Eocene to Miocene Composite Total Petroleum System, Irrawaddy-Andaman and North Burma Geologic Provinces, Myanmar

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

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Foreword

This report describing the petroleum resources within a total petroleum system in Myanmar 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” provinces (exclusive of the United States and chosen for their high ranking) and 26 “boutique” provinces (exclusive of the United States and chosen for their anticipated petroleum richness or special regional economic importance) were selected for assessment of oil and gas resources. The petroleum geology of these priority and boutique 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) and 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 events 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, 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:

Example

Region, single digit	**2**
Province, three digits to the right of region code	2**004**
Total Petroleum System, two digits to the right of province code	2004**01**
Assessment Unit, two digits to the right of petroleum system code	200401**01**

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 Petroconsultants’ Petroleum Exploration and Production database (Petroconsultants, 1996) and other area reports from Petroconsultants, Inc., unless otherwise noted.

Figures 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 on these figures are reproduced, with permission, from Petroconsultants (1996).

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Abstract

The Eocene-Miocene Composite Total Petroleum System (804801) was divided into two units for the purpose of assessment, the Central Burma Basin Assessment Unit (80480101) and Irrawaddy-Andaman (80480102) Assessment Unit.

The Irrawaddy-Andaman (80480102) Assessment Unit is located in the southern central basin of Myanmar, the Irrawaddy Delta, and Andaman Basin. It is a gas-prone onshore and offshore basin developed subparallel to the converging continental and marine plate boundaries. The rocks that compose this assessment unit include Eocene sandstones and shales and the Oligocene-Miocene Pegu Group, which in places exceeds 6,500 meters in thickness. This group is made up of interbedded, shallow marine shales, limestones, and sandstones, and the sandstones, shales, and coals of deltaic and lagoonal facies.

Source rocks include the lower Oligocene shales of the Yaw, Shwezetaw, and Okhmintaung Formations and shales of the Pegu Group. Total organic carbon percent is generally low (<1.75 percent) where sampled. Organic material is primarily terrestrially derived type III kerogen. Maturities are generally low, from R_0 0.2 to 1.5 percent where sampled in the Gulf of Martaban. Maturities are likely higher in areas of the basin where burial depths are greater.

Significant generation commenced during the Pliocene. Migration is primarily vertical through fault and fracture systems associated with the plate collision. These fault systems have been periodically reactivated through the present. Short updip migration along the flanks of the basin is also likely.

Primary reservoir rocks are interbedded sandstones of the Pegu Group. Permeability ranges from less than 32 millidarcies (mD) to as high as 3,200 mD. Porosity ranges from less than 20 percent to 30 percent. Reservoir quality is fracture enhanced in many cases.

Traps include anticlines, faulted anticlines, and a few stratigraphic traps. Seals include interbedded Oligocene and Miocene shales and clays, and the thick clays of the upper Miocene–Pliocene Irrawaddy Group. Although few stratigraphic traps have been discovered, potential for more discoveries exists in the deltaic sequences. There is also potential for growth-fault related traps and in the offshore fans.

The Central Burma Basin Assessment Unit (80480101) is located in the north and central basins of Myanmar. It is an oil-prone onshore basin developed parallel to the converging continental and marine plate boundaries. The rocks that compose this assessment unit include the Eocene Laungshe Shale, Tilin and Pondaung Sandstones, and the Oligocene-Miocene Pegu Group, the thickness of which exceeds 6,500 meters. This group includes interbedded sandstones, shales, and coals of deltaic to fluvial facies, and shallow marine shales, limestones, and sandstones.

Source rocks include the upper Eocene–lower Oligocene shales of the Yaw, Shwezetaw, and Okhmintaung Formations. Total organic content is generally low where sampled (>1.7 percent). Organic content is primarily terrestrially sourced type III kerogens. Maturities are generally low, from R_0 0.2 to 1.5 percent where sampled outside of this assessment unit to the south in the Gulf of Martaban. The onset of generation probably occurred in late Miocene. Migration is primarily short updip and vertical through fault and fracture systems associated with the plate collision. These fault systems have been periodically reactivated through the present.

Interbedded sandstones of the Pegu Group are the primary reservoirs. Permeability ranges from less than 32 mD to as high as 3,200 mD. Porosity ranges from less than 20 percent to 30 percent. The Eocene Pondaung and Tilin sandstones may also have reservoir potential and have a combined thickness of as much as 3,500 meters, including the interbedded shales.

Traps include anticlines, faulted anticlines, fault truncations, and stratigraphic traps. Seals include interbedded Oligocene and Miocene shales and clays, and the thick clays of the upper Miocene and Pliocene Irrawaddy Group. Structures in the Chindwin Basin area and stratigraphic traps developed in alluvial and deltaic systems have been only lightly explored and may have significant potential.

Introduction

Among the 26 boutique provinces identified for the U.S. Geological Survey World Energy Assessment (2000) was the Irrawaddy-Andaman geologic province (8048) (fig. 1). The Eocene to Miocene Composite Total Petroleum System (TPS) (804801) (fig. 2), as defined for this assessment, extends north and also encompasses most of the North Burma geologic province (8035); therefore, that province is also included in this report. Located in central Myanmar, Gulf of Martaban, and the Andaman Sea, it is an onshore and offshore TPS covering approximately 800,000 km^2 (fig. 3).

The North Burma and Irrawaddy-Andaman geologic provinces are bounded on the north and west by the Indo-Burman and Arakan Yoma Mountain Ranges and on the east by the Sino-Burman Ranges, Shan Plateau, and Tenasserim Ranges. The area includes the Chindwin Basin, Salin Basin, Prome Embayment, Irrawaddy River Delta, Gulf of Martaban, and the Andaman Sea east of the Andaman Islands. The area described is essentially a complex back-arc/fore-arc basin (fig. 4), with portions of, or the entire onshore part being variously referred to as, the Central Basin, Central Burma Basin, Inner or Central Burma Tertiary Basin, and Central Burma Tertiary Geosyncline. In this report the entire onshore part will be referred to by the most commonly used term—the Central Burma Basin.

In the Central Burma Basin, the Cretaceous Kabaw Group (fig. 5) or younger rocks rest on the marine basement in the western basin and on continental basement rocks in the eastern basin. In the ranges to the west, sedimentary and metamorphic rocks as old as Early Triassic have been identified. East of the Central Burma Basin, rocks younger than Cretaceous were not deposited or were almost completely removed by erosion, leaving a nearly continuous stratigraphic section from Cambrian to Lower Cretaceous. The offshore portion of the TPS consists of Eocene and younger rocks (Curray and others, 1979; Pivnik and others, 1998). Structurally, the TPS consists of a north-south-trending trough or fore-arc/back-arc basin that developed as a result of Eocene oblique multi-plate collision.

The Eocene-Miocene Composite TPS was further divided into two assessment units (AU) (fig. 2). These AUs are the Irrawaddy-Andaman AU (80480102) and the Central Burma Basin AU (80480101). The Irrawaddy-Andaman AU is located in the southern part of the Central Burma Basin of Myanmar, the Irrawaddy Delta and Andaman Basin. It is a gas-prone basin, developed both on and offshore subparallel to the converging continental and marine plate boundaries. The Central Burma Basin AU is located in the northern and central part of the Central Burma Basin of Myanmar. It is an oil-prone, onshore area, and it also developed parallel to the converging continental and marine plate boundaries.

Acknowledgments

The author thanks Hugh Balkwell and technical reviewers D.K. Higley and R.R. Charpentier for their valuable suggestions and insight.

Geologic and Tectonic History

The total petroleum system (TPS) and assessment units (AU) discussed herein owe their primary structural and stratigraphic features to a series of plate tectonic events dating from latest Paleozoic time to the present. The continental plates that were involved in the development of present-day Myanmar are the Indian and Eurasian plates and the Burma or Sunda microplate or fore-arc sliver. The Burma plate has been described as a micro-plate or fore-arc sliver bounded on the west by a subduction zone, on the east by a strike-slip fault, on the south by a spreading center, and on the north by a compressional plate boundary (Curray and others, 1979; Pivnik and others, 1998). This sliver or micro-plate has also been described as an accretionary prism that consists of sedimentary, meta-sedimentary, intrusive, and volcanic rocks (Curray and others, 1979; Bender, 1983) (fig. 4). Studies of the eastern part of the Indian plate suggest alternatively that the Burma plate may have been located north of the Indian plate prior to collision, and then underwent extrusion and 90° of clockwise rotation to reach its present position (Tapponnier and others, 1982; Besse and Courtillot, 1984; LeDain and others, 1984; Everett and others, 1990). Lee and Lawver (1995) and Pivnik and others (1998) suggested that the Burma plate originated as a part of the early Tertiary continental shelf of southeast Asia located southeast of its present location.

From Permian through Middle Jurassic time, the Eurasian plate (or plates) and probably the Burma plate extended just south of the equator. The Indian plate was located farther to the southwest, between the African, Antarctic, and Australian plates, making up part of southern Gondwana (fig. 6). During the Late Jurassic and Early Cretaceous, Southeast Asia and the area of the Burma plate moved northward across the equator to between lat 10° and 20° N.

During the Cretaceous, the Indian plate continued to drift northward toward the Burma and Eurasian plates (figs. 7 and 8), and by latest Cretaceous time the sea floor of the Bengal Basin began to form (Scotese and others, 1988). Along the Ninety East Ridge a transform fault became active (fig. 9), and in the Assam area, a southeasterly dipping block-faulted shelf developed. Counterclockwise rotation of the Indian plate began, and the western part of the Indian plate that is now the Seychelles began to break away from the Indian plate (Waples and Hegarty, 1999) (fig. 9). During Paleocene time, oceanic plate subduction occurred along the west edge of the Burma

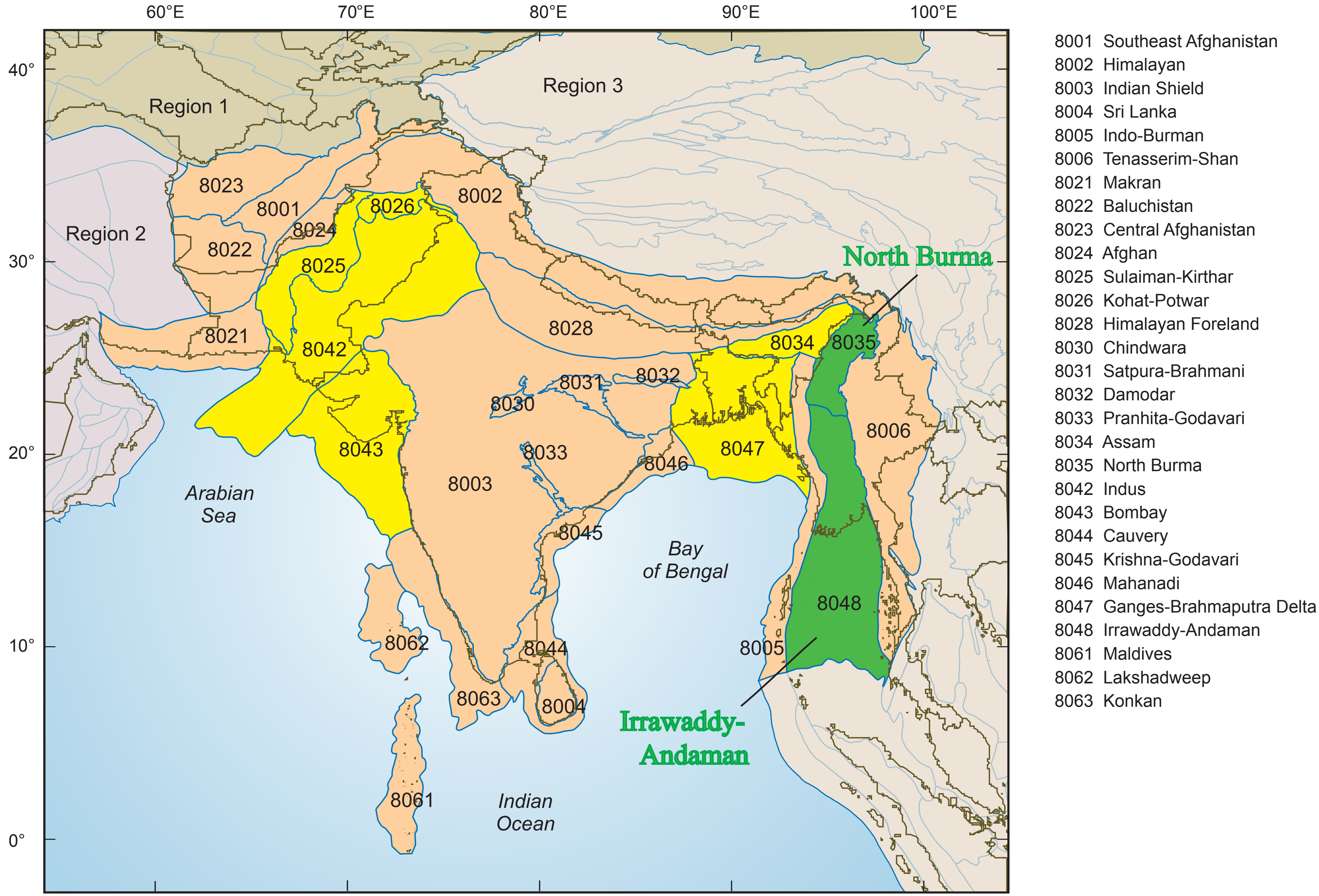


Figure 1. Location of Irrawaddy-Andaman (8048)and North Burma (8035) geologic provinces shown in green; other assessed provinces in region 8 shown in yellow.

