indication of exploration effort. Based on Petroconsultants well and field data (Petroconsultants, 1996).

Exploration history in the Assam geologic province indicates that it is a mature basin where the largest fields were found early in the exploration history. The known oil fields ranked by size and grouped by discovery date in thirds (fig. 15) shows a marked decrease in field size in the second and third thirds. The number of gas fields was not sufficient to produce a meaningful plot. The decrease in field size through time indicates that the province is relatively mature in terms of exploration, at least for the type of play that the discovered fields represent on the plot. An assessment unit that is mature in terms of exploration should show a large decrease in field sizes between the first and third thirds. Note that the second and the third third show similar distributions. Figure 16 shows plots of cumulative grown oil volume versus cumulative new-field wildcat wells in Assam province and cumulative grown oil volume versus field discovery year. Comparison of these plots shows that the number of new-field wildcat wells (measure of effort) required to find the same volume of oil has increased, but the effort required to find more, though smaller, fields has remained consistent.

Figure 15. Maturity of exploration indicator plot, showing grown (expected final size when production is ended) field sizes grouped in thirds by age of discovery and ranked by size. Based on Petroconsultants field data (Petroconsultants, 1996).

Figure 16. Cumulative grown oil volume versus cumulative new-field wildcat wells and cumulative grown oil volume versus field discovery year in Assam geologic province.

The reservoir depth versus field discovery year plot (fig. 17) indicates that, while generally deeper, some reservoirs found later were very shallow. This may indicate that substantial resources remain to be found in known hydrocarbon-producing zones by use of recently improved borehole and seismic technology (Mathur and others, 2001).

Figure 17. Reservoir depth versus oil field discovery year, showing that depth range of discoveries has not increased significantly with time. Based on Petroconsultants field data (Petroconsultants, 1996).

Composite Petroleum System

Source Rock

The USGS recognizes that several petroleum systems are present within the Assam geologic province (Chandra and others, 1995; Naidu and Panda, 1997; Kent and others, 2002) . For assessment purposes, however, they were combined into a composite petroleum system designated the Sylhet-Kopili/Barail-Tipam TPS (803401). A composite TPS was used because few correlations of source to reservoir hydrocarbons were available at the time of the assessment. Efforts continue to better define the source-rock reservoir-rock relationships (Mathur and others, 2001). Multiple stacked source and reservoir rock sequences, and extensive fault systems allowing mixing of hydrocarbons from multiple sources (Chandra and others, 1995) also make distinguishing individual systems difficult. When more geochemical data become available, it may be possible to identify three or more distinct petroleum systems and one or more composite systems in this area. The distinct systems might include the Sylhet-Kopili, Barail-Tipam, and in the southwest a Buban-Bokabil system. The petroleum systems of the Assam Shelf most likely are also genetically and temporally related to some of the gas-prone petroleum systems in the Bengal Basin (Wandrey and others, 2000).

The Sylhet-Kopili/Barail-Tipam TPS is composed of the rocks of the Eocene-Oligocene Jaintia Group Sylhet and Kopili Formations, the Oligocene Barail Group, and the Oligocene-Miocene Surma and Tipam Groups. These rocks include platform carbonates, shallow marine shales and sandstones, and the sandstones, siltstones, shales, and coals of deltaic, alluvial, and lagoonal facies.

With the exception of the Barail Coal Shale (BCS), most rocks in the Assam geologic province do not have high total organic carbon (TOC) contents today. Many formations, though, have low to moderate TOC values. The Eocene Jaintia Group contains the oldest source rocks in this TPS and includes interbedded shales of the Langpar and Lakadong members of the Sylhet Formation (see fig. 23) (Mathur and others, 2001). The Sylhet Formation is a shallow marine limestone interbedded with thin sandstones and shales deposited in marine to lagoonal environments. In places its thickness exceeds 400 m. The overlying Eocene Kopili Formation consists of alternating fossiliferous fluvial shales and fine-grained sandstones more than 500 m thick; it contains numerous potential source rock intervals (Naidu and Panda, 1997). Naidu and Panda (1997) calculated source rock richness for the Kopili as a product of the average TOC values and thickness of the source rock. The point values derived were used to create an isopach map

showing source rock richness (fig. 18). The product of the source rock richness value and a scaled maturity value (R_o) provides a source-potential value (Naidu and Panda, 1997). Source rocks within these formations contain types II and III kerogens and have TOC values commonly ranging from less than 0.5 percent to 1.5 percent. TOC values are higher in the Kopili Formation shales, where the maximum TOC values exceed 1.8 percent.

