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A GEOLOGIC EVALUATION OF THE HYDROCARBON POTENTIAL OF THE BENGAL DELTA, BANGLADESH

A THESIS SUBMITTED TO THE GRADUATE DIVISION OF THE
UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT
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MASTER OF SCIENCE

IN GEOLOGY AND GEOPHYSICS

MAY 1987

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By

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ABSTRACT

The Bengal Delta (Bengal Basin) began to form in the Early Oligocene following the collision of the Indian and Eurasian plates; the later history of the delta is directly related to the orogenic activity in the Himalayas.

Large scale basement faulting in Bangladesh has divided the Bengal Basin into a northwestern stable shelf and a southern foredeep. There is greatly reduced sediment thickness in the stable shelf region compared to the foredeep area which is covered by a thick sequence (about 60000 ft) of monotonous Tertiary sand and shale derived from the denudation of the Himalayas. The Bengal Basin is an asymmetrical basin. Sedimentary and seismic data indicate that the basin formed as a result of sedimentation associated with a number of transgressive and regressive marine phases, which occurred throughout the Tertiary period. Two prominent marker horizons occur in the stratigraphy, i.e. the Eocene fossiliferous limestone and an Upper Miocene "Upper Marine Shale", which may be used for basin wide correlation.

Isopach maps of the Miocene Surma Group of sediments indicate that basin sedimentation took place in a number of depocenters that shifted position throughout the Tertiary. The depobasins show a deepening towards the south.

Lithologic data, derived from hydrocarbon exploration, from Oligo-Miocene sequences show a dominance of shale in most of the

wells. Thicker sandstone layers however, occur in the eastern Titas, Rashidpur and Beani Bazar areas.

Like other major deltas (Mississippi and Niger), the Bengal Delta has been actively explored for hydrocarbons. However, with over seventy years of exploration no oil has been discovered. Nevertheless, thirteen trillion cft. of natural gas of marine origin have been reserved in the Miocene rocks of Bangladesh.

The temperature and maturation history of the Bengal Delta suggests that the gas formed within the "Oil Window". Considerable evidence exists that liquid hydrocarbons have migrated towards the east following formation. Migration distances of the Chhatak and Sylhet gas deposits have long (2-5 km) migration indications whereas the gas deposits of the Titas show considerably less movement.

Paleogeography, sediment behavior and regional geology suggest that the basal Barail rocks of the Oligocene and downdip areas of the Miocene gas layers have good potential for the occurrence of liquid hydrocarbon in structural traps. Additionally, the paleohighs in the eastern part of the country and the flank of the Surma Basin are areas of interest for potential hydrocarbon exploration. Many of the highly prospective areas are yet to be drilled in Bangladesh.

ACKNOWLEDGEMENTS

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Special acknowledgement is extended to my brother Dr. Kamaluddin, who coordinated the transfer of data from Bangladesh to Honolulu, Hawaii, and to my mother for her support and best wishes from home. I wish also to acknowledge Ashraf Chowdhury and Shagufta Jabeen for their assistance in many aspects of the work. Finally, I wish to thank my wife, Jasmine, for her assistance and support throughout my work.

We certify that we have read this thesis and that, in our opinion, it is satisfactory in scope and quality as a thesis for the degree of Master of Science in Geology and Geophysics.

THESIS COMMITTEE

Chairperson

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Many of the major delta areas of the world have been the source of major liquid and gaseous hydrocarbon production. In general, delta areas are considered as possible areas for the generation and concentration of hydrocarbon for the following reasons:

a) Delta sedimentation normally involves large and rapid deposition of sediments within a relatively rapid downwarping area. As a result, delta areas commonly contain both structural and stratigraphic traps.

b) Deltas normally contain extensive areas of thick sand which provide potential reservoirs for hydrocarbon accumulation.

c) Deltaic areas have high bioproductivity which may contribute significantly to potential source beds for hydrocarbon generation.

d) Because of thick sediment accumulation and downwarping most deltas have a thermal maturation history condusive to the formation of oil and gas.

Deltas however, are extremely complex geologic phenomena and detailed studies are required to define possible hydrocarbon formation, migration and accumulation that leads to effective exploration and evaluation.

METHODOLOGY OF STUDY

Most of the major deltas of the world, like the Niger of Nigeria and the Gulf of Mexico of the south coast of USA, have been studied in great detail and considerable numbers of oil and gas deposits have been discovered.

The Bengal Delta is one of the largest deltas in the world and as such is considered a promising area for the discovery of large quantities of hydrocarbons. Within Bangladesh Quaternary sediments, exceeding 35000 feet in thickness and comprising a large portion of the entire Ganges/Bengal Delta, were deposited by the Ganges-Brahmaputra river system. During Eocene to Pliocene time the delta was the site of large scale sedimentation. Subsequent Pliocene-Pleistocene alluvial deposits completely covered the earlier deltaic deposits. Tertiary rock sequences within the basin increases in thickness from west to east and from north to south. The basin is thus asymmetrical. Subsequent deformation compressed these Tertiary sediments into long and narrow folds which have been explored for petroleum. The search for oil within Bangladesh has been going on since 1910's and has resulted in the discovery of over 13 trillion cft of natural gas. To date the lack of significant discoveries of oil in Bangladesh suggests that perhaps the Bengal Delta do not have the same potential for hydrocarbon accumulation as other deltas internationally. However, hydrocarbon development and accumulation is dependent on many geologic factors and unlike other deltas, where oil and gas has been discovered, the Bengal Delta is less well studied. As a result many important aspects of hydrocarbon accumulation are not known. Therefore the Bengal Delta may actually be more similar to other deltas than would be inferred from present studies, but appeared less favorable only because insufficient geologic studies have been undertaken. The purpose of the present study is to address many of these uncertainities and to develop a more comprehensive knowledge of this most important Delta. Emphasis of the study will be to focus on the geomorphology, stratigraphy, structure and geological history, sediment maturation, geophysical interpretation and status of the hydrocarbon potential of the region.

Data for this study were collected by initially travelling to Bangladesh, and by gathering information from the national geological and industrial agencies who are presently, or have in the past, worked on the Bengal Delta. Among the most significant are the research conducted by the Bangladesh Oil, Gas and Mineral Corporation (BOGMC), formerly known as Oil and Gas Development Corporation (OGDC) and later Petrobangla. Data collected included Electric (Spontaneous Potential and Resistivity) logs (E-logs) of few wells, published and unpublished reports on structure and tectonics, geological history, stratigraphy (conventional, seismo), borehole temperature and pressure, petrophysical reports of a few wells and reports on hydrocarbon potentials. Access to some reports was limited as much of the data has been designated as classified by the BOGMC authority.

All the available literature were studied, compared and compiled into the format of the present research and reproduced. Stratigraphic and facies maps, drawn on the basis of E-logs, included sand-shale ratio maps, sandstone-shale percentage maps and isolith maps of the respective lithologies. A stratigraphic panel diagram was also compiled on the basis of information obtained from the well logs.

A part of the research included a comparison of the Bangladesh data with data of the Mississippi and the Niger Delta to assist in a reinterpretation and evaluation of the Bengal Delta.

As access to data was limited for the present program, modification to the overall research project had to be made in order to insure the timely completion of the work.

GENERAL GEOLOGY

Bangladesh constitutes the eastern continuation of the central broad Indo-Gangetic plains portion of India, dividing the Peninsular (shield area) of the south from the Extra-Peninsular (Himalayan mountain ranges) of the north and northeast (Fig. 1).

The oldest exposed rocks in Bangladesh are of Tertiary age which outcrop in the southeast and northeast of the country (Fig. 2). Pleistocene rocks outcrop sporadically in the form of a few inliers dissected by streams. A Pleistocene coralline bed occurs on St. Martins Island offshore of southeastern Bangladesh. The remainder of the country is comprised predominantly of recent alluvial deposits which locally contain peat of commercial quantity.

The exposed Tertiary rocks are mostly of thick monotonous sand-shale sequences with small nonclastics. Pleistocene Inliers are made of mottled red clays.

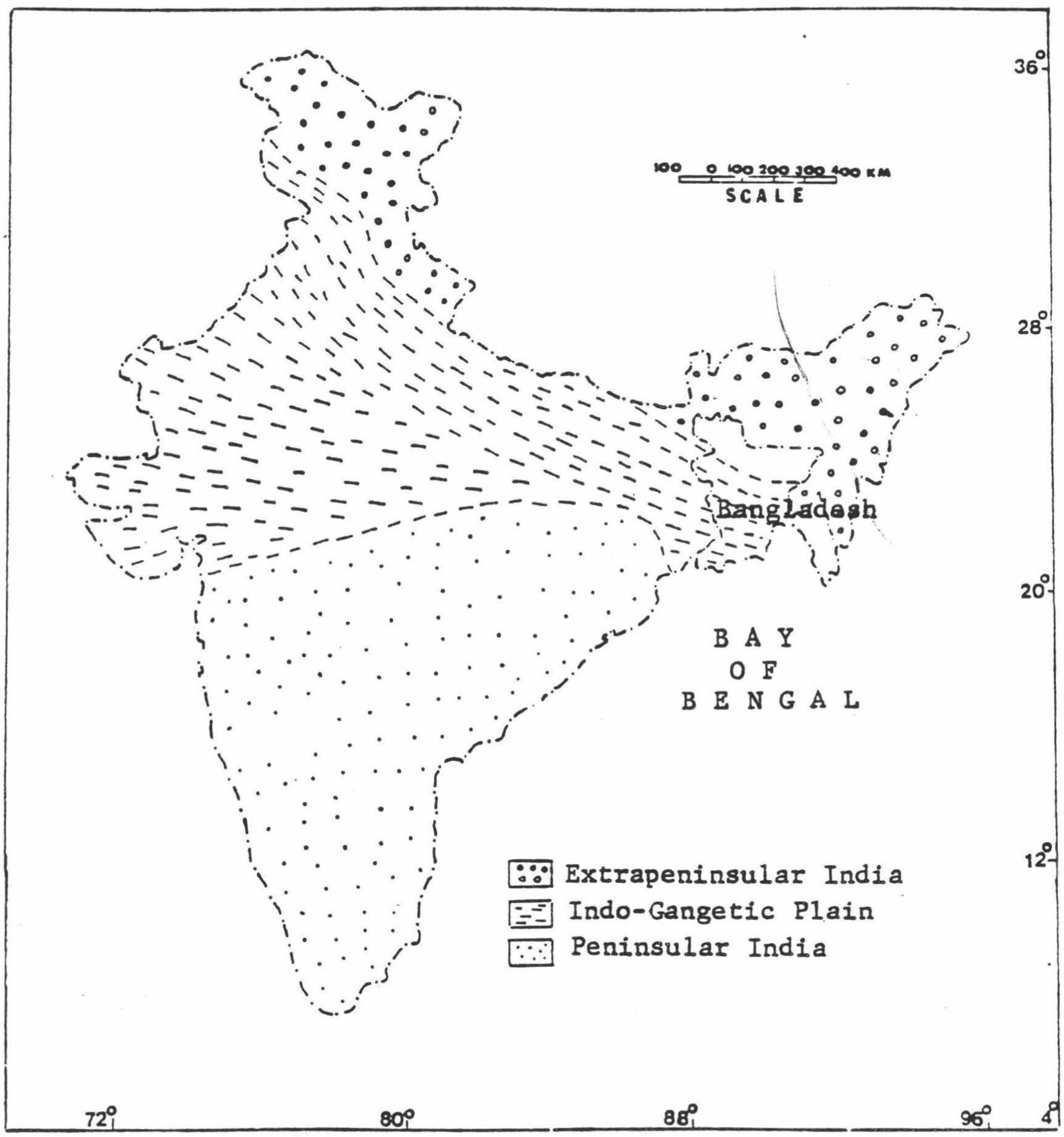

Figure 1. Location of Bangladesh in the Indo-Gangetic Plain division of India.

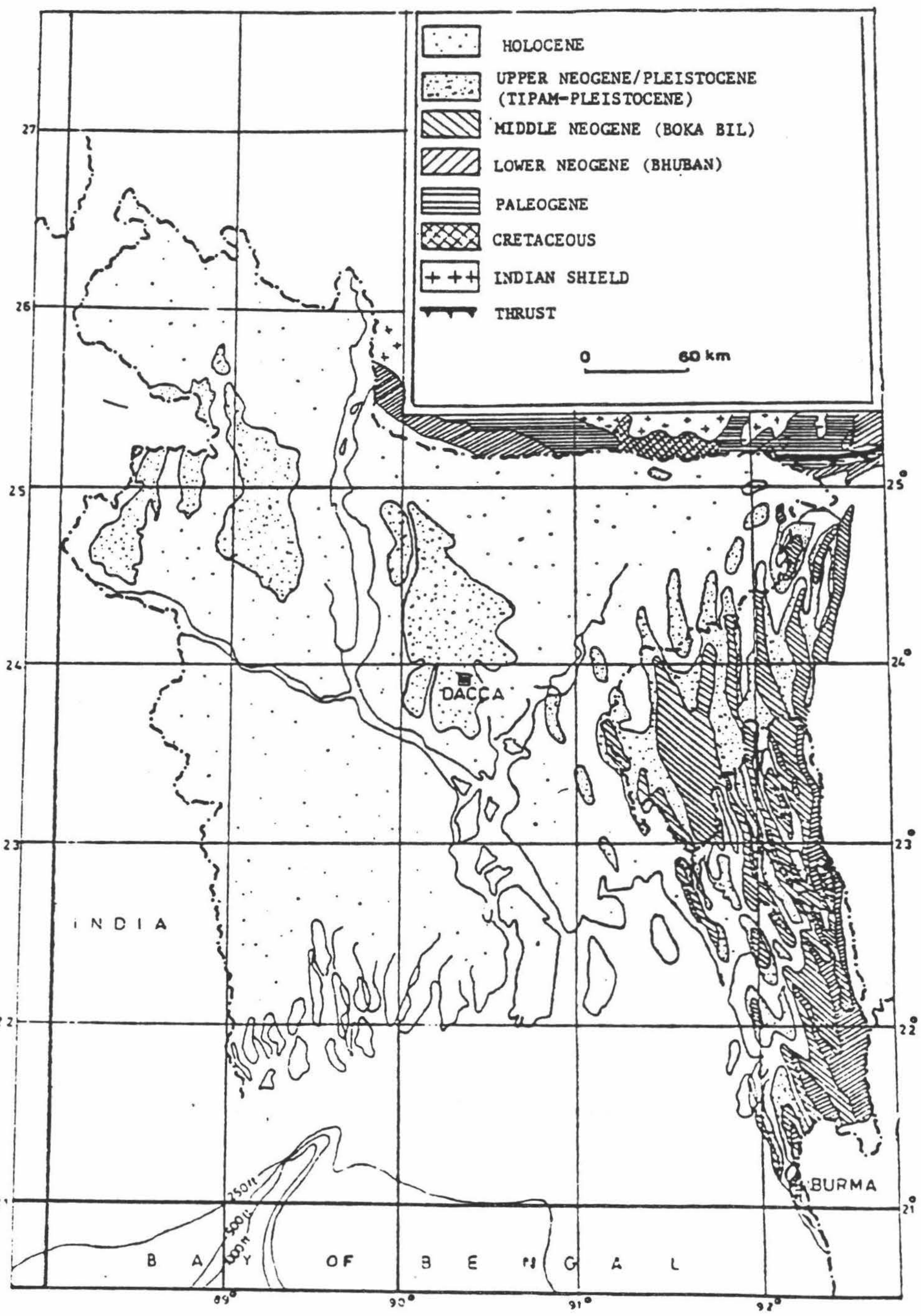

Figure 2. Geological sketch map of Bangladesh.

source: Brunnschweiler (1978)

LOCATION AND PHYSIOGRAPHY

Bangladesh has an area of about 55000 sq. miles (144,000 sq. km.) and lies roughly between 20° 34'N to 26° 38'N latitudes and 88° 01'E to 92° 41'E longitudes. The major tectonic feature of the country is the Bengal Delta, also known as the Ganges Delta, which is located primarily in Bangladesh and part of the West Bengal state of India. The Bengal Delta is frequently referred to in the literature as the Bengal Basin.