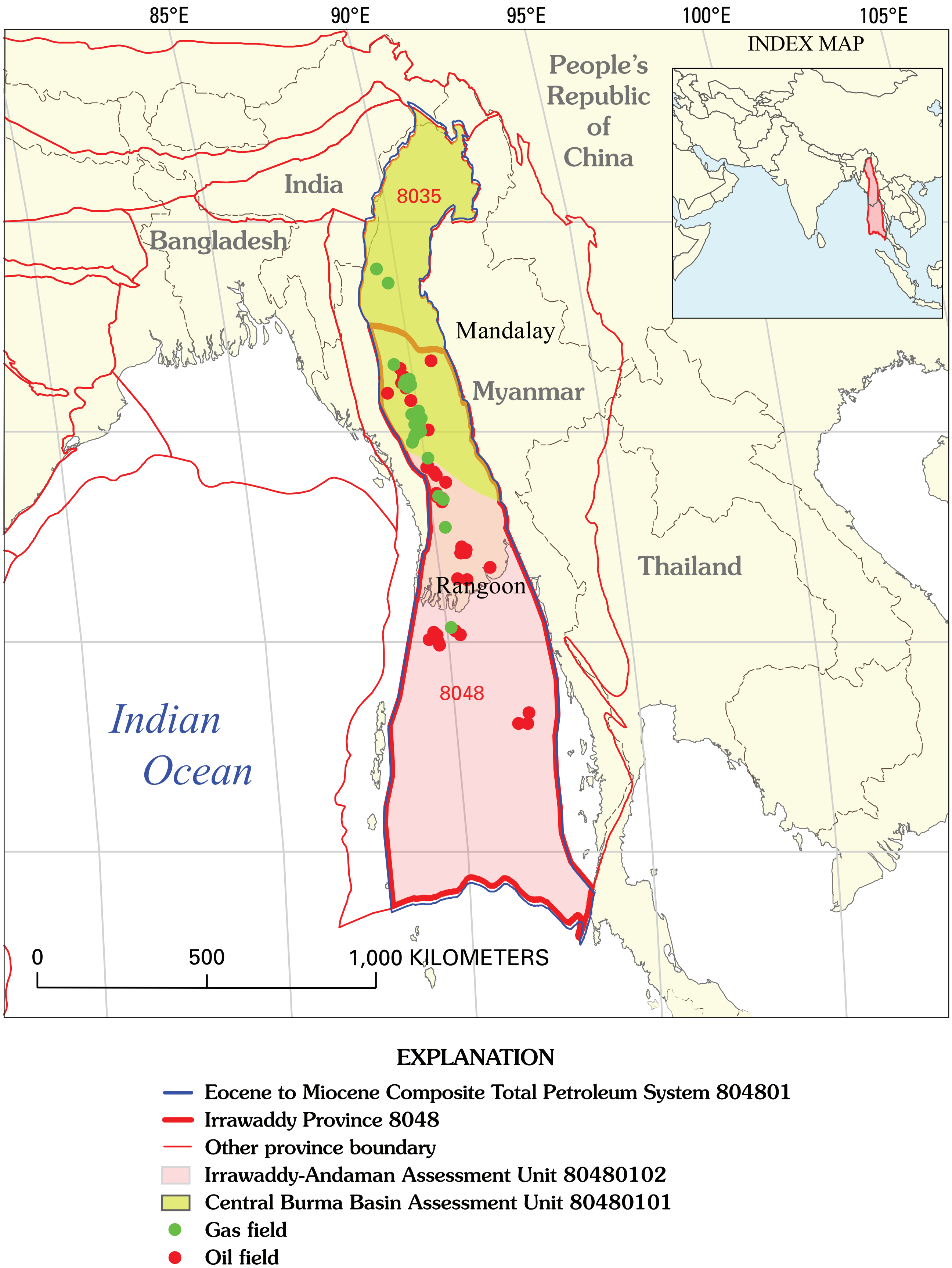


Figure 2. Geologic province and total petroleum system boundaries.

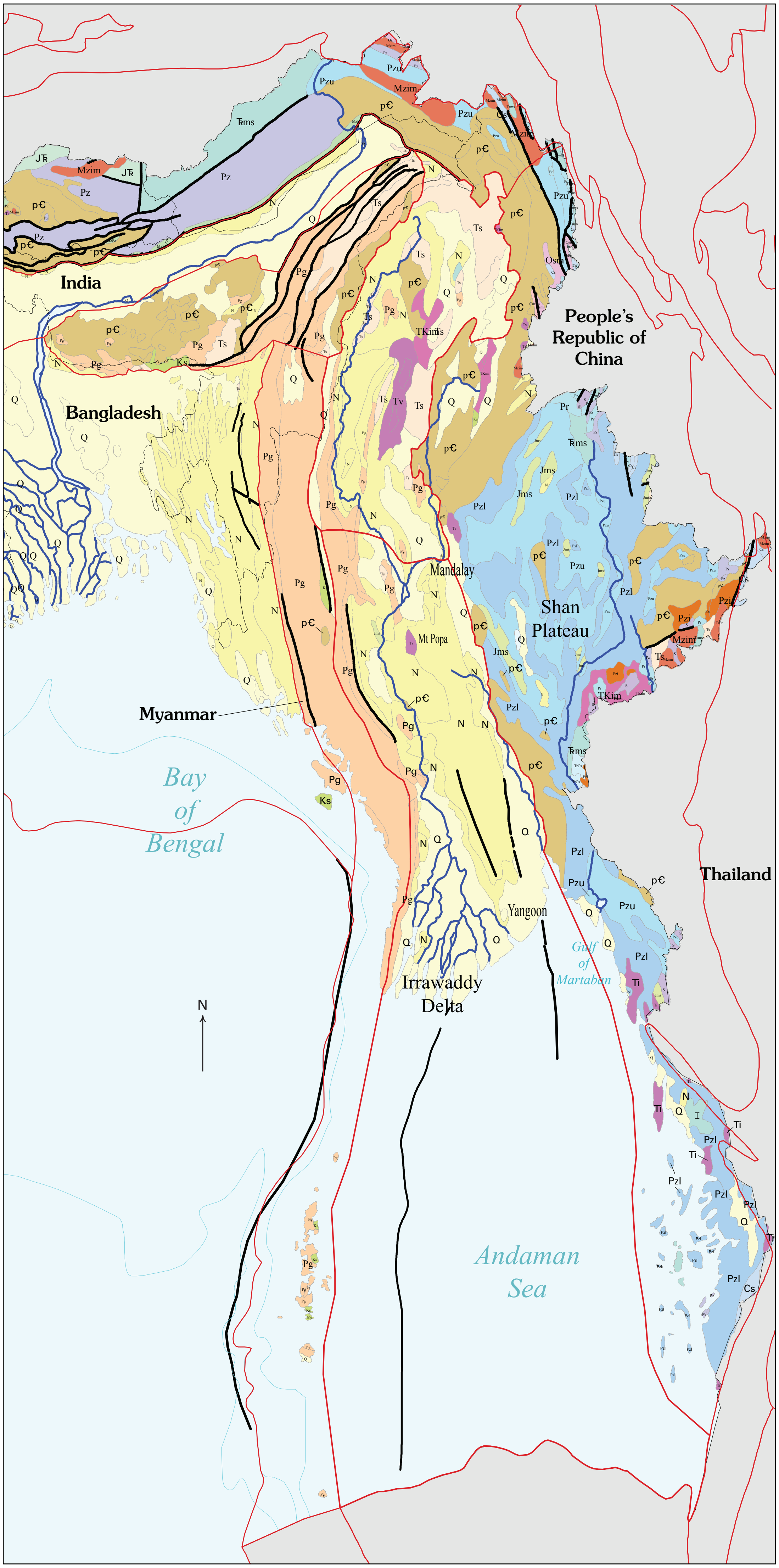


Figure 3. Generalized geology and geologic province boundaries (Wandrey and Law, 1999).

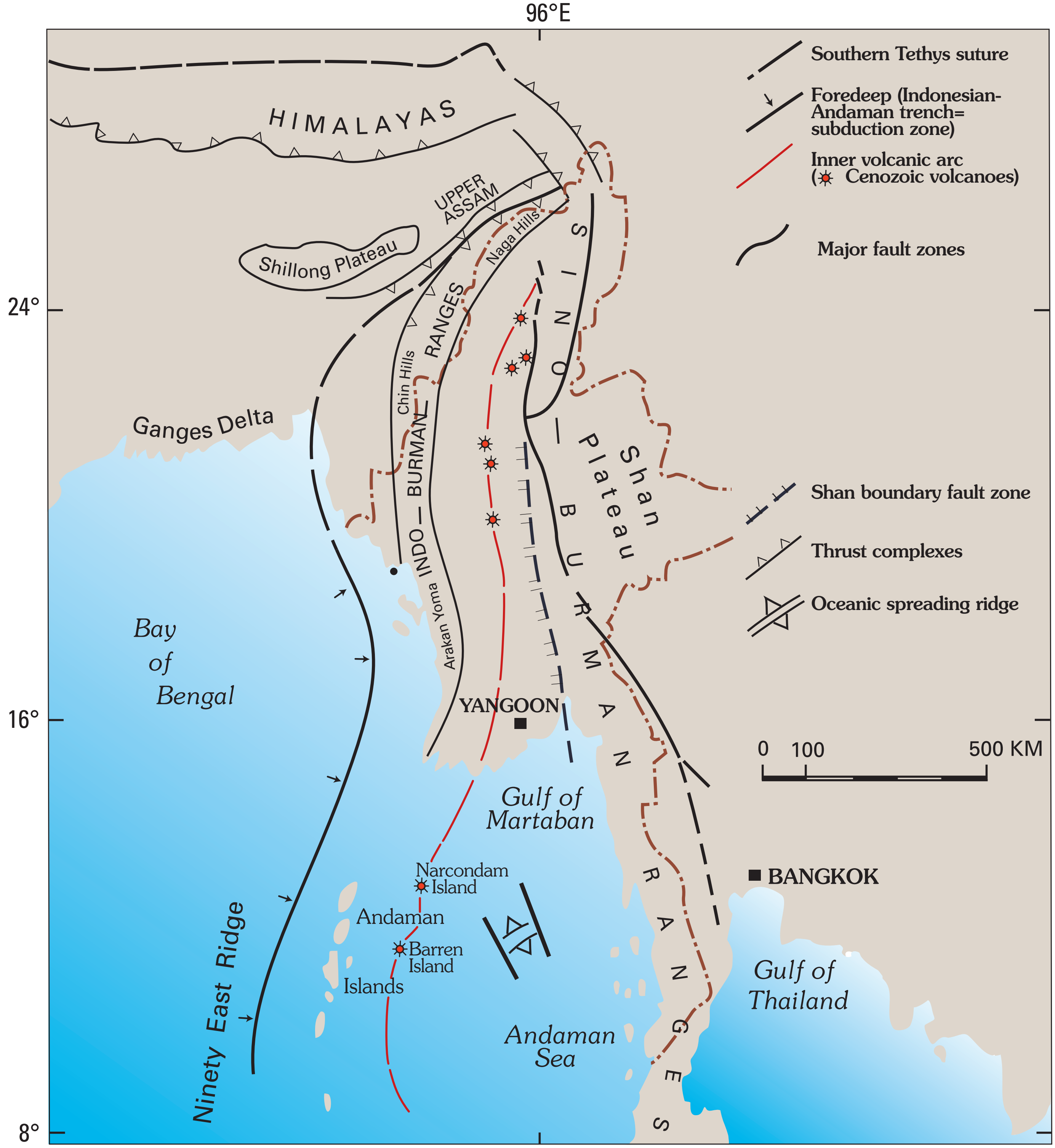


Figure 4. Tectonic map of Myanmar and Andaman Basin (modified from Bender, 1983).

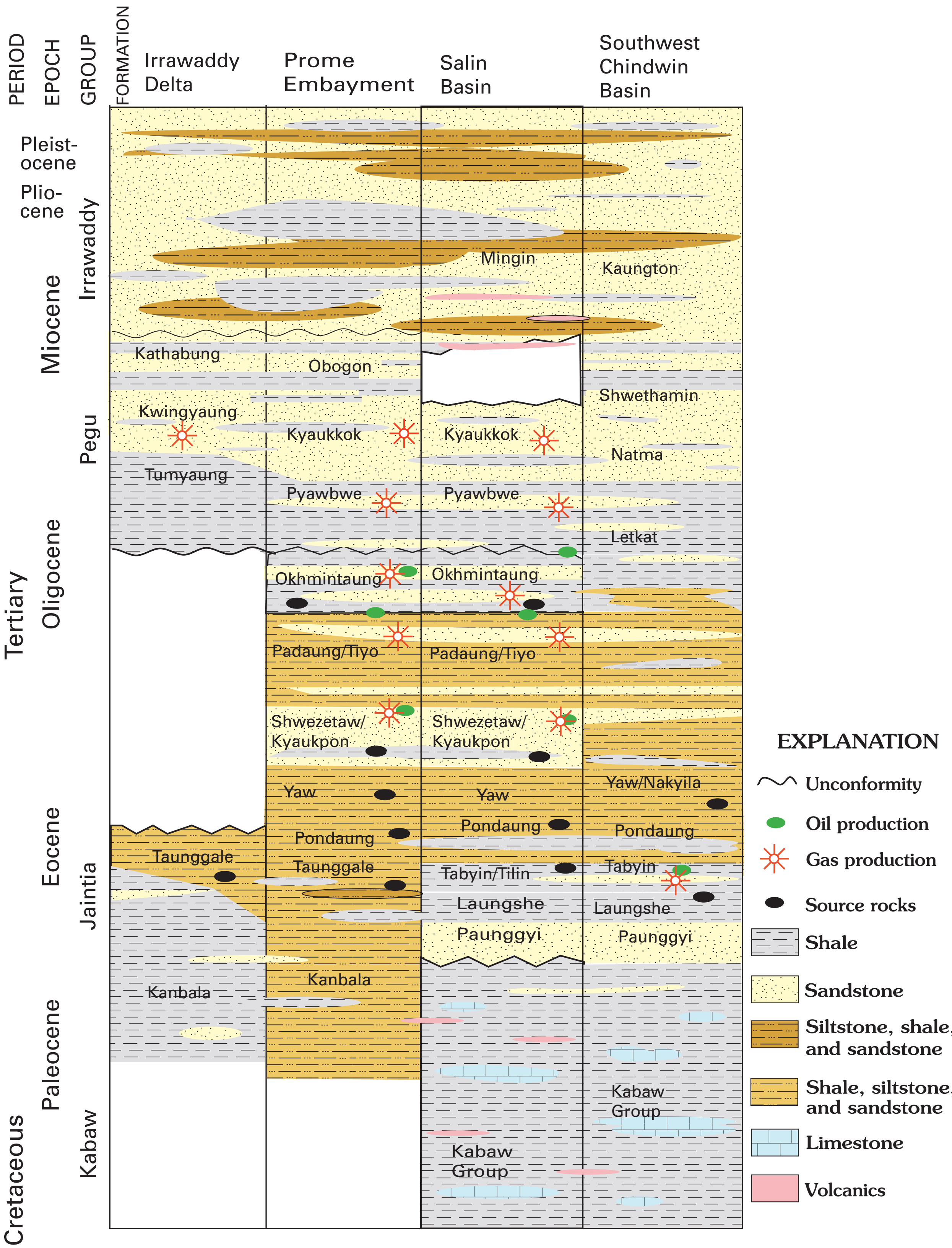


Figure 5. Generalized stratigraphy of Central Burma Basin, Myanmar (modified from Stamp, 1927; Khin and Win, 1969; and Bender, 1983).