Figure 18. Kopili Formation richness map (percent TOC × thickness of source rock) (modified from Naidu and Panda, 1997).

API gravities range from 13° for heavy oils to 45° for "normal" oils (fig. 19). The "normal oils" from the Kopili Formation range from 29° to 45°. Oils derived from the Sylhet range from 24° to 37°, and wax content ranges from 11 to 15.6 percent.

Figure 19. Gas chromatograms and a composition plot for two Eocene crude types (heavy and normal), found at Dikom, Kathalani, and Tengahat fields. Samples were analyzed from 18 wells (modified from Mallick and others, 1997).

The upper Eocene and Oligocene Barail Coal-Shale Unit reaches a maximum thickness of 660 m between the Naga and Disang thrusts (Balan and others, 1997); TOC values range from less than 0.8 percent to more than 12 percent in the Barail Coal-Shale Unit. The Barail is considered to be the primary source rock throughout much of the Assam geologic province. Although younger rocks with sufficient organic content occur, they are immature where sampled. To the southwest in Bangladesh, the Miocene Surma Group Bubhan Formation is hypothesized to be the most likely source rock.

Maturation

Thermal maturity values range from R_o 0.5 to 0.7 percent in both the Sylhet and Kopili Formations (fig. 20). Maturity is expected to increase with depth to the southeast toward the Naga thrust fault and be even higher in the subthrust. In younger rocks, such as the Barail Group, source rock maturities are also generally low, from R_o 0.45 to 0.7 percent where sampled. The vitrinite reflectance values may be suppressed where the sediments were deposited in reducing marine or lacustrine environments. Surma Group source rocks are only mature in the southwestern part of the Assam geologic province where burial depths are greater.

Figure 20. Temperature, maturity, and subsidence history for Geleki-174 (modified from Balan and others 1997).

Generation and Migration

Oil generation began by early to middle Miocene for the Sylhet and Kopili Formations near and below the Naga thrust fault. Mathur and others (2001) placed the onset of generation for the Langpar and Lakadong members of the Sylhet at about 1,750 million years ago (Ma), and generation is continuing today in the deeper portions of the Assam geologic province. Although volumetric estimates of suitable mature organic material in place for the Sylhet are not available, estimates of source rock potential by Naidu and

Panda (1997) provide a basis for estimating source rock volumes for the Kopili. For this study, sufficient organic material is assumed to remain for continuing generation. Migration is primarily updip, along the northeast-trending slope of the Assam Shelf. Migration paths may extend to adjacent reservoirs but more often as far as 15 km. The source rocks in many fields are reported to be only marginally mature; therefore, significant volumes of the oil found there must have migrated from deeper areas along the Naga thrust fault. Oil generated beneath the thrust sheet has probably migrated to the leading edge of the thrust sheet and contributes materially to the total oil volume in reservoirs along the leading edge of the thrust sheet. Vertical migration through reactivated basement-rooted faults associated with plate collision may predominate in some areas, particularly near the edge of the Naga thrust fault.

Reservoir Rocks

Reservoir rocks are present throughout most of the stratigraphic section in the Assam geologic province (fig. 21). Reservoir rocks include the Eocene-Oligocene Jaintia Group Sylhet Formation limestones and Kopili Formation interbedded sandstones; Tura and Langpar (basal) marine sandstones also have reservoir potential, and Surma Group alluvial sandstone reservoirs are productive in the southwestern part of the Assam geologic province. The most productive reservoirs are the Barail main pay sands and the Tipam Group massive sandstones. Permeability ranges from less than 8 millidarcies to as much as 800 millidarcies in the Tipam Group sandstones with porosities ranging from less than 7 percent to 30 percent.

Figure 21. Temporal and lithologic distribution of producing reservoirs by youngest age and predominant lithology. Percentages represent number of reported occurrences (IHS Energy, 2001).

Traps and Seals

Anticlines and faulted anticlinal structures, subparallel to and associated with the northeast-trending Naga thrust fault, are the primary traps (figs. 3, 11). Subthrust traps are probably present below the Naga thrust sheet. There have also been stratigraphic trap discoveries, such as Dholiya gas field, described as an Oligocene Barail clastic depositional lense, and Hapjan and Sarojani oil fields identified as Barail depositional sandstone lenses (Petroconsultants, 1996) (figs. 22, 23).

Figure 22. Distribution of trap types. Percentages represent number of reported occurrences (IHS Energy, 2001).