The Bengal Delta is surrounded by India on three sides. The Shillong Plateau of Assam lies to the immediate north and the Himalaya to the distant north. The Indo-Burmese Arakan-Chin Hills geanticline lies to the east and the Indian Shield to the west. The area is open on the south and extends into the Bay of Bengal (Sengupta, 1966) (Fig. 3). The climate of Bangladesh is characterized by high temperatures, rainfall, humidity and marked seasonal variations. The average temperature varies from 50° F to 95° F. The Nor'westers (North Westerlies), S.W. Trades and winter depressions are the main sources of rainfall in Bangladesh. Mean annual rainfall varies from 50 inches (127 cm) in the west to above 200 inches (508 cm) in the northeast of the country.

Bangladesh is a land of rivers (Fig. 4). Three major rivers - the Ganges, the Brahmaputra and the Meghna drain the country from three different directions. These three rivers and their numerous tributaries and distributaries make the Bengal/Ganges Delta one of the largest in the world (Coleman, 1969 and Islam, 1978). The Ganges flowing along the southern slope of the Himalaya carries an annual

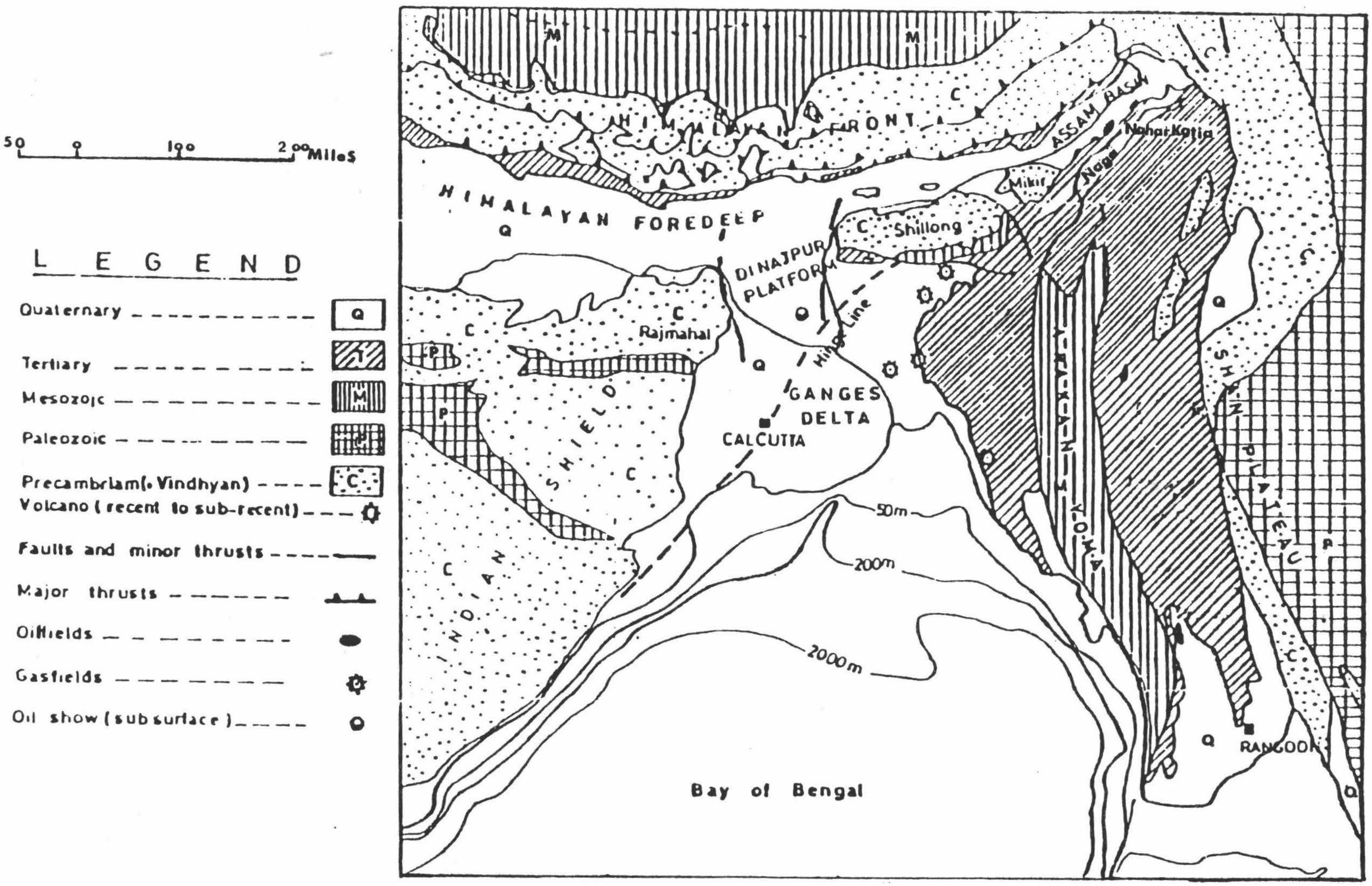

Figure 3. Tectonic Sketch map of Bangladesh and Surrounding areas.

source: Anwar and Husain (1980)

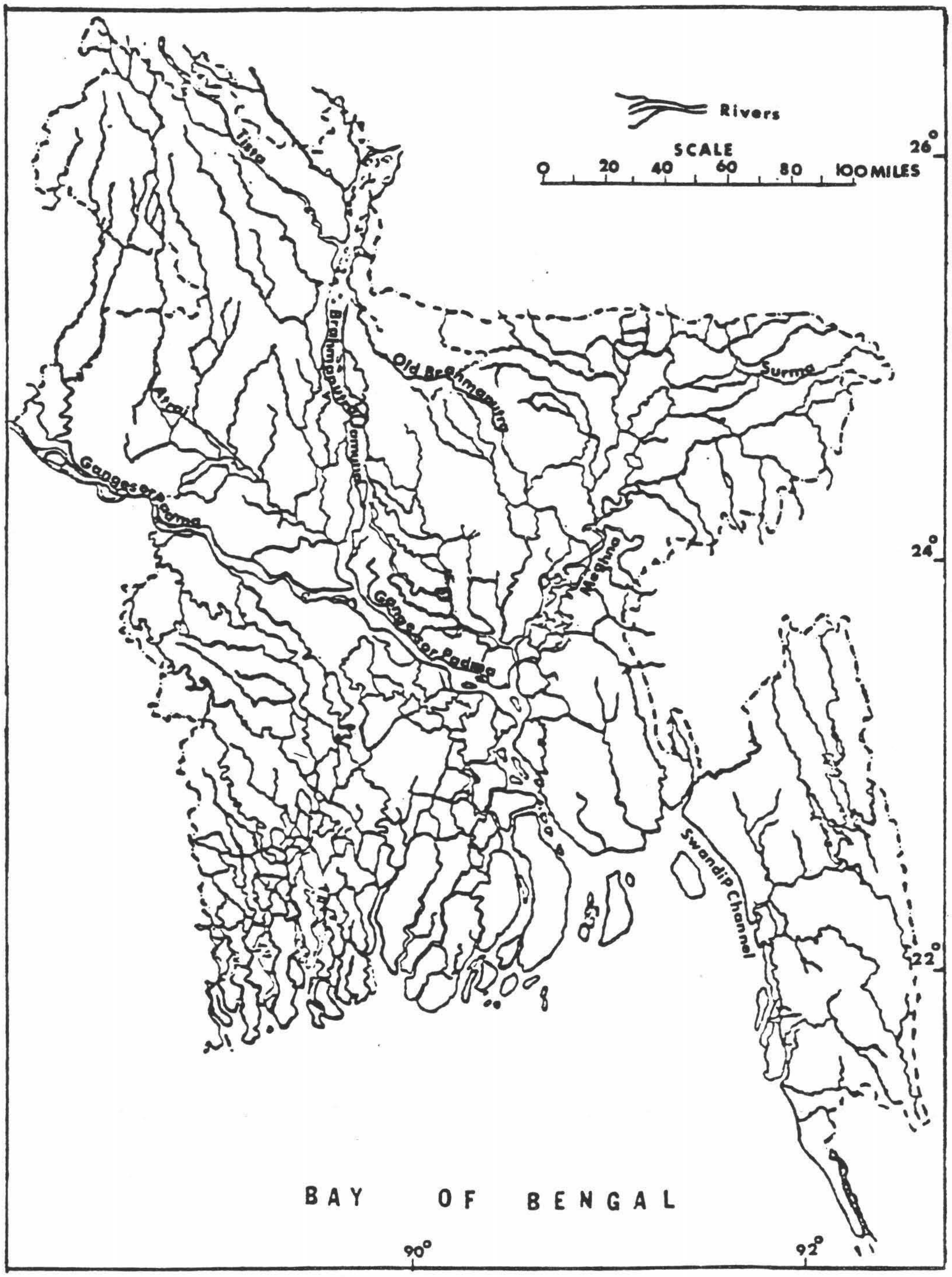

Figure 4. Rivers of Bangladesh.

source : Rashid (1977)

suspended load of 1,451 million tons (Islam, 1978), ranking highest in the world (Table 1). The Brahmaputra draining the northern part of the Himalaya carries an annual suspended load of 726 million tons (Islam, 1978). Coleman (1969) and Curray and Moore (1971) estimated that the two rivers carry a bedload of at least 8000 million tons. The peak flood discharge of the rivers rise to the order of 750,000 cum/sec. (2,647,5000 cft/sec.) in the Ganges 700,000 cum/sec. (2,520,000 cft/sec.) in the Brahamputra (Islam, 1978). In the lean period the discharge drops down to 15,000 cum/sec. (54,000 cft/sec) and 33,500 cum/sec. (1,206,000 cft/sec.) respectively for the two rivers. The Ganges is a meandering river with 3 to 8 Km (1.9 to 5 miles) width but locally shows a braided character (Islam, 1978 and Uddin, 1982). The Brahmaputra is 6 to 12 Km (4 to 7 miles) in width and is a braided river (Coleman, 1969 and Morgan and McIntyre, 1959). The river Meghna originates in the Assam Himalaya and meets the Ganges-Brahmaputra at near Chandpur, south of Dhaka (Fig. 4).

Channel migration of the major rivers and their numerous tributaries is a common phenomenon in Bangladesh (Coleman, 1969, Morgan and McIntyre, 1959). In describing the factors dominating and controlling river migration Coleman (1969) emphasized the importance of recent active tectonic movements, erratic catasrophic floods caused by tropical monsoons, extreme sediment loads and modifications by man in an extremely densely populated basin. He however, overlooked the gentler gradient of the rivers, 0.11-0.26 feet/mile, for the Brahmaputra and 0.25 to 0.50 ft/mile for the Ganges (Morgan and McIntyre, 1959), as a major cause for the channel shifting of the

River System	Drainage Area (1000 sq.km)	Average Discharge (cu.m./sec.)	Average Annual Suspended Load (million tons)	Delta Area (sq. km.)
Ganges	1116	11700	1451	60500
Brahmaputra	935	19600	726	
Irrawaddy	374	13400	291	35000
Niger	1113	6020	100	28800
Mississippi	3111	17108	312	26159
Lena	3028	16316	12	25900
Nile	2978	2600	111	20227
Amazon	7766	226000	1000	estuary
Yangtze	1942	21560	499	estuary

Table I Comparison of some major river systems of the world.

source: Islam (1978)

rivers of Bangladesh.

The sediments carried by all the rivers are distributed to the Bengal Deep Sea Fan by turbidity currents through the "Swatch of No Ground" (Curray and Moore, 1971), a submarine canyon which is 27 km (16 miles) wide and 180 m (590 ft) deep (Islam, 1978). The average rate of sedimentation in the Bay of Bengal is in the order of 38 cm per year (compact) (Islam, 1978) but at the delta head the value is double of that in the Bay (Islam, 1976).

The Bengal Delta slopes from the northwest to the southeast and the thickness of recent sediments in the Delta varies from a little over three hundred feet in the northwest to over a thousand feet in the southeast of the Delta (Islam, 1978).

The Bengal (Ganges) Delta occupies an area of 23,360 sq. miles (60,500 sq. km) in Bangladesh and the west Bengal state of India (Islam, 1978). The Delta, formed by tidal processes, is triangular in form and extends from the Bhagirathi-Hoogli distributary channel in the west to the main Ganges-Padma-Meghna channel in the northeast (Bagchi, 1944) (Fig. 5). The apex of the triangle comprising the Delta is at around latitude 24° 40' N and longitude 88° E, and the southern extremity stretches as far down as 21° 30' N latitude. The longitudinal extension of the base of the Delta is from 88° E to 91° 50' E (Bagchi, 1944). The Delta was built out from west to east from the point where the Ganges enters the Bengal Basin (Islam, 1978).