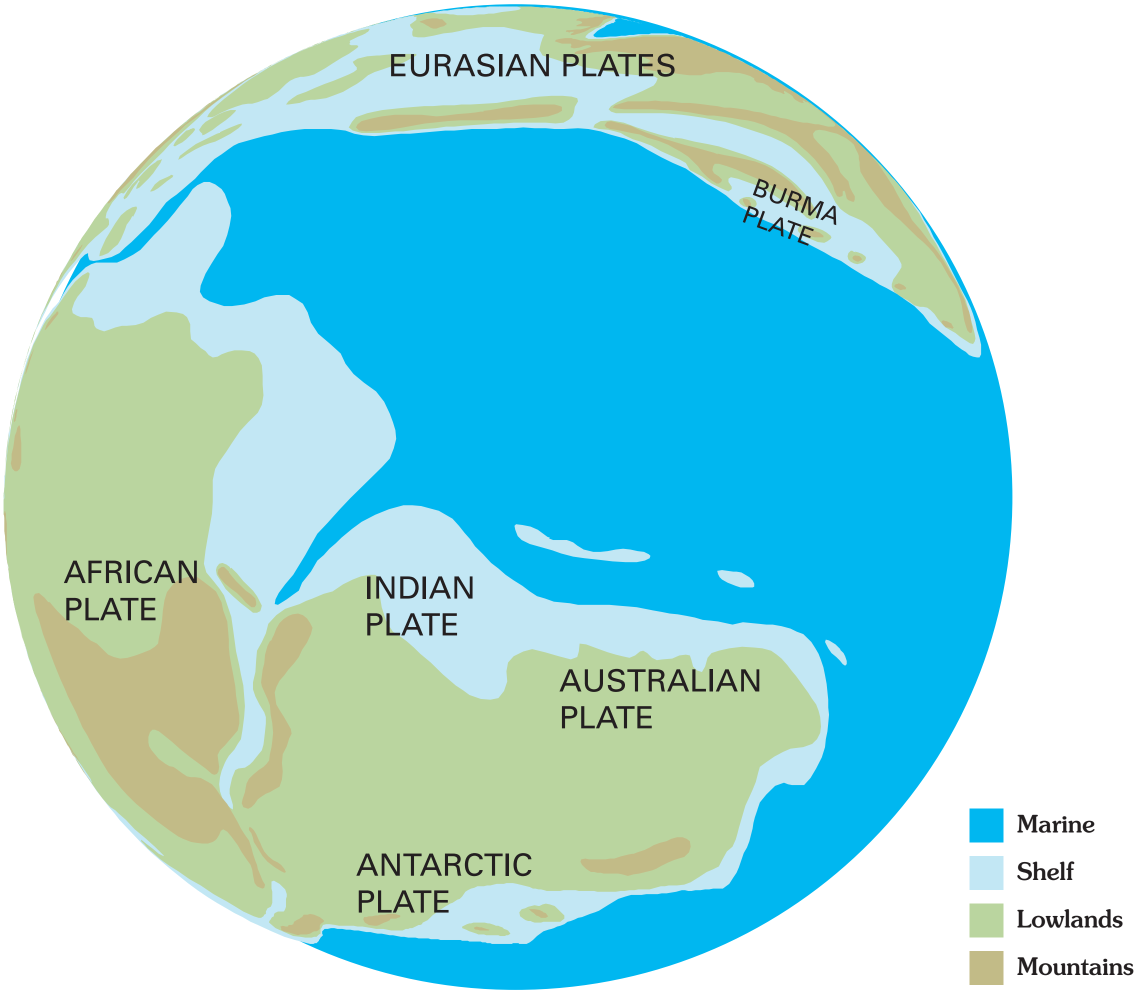


Figure 6. Middle Jurassic (approximately 166 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

plate (Pivnik and others, 1998). Paleocene oblique subduction of the oceanic plate may have also detached the Burma plate from the Eurasian plate. Initial collision of the northeastern Indian and Burma plates occurred during the Eocene, possibly resulting in the coupling of the plates and accelerating the northward movement of the Burma plate (Pivnik and others, 1998). From Eocene to early Miocene time, tectonic activity increased due to plate collision and rotation (figs. 10 and 11). During the Miocene, faulting, sedimentation, and the opening of the Andaman Sea were controlled primarily by northwest-southeast extension and rifting. Regionally, terrestrial sediment influx from the rapidly rising Sino-Burman, Indo-Burman, and Himalayan ranges significantly exceeded carbonate accumulation rates on late Miocene platforms (Roychoudhury and Deshpande, 1982); and this influx smothered carbonate reef formation along the shelf areas. The former shelf areas along these collision zones were either subducted or became emergent fluvial-deltaic environments.

Early Pliocene collision of the Burma plate resulted in southwest-northeast transpressional forces that created reverse faults and north-south elongate anticlinal features such as the Pegu Yoma (fig. 3). The Pegu Yoma rose 900–1,200 m in the middle of the Central Burma Basin, dividing it into east and west subbasins. During the Pliocene, Mount Popa and other volcanoes along the volcanic arc to the south became more active, depositing volcanic mud and ash. The proto-Chindwin, Irrawaddy, and Sittang drainage systems developed. East-west uplift and faulting occurred near Mandalay, causing the Irrawaddy River to turn abruptly west and capture the Chindwin River. By Holocene time, anticlinal ridges in the eastern part of the Central Burma Basin were again uplifted and 300–450 m of sediments were stripped off. To the west, 300–900 m of the newly uplifted Pegu Yoma were eroded. Myanmar now consists of three primary features; from east to west these are the Sino-Burman Ranges and Shan Plateau, the Central Burma Basin, and the Indo-Burman Ranges (fig. 3). The TPS rests on both marine and continental crusts, and the oceanic-continental plate boundary trends north up through the Central Burma Basin and coincides approximately with the northern boundary of the Irrawaddy-Andaman AU.

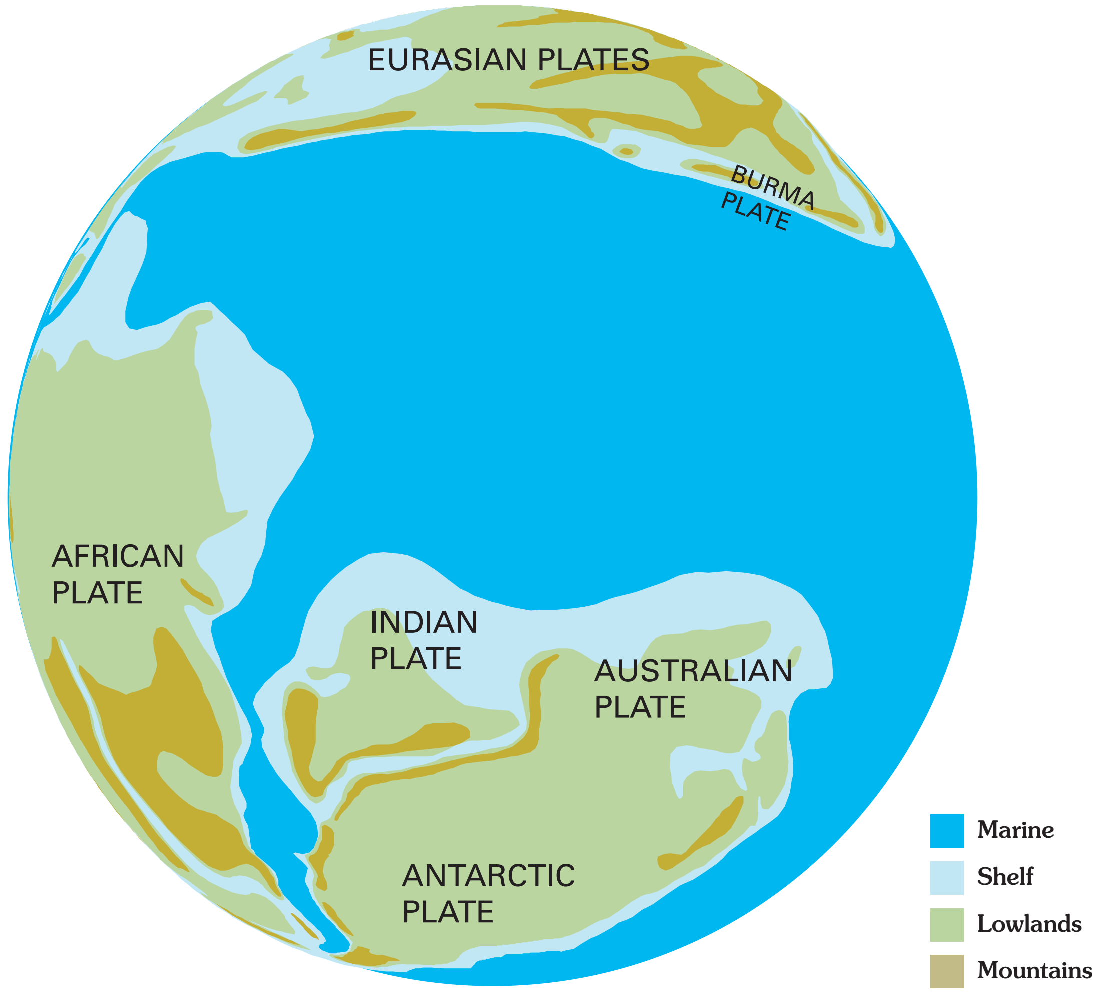


Figure 7. Early Cretaceous (approximately 130 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

Stratigraphy

Stratigraphic sequences ranging in age from Cretaceous to Pleistocene are shown in figure 5 for four different parts of the Central Burma Basin. The discussion that follows, however, includes mention of rocks (mostly older, but some of Cretaceous age and younger) not shown in figure 5; some of these strata are described from observations within the basin, but others are described from exposures elsewhere.

From Carboniferous to Jurassic time, extensive carbonates such as the Plateau Limestone Group and Shan Dolomite Group were deposited in what is now eastern Myanmar, including the area of the Shan Plateau and Tenasserim Mountain Ranges (Rau and Sethu, 1933; Hobson, 1941; Brunschweiler, 1974; Bender, 1983) (fig. 3).

The Jurassic Tati Limestone Formation in northeastern Myanmar and the Shan Plateau and the Kamawkala Limestone Formation in the east and southeast accumulated in a shallow marine environment before a period of uplift that was marked by a regional unconformity. On this unconformity, Upper Jurassic and Cretaceous redbeds of the Hsipaw, Kalaw, Mergui, and Khorat Formations were deposited (Bender, 1983). Jurassic and Lower Cretaceous rocks are missing or not identified in the Central Burma Basin and in most of the Indo-Burman Ranges to the west. Following this hiatus, in the area of the Indo-Burman Ranges, Early Cretaceous volcanic tuffs and cherts of the Kyauknimaw Formation were deposited. Throughout the Central Burma Basin, the Albian to Turonian age Lower Kabaw Group Paung-Chaung and Ywahaungyi Formation limestones were deposited. Campanian-age graded volcanoclastics then covered much of the Central Burma Basin and what are now the Indo-Burman Ranges. Following this episode of volcanic activity, extensive limestone reefs such as those in the Upper Cretaceous–Paleocene Falam Formation were deposited in the area of the Indo-Burman Ranges.