Figure 23. Events chart summarizing stratigraphy, source rocks, reservoirs, seals, traps, and petroleum information for the Syllhet-Kopili/Barail-Tipam Composite Total Petroleum System.

Seals include interbedded Oligocene and Miocene shales and clays, and the thick clays of the Pliocene Gurjan Group. In the southwestern part of the Assam geologic province, the upper marine shale at the top of the Tipam Sandstone is a regional seal that extends into and throughout much of Bangladesh.

Assessment Unit

The Sylhet-Kopili/Barail-Tipam Composite AU (80340101) consists of the same rock intervals described for the TPS, and its boundaries correspond with those of the TPS (fig. 4). As more data are accumulated, the AU could be divided in several distinct units.

Assessment of Undiscovered Oil and Gas

Based on Petroconsultants International Data Corp. data current to 1996, Assam geologic province (8034) was ranked 83rd in the world, including United States provinces. This categorized it as a priority province for the USGS Assessment of World Oil and Gas Resources (Klett and others, 1997, U.S. Geological Survey World Energy Assessment Team, 2000). Known petroleum volumes are 2.5 BBO and 6.5 TCFG for a total of 3.6 BBOE including natural gas liquids (Petroconsultants, 1996). This volume is approximately 0.1 percent of world volume excluding the United States

Previous USGS estimates of undiscovered oil and gas in this region include those by Kingston (1986) and Masters and others (1998). Kingston (1986) estimated the mode for remaining undiscovered oil at 0.1 billion barrels (BBL) and mode for gas at 1 trillion cubic feet (TCF). The 1998 assessment estimate (Masters and others, 1998) for North Assam mean undiscovered oil was 0.1 BBL and for mean undiscovered gas was 2.0 TCF. Both previous assessments considered a smaller area than was considered in this report. The methodology utilized in those earlier assessments employed analogs from well-known productive regions of the world and also relied heavily on volumetric considerations.

The 2000 assessment incorporates the petroleum system concept as defined by Magoon and Dow (1994). The TPS used for the geologic basis of the 2000 assessment in the Assam geologic province is the Sylhet-Kopili/Barail-Tipam Composite TPS (803401). Table 1 shows the estimated ranges of assessed undiscovered oil and gas volumes allocated by assessment unit and the totals for the TPS

Summary

The Sylhet-Kopili/Barail-Tipam Total Petroleum System has produced the majority of the hydrocarbons on the Assam geologic province (fig. 23). It is likely that portions of this system buried near or beneath the Naga thrust fault are more mature than the rocks northwest of the thrust fault. The rocks beneath the thrust fault contribute a significant portion of the oil and gas produced from reservoirs adjacent to and northwest of the thrust fault. Dense, crosshatched fault systems may enhance migration of generated hydrocarbons to adjacent reservoirs and updip over longer distances. Although structural traps are predominant, stratigraphic traps such as updip pinchouts are likely.

Favorable elements of this TPS are suitable organic material, sufficient maturation, ongoing charging of reservoirs, short migration paths, and early trap formation relative to generation. There are probably untested structures in the subthrust yet to be discovered. The subthrust area, although difficult to explore, may contain significant resources. Source rocks are likely to be more mature in or near the

subthrust. Heavier oils found in bypassed Eocene and Oligocene reservoirs, in the future, may be produced with the use of secondary recovery techniques such as steam injection.

Although the prospective stratigraphic section to the north of the Brahmaputra River is thinner and probably contains leaner, less mature source rocks, it has some potential, particularly for gas.

Selected References

Balan, K.C., Banerjee, B., Pati, L.N., Shilpkar, K.B., Pandey, M.N., Sinha, M.K., and Zutshi, P.I., 1997, Quantitative genetic modeling of Upper Assam Shelf, *in* Proceedings Second International Petroleum Conference & Exhibition, PETROTECH-97: New Delhi, v. 1, p. 341–349.

Biswas, S.K., and Deshpande, S.V., 1983, Geology and hydrocarbon prospects of Kutch, Saurashtra, and Narmada basins: Petroleum Asia Journal, v. 6, no. 4, p. 111–126.

Chandra, U., Dhawan, R., Mittal, A.K., Dwivedi, P., and Uniyal, A.K., 1995, Stable isotope geochemistry of associated gases from Lakwa-Lakhmani Field, Upper Assam Basin, India, *in* Proceedings First International Petroleum Conference & Exhibition, PETROTECH-95: New Delhi, v. 3, p. 361–364.