Bagchi (1944) divided the Delta into moribund (or dead), mature and active parts (Fig. 5). The moribund delta comprises the

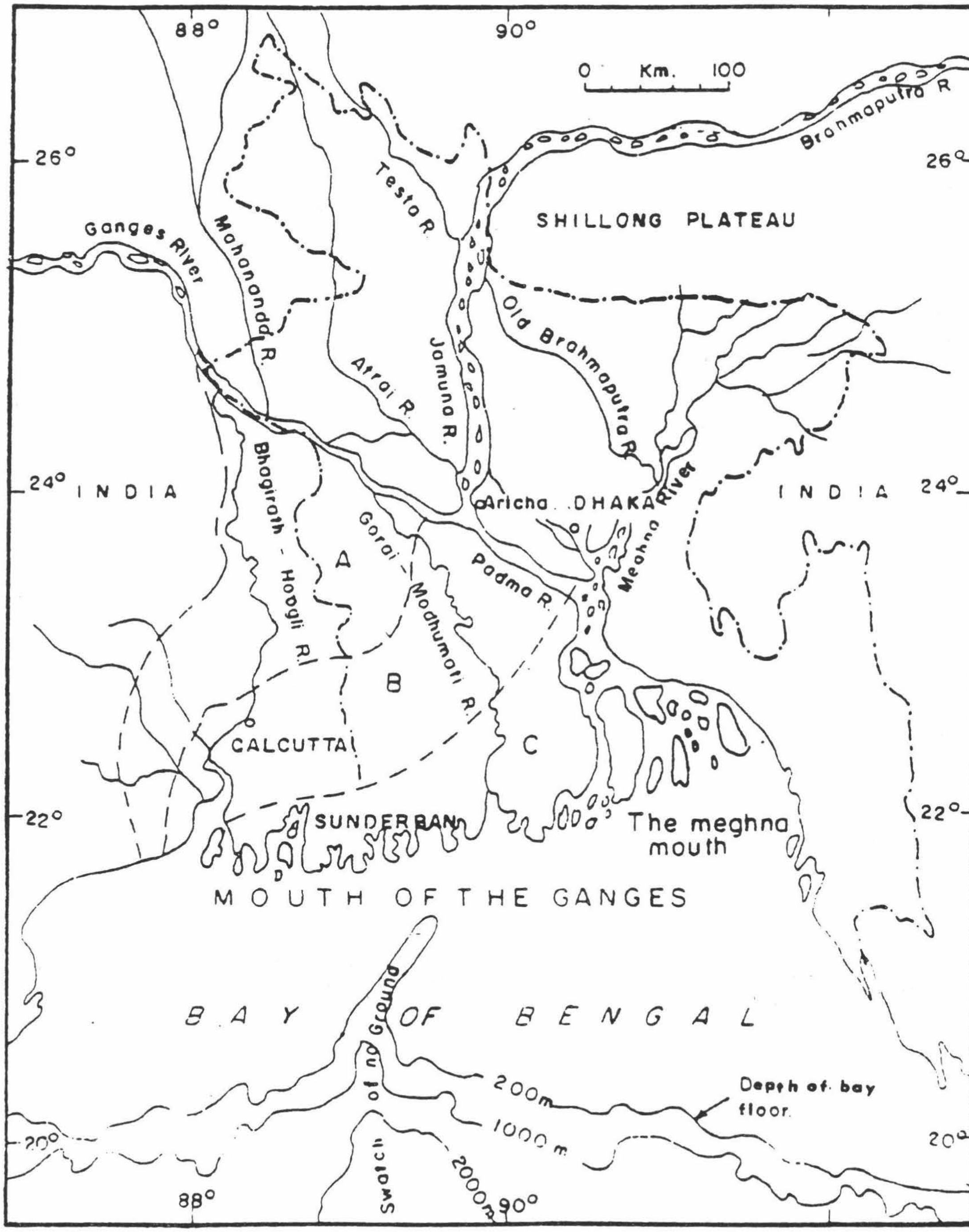

Figure 5. The Ganges-Brahmaputra River Delta and adjoining continental shelf. A,B and C are Bagchi's (1944) dead, mature and active parts of the Delta.

source: Islam (1978)

northwestern part and generally has been built above flood level. The mature delta lies in the southeast contiguous with the moribund delta. The active delta is located further southward adjacent to the coastal parts in the Bay of Bengal.

Morton and Khan (1979) proposed the Quatenary deltaic arcs of Bangladesh (Fig. 6) as interpreted from the landsat pictures. They delineated the areas of the Early Brahma Delta, Early Ganges Delta, Early Meghna Delta and the present day Delta known as the Meghna Delta at the southeast. Coleman (1969, Fig. 3) suggested that the successive deltaic deposits lie parallel to the main distributaries of the Ganges indicating that the deposition took place in successive overlapping lobes as the delta grew. Morton and Khan (1979) found the delta to progress actively towards the east whereas Morgan and McIntyre (1959), Chowdhury (1966), Coleman (1969) and Islam (1978) suggested that the delta is growing more in the western part than in the east due to offshore hydrological conditions, tectonic subsidence in the east and coriolis force which deflects the sediments to build up the right flank of a wide river mouth more than the left flat continental shelf.

The present day delta growth in Bangladesh is shown by the development of an average 150 mile (240 km) wide continental shelf in the proximal fan that slopes 1 in 230 extends to 220 m (728 ft) isobath and has an area of over 100,000 sq.km. (38,600 sq. mile) (Islam, 1978). The natural growth of the Delta has contributed an area of 965 sq. km (372.5 sq. miles) to the territory of Bangladesh.

The tidal range at the Meghna mouth is 5.64 m (18.5 ft). The monsoonal drift and flood discharges in summer coincide to cause local

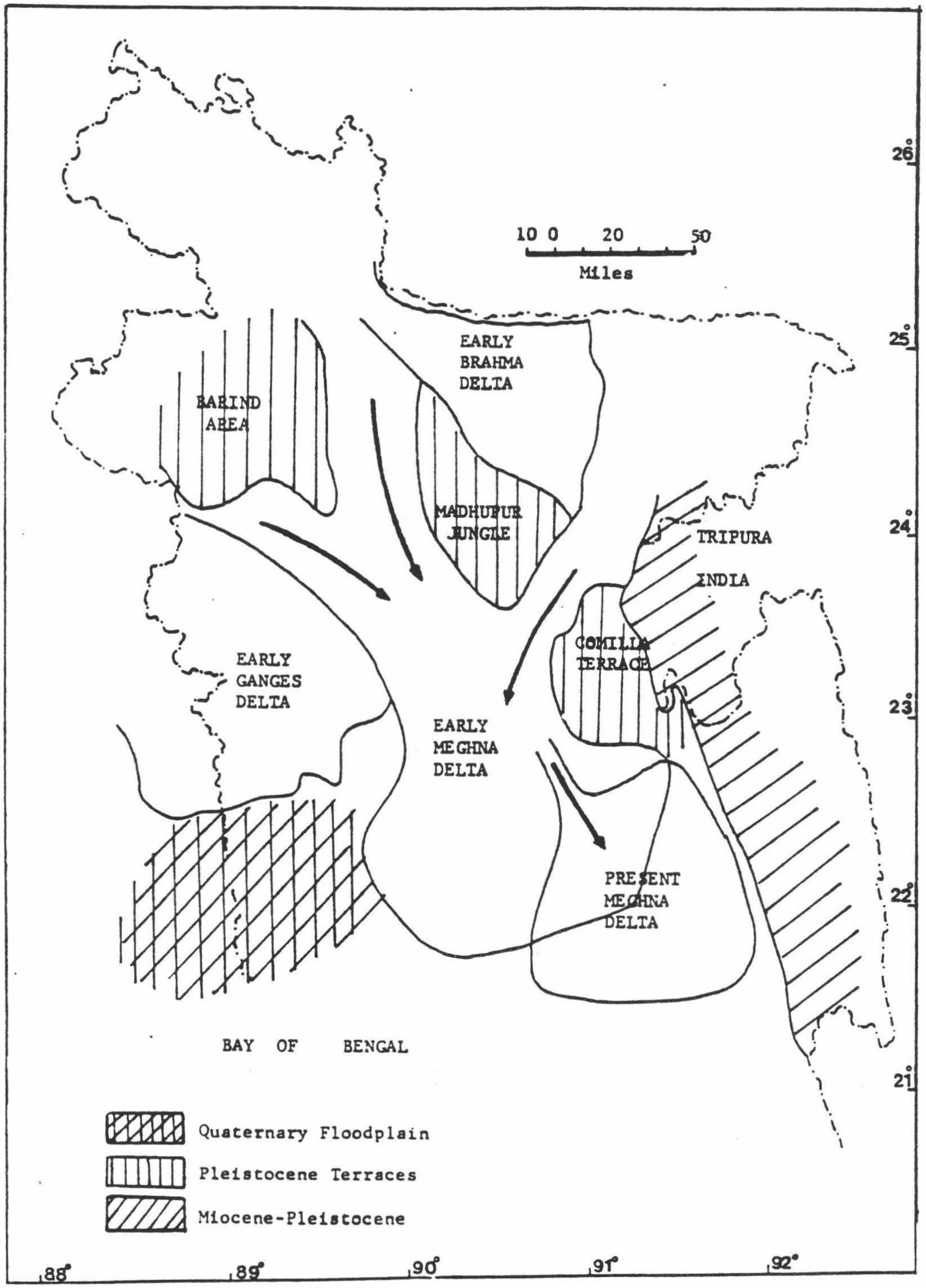

Figure 6. Quaternary Deltaic arcs of Bangladesh.
source: Morton and Khan (1979)

rise of the sea level by up to 5 ft (1.5 m). Thus, the Delta shoreline changes seasonally. Surface salinity in the Bay of Bengal at latitude 17^{o} N varies from 33-34‰ to as low as 18‰ (Das, 1983).

The soils of Bangladesh are primarily rich in calcium, magnesium and potassium and are deficient in nitrogen and phosphate (Islam, 1966).

Physiographically, the country is divided into 3 broad parts: 1) Tertiary uplands in the northeast and southeast parts; 2) Pleistocene terraces and 3) Recent floodplains, Piedmont plains, swamps, levees and coastal deposits. Structural patterns and tectonics of the Tertiary uplands are described in detail in the later part of this chapter.

Like Gulf Coast Pliestocene terraces (Morgan and McIntyre, 1959) multiple Pleistocene terraces were formed in the Bengal Basin (Rizvi, 1957). The four Pleistocene terraces and a recent alluvial surface in the Gulf Coast have been related to five glacial and interglacial periods.

On the basis of a) tonal differences in aerial photographs, b) elevation differences between flanking Tertiary uplands and recent flood plains, and c) entrenched meandering dendritic drainage patterns, three areas of Pleistocene terraces have been outlined (Morgan and McIntyre, 1959). These are: the Barind Tract, at the northwest with an area of 3,600 sq. miles, the Modhupur Tract (1,585 sq. miles) at the central part of the country and the Tripura-Lalmai Tract at the central eastern part of the country.

Periodic disastrous earthquakes, resulting in major stream diversions, and the south westward tilting of the eastern part of the Barind Tract along a major fault, suggest continuous structural activity in this region (Morgan and McIntyre, 1959). Standard Vacuum Oil Company surveyed the southwestern edge of the area in the late 1950's and found two terrace levels, one at 130 feet above sea level and the other at 65 to 75 feet above sea level. Like the Barind Tract, the Madhupur Tract was also subjected to structural activity. There are six echelon faults (Fig. 7) at the western margin of the Madhupur tract with a minimum throw of 20 to 60 feet.

In the Lalmai Hills, the eastern margin is bounded by a single continuous fault, upthrown to the west. Multiple terraces might have developed only in the Barind and the Madhupur Tracts, but neotectonic activity has obscured the observation.

In Bangladesh, recent sediments occur as stream deposit, coastal deposit, swamp deposit, deltaic deposit, piedmont deposits, and interstream deposit. These deposits occur in different places on the basis of physiographic configuration of the country. Stream deposits are most conspicuous. Piedmont deposits are found at the foothills of the Sub-Himalayan Foredeep region. Coastal deposits in the form of beach sands, sandbars and tidal deposits occur at the southeastern belt and at the active deltaic part of the country. Swamp deposits occur at the broad depressions and at places between streams. Deltaic deposits are found at the southwestern and southern part of the country.