Along the eastern portion of the approaching Indian plate, Rajmahal Trap volcanics and carbonates of the Bolpur and Ghatal Formations accumulated. Although these carbonates are recognized today primarily on the eastern and western shelves, they were also likely deposited over much of the

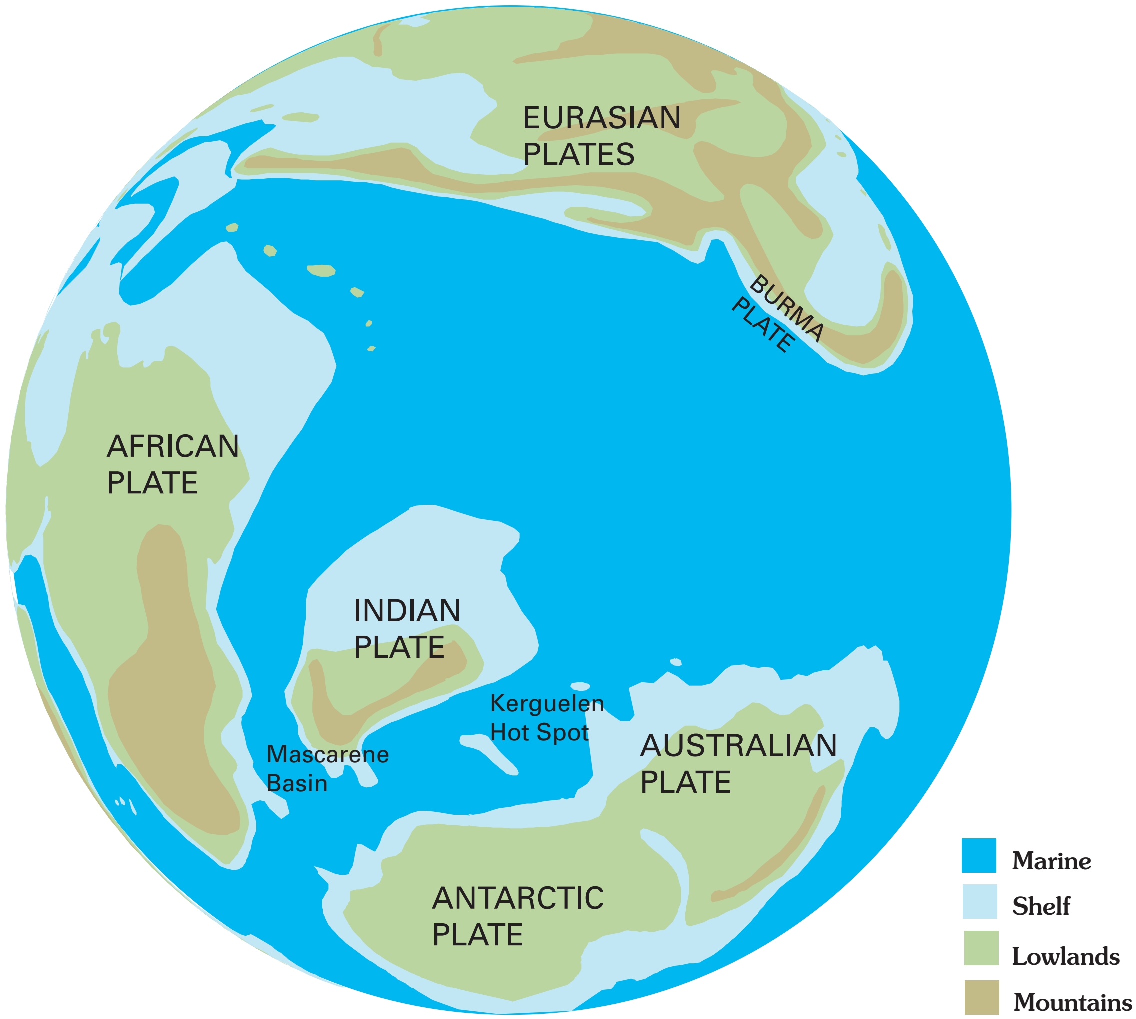


Figure 8. Late Cretaceous (approximately 94 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

northern Indian shelf and the area of the Burma plate. This shelf environment persisted through Late Cretaceous when regressive sandstones such as the Tura Formation in the east and Pab Formation in the west were deposited.

From Paleocene through middle Eocene time, shales of the Kanbala and Taunggale Formations were deposited in the Irrawaddy Delta and Prome Embayment areas. Upper Cretaceous–Paleocene Kabaw Group (the Laungshe Shale of Stamp, 1927) shales, limestones, and sandstones (fig. 5) were deposited in the Salin Basin. The lower Eocene Paunggyi Formation limestones rest unconformably on the Kabaw Group in the Salin Basin and conformably in the western Chindwin Basin (Bender, 1983). Overlying the Paunggyi Formation are the shales and sandstones of the middle Eocene Laungshe Formation of Bender (1983) (a different formation than the Laungshe of Stamp, 1927). Deposited on the Laungshe are the upper Eocene shales and sandstones of the Tabyin and Tilin Formations. Tabyin Formation shales have good source potential in the Salin Basin (Khin, 1991). Conformably overlying the Pondaung Formation (fig. 5) in the Central Basin, southwest Chindwin Basin, Prome Embayment, and Thayetmyo area are the shales and sandstones of the middle Eocene Yaw Formation. The eastern portion of the Central Burma Basin, which is part of the Asian plate, was emergent during the early Eocene. The area south of Mandalay and west of the Irrawaddy River was primarily a shallow marine environment, with the exception of the area of the present-day Indo-Burman Ranges (figs. 4 and 12). The area north of Mandalay and in the eastern Chindwin Basin was emergent with a shallow marine environment only in the west.

The Eocene to upper Miocene lower Pegu Group in the Salin Basin and Prome Embayment area contains many of the identified source rocks and reservoirs within the Eocene to Miocene TPS. For example, upper Eocene–lower Oligocene Shwezetaw or Kyaukpon Formations of the Pegu Group consist of shallow marine interbedded clays, shales, and sandstones.

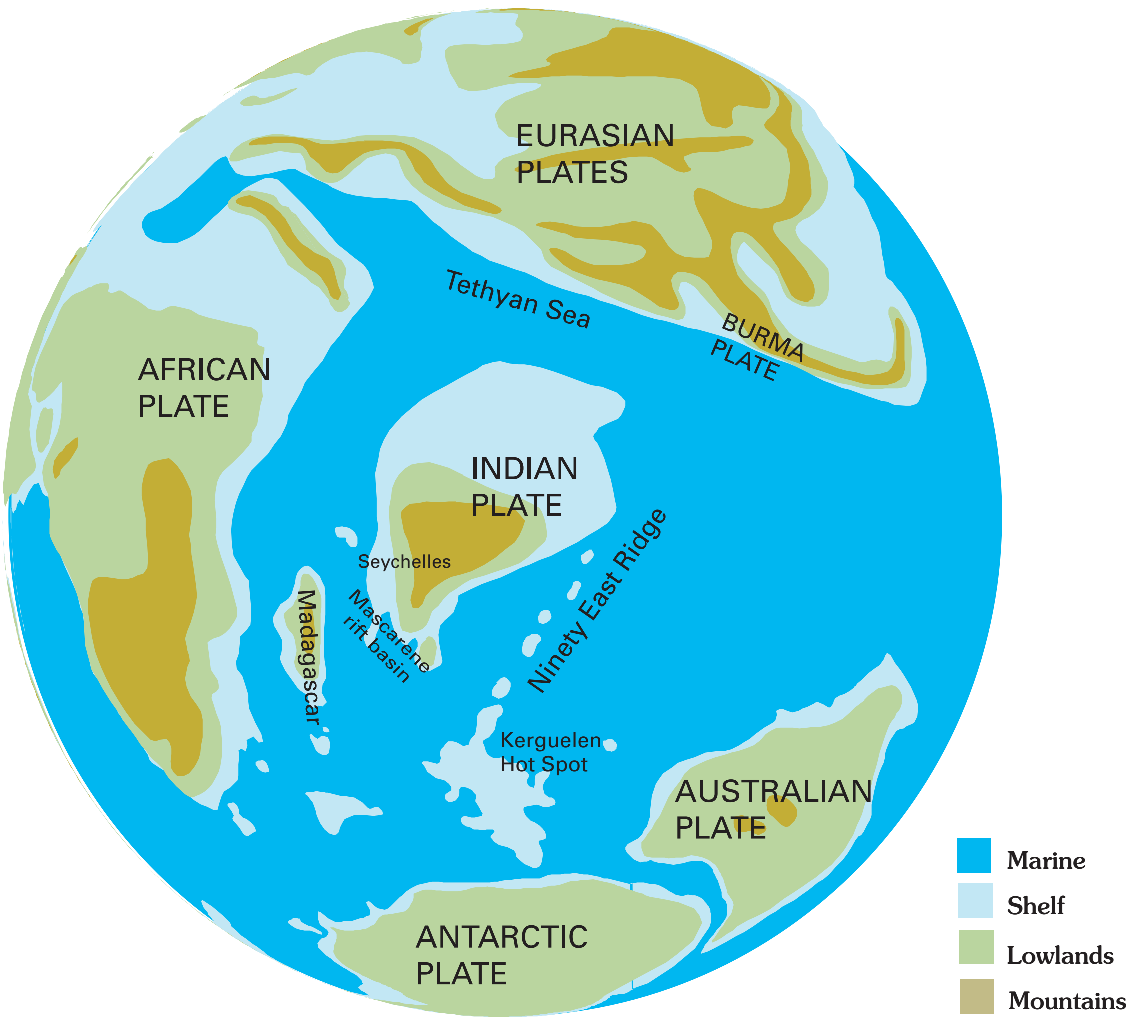


Figure 9. Latest Cretaceous (approximately 69 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

The Shwezetaw and Kyaukpon Formations contain both source and productive reservoir rocks, and they are conformably overlain by the Padaung Formation (fig. 5) clay and sandstone, which produces both oil and gas. Upper Eocene–lower Oligocene rocks were not deposited, or were eroded, in the western Irrawaddy Delta (Bender, 1983). Following this hiatus, shallow marine shales, sandstones, and limestones of the upper Oligocene Tumyaung Formation were deposited in the Irrawaddy Delta area. To the north, in the Prome Embayment and Salin Basin, the sandstones and limestones of the Okhmintaung Formation accumulated. On an unconformable late Oligocene surface marking the top of the Okhmintaung, as much as 1,000 m of sandy shales and fine- to medium-grained sandstones of the upper Oligocene–lower Miocene Upper Pegu Group Pyawbwe Formation was deposited. The Pyawbwe sandstones produce both oil and gas. As much as 1,500 m of sandstones of the lower to middle Miocene upper Pegu Group Kyaukkok Formation overlies the Pyawbwe Formation. The Kyaukkok Formation also produces both oil and gas. The middle Miocene Obogon Formation (as much as 1,000 m thick) consists of fine- to medium-grained sandstones, sandy shales, and siltstones. The unconformity at the top of the Obogon Formation marks the top of the Pegu Group. Deposited in alluvial environments, on the unconformable top of the Pegu Group, was as much as 3,000 m of nonmarine medium- to coarse-grained massive crossbedded sandstones, clays, and conglomerates of the upper Miocene to Quaternary Irrawaddy Group (fig. 13).

Today the total sedimentary column in the Central Burma Basin exceeds 12,000 m in places, with the greatest thickness in the Irrawaddy Delta and the thinnest along the east edge of the basin.

Exploration and Production

Oil seeps and production from hand-dug wells were reported in the Yenangyuang area as early as the thirteenth century. By 1797 production at Yenangyuang (fig. 14) from

Figure 10. Middle Eocene (approximately 50 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

several hundred hand-dug wells on 12.8-m spacing yielded a total of 200–400 barrels per day. Hand-dug wells were reported as late as 1949, and to be as deep as 120 m. In 1888, the first “drilled” (cable tool) well was brought in, and rotary drills were used as early as 1911 (Stamp, 1927). Although the total number of exploratory wells drilled was not large, successes continued until World War II, when the petroleum industry infrastructure was almost completely destroyed. Following that war, rehabilitation of the industry was slow. In 1959, the Payagon oil and gas field was discovered, and the rate of exploration increased (fig. 15). The oil industry was nationalized in 1965 and the national oil company Myanma Oil Company (MOC) was formed. In 1970 MOC discovered Mann oil field, and between 1972 and 1974 MOC drilled 12 wells in the Gulf of Martaban. That drilling effort resulted in several uneconomic gas discoveries. In 1974 MOC invited foreign oil companies to bid on offshore blocks. Thirteen offshore blocks were awarded. After numerous dry holes and one gas discovery off the Arakan coast, all of the blocks were relinquished by 1977.

Interest in offshore exploration was revived in 1982, when Yadana gas field was discovered 70 km offshore in the Irrawaddy Delta fan at a water depth of 45 m (fig. 14). Reserves are estimated at more than 5 trillion cubic feet of gas (TCFG), with the nearby Sein and Badamyar discoveries adding 0.7 TCFG of reserves. Total Myanmar Exploration and Production (TMEP), Unocal, Petroleum Authority of Thailand Exploration and Production International Limited (PTTEP), and Myanma Oil and Gas Enterprise (MOGE), in a joint venture, began development of the field in 1992, and in 1998 Yadana field came on line (www.energy.gov.mm/MOGE; accessed 2003). Yetagun gas field, with reserves in excess of 3 TCFG and 80 million barrels (mmb) of condensate, in the Taninthayi offshore area of the eastern Andaman Sea (fig. 14), was discovered in 1992 (www.energy.gov/mm/MOGE_2.htm; accessed 2003). As demand for gas in the region increases and