Datta, N.R., Mitra, N.D., and Bandyopadhyay, S.K., 1983, Recent trends in the study of Gondwana basins of peninsula and extra-peninsular India: Petroleum Asia Journal, v. 6, no. 4, p. 159–69.

Dehadrai, P.V., 1970, An outline of the stratigraphy and structure of the sedimentary basins in India, *in* U.N. ECAFE Mineral Resources Development Series 36: 93–94.

Deshpande, S.V., and Krishna, M.J. Rama, 1995, Analysis of abnormal geopressures to evaluate equilibrium compaction depth in parts of Assam-Arakan Fold Belt, *in* Proceedings First International Petroleum Conference & Exhibition, PETROTECH-95: New Delhi, v. 2, p. 417.

Dhar, P.C., and Debashis, Das, 1997, Stratigraphy and petroleum potential of the Bokabil Formation of the Dhansiri Valley, Assam, *in* Proceedings Second International Petroleum Conference & Exhibition, PETROTECH-97: New Delhi, v. 1, p. 373–389.

Environmental Systems Research Institute Inc., 1992, ArcWorld 1:3M digital database: Environmental Systems Research Institute, Inc. (ESRI), available from ESRI, Redlands, CA; scale 1:3,000,000.

Gupta, P.K., and Vig, K.C., 1995, Diagenetic features and porefil minerals of Barail Main Sands in Geleki and Lakwa fields of Upper Assam, India, *in* Proceedings First International Petroleum Conference & Exhibition, PETROTECH-95: New Delhi, v. 2, p. 15–18.

IHS Energy Group (formerly Petroconsultants), 2001, Probe 4.0 Petroleum exploration and production database [includes data current as of September 2001]: IHS Energy Group; database available from IHS Energy Group, 15 Inverness Way East, D205, Englewood, CO 80112, U.S.A.

Indian Ministry of Petroleum, 1999, Indian Ministry of Petroleum and Natural Gas website: Available at URL http://petroleum.nic.in/ [accessed 1999].

Kent, W.N., Hickman, R.G., and Dasgupta, Udayan, 2002, Application of a ramp/flat-fault model to interpretation of the Naga thrust and possible implications for petroleum exploration along the Naga thrust front: American Association of Petroleum Geologists Bulletin, v. 86, no. 12, p. 2023–2045.

Klett, T.R., Ahlbrandt, T.A., Schmoker, J.W., and Dolton, G.L., 1997, Ranking of the world's oil and gas provinces by known petroleum volumes: U.S. Geological Survey Open-File Report 97-463, one CD-ROM.

Kingston, John, 1986, Undiscovered petroleum resources of South Asia: U.S. Geological Survey Open-File Report 86-80, p. 35–44.

Magoon, L.B., and Dow, W.G., 1994, The TPS—From source to trap: American Association of Petroleum Geologists Memoir 60, 664 p.

Mallick, R.K., Raju, S.V., and Choudhuri, B., 1995, Reservoir heterogeneities and their influence on hydrocarbon production potential of Lower Miocene (Tipam) reservoirs in parts of Upper Assam Basin, India, *in*

Proceedings First International Petroleum Conference & Exhibition, PETROTECH-95: New Delhi, v. 3, p. 125–132.

Mallick, R.K., Raju, S.V., and Mathur, N., 1997, Geochemical characterization and genesis of Eocene crude oils in a part of Upper Assam Basin, India, *in* Proceedings Second International Petroleum Conference & Exhibition, PETROTECH-97: New Delhi, v. 1, p. 391–402.

Masters, C.D., Root, D.H., and Turner, R.M., 1998, World conventional crude oil and natural gas identified reserves, undiscovered resources, and futures: U.S. Geological Survey Open-File Report 98-468, 105 p.

Mathur, N., Raju, S.V., and Kulkarni, T.G., 2001, Improved identification of pay zones through integration of geochemical and log data—A case study from Upper Assam basin, India: American Association of Petroleum Geologists Bulletin, v. 85, no. 2, p. 309–323.

Murty, K.N., 1983, Geology and hydrocarbon prospects of Assam Shelf—Recent advances and present status: Petroleum Asia Journal, v. 6, no. 4, p. 1–14.

NASA, 1998, Geomorphology from space: Available at URL http://daac.gsfc.nasa.gov/DAAC_DOCS/geomorphology/GEO_HOME_PAGE.html [accessed 1998].

Naidu, B.D., and Panda, B.K., 1997, Regional source rock mapping in upper Assam Shelf, *in* Proceedings of the Second International Petroleum Conference and Exhibition, PETROTECH-97: New Delhi, v. 1, p. 350–364.