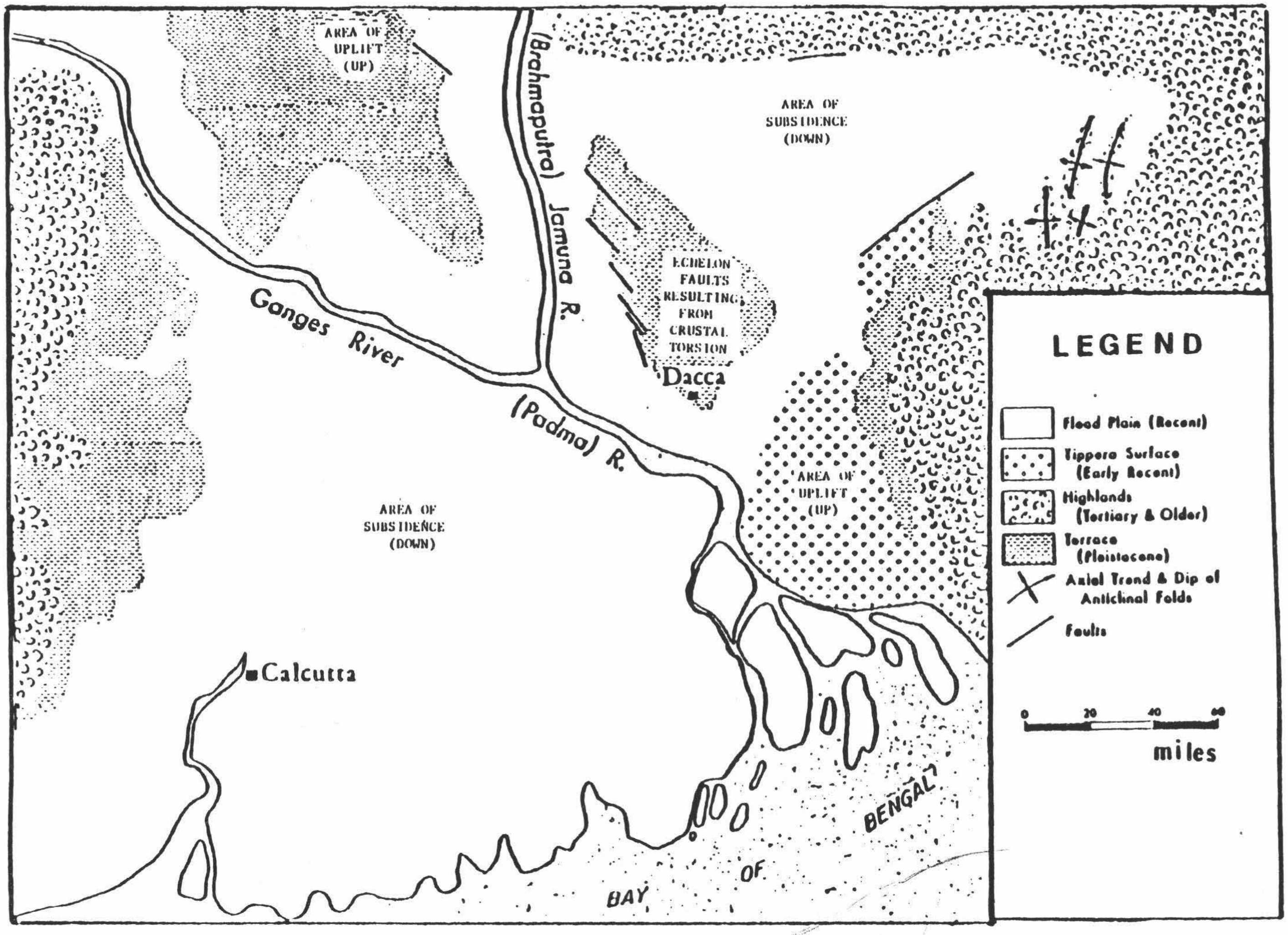

Figure 7. Structural forces affecting the Bengal Basin.

source: Morgan and McIntyre (1959)

BASIN STRUCTURE AND TECTONICS

There are several schools of thought regarding the tectonic classification of the Bengal Basin structure. Bakhtine (1966) and Guha (1978) classified the Bengal Basin into three parts. Two of the three parts are: A) Pre-cambrain "Indian Platform" at the northwest and west; and B) "Bengal Foredeep" at the south and southeast (Fig. 8). Bakhtine's (1966) third division is the "Sub-Himalayan Foredeep" in a small portion in the northwest part of Bangladesh. Guha (1978) included the eastern "Arakan - Yoma Fold System" as the third tectonic division. Table II shows the major tectonic divisions of Bengal Basin and their subdivisions.The Bengal Foredeep separates the Platform from the Young Arakan - Yoma mega anticlinorium while the Sub-Himalayan Foredeep separates the Platform from the Himalayan Mega anticlinorium.

A) The Pre-cambrian platform is further subdivided on the basis of alignment and topography of the basement into: (1) the "Ruhea Flank" or the northern slope of the "Rangpur Saddle", (2) the Rangpur Saddle, and (3) the"Bogra Flank" or the southern slope of Rangpur saddle.

The Ruhea Flank has a width of about 60 km (40 miles) and the basement plunges at about 3^o-4^o towards the Sub-Himalayan foredeep and the basement is over 2000 m (6500 ft) at the northwestern part of Bangladesh (Guha, 1978). The northern contact of the Ruhea Flank and the Sub-Himalayan Foredeep is not known.

The Rangpur Saddle is the shallowest expression of Basement in Bangladesh. The thinnest cover of the basement is 422 feet in the

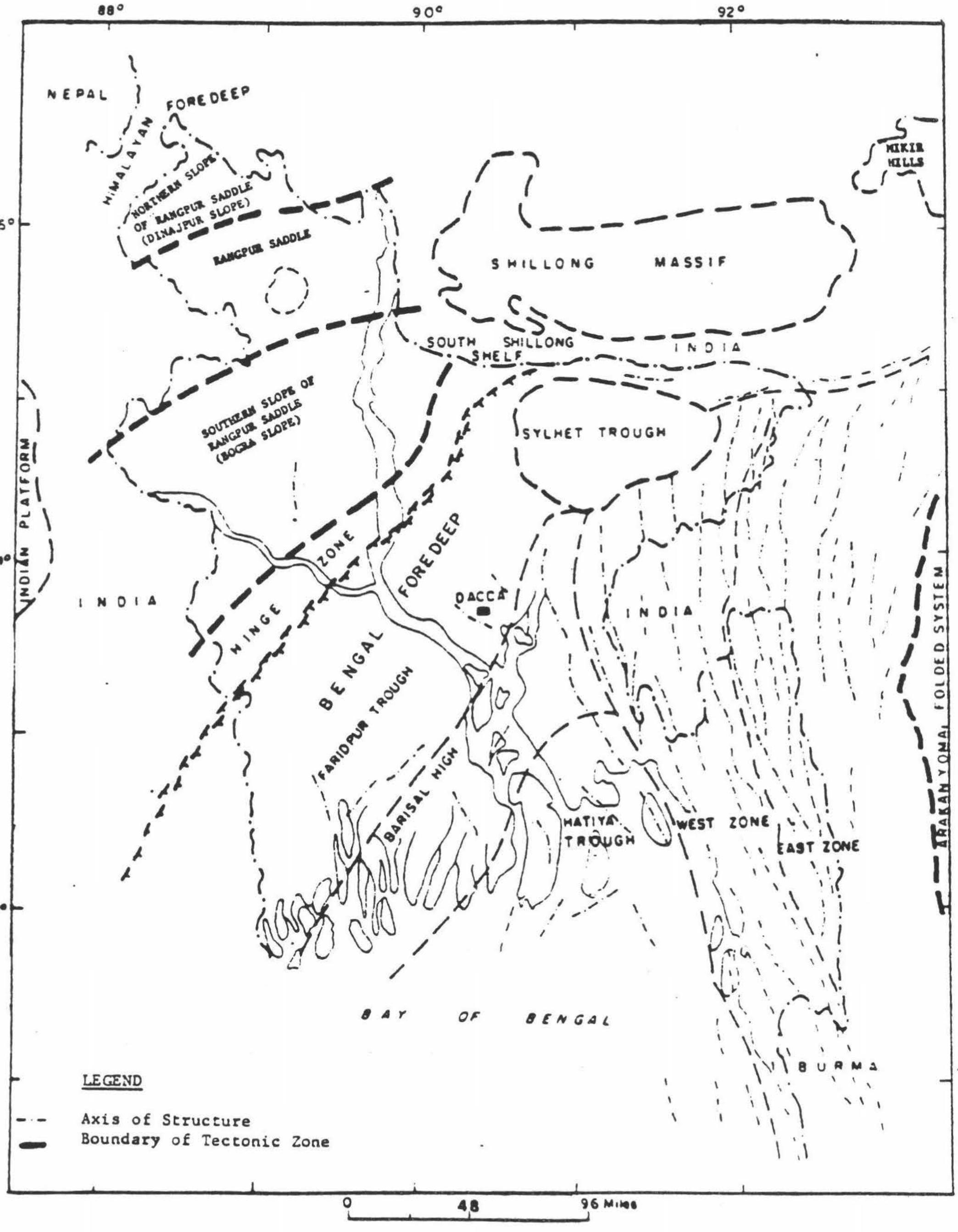

Figure 8. Tectonic map of Bangladesh.

(after Guha, 1978)

<table>
<tr><td colspan="7">SUB-HIMALAYAN FOREDEEP (BAKHTINE, 1966)</td></tr>
<tr><td>STABLE SHELF</td><td colspan="4">A. NORTHERN SLOPE OF RANGPUR SADDLE (RUHEA FLANK)
B. RANGPUR SADDLE (SHALLOWEST OCCURRENCE OF BASEMENT COMPLEX)
C. SOUTHERN SLOPE OF RANGPUR SADDLE (BOGRA FLANK)</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>HINGE ZONE</td><td colspan="4">HINGE ZONE (CALCUTTA-MYMENSINGH GRAVITY HIGH)</td></tr>
<tr><td rowspan="4">FOREDEEP
(DEEPER BASIN)</td><td>A. DHAKA MONOCLINAL ZONE
B. FARIDPUR TROUGH</td><td colspan="3">C. SYLHET TROUGH (SURMA BASIN)</td></tr>
<tr><td>D. CHANDPUR-BARISAL GRAVITY HIGH
(BARISAL UPLIFTED ZONE)</td><td rowspan="3">Fa. WESTERN QUIET ZONE OF FOLDED FLANK</td><td rowspan="3">Fb. MIDDLE DISTURBED ZONE OF FOLDED FLANK</td><td rowspan="3">Fc. EASTERN HIGH ZONE OF FOLDED FLANK</td><td rowspan="3">G. SUB LATITUDINAL FAULT</td><td rowspan="3">H. ARAKAN -YOMA FOLDED SYSTEM (GUHA, 1978)</td></tr>
<tr><td>E. HATIYA TROUGH</td></tr>
<tr><td>I. BENGAL FAN</td></tr>
</table>

Table II Tectonic divisions of Bangladesh.

(after Bakhtine, 1966; Sengupta, 1966; Guha, 1978)

Madhyapara of Rangpur district. The oval shaped saddle is 60 miles (100 km) in width and is bounded by 2300 ft (700 m) contour lines on both north and south side. The sedimentary deposits form monoclinal beds with dips of 1^o-2^o. The area is characterized by a gravity anomaly with values up to +60 mgl. in the southeast which gradually diminish to +50 mgl. to the east (Bakhtine, 1966). Aeromagnetic anomalies are sublatitudinal.

There are several theories proposed for the origin of the Rangpur Saddle. Rao (1973) suggested that the saddle is a graben formed by block faulting between the once continuous Pre-cambrian Rajmahal hills in the west and the Shillong Plateau in the east. Evans (1964) opined that the Shillong Plateau was detached a distance of 155 miles (250 km) from the Rajmahal hills by strike-slip fault. The fault is known as the "Dauki Fault" located along the southern edge of the Shillong Shelf (Fig. 9).

The southern slope of Rangpur or the Bogra slope inclines gently (1^o-3^o) into Bogra and then the inclination increases farther south. The width of the zone varies from 40-75 miles (60 to 125 km). The Bogra slope is terminated in the Hinge Zone which is a transitional zone between the Bogra slope and the Bengal Foredeep. This is also known as the "Calcutta-Mymensingh Gravity High" (Sengupta, 1966; Alam 1972; Guha, 1978), and runs in a NE-SW direction (Fig. 10). This gravity high is due to deep seated basement faults (Raju, 1968). This Hinge zone is 290 miles (480 km) from the Dauki Fault in the north to Calcutta and farther south into the off shore of the Bay of Bengal.

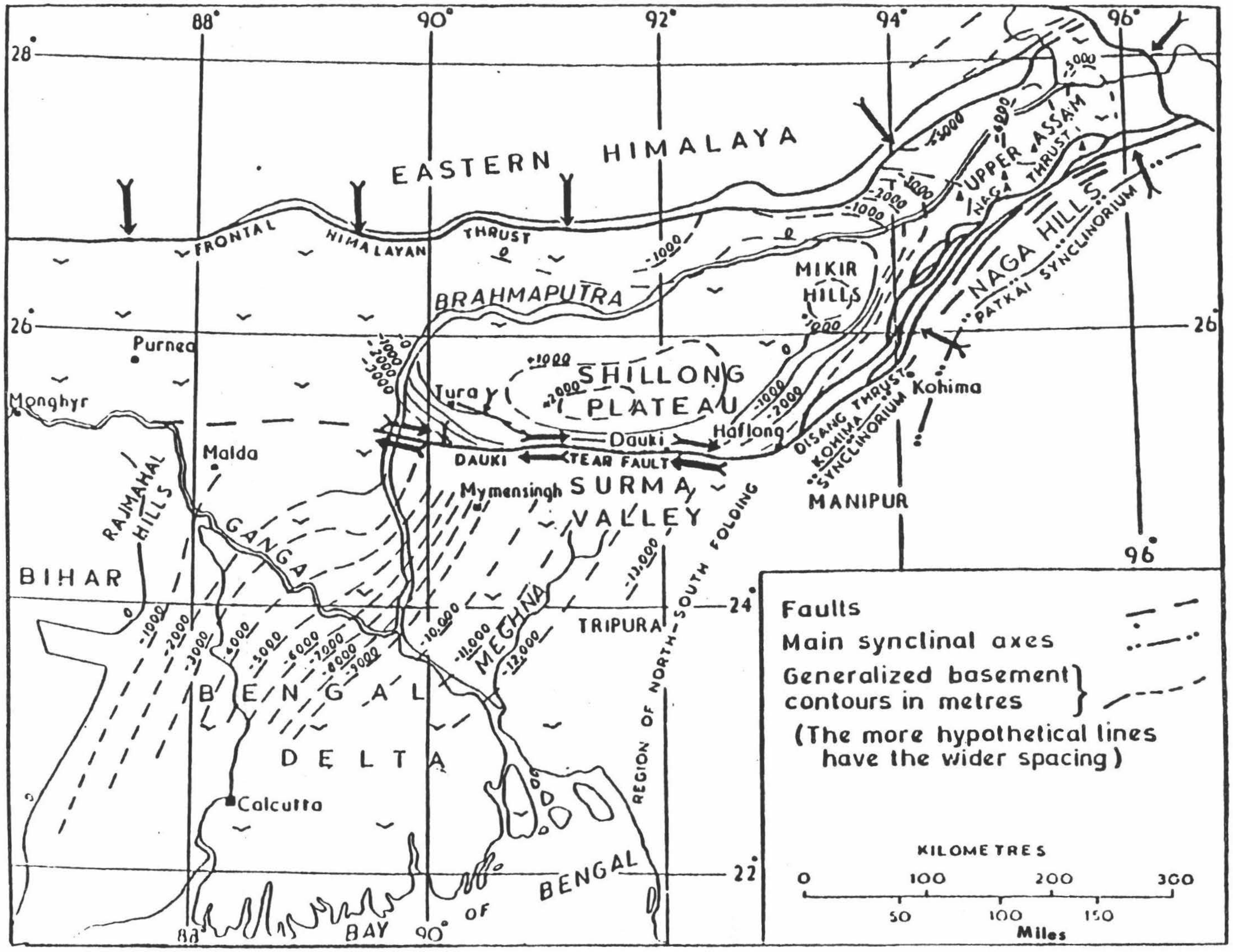

Figure 9. Structure map of Assam. source : Evans (1964)