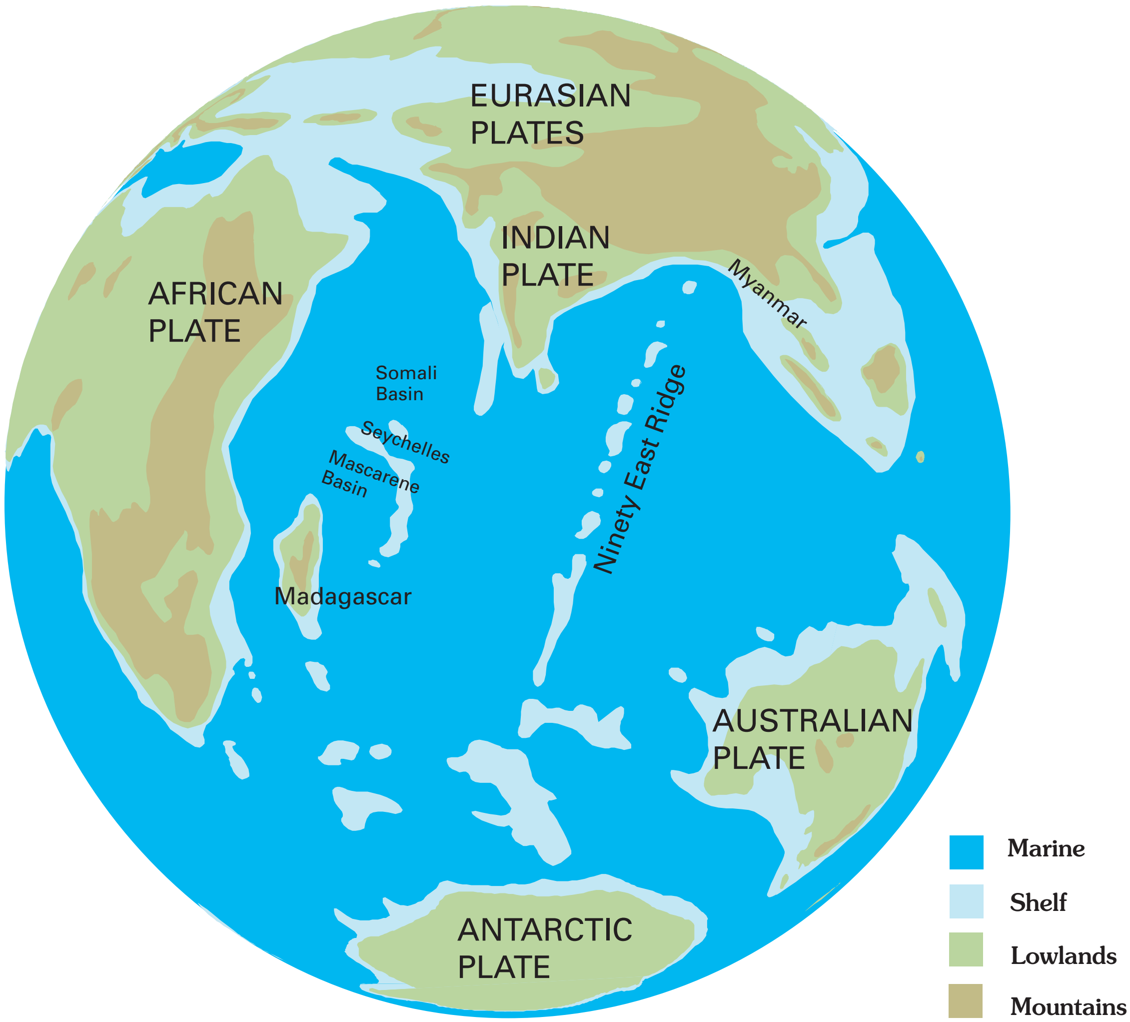


Figure 11. Late Oligocene (approximately 27 Ma). Perspective lat 20° S., long 68° E. (modified from Scotese and others, 1988, and Scotese, 1997).

a pipeline system is developed, further exploration and development in the area are likely. Recently a large gas discovery has been made off the west coast of Myanmar.

Within the Central Burma Basin at least 59 fields were discovered between 1864 and 1996 (Petroconsultants, 1996). These fields contain at least 76 reservoirs that have produced oil, gas, or condensate. The largest fields are Yenangyuang (>200 mmbo), Yadana (>5 TCFG), and Yetagun (>3 TCFG) discovered in 1889, 1983, and 1992, respectively (fig. 14).

The plot of cumulative new-field wildcat wells versus completion year for the Irrawaddy-Andaman geologic province (fig. 15) shows that, although the total number of exploration wells drilled is low, the rate of exploration increased substantially in the 1960s and the rate has remained relatively constant since the 1970s.

The plots of known oil and gas fields ranked by size and grouped in thirds by date of discovery do not show a significant decrease in field size in progressive thirds (fig. 16). The small decrease in field size through time indicates that the province is still not mature in terms of exploration; a mature province would show a larger decrease in field sizes between the first and third thirds. The largest fields were found in the first and third thirds for oil and the second and third thirds for gas. Known field size versus discovery year plots (fig. 17) also show that relatively large gas fields are still being found.

The plots of cumulative volume of known (cumulative production plus proven reserves) oil and gas versus the field discovery year (fig. 18) show recent large increases in cumulative known volumes. The reservoir depth versus field discovery year plots (fig. 19) indicate that, although generally deeper, in some cases the reservoirs found later were very shallow. This may indicate that significant resource is to be found that was previously bypassed. These are also areas where seismic data acquisition and interpretation are difficult. Application of the most recent seismic technology and methods to these areas may reveal additional shallow traps. Note that data for gas

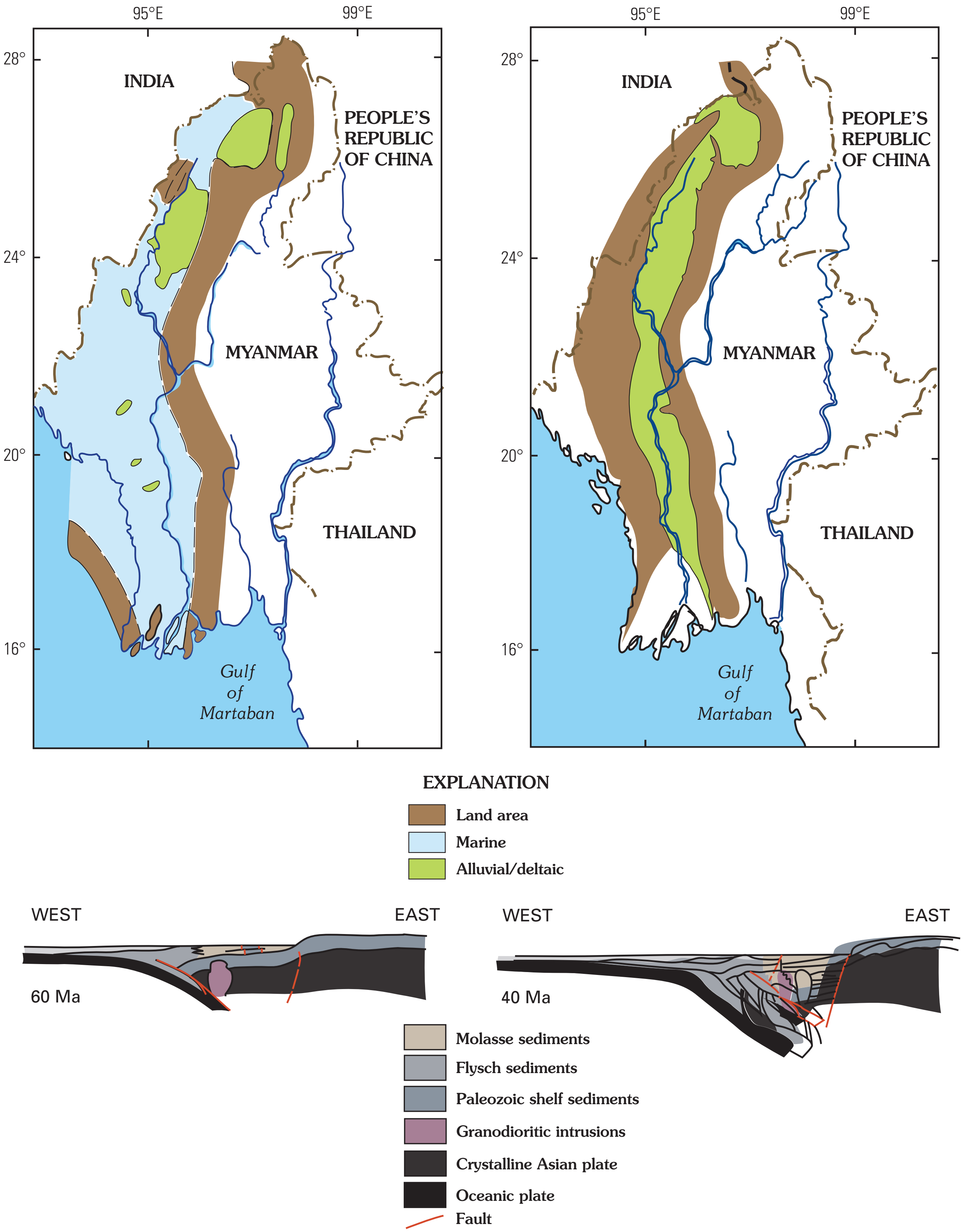


Figure 12. Generalized early (left) and late (right) Eocene paleogeography (modified from Khin and Win, 1968) and associated cross sections near lat 20° N. (modified from Bannert and Helmcke, 1981).

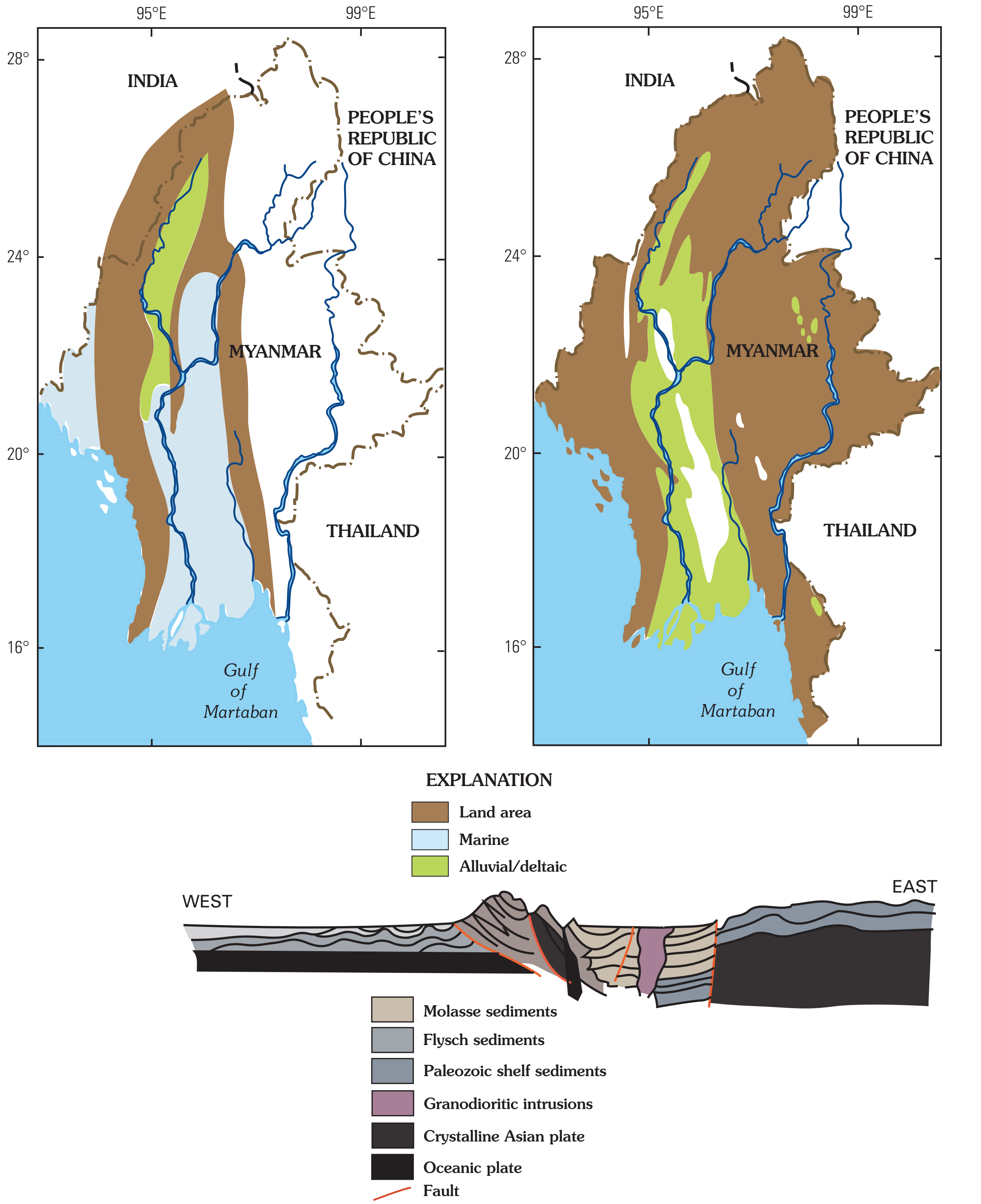


Figure 13. Generalized early Miocene (left) and Pliocene (right) paleogeography (modified from Khin and Win, 1968) and recent cross section near lat 20° N. (modified from Bannert and Helmcke, 1981).