Petroconsultants, 1996, Petroleum exploration and production database: Petroconsultants, Inc., P.O. Box 740619, 6600 Sands Point Drive, Houston, TX 77274-0619, U.S.A., or Petroconsultants, Inc., P.O. Box 152, 24 Chemin de la Mairie, 1258 Perly, Geneva, Switzerland.

Pratap, Mahendra, Kutty, Abdurahman, and Patra, S.K., 1997, The modified geological model for Charali Field, Assam by reservoir simulation study, *in* Proceedings Second International Petroleum Conference & Exhibition, PETROTECH-97: New Delhi, v. 1, p. 419–428.

Rangaroo, A., 1983, Geology and hydrocarbon potential of a part of Assam-Arakan basin and its adjacent region: Petroleum Asia Journal, p. 1–14.

Reddy, B.R.P., Basumatary, J.K., Rizvi, S.F.H., and Kumar, Kishan, 1995, Contribution of Tertiary coals towards commercial hydrocarbon deposits in a part of Upper Assam Basin, India, *in* Proceedings of the First International Petroleum Conference and Exhibition, PETROTECH-95: New Delhi, v. 2, p. 279–282.

Roychoudhury, S.C., and Deshpande, S.V., 1982, Regional distribution of carbonate facies, Bombay offshore region, India: American Association of Petroleum Geologists Bulletin, v. 66, no. 10, p. 1483–1496.

Sastri, V.V., and Avashi, D.N., 1997, Hydrocarbon prospectivity of Indian sedimentary basins, *in* Proceedings Second International Petroleum Conference & Exhibition, PETROTECH-97: New Delhi, v. 1, p. 71–84.

Scotese, C.R., Gahagan, L.M., and Larson, R.L., 1988, Plate tectonic reconstructions of the Cretaceous and Cenozoic ocean basins: Tectonophysics, v. 155, p. 27–48.

Scotese, C.R., 1997, PALEOMAP Software, Paleomap project, http://scotese.com.

Shah, S.M.I., Ahmed, R., Cheema, M.R., Fatmi, A.N., Iqbal, M.W.A., Raza, H.A., and Raza, S.M., 1977, Stratigraphy of Pakistan, *in* Shah, S.M.I., ed., Geological Survey of Pakistan, Memoirs, v. 12: Quetta, Geological Survey of Pakistan, 137 p.

Sharma, A.K., Dwivedi, P., Pande, Anil, Singh, B.P., Khan, M.S.R., Manju, Mathur, and Miara, K.N., 1997, Biomarker and isotopic fractionation of crude oils during migration-laboratory studies, *in* Proceedings Second International Petroleum Conference & Exhibition, PETROTECH-97: New Delhi, v. 1, p. 331–340.

Sinha, N., Kumar, V., and Kalita, P.C., 1997, Hydrocarbon plays in frontal part of Naga thrust and fold Belt, Dimapur Low, Dhansiri Valley, Assam, *in* Proceedings Second International Petroleum Conference & Exhibition, PETROTECH-97: New Delhi, v. 1, p. 365–372.

Upadhyay, M.N., Prabhakar, Vibha, Barry, V.K., Dwivedi, P., and Nain, Kamal, 1997, Oil occurrence trends in Lakwa-Lakhmani area of Upper Assam Basin, India, *in* Proceedings Second International Petroleum Conference & Exhibition, PETROTECH-97: New Delhi, v. 1, p. 403–408.

U.S. Geological Survey World Energy Assessment Team, 2000, U.S. Geological Survey world petroleum assessment 2000—Description and results: USGS Digital Data Series DDS-60, 4 CD-ROMs.

Wandrey, C.J., and Law, B.E., 1999, Map showing geology, oil and gas fields, and geologic provinces of South Asia: U.S. Geological Survey Open File Report 97-470-C; version 2, one CD-ROM.

Wandrey, C.J., Milici, R.C., and Law, B.E., 2000, Region 8, South Asia, *in* U.S. Geological Survey Assessment Team, 2000, U.S. Geological Survey world petroleum assessment 2000—Description and results: U.S. Geological Survey Digital Data Series DDS-60, version 1.1, 4 CD-ROMs.

Waples, D.W., and Hegarty, K, 1999, Seychelles thermal history hydrocarbon generation traced: Oil and Gas Journal, v. 97, no. 21, p. 78–82.

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

This publication is only available online at:
http://pubs.usgs.gov/bul/b2208-d/

Posted online June 2004, version 1.0