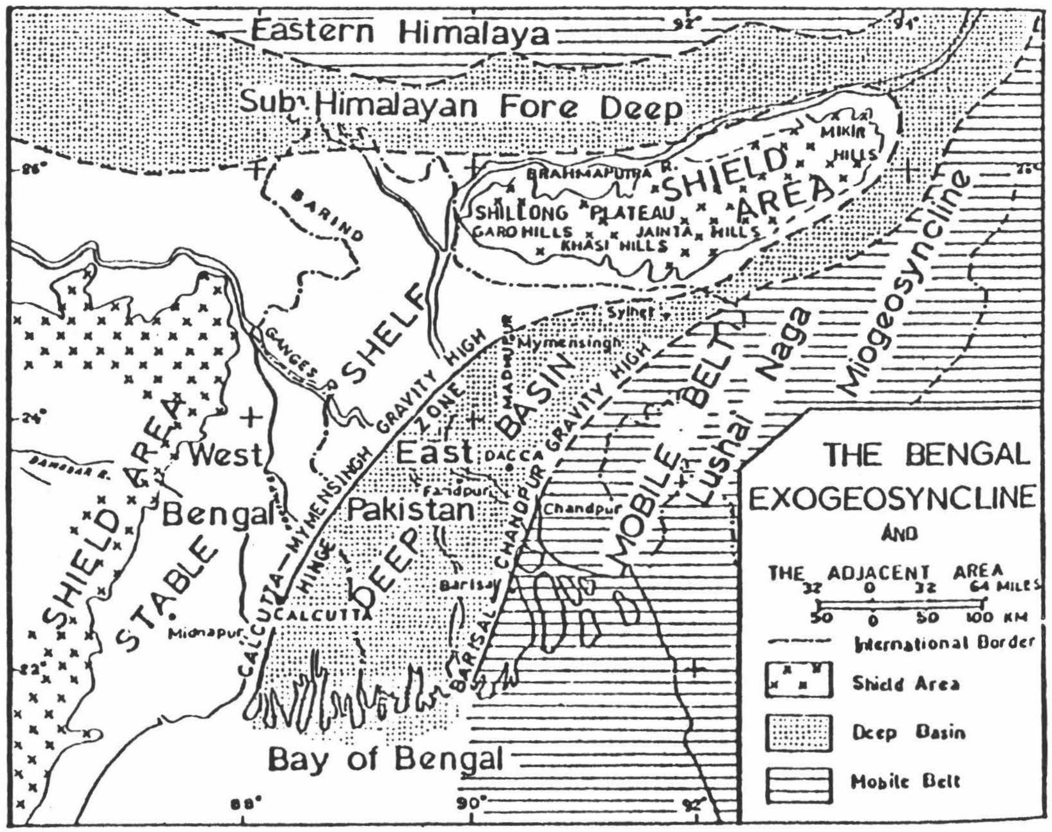

Figure 10. Geosynclinal division in the Bengal Basin.

source: Alam (1972)

Its width amounts to 15 miles (25 km) in the north, 70 miles (110 km) in the central part and 22 miles (35 km) in. the south (Matin et al. 1986). Within these small widths the Eocene Sylhet limestone increases in thickness from 6000 ft. (1800 m) to 13000 ft. (4000 m). Salt et al. (1986) calculated that the structural dip on the Eocene limestone reflectance (R-8) increased from 2-3^{o} in the shelf edge, 6-12^{o} in slope and 1-2^{o} in the Basin Foredeep.

B) The Bengal Foredeep starts at the southern limit of the Calcutta-Mymensingh Gravity High (Fig. 10). This is a zone of extensive sediment thickness lying over the deeply subsided basement. The Foredeep has a width of 340 to 370 miles (550-600 km) practically equalling its length.

The Bengal Foredeep is subdivided, based on gravity studies, into (1) the northwestern platform flank and (2) the eastern folded flank. The platform flank shows small amplitude isometric anomalies whereas large amplitudes and linear-elongated anomalies are represented by the Folded Flank (Bakhtine, 1966).

(1) The Platform Flank is further subdivided into four different sections: the Dhaka Monocline Zone (the Faridpur Trough), the Sylhet Trough, the Barisal-Chandpur High and the Hatia Subsided Zone.

In the Dhaka Monoclinal Zone, Neogene rocks slope southeast toward the Foredeep from the Hinge Zone. Seismic investigations indicate a slope of 1 to 200, with the slope increasing towards the northeast Sylhet Trough. Gravity decreases from +40, +20 mgl. at the Platform to an average of -15, -20 mgl. at the edge of the Sylhet

Trough. The magnetic field of the Dhaka Monocline suggest a general uplift (postivie values) of the basememt to the northeast towards the Shillong Massif.

The Sylhet Trough represents an area of later tectonics than the Bengal Foredeep itself (Bakhtine, 1966). The trough is 80 miles (130 km) long and 37 miles (60 km) wide. The formation of the Sylhet trough is connected with the basement subsidence in late Neogene time which resulted in development of younger sediments like Dupi Tila in the Sylhet district. The Sylhet Trough is oval shaped, extending in latitudinal direction. The Sylhet Trough is reflected by negative gravity anomaly of 86 mgl., which is the lowest in Bangladesh (Fig. 11). Aeromagnetic data also show an extensive magnetic maximum over the Sylhet Trough (Guha, 1975). Some structures in the Trough are anticlinal but two faulted domal structures are also present. Seismic data indicate that the thickness of post-Eocene sediments in the trough is about 57000 ft (17000 m). The Eocene Sylhet limestone, with some older sediments, may account for another few thousand feet of sedimentary fill.

The gravimetric field in the Barisal uplifted zone is expressed by positive maximum which corresponds to an uplift in the sedimentary cover in the northeastern part of the zone. The structures in the eastern part of this zone show folds similar to the folded flank of the foredeep and the western part shows some domal structures. The magnetic data at some southwest part of the region shows positive (+25 to +50) values which may be due to an extension of the relief of the

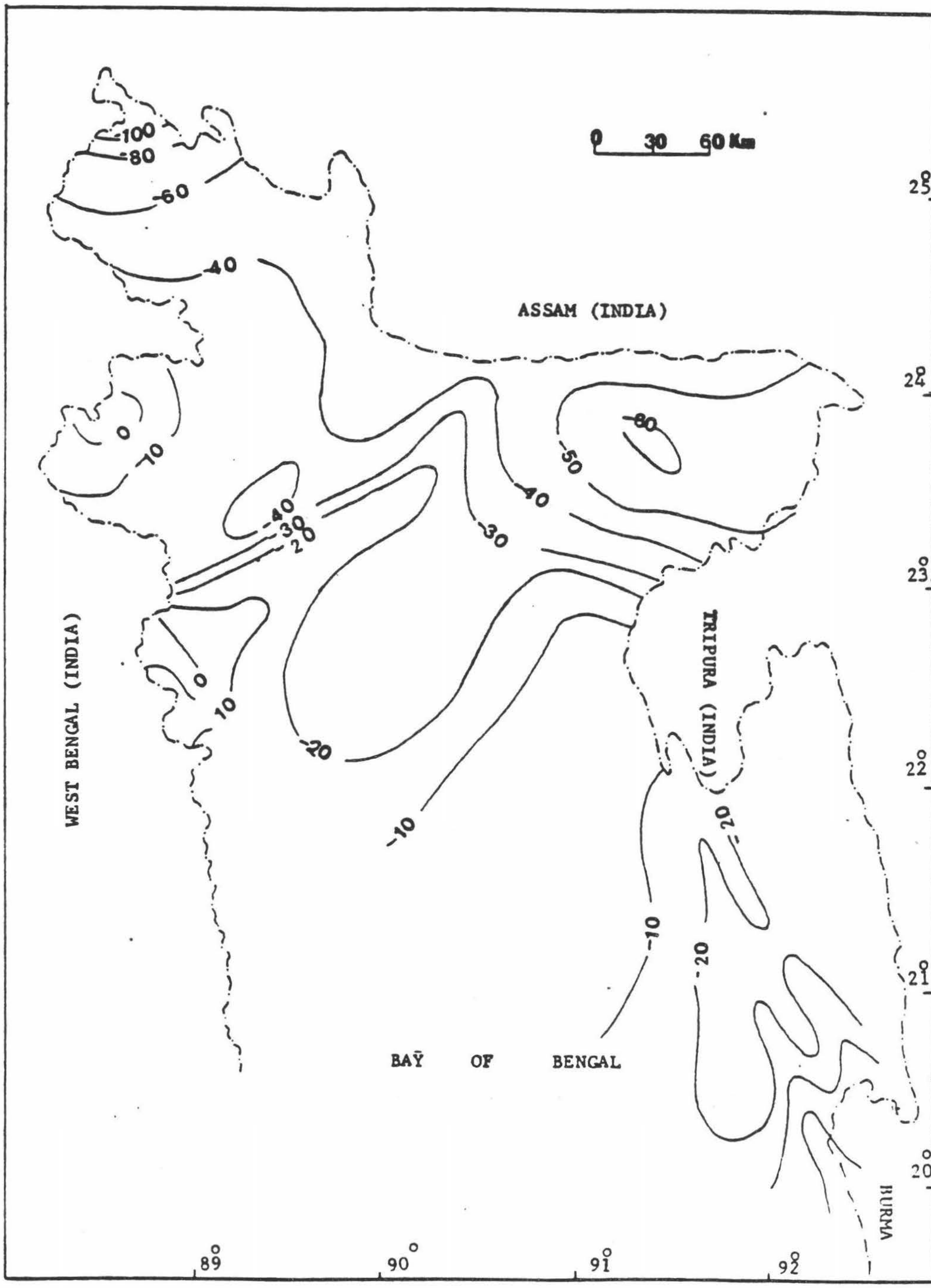

Figure 11. Bouguer anomaly map of Bangladesh.

source: Brunnschweiler (1978)

basement (Bakhtine, 1966). It is evidenced from some geomorphological data that the southeastern parts have suffered recent tectonic activities. Sengupta (1966), Alam (1972), Guha (1978) suggested the uplift zone in Barisal is an elongated zone similar to the "Calcutta-Mymensingh Gravity High" (Fig. 10). The above authors have connected the Barisal with the Chandpur and termed this as the "Barisal Chandpur Gravity High" and suggested that this gravity high should have the same origin, basement faulting, as suggested for the "Calcutta-Mymensingh Gravity High". The width of the zone is 45 miles (60 km).

The largest thickness of the sedimentary complex can be expected in the Hatiya Subsided Zone because this is the area where the present day delta is located. The exact sediment thickness is however, not known. In the southwest of the area rocks plunge to the southeast towards the axial part of the Bengal Foredeep. The trend of the structure is aligned parallel to the structure of the Folded Flank.

(2) The Folded Flank of the Bengal Foredeep is composed of elongated folds of submeridional trend. The folding is disproportional in the width of the synclines and anticlines; anticlines have box and ridge-like forms and are of considerable amplitude and demonstrate en-echelon like junctions which are better exposed in the eastern areas of the fold better. There have been pronounced complications of structures and uplift of the Folded Flank from west to east. A prominent negative gravity anomaly increases from west to east reaching -50 mgl. in Chittagong Hill Tracts and -195 mgl. in the central part of the Burma Basin (Bakhtine, 1966). The

elevation of the structure varies from 300ft (100 m) to 3000ft (1000 m).

Based on structural differences the Folded Flank is divided into three divisions:

i) Western quiet zone with box-like structures

ii) Middle disturbed zone with asymmetric structures and

iii) Eastern highly disturbed zone with narrow ridge like structures.

The western quiet zone is about 40-50 miles (60-70 km) wide in the north and about 20 to 25 miles (30-40 km) in the south. Characteristic of southern structures is that the width of the synclines are approximately twice the width of the anticlines because of low dipping beds in the synclines. Faulting is not common within the western zone.

The middle zone of the Folded Flank of the Bengal Foredeep has a width of 20 to 25 miles (30-40 km) in the south and about 35 miles (50 km) in the north. The folds of this zone are more compressed than in the western quiet zone. The western flanks of the folds are gentler than the steeper and overthrusted eastern flanks and the width of synclines are nearly equal to the width of the predominately ridge-like anticlines.

The eastern zone of the Folded Flank marks the approximate border region between India and Burma. The width of the zone is about 5 to 15 miles (10-20 km). The area is moderately faulted and has elongated anticlines. The structures are characterized by steeply dipping flanks, sometime 90^{o}, tight folding, and thrusted and imbricate structures. Linearly elongated folds lie en-echelon to each other (Guha, 1978).

Guha's (1978) Arakan-Yoma Folded System is partially shown in the tectonic map (Fig. 8). These are intensively folded and faulted by thrusts. Granite instrusions are common. The system is composed of Pre-cambrian, Paleozoic and Mesozoic rocks.

The Bengal Foredeep is related to Arakan-Yama Folded System by a regional fault of submeridional strike which separates the Neogene molasses from the Paleogene flysch (Guha, 1978).

Bakhtine's (1966) Platform Flank of the Sub-Himalayan Foredeep occupies a small area of the northwest tip of Bangladesh. Much is not known about this area. Although the area is poorly studied, available information shows that the area has numerous Himalayan frontal thrust sheets.

Matin et al. (1986) proposed another school of thought regarding the tectonic zonation of Bangladesh (Fig. 12). Their classification is based on historical genetic features. They have included the Bogra Slope of Bakhtine (1966) and part of Assam into the Bengal Foredeep and divided that into two zones, viz: 1) External and 2) Internal.

The External zone is further subdivided into i) Rajshahi subzone, ii) A Hinge subzone and iii) The Upper Assam subzone. The Rajshahi Subzone is the same as the Bogra Slope of Bakhtine (1966). The Upper Assam Subzone includes the areas adjoining the Shillong Massif and Mikir Hills in the south and the autochthonous part of Upper Assam.