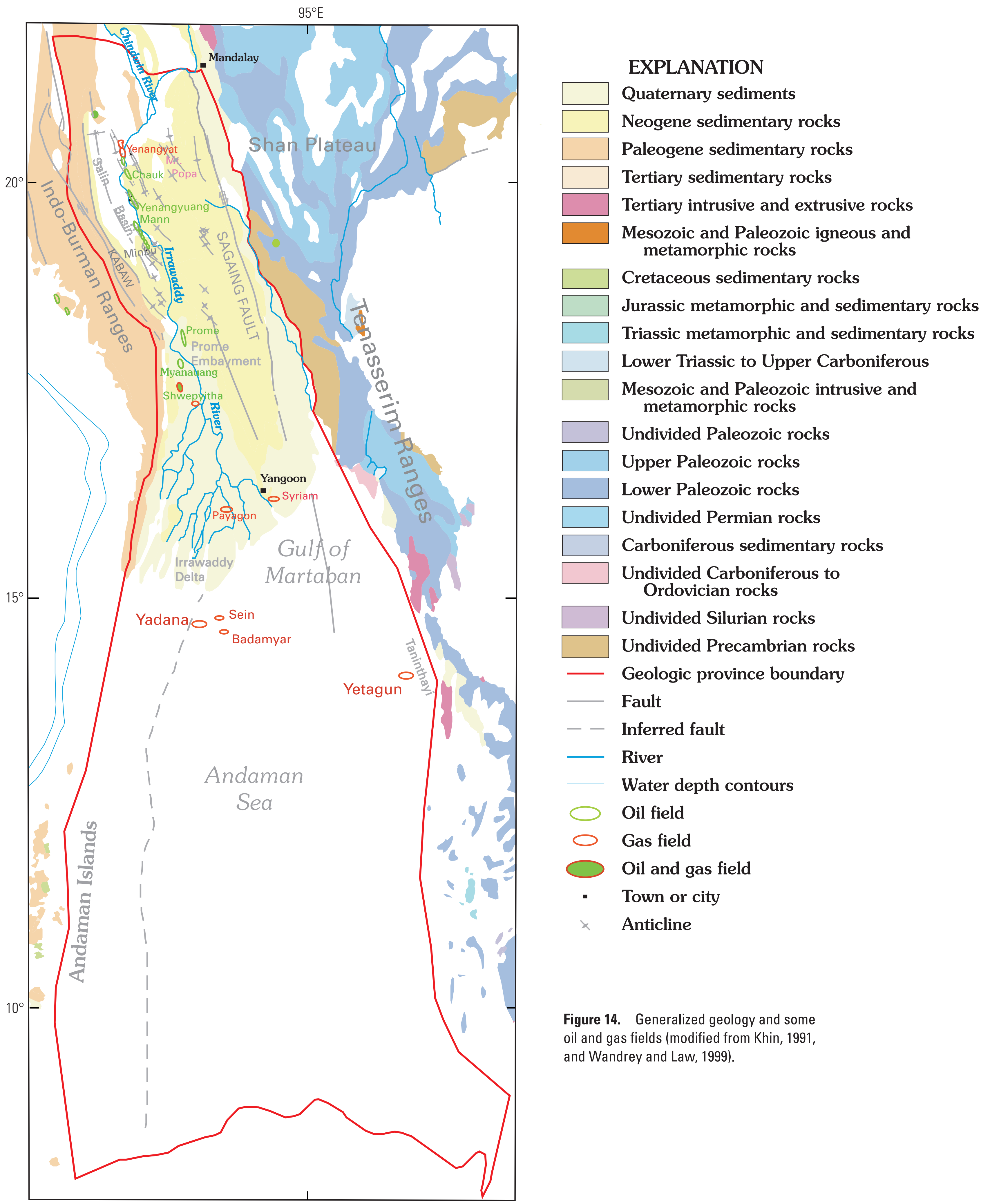


Figure 14. Generalized geology and some oil and gas fields (modified from Khin, 1991, and Wandrey and Law, 1999).

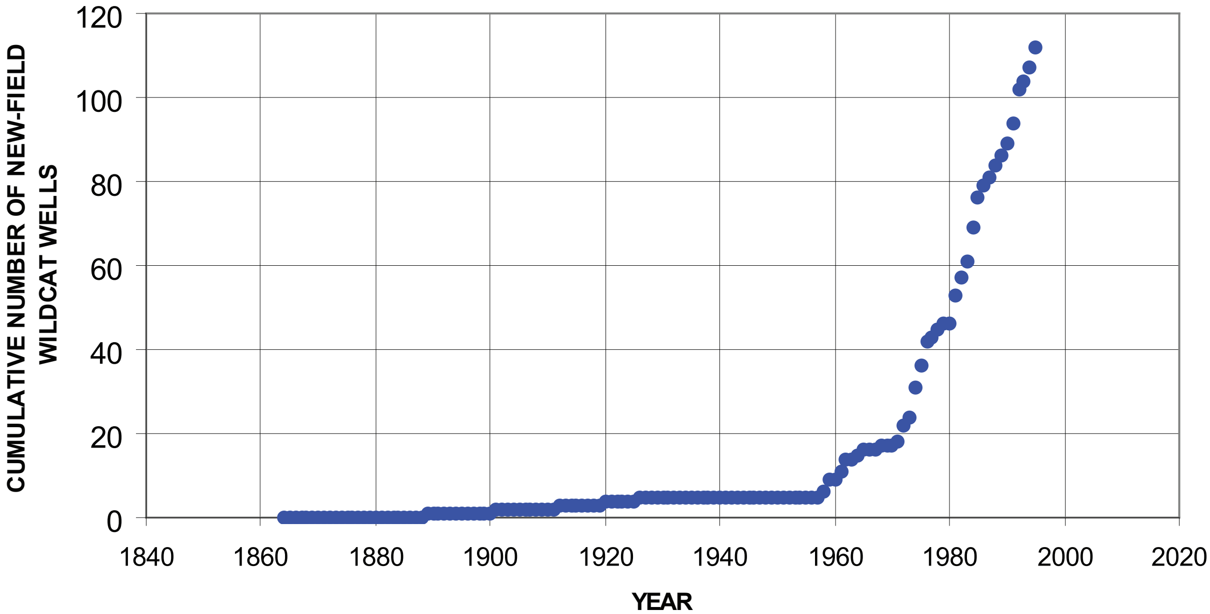


Figure 15. Cumulative number of new-field wildcat wells versus completion year for the Irrawaddy-Andaman geologic province (Petroconsultants, 1996).

discoveries do indicate a slight trend toward deeper discoveries. Exploration strategies designed to find larger commercially viable gas fields offshore are driving this trend toward deeper drilling.

Exploration is presently controlled by the limited market for gas within Myanmar as well as the neighboring countries of Thailand and Bangladesh. When gas demand increases, exploration for and development of Myanmar's gas potential will likely accelerate.

Total Petroleum System

The USGS recognizes several petroleum systems within the Irrawaddy-Andaman and North Burma geologic provinces. For assessment purposes, however, they were combined into one composite petroleum system, the Eocene to Miocene Composite Total Petroleum System (804801). This combination was made because correlations between source rocks and reservoir hydrocarbons were available for only the Central Burma Basin at the time of the assessment. Oil analyses indicate Eocene and Oligocene–lower Miocene sources (Curiale and others, 1994; M.D. Lewan, oral commun., 1998). Multiple stacked source and reservoir rocks, connected by extensive fault systems, allow mixing of hydrocarbons; this makes identification of distinct TPS difficult.

The rocks that compose this TPS are of Eocene through middle Miocene age (fig. 23). These formations include carbonates, shallow marine shales and sandstones, and the sandstones, siltstones, shales, and coals of deltaic, alluvial, and lagoonal facies.

Source Rocks

The primary source rocks identified in the Central Burma Basin are the middle Eocene Tabyin/Tilin, Taunggale, and Laungshe Formations; upper Eocene Yaw Formation; lower Oligocene Shwezetaw, Padaung, and Okhmintaung Formations (Khin, 1991) (fig. 5). Up to 1,200 m thick, the Tabyin Formation consists of weathered clays with coal particles, platy limestone, lignite seams, and thin tuffaceous sandstone layers that increase in number to the north (Cotter, 1914). The Yaw Formation consists of as much as 300 to 600 m of shales, interbedded limestones, and bituminous coal in the Chindwin Basin (Cotter, 1914). The Yaw Formation was primarily deposited in a marine environment in the western portion of the Central Burma Basin and lagoonal to alluvial environment in the eastern portion. The Shwezetaw Formation, as much as 1,200 m thick, consists of sandstones (calcareous in the lower part), shales, and thin coal seams deposited in shallow marine to alluvial environments (Vredenburg, 1922). The Padaung Formation consists of as much as 1,500 m of marine shales with interbedded sandstones that increase in thickness and frequency near the top of the formation (Bender, 1983). The Okhmintaung Formation consists of shallow marine sandstones, shales, and infrequent limestones.

Oligocene and Miocene source and reservoir rocks occur along the north, east, and west sides of the Andaman Sea, but near the spreading center sediment thickness was probably insufficient for generation to occur.

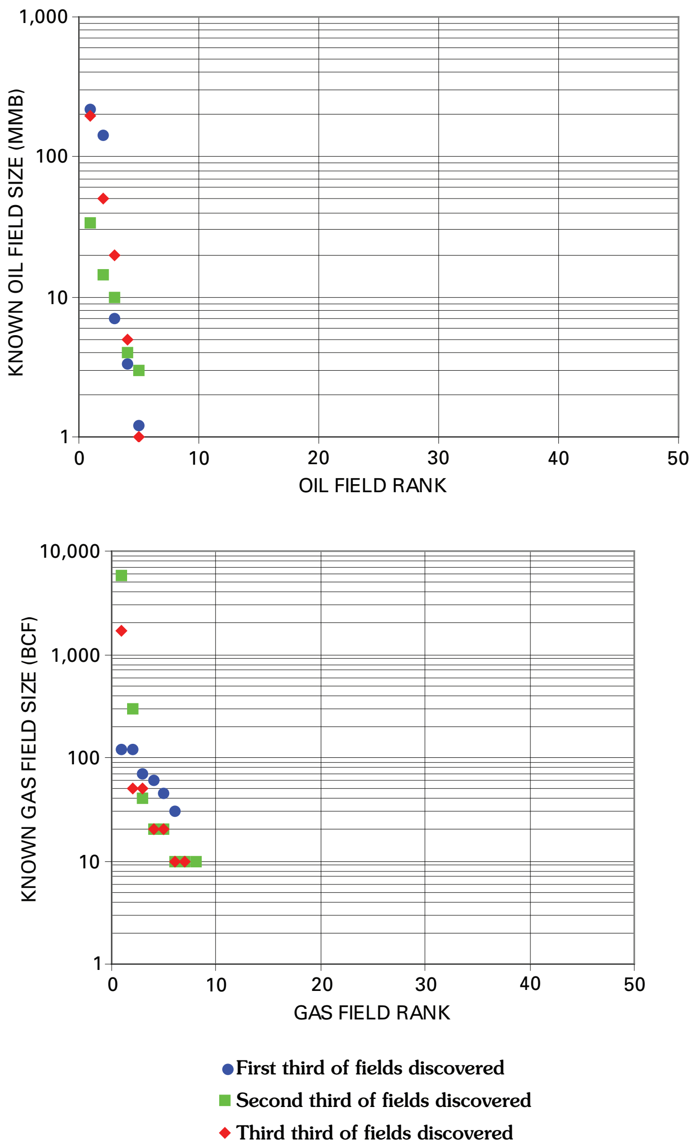


Figure 16. Known oil and gas field sizes grouped in thirds by discovery date and ranked by size for the Irrawaddy-Andaman geologic province (Petroconsultants, 1996).

Source Rock Richness

Total organic carbon (TOC) content is generally low where sampled, with a TOC minimum in the Gulf of Martaban of <0.2 percent and a maximum of 1.5 percent. The kerogen is primarily gas prone, terrestrial, type III in the Gulf of Martaban. API gravities of oils range from 8° to 52°. Sulfur content ranges from 0.01 to 0.23 percent. Curiale and others (1994) and Khin (1991) suggested that only one oil family is present in the Central Burma Basin and that variations in chemical characteristics of oil samples are due primarily to biodegradation. Khin (1991) also suggested a possible Mesozoic source in the Salin Basin, the Cretaceous Paung Chaung Limestone Formation of the Kabaw Group (fig. 5).

Maturation

Burial depths generally increase from north to south in the Central Burma Basin, with the youngest source rocks (Miocene) found in the Gulf of Martaban and northern Andaman Sea (Matthews and others, 2000). In the Salin Basin (fig. 3) the thermal gradient is low, with mature source rocks at depths of 4 km or greater (Khin, 1991; Curiale and others, 1994). Given the low thermal gradient, upper Eocene and lower Oligocene source rocks are likely to be the youngest mature rocks in the north. Elevated temperatures associated with the tectonic and volcanic activity are generally localized and would have had little effect on regional maturation (Barker and others, 1984). The R_0 value versus depth plot for the Gulf of Martaban indicates that rocks of Miocene age were sufficiently mature to generate oil and gas (fig. 20) (Bender, 1983).

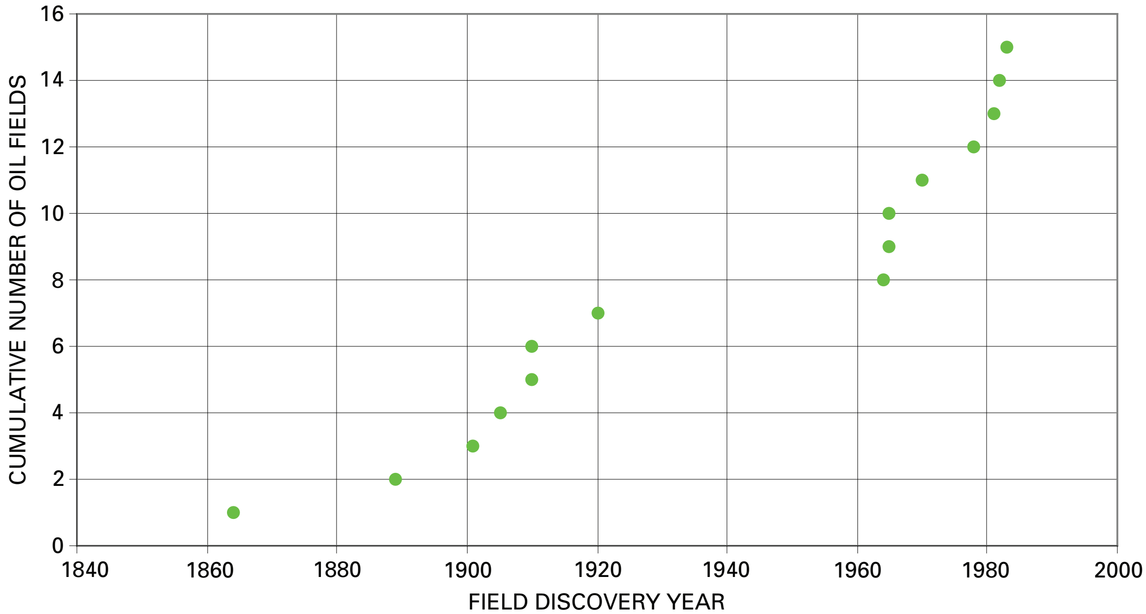
Samples taken from depths of 3,048 m in the Salin Basin have a maturity of 0.5 percent R_m. In order to reach thermal maturities sufficient for generation and expulsion, Khin (1991) suggested, the source must be deeper in the Salin Basin. Curiale and others (1994) argued that Eocene and lower Oligocene source rocks reached the minimum maturity required for generation. Further burial history data and collection of samples from greater depths may resolve this question.