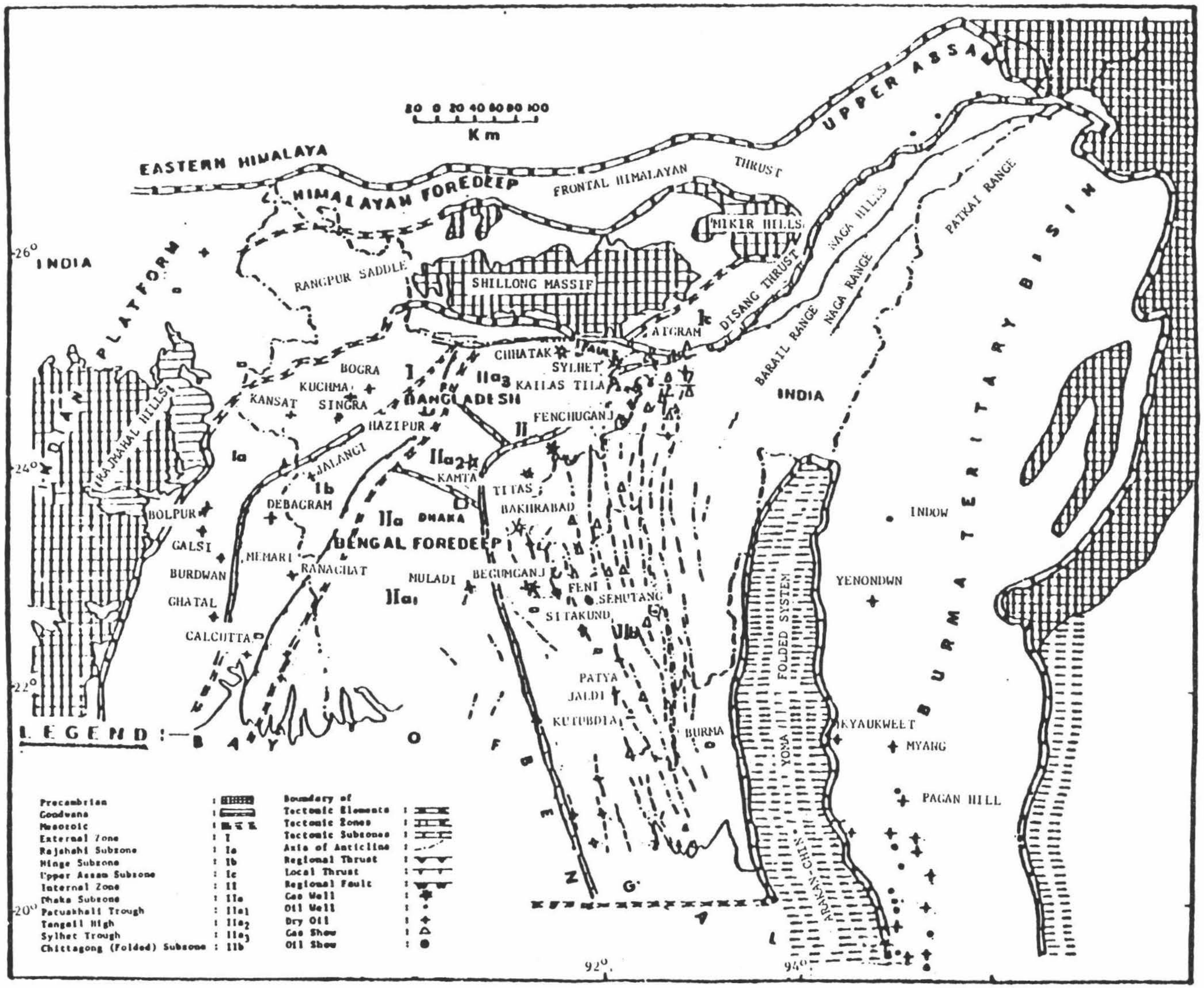

Figure 12. Tectonic scheme of Bangladesh and adjacent areas. source: Matin et al. (1986)

The basement depth in the Upper Assam Subzone is 16000 ft. (5000 m).

The internal zone of the Foredeep is characterized by 60,000 ft. (18 km) of sediments in the deepest part of the basin. The thickness of sediments decreases towards the east. The internal zone has been divided into i) the Dhaka Subzone and ii) the Chittagong Subzone. The Dhaka Subzone is further subdivided into 1) the Patuakhali Trough in the south where the basement is at 25000 ft to 60000 ft (8-18 km); 2) the central Tangail-Tripura High at the central where the basement is about 25000 to 40000 ft (8-12 km) below the sea level; and 3) Sylhet Trough at the northeast where the basement is at a depth of 20000 to 40000 ft (6 to 12 km).

Alam (1972) classified the tectonic elements of the Bengal Basin on the basis of the geosynclinal concepts of Kay (1951) and Badgely (1965). Based on these concepts he concluded that the Bengal Basin is an exogeosyncline located near the margin of the Naga-Lusai miogeosyncline on one side and the Indian Shield, acting as craton, on the other side and that the Bengal Basin is the continuation of the Sub-Himalayan Foredeep (Fig 10).

Bengal Basin is an asymmetrical basin (Fig 13). The thickness of sediments increases to the south upto 12 km and towards east upto more than 16 km.

Desikachar (1974) proposed a tectonic model of the region on the basis of "Plate Tectonics." He considered the Bengal Basin as a peri-cratonic basin of the Indian plate and suggested that it does not have

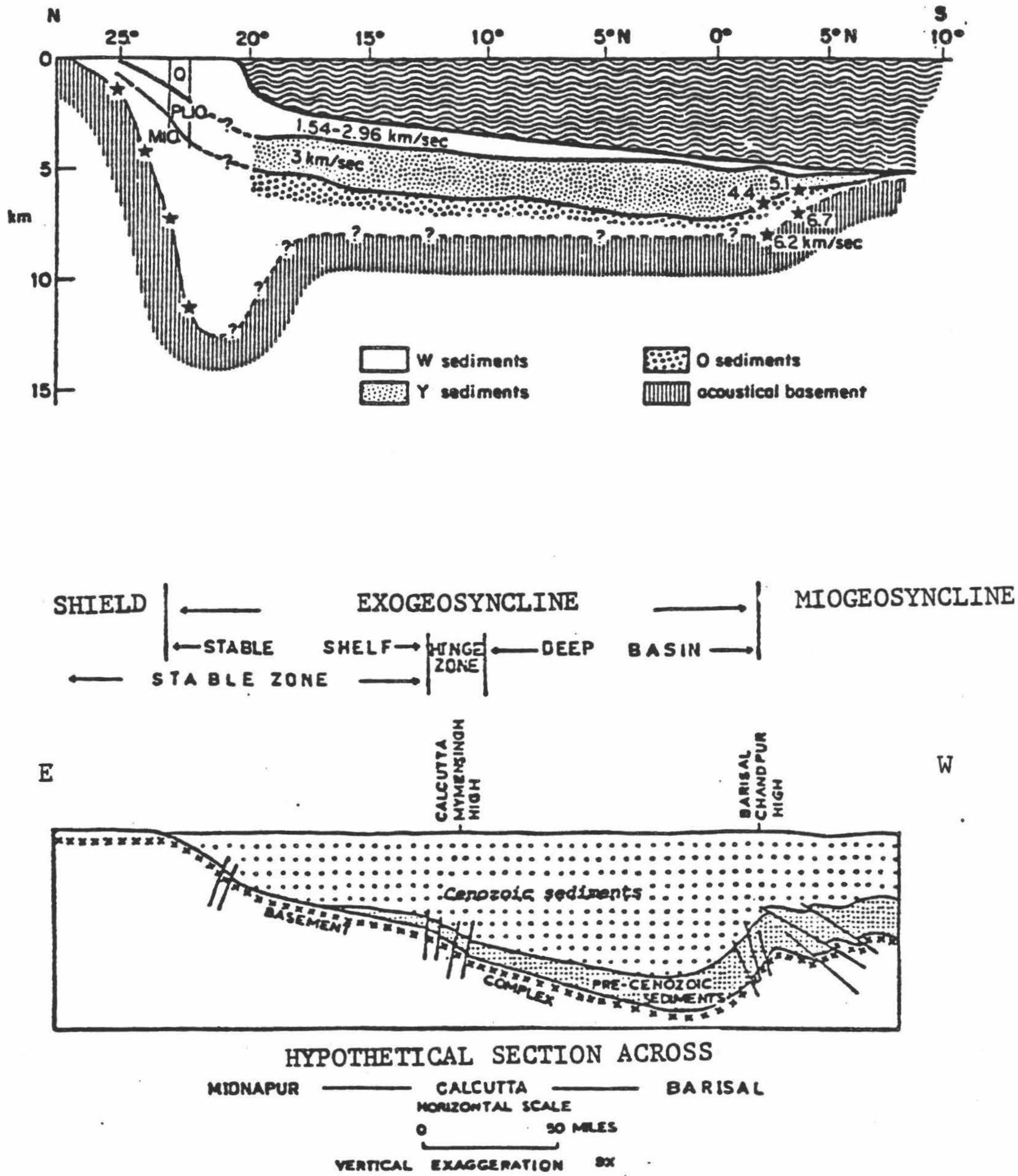

Figure 13. North-South and East-West section across Bengal Basin.

source: Curray and Moore (1974) (for N-S)
&
Alam (1972) (for E-W)

the characteristics of a classical geosyncline. His proposition further suggests that the west subsiding part of the Bengal Basin forms a part of the Indian Plate and the eastern part forms part of the Burmese Plate. During the Miocene time the Burmese Plate has moved towards the Indian Plate and just east of the 90 E ridge, where there is maximum subsidence, the Burmese Plate overrode the Indian Plate forming a subduction zone between the two plates. Desikachar (1974) further indicated that the highs are the result of the movement of deepseated basement blocks along old fracture lineaments. He further suggested that the Shillong Plateau did not move east along the Dauki tear fault rather it underwent only vertical uplift.

Reading (1978) and Curray and Moore (1974) termed the Bay of Bengal as a remnant ocean basin. They suggested that the basin is closing as a result of the easterly subduction of the basin beneath the Indo-Burmese ranges and the Andaman and the Sunda Outer Arc. On the basis of experimental drilling and geophysical results the Ninety East Ridge is termed as an aseismic ridge (Kennet, 1982). Faruquee (1975) suggested that the Bengal Basin has originated as a rift valley on the crest of the Ninety East Ridge which may extend into the Himalayan mountains where the Indian Plate meets the Tibetan Plate (Fig. 14).

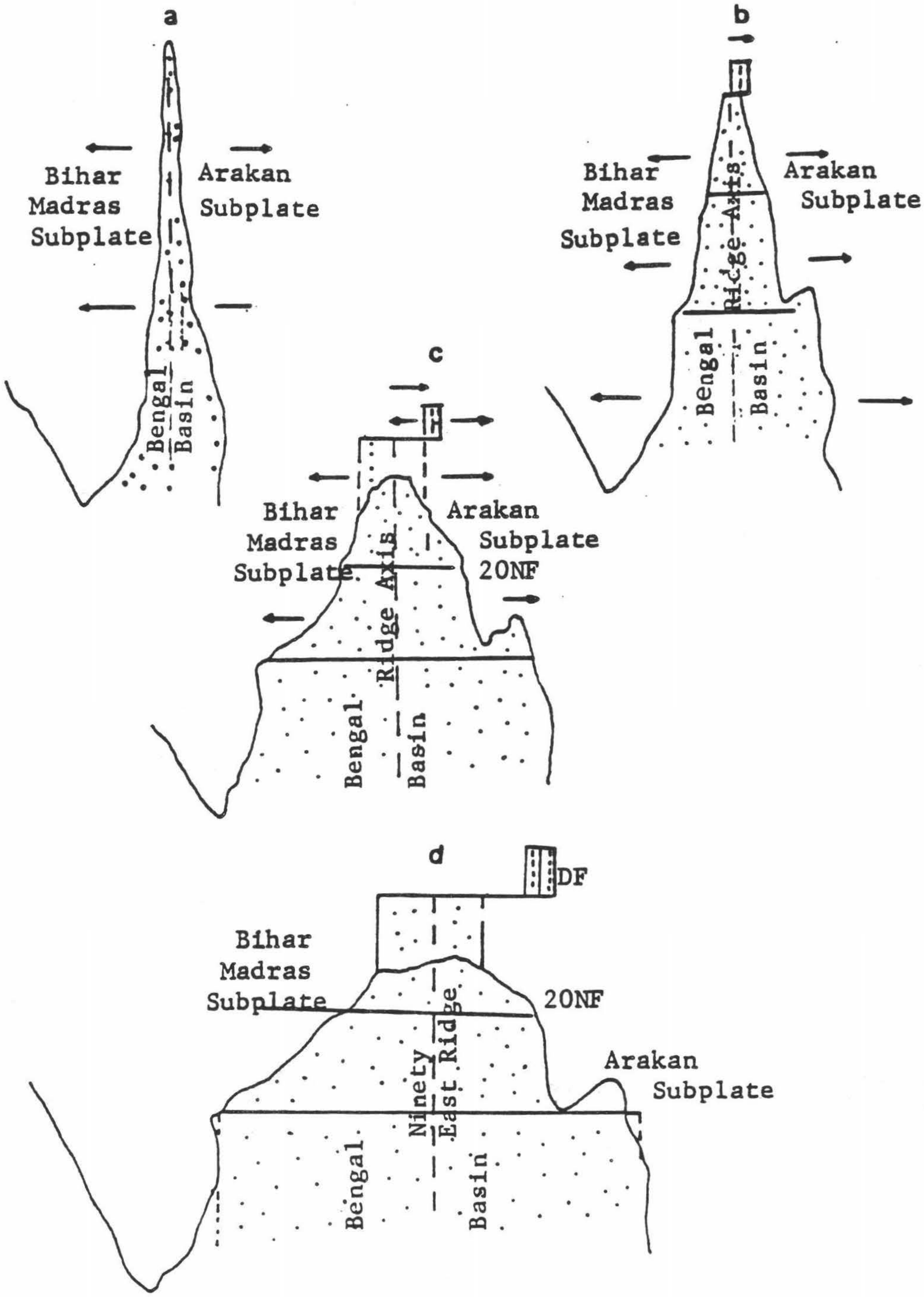

Figure 14. Growth of the Bengal Basin due to east west opening of the Bay of Bengal.

source: Faruqee (1975)

STRATIGRAPHY

The stratigraphy of Bangladesh is incompletely known because of the thick sequences of alluvium cover and relative paucity of fossils. Comparative lithologic studies have been the only mean to establish and to interpret the stratigraphy. Recently there have been some efforts to establish a regional stratigraphy on the basis of a) spore-pollens and available faunal fossils and b) seismic stratigraphy. These works are quite interesting and helpful in intrepreting the systematic geology and paleogeography of the region.

The stratigraphy of Bangladesh and type sections of the lithology are based on the nomenclature and classification of the Assam Basin (India) established by various geologists during the British rule of India (Evans, 1932). The stratigraphic subdivisions are based on lithostratigraphy though it is meant to be chronostratigraphic (Khan and Muminullah, 1980). As there are variations in the depositional mode and time between the Assam Basin and Bengal Basin, there always remains some problem and inaccuracy in defining the vertical and lateral boundary of a particular stratigraphic horizon in the Bengal Basin of Bangladesh.

The present limited knowledge of the stratigraphy and facies development of the Bengal Basin is based primarily on the wells drilled in Bangladesh since the 1910's. The Eocene Hinge Zone (Calcutta-Mymensingh Gravity High) broadly subdivides the Bengal Basin into a northwest shelf area and a southeast geosynclinal area. There are two separate stratigraphic successions for these two facies with the stratigraphy of the shelf and geosynclinal facies characterized by much thicker geosynclinal sediments.

The stratigraphic successions of the two regions are shown in Table III and IV and the thicknesses used are those given by Khan and Muminullah (1980). The Pre-Cambrian (Archean) basement complex has been reported in most of the drill holes in the northwest Bangladesh. The depth of the basement complex varies from 422 feet (129 m) in the Rangpur district to 7039 feet (2146 m) in the surrounding region. The basement complex is composed of gneisses with orthoclase, quartz, muscovite, biotite and hornblende.

The basement complex is uncomformably overlain by the Permian coal bearing Kuchma and Paharpur Formations of the Gondwana Group of sediments. The Kuchma Formation is approximately 1622 feet (495 m) thick and contain five coal seams, ranging from 13 to 72 feet (4 to 22 m) in thick. The Kuchma Formation can be correlated with the Early Permian Barakar stage of India. The Paharpur Formation approximately 1680 feet (512 m) in thickness, is composed of gritty feldspathic sandstone and containes four coal seams. The Paharpur Formation can be correlated to the late Permian Raniganj stage of the Lower Gondwana Group of India (Ahmed and Zaher, 1965). Jurassic Rajmahal trap rocks (basaltic and andesitic) unconformably overlie the Gondwana coal formation. This is in turn unconformably overlain by the Albian Stage Shibganj Formation, approximately 480 feet (146 m) in thickness. This is a trapwash consisting of ferruginous shale, claystone, and green and red ferruginous sandstone. Volcanic lava flows and their trapwash were unconformably followed by the Jaintia Group of sediments which are divided into: 1) the Tura Sandstone, 2) the Sylhet Limestone and

Age	Central & Lower Assam (India)		Bangladesh		West Bengal (India)
	Series	Stage	Group	Formation	Formation
Recent				Alluvium (270')	Alluvial
		Unconformity			
Pleistocene				Madhupur Clay (50')	
		Unconformity			
Pliocene	Dihing				
		Unconformity			
	Dupi Tila			Dupi Tila (900')	Debagram (4900')
		Unconformity			
Miocene	Tipam	Girujan Clay Tipam Sandstone			
	Surma	Boka Bill Bhuban		Jamalganj (1355')	Pandua (2830')
		Unconformity			
Oligocene	Barail	Renji Jenam Laisong		Bogra (535')	Memari (95') Burdwan (535')
		Unconformity			
Late Eocene		Kopili		Kopili (140')	Kopili (78')
Middle Eocene	Jaintia	Sylhet Limestone	Jaintia	Sylhet Limestone (645')	Sylhet Limestone (1060)
Early Eocene		Therria/ Cherra		Tura Sandstone (340')	Jalangi (850')
Paleocene					
		Unconformity			
Cretaceous		Langpar Mahadek Sylhet Trap	Upper Gondwana	Sibganj (480') Rajmahal Trap (1100')	Ghatal (376) Bolpur (375') Rajmahal Trap
		Unconformity			
Permian			Lower Gondwana	Paharpur (1680') Kuchma (1620')	
		Unconformity			
Pre-Cambrian	Archean Complex		Basement Complex		

Table III Stratigraphy of the shelf facies.

source: Khan and Muminullah (1980)

Age	Upper Assam (India)		Bangladesh	
	Series	Stages	Group	Formation
Recent		Unconformity	Alluvial	Alluvium
Pleistocene				Madhupur Clay
		Unconformity		
Pliocene	Dihing			Dihing
		Unconformity		
Mio-Pliocene	Dupi Tila	Namsang		Dupi Tila
		Unconformity		
Miocene	Tipam	Girnjau Clay Tipam Sandstone	Tipam	Girnjau Clay Tipam Sandstone
	Surma	Boka Bil Bhuban	Surma	Boka Bil Bhuban
		Unconformity		
Oligocene	Barail	Tikak Parbat Baragoln Naogoan	Barail	?
		Unconformity		
Eocene	Disang			

Table IV Stratigraphy of the Geosynclinal facies.

source: Khan and Muminullah (1980)

3) the Kopili Formation. This sequence represents the oldest exposed rock types in Bangladesh. The Tura Sandstone, 340 feet (104 m) consists of sandstone in subordinate shale, marl and carbonaeous materials. The age range of this formation is from Early Paleocene to Middle Eocene. The Sylhet Limestone which is approximately 645 feet (197 m) in thickness, is a marker horizon in the region and overlies the Tura Sandstone Formation. Paleontological results indicate that the age of the Sylhet Limestone is Middle Eocene (Ismail, 1978). The Kopili Formation which constitutes of grey calcareous shale with interbedded sandstone and limestone, overlies the Sylhet Limestone Formation. The microforminfera of the Kopili Formation indicates Globorotalia Cocoensis Biozone (Bolli, 1957) for this Formation. The Bogra Formation (Ahmed and Zaher, 1965) is 535 feet (163 m) in thickness and overlies the Kopili Formation. The Bogra Formation is equivalent to the Barail Formation of Lower Assam and Burdwan and Memari Formation of West Bengal. The floral presence of Burdwan Formation indicates an Oligocene age (Biswas, 1963). The Jamalganj Formation (Ahmed and Zaher, 1965) consisting of sandstone, siltstone and claystone is 1355 feet thick (413 m) and can be correlated to the Surma and Tipam Series of rocks of the Lower Assam and the geosynclinal area of Bangladesh. Biswas (1963) studied the floras of the Pandua Formation of West Bengal and correlated them with the Jamalganj Formation and found the age to range from Miocene to Early Pliocene.

The Jamalganj Formation is overlain uncomformably by the Dupi Tila Formation, 900 feet (275 m), which consists of pebble, grit beds, coarse to fine sandstone and shale. The Dupi Tila Group is followed uncomformably by a mottled clay formation (Madhupur Clay) which is 50 feet thick (15 m). The Madhupur Clay is overlain by the Recent-Subrecent alluvial deposist throughout the entire Bangladesh.

The stratigraphy of the Geosynclinal facies represents a thick sequence (7 to 9 miles (12 to 15 km)) (Guha, 1978) of Tertiary rocks of the Jenam Formation and younger. Rocks older than the Jenam Formation have not been reached in the Geosynclinal facies . This is also suggested (Holtrop and Keizer, 1970) by the presence of Bulimina -3. It mainly consists of sandstone and shale. In Assam this unit contains oil, gas as well as coal. The Jenam Formation is followed by the Surma Group of rocks in the geosynclinal facies.

The Surma Group is the rock group of particular interest from the perspective of hydrocarbon occurrence in Bangladesh because all the natural gas pay zones are found in this group of rocks which are well developed in the geosynclinal area. The Surma Group is a diachronous unit consisting of a succession of alternating shale, sandstone, siltstone and sandy shales with occassional thin conglomerates (Imam and Shaw, 1985). The group is divided into the Bhuban and the Boka Bil Formations in Upper Assam and as well as in Bangladesh. Upon reading the E-log curves and the reports on different hydrocarbon wells done by the Bangladesh Oil, Gas and Mineral Corporation (BOGMC), the thickness of the Surma Group (the Bhuban and the Boka Bil Formations) is calculated. Table V shows the thickness of the Surma Group of rocks in different wells of Bangladesh. The Surma Group is

TECTONIC MAJOR	LOCATION SUBDIVISION	WELL	BOKA BIL THICKNESS (M) FROM	TO	TOTAL	BHUBAN THICKNESS (M) FROM	TO	TOTAL	SURMA THICKNESS (M) BOKA BIL FM +BHUBAN FM
SHELF	BOGRA SLOPE	BOGRA-1	217	782	565*	782	1593	811*Lower not fd.	1376*
		KUCHMAX-1	340	1090	750*	1090	1606	516*Lower not fd.	1266*
		SINGRA-IX	1290	1600	310*	1600	1880	280	590*
HINGE ZONE		HAZIPUR-1	1393	2247	854	2247	3130	883	1737
GEOSYNCLINE	SURMA BASIN (SYLHET TROUGH)	CHATTAK-1	626	1081	456	1082	2134	1052 Lower not fd.	1508
		SYLHET-2	1240	1915	675	1915	2818	903	1578
		ATGRAM-IX	1085	2256	1171	2256	4178	1920	3091
		KAILASTILA-1	2150	2900	750	2900	4138	1238	1988
		BEANI BAZAR-IX	2631	3640	1009	3640	4109	469	1478
		RASHIDPUR-2	1036	2710	1674	2710	3851	1141	2785
		HABIGANJ-1	1165	2326	1161	2326	3506	1180	2341
	FARIDPUR TROUGH DHAKA MONO CLINAL ZONE	KAMTA-1	1030	2740	1710	3614	2740	874 Lower not fd.	2584
	BARISAL HIGH	TITAS-1	832	2362	1531	2362	3758	1396	2926
		BAKHARABAD-1	560	1770	1210	1770	2838	1068	2278
	HATIYA TROUGH	BEGUMGANJ-1	1480	2580	1100	2580	3656	1076	2176
		MULADI-1	750(?)	2590(?)	1840(?)	2590(?)	4395(?)	1805(?)	3645(?)
		FENI-1	1300(?)	2440(?)	1140(?)	2440(?)	3200(?)	705(?)	1900(?)
						Lower not found			
	FOLDED BELT	SEMUTANG-1	250(?)	1530(?)	1280(?)	1530(?)	3500(?)	1970(?)	3250(?)
		JALDI-3	500(?)	1380(?)	880(?)	1380(?)	2930(?)	1550	2430(?)
	OFFSHORE	KUTUBDIA	1713(?)	3606(?)	1792(?)	----	?	----	----

*ACTUALLY SURMA GROUP IN THE SHELF REGION IS KNOWN AS JAMALGANJ FM (KHAN AND MUMINULLAH, 1980). HOWEVER THESE ARE EQUIVALENT TO EACH OTHER

Table V Thickness of the Miocene Surma Group (the Bhuban and the Boka Bil Formation) in different wells.

bounded at the top by a marker shale horizon, known as the " Upper Marine Shale " which lies at the upper part of the Boka Bil Formation. The Shale represents a regional marine transgression in the region. The Surma Group is bounded at the bottom by an unconformity with the Oligocene Barail Group of rocks. Due to its position between an upper key bed and a lower Miocene-Oligocene unconformity, a number of isopach maps have been drawn (Fig. 15 to 17). The isopach map of the Bhuban Formation (Fig. 15) shows four depobasins in the early to middle Miocene time. Two of those are closed and the other two at the northeastern part are open. There is another broad depobasin in the southern part. The maximum thickness of the Bhuban sediments are found in the Muladi and Semutang areas whereas the minimum thickness is found in the northwest Singra area. The closed depocenter near the Feni structure is elongated. At the northeastern tip, there is a part of a steeper depobasin, the central part of which should lie in the Assam, India.

Isopach map of the Boka Bil Formation (Late Miocene) (Fig. 16) shows three depobasins. The principal one is located at the central part of the country, near Kamta, Dhaka. Thickness of the Boka Bil sediments increase southward and northwestward in the stable shelf region.