Generation and Migration

The onset of generation may have been as early as late Miocene (12 to 8 Ma), and generation is likely continuing today in at least the northern part of the Central Burma Basin. Generation probably occurred first in the Gulf of Martaban and Irrawaddy Delta area where burial depths were the greatest. Miocene rocks in the deep basin entered the oil window 8 to 5 Ma, the "gas window" 6.5 to 5 Ma, and the "dry gas window" 6 to 4.5 Ma (Matthews and others, 2000). Migration is primarily into adjacent reservoirs and vertically through faults that developed during compressional stages that created the anticlinal structures present in the Central Burma Basin.

Reservoir Rocks

Reservoir rocks range through almost the entire stratigraphic section from Eocene to Miocene (figs. 21 and 23). Primary reservoir rocks include sandstones of the Eocene–lower Oligocene Shwezetaw, Padaung, and Okhmintaung Formations and the Miocene Pyawbwe and Kyaukkok Formation sandstones. These reservoir sandstones were deposited in alluvial, deltaic, and near-shore marine environments. Reservoir quality within the Pegu Group reservoirs varies throughout the province, with porosity ranging from less than 20 percent to more than 30 percent and permeabilities from less than 92 millidarcies to more than 3,200 millidarcies.



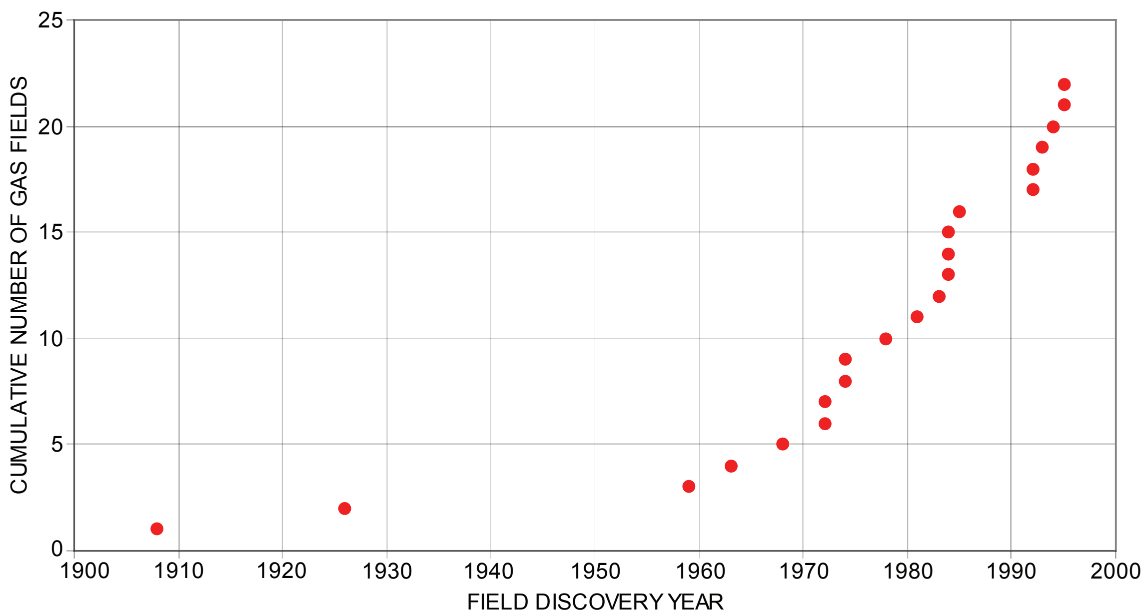


Figure 17. Cumulative number of oil and gas fields versus discovery year for the Irrawaddy-Andaman geologic province (Petroconsultants, 1996).

Traps and Seals

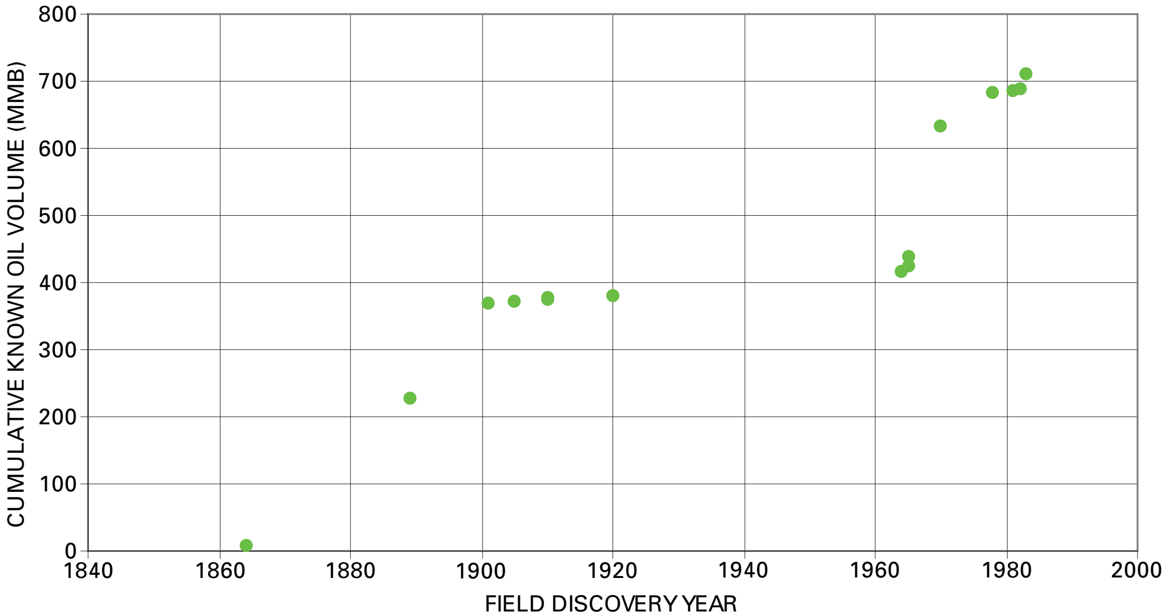
Anticlines, faulted anticlines, fault blocks, and stratigraphic traps are the primary traps (Petroconsultants, 1996) (fig. 22). Seals include interbedded Oligocene and Miocene shales and clays of the Pegu Group and overlying Irrawaddy Group.

The primary elements of the Eocene to Miocene Composite Total Petroleum System and their relationship to timing of events are shown in the events chart (fig. 23).

Assessment Units

The Eocene to Miocene Composite TPS was subdivided into two units for assessment purposes: these are the Irrawaddy-Andaman (80480102) Assessment Unit (AU) and the Central Burma Basin (80480101) AU (fig. 2).

The Irrawaddy-Andaman AU is located in the southern Central Burma Basin, the Irrawaddy Delta and Andaman Basin. It is a gas-prone onshore and offshore basin developed subparallel to the converging continental and marine plate



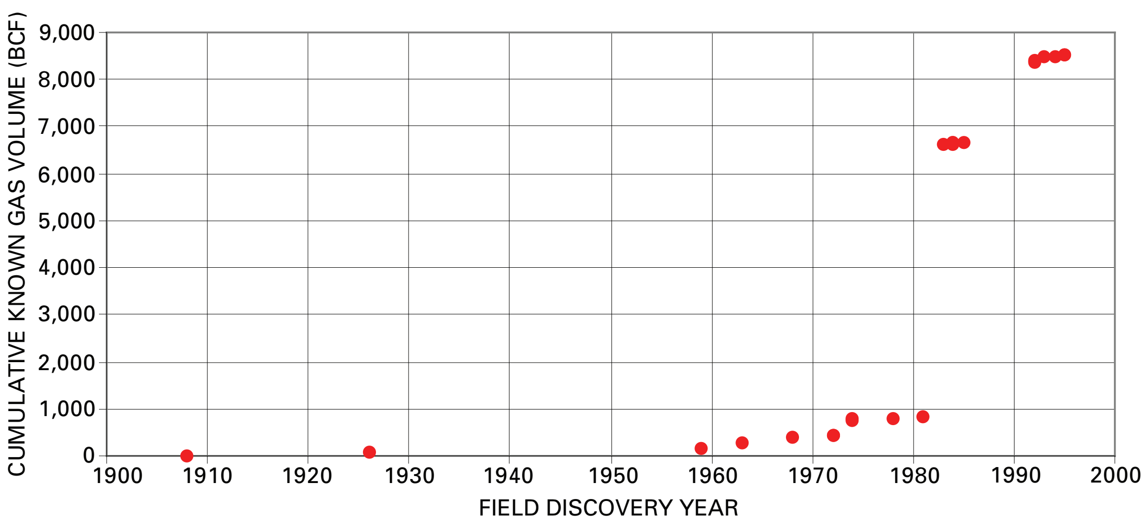


Figure 18. Cumulative known (cumulative production plus reserves) oil and gas volumes versus discovery year for the Irrawaddy-Andaman geologic province (Petroconsultants, 1996).

boundaries. The rocks that compose this assessment unit include Eocene sandstones and shales and the Oligocene-Miocene Pegu Group, with a thickness exceeding 6,500 m in places. This group is made up of interbedded, shallow marine shales, limestones, and sandstones, and the sandstones, shales, and coals of deltaic and lagoonal facies.

Source rocks include the lower Oligocene shales of the Yaw, Shwezetaw, and Okhmintaung Formations and shales of the Pegu Group. Total organic content is generally low (<1.75 percent) where sampled. Organic material is primarily terrestrially derived type III kerogen. Maturities are generally low, from R_0 0.2 to 1.7 percent where sampled in the Gulf of Martaban, but maturities are likely higher in areas of the basin where burial depths are greater.

Significant generation commenced during the Pliocene. Migration is primarily vertical through fault and fracture systems associated with the plate collision. These fault systems have been periodically reactivated through the present. Short updip migration along the flanks of the basin is also likely.

Primary reservoir rocks are interbedded sandstones of the Pegu Group. Reservoir quality is fracture enhanced in many cases. Traps include anticlines, faulted anticlines, and a few stratigraphic traps. Seals include interbedded Oligocene and Miocene shales and clays, and thick clays of the upper Miocene–Pliocene Irrawaddy Group. Although few stratigraphic traps have been discovered, potential exists for more discoveries in the deltaic sequences. There is also potential for growth-fault related traps in the offshore fans.

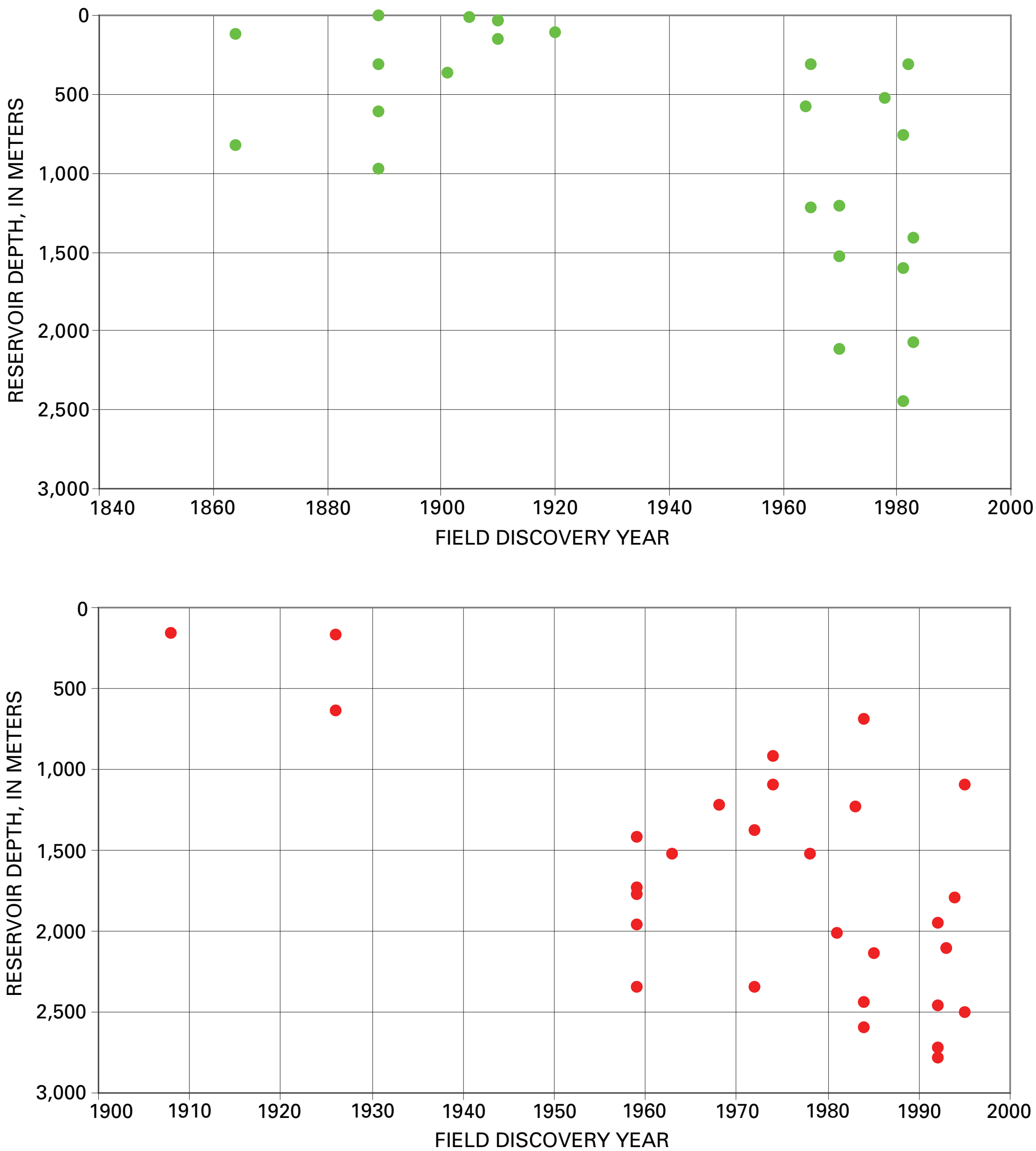


Figure 19. Reservoir depth versus field discovery year for oil (top) and gas (bottom) in the Irrawaddy-Andaman geologic province (Petroconsultants, 1996).

The Central Burma Basin AU is located in the north and central part of the Central Burma Basin of Myanmar. It is an oil-prone onshore basin developed parallel to the converging continental and marine plate boundaries. The rocks that make up this assessment unit include the Eocene Laungshe Shale, Tilin, and Pondaung Sandstones, and the Oligocene-Miocene Pegu Group, the latter exceeding 6,500 m in thickness. This group includes interbedded sandstones, shales, and coals of deltaic to fluvial facies, and shallow marine shales, limestones, and sandstones.

Source rocks include the upper Eocene–lower Oligocene shales of the Yaw, Shwezetaw, and Okhmintaung Formations. Total organic carbon content, generally low where sampled (less than 1.7 percent), is primarily terrestrially sourced type II and III kerogens. The onset of generation probably occurred in late Miocene. Migration is primarily over short distances, updip, and vertically through fault and fracture systems associated with the plate collision. These fault systems have been periodically reactivated through the present.

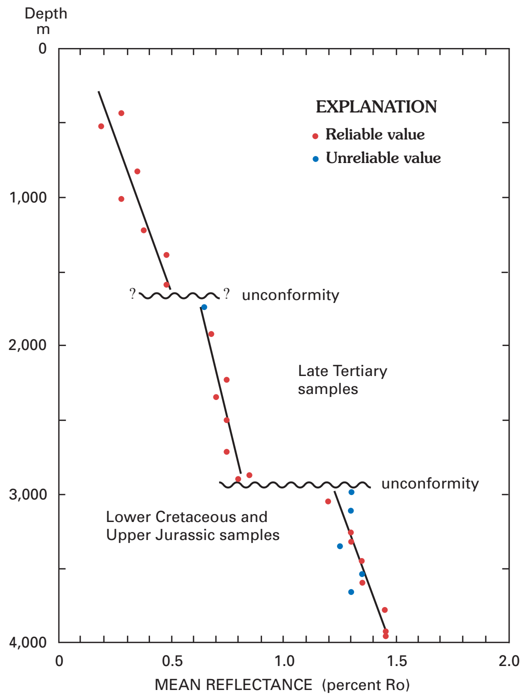


Figure 20. Mean vitrinite reflectance of rock samples in Gulf of Martaban (modified from Bender, 1983).

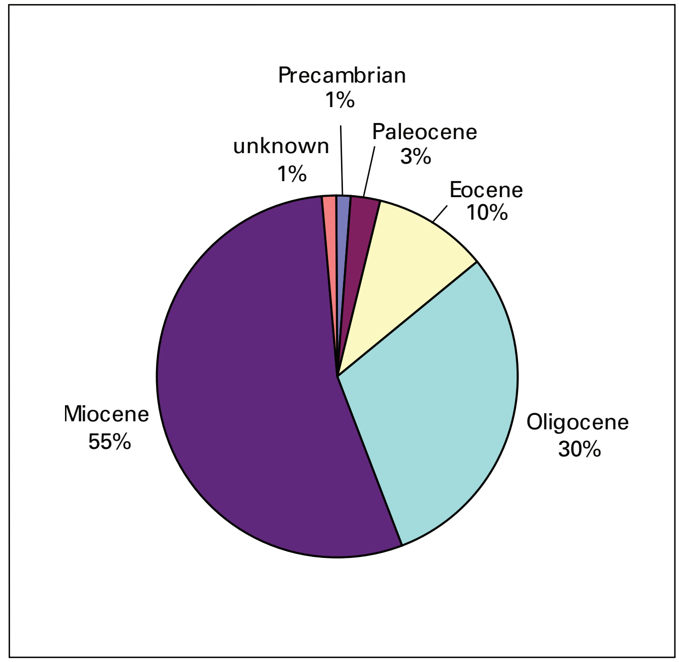


Figure 21. Temporal distribution of producing reservoirs by youngest age. Percentages represent number of reported occurrences by reservoir (IHS Energy Group, 2001).

Interbedded sandstones of the Pegu Group are the primary reservoirs. The Eocene Pondaung and Tilin sandstones may also have reservoir potential and have a combined thickness of as much as 3,500 m including the interbedded shales.

Traps include anticlines, faulted anticlines, fault truncations, and stratigraphic traps. Seals include interbedded Oligocene and Miocene shales and clays, and the thick clays of the upper Miocene and Pliocene Irrawaddy Group. Structures in the Chindwin Basin area and stratigraphic traps developed in alluvial and deltaic systems have been only lightly explored and may have significant potential.

Cumulative Production Data

Based on Petroconsultants International Data Corporation data to 1996, the Irrawaddy Province (8048) was ranked 103rd in the world (including United States provinces). This volume is approximately 0.1 percent of world volume excluding the United States. Known petroleum volumes are 0.7 billion barrels of oil (BBO) and 10.3 TCFG for a total of 2.5 billion barrels of oil equivalent (BBOE) including natural gas liquids (NGL).

Assessment Comparisons

Kingston (1986) estimated the mode of undiscovered petroleum resources in the Irrawaddy basin at 1.1 BBO and at <2.1 TCFG. Masters and others (1998) estimated the mean for undiscovered petroleum resources at 1.4 BBO for the Burma Basin and 6.2 TCFG for the Burma Basin and Andaman Sea. In this study mean undiscovered resources were estimated to be 725 mmbo and 20.5 TCFG (table 1).

Differences in estimates for undiscovered oil and gas result because the areas assessed are not the same size and significantly more data were available for the most recent assessment.

Summary

The Eocene-Miocene Composite Total Petroleum System has produced the majority of the hydrocarbons in the Central Burma Basin and Irrawaddy Delta. Structural traps are predominant, but stratigraphic traps are likely to be found in both ancient and modern delta environments.

Table 1. USGS estimates of undiscovered oil and gas resources by assessment unit and aggregated for the total petroleum system (Wandrey and others, 2000).

[MMBO, million barrels of oil. BCFG, billion cubic feet of gas. MMBNGL, million barrels of natural gas liquids. MFS, minimum field size assessed (MMBO or BCFG). Prob., probability (including both geologic and accessibility probabilities) of at least one field equal to or greater than the MFS. Results shown are fully risked estimates. For gas fields, all liquids are included under the NGL (natural gas liquids) category. F95 represents a 95 percent chance of at least the amount tabulated. Other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. Shading indicates not applicable]

Code and Field Type	MFS	Prob. (0-1)	Undiscovered Resources											
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
80480101 Central Burma Basin Assessment Unit														
Oil Fields	1	1.00	75	446	1,192	516	158	951	2,751	1,134	9	55	171	68
Gas Fields	6						133	759	2,011	874	4	26	73	31
Total		1.00	75	446	1,192	516	291	1,709	4,763	2,008	13	81	244	99
80480102 Irrawaddy-Andaman Assessment Unit														
Oil Fields	1	1.00	27	177	498	209	197	1,285	3,903	1,563	11	74	242	94
Gas Fields	6						3,710	14,982	36,669	16,949	125	513	1,327	593
Total		1.00	27	177	498	209	3,908	16,266	40,572	18,512	136	587	1,569	686
804801 Total: Eocene to Miocene Composite Total Petroleum System														
Oil Fields		1.00	102	624	1,690	724	356	2,235	6,654	2,697	20	130	413	162
Gas Fields							3,843	15,740	38,680	17,824	129	539	1,399	623
Total		1.00	102	624	1,690	724	4,199	17,976	45,334	20,521	149	669	1,813	785

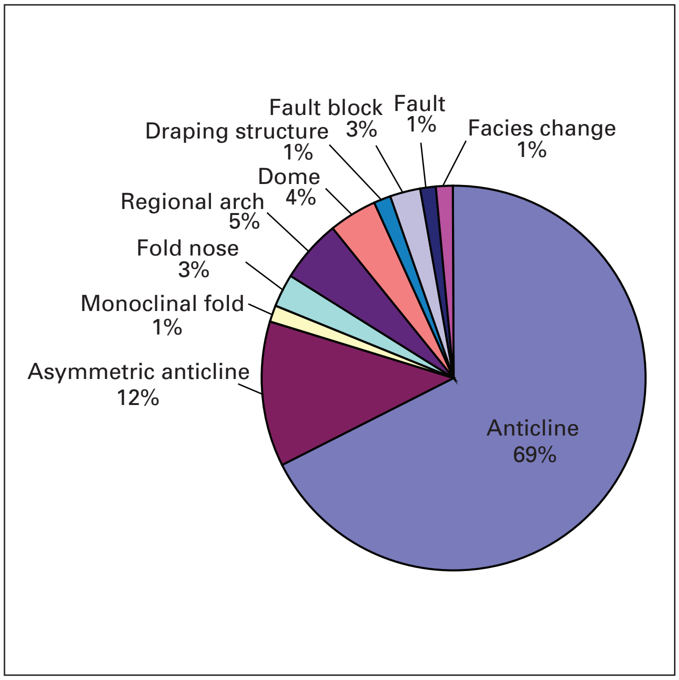


Figure 22. Distribution of trap type. Percentages represent number of reported occurrences (IHS Energy Group, 2001).

Favorable elements of this petroleum province are suitable organic material, sufficient maturation, ongoing charging of reservoirs, short near-vertical migration paths, and early trap formation.

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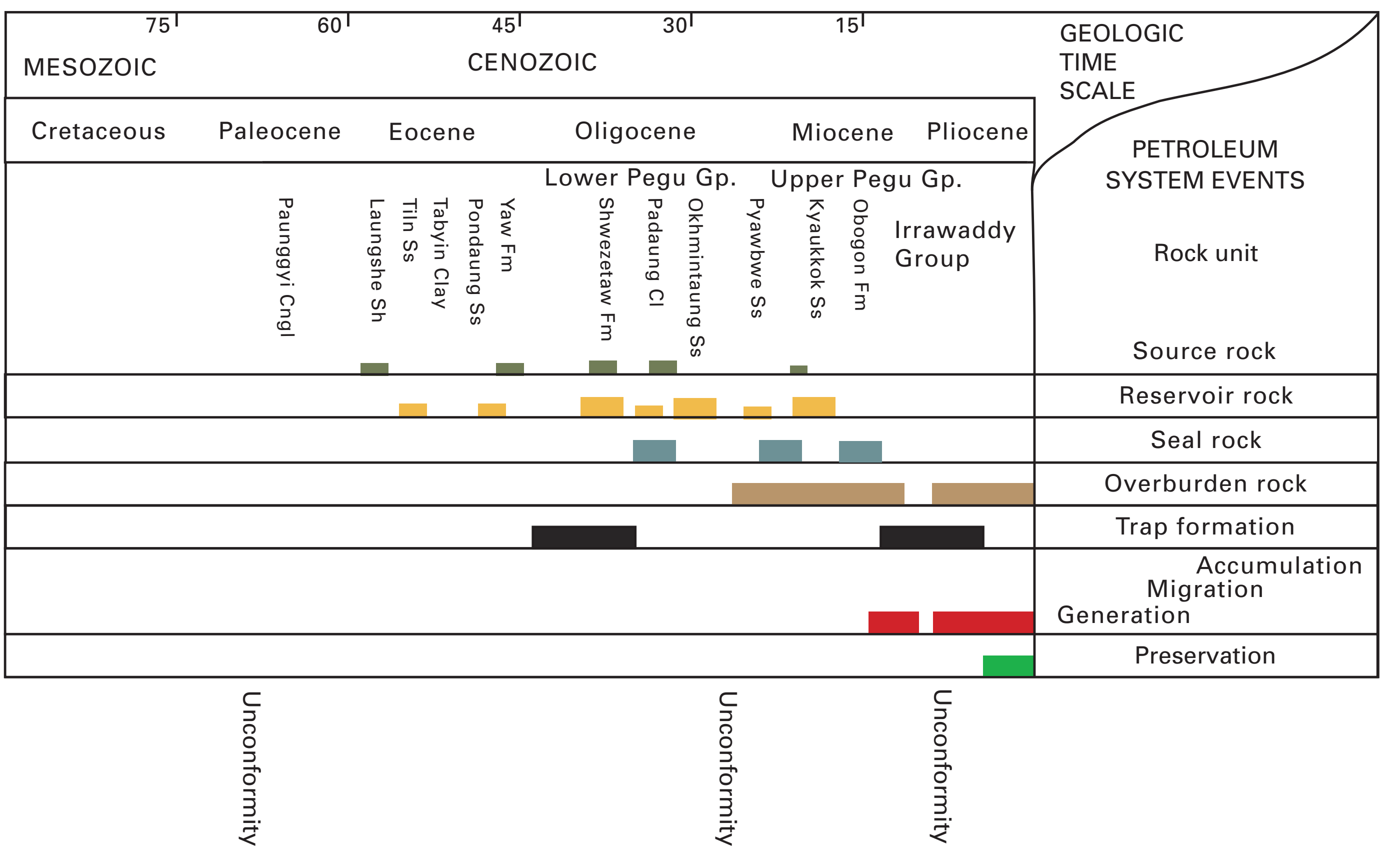

Figure 23. Events chart summarizing stratigraphy, source rocks, reservoirs, seals, traps, timing, and petroleum information for the Eocene to Miocene Composite Total Petroleum System.

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