Isopach map of the overall Surma Group (Bhuban + Boka Bil Formations) (Fig. 17) shows only one depobasin near Feni which was also detected in the isopach map of the Bhuban sediments. The other depocenters are not within the country. Figure 18 shows the lithofacies panel diagram of different wells of Bangladesh. The wells

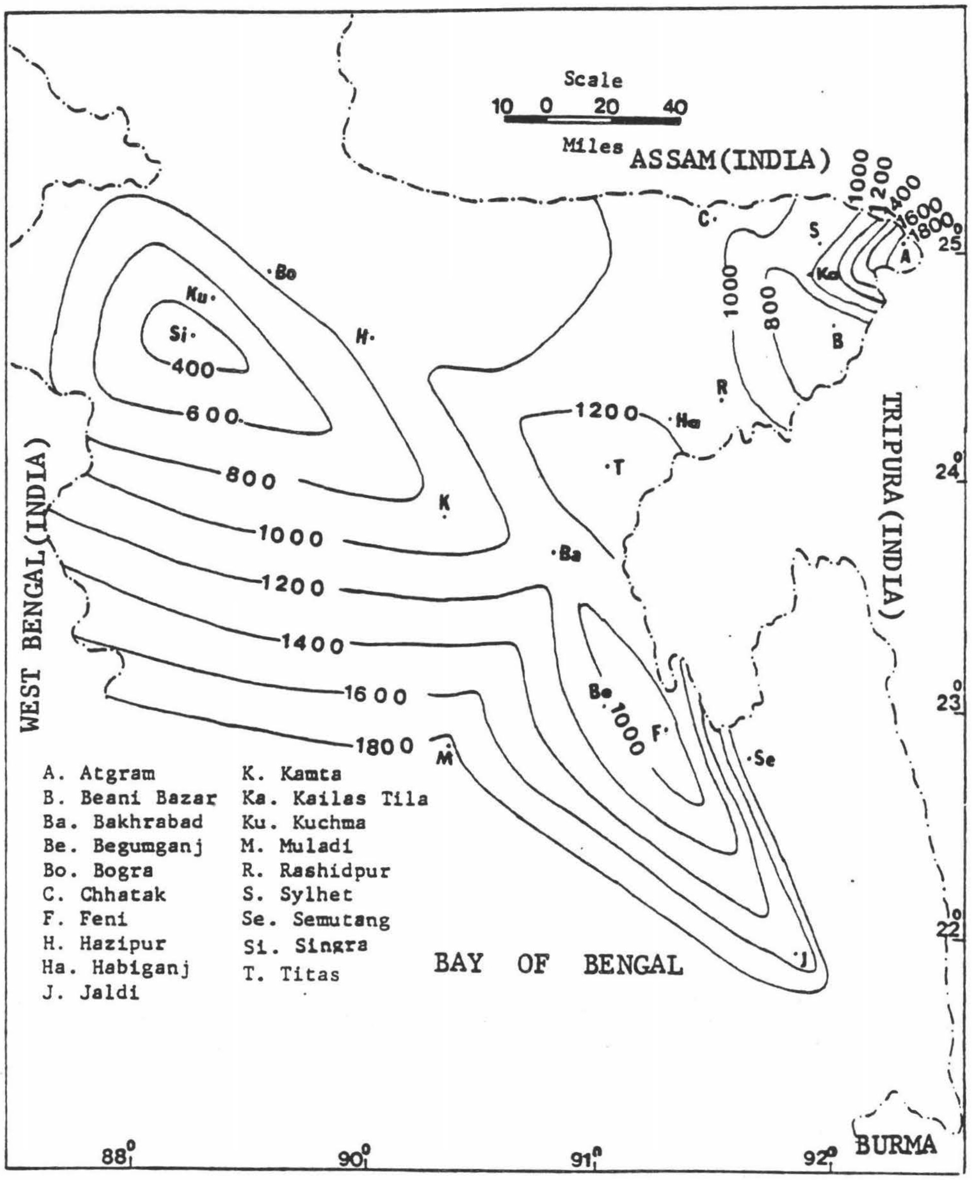

Figure 15. Isopach map of the Bhuban Formation (Lower to Middle Miocene). Contour Interval 200 m.

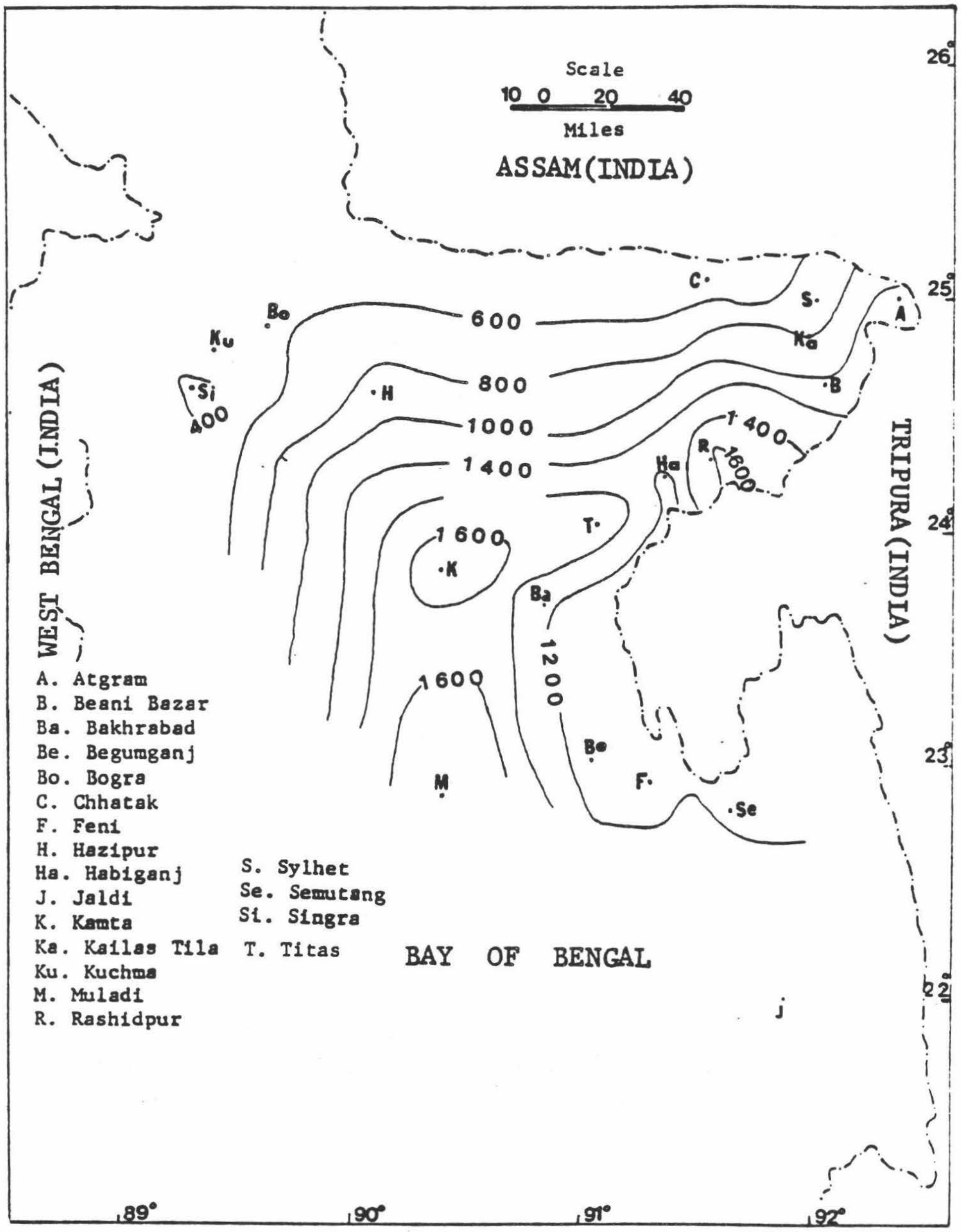

Figure 16. Isopach map of the Boka Bil Formation (Upper Miocene). Contour Interval 200 m.

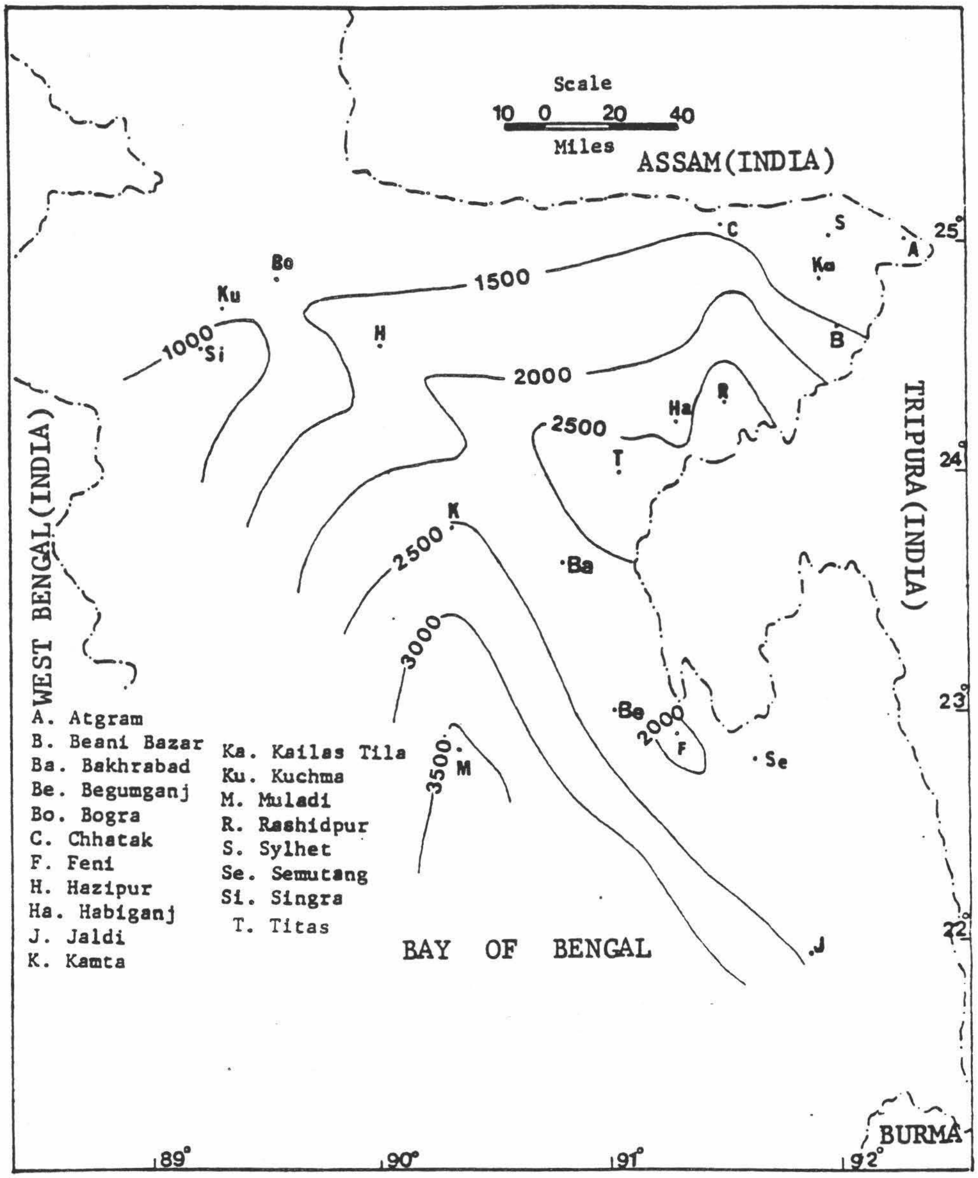

Figure 17. Isopach map of the Surma Group (The Bhuban and the Boka Bil Formation) (Miocene). Contour Interval 500 m.

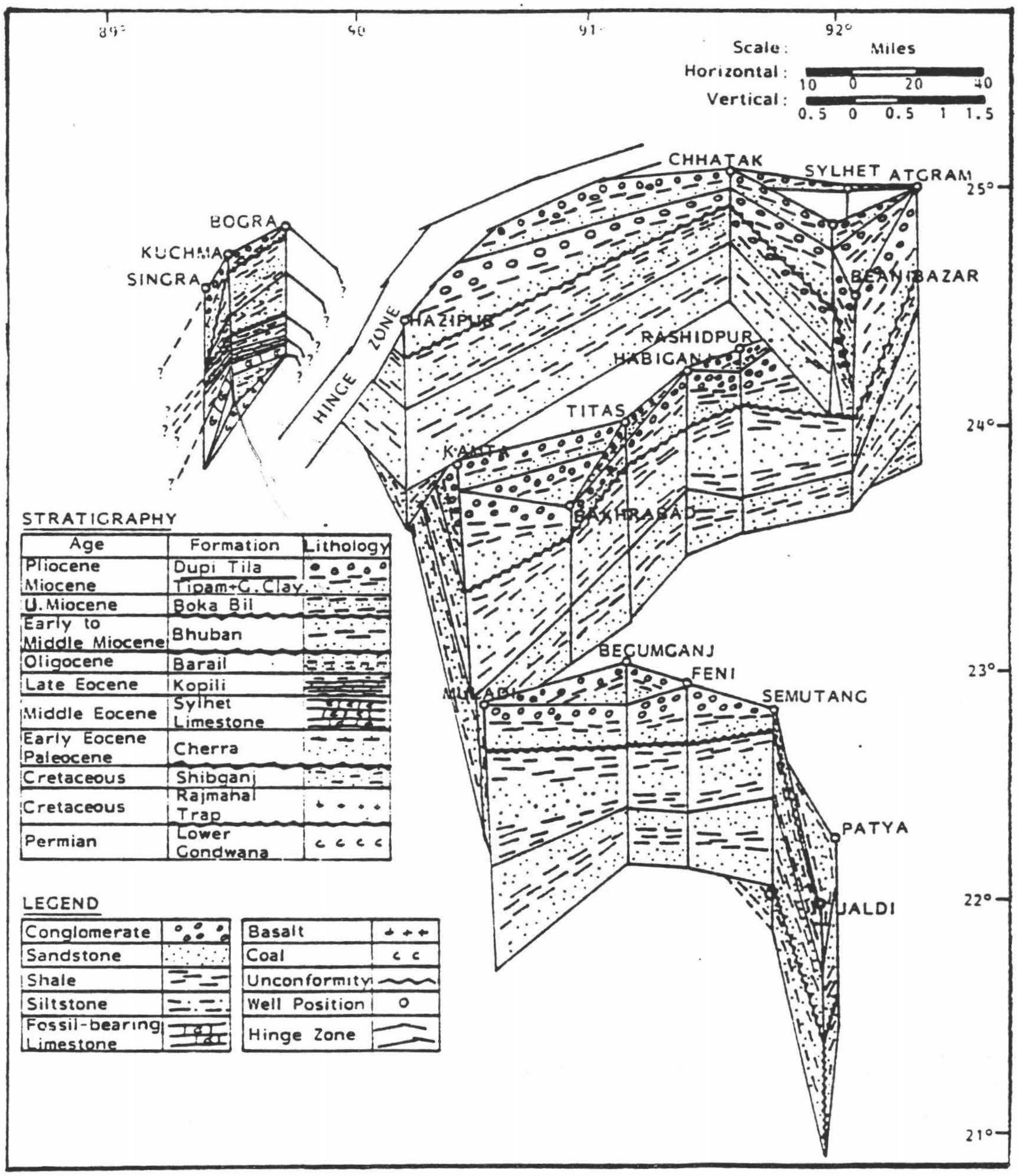

Figure 18. Fence diagram showing correlation of lithofacies and their distribution.

of the northwest Bangladesh however, were not correlated to the wells of the southeast because of there position in the north of the Hinge Zone.

The lithologies of the Miocene Surma Group and part of upper Barail Group have also been studied from the well logs (Tables VI to VIII). This is to be mentioned here that the Barail sediments have only been encountered in Hazipur, Chhatak, Atgram, Rashidpur, Titas-1 and Semutang wells. The drilled Barail rocks are dominantly shaly with few sandstone in Hazipur, Atgram and Semutang wells.

Figures 19 to 23 show the net thickness, percentage and ratio of the sand and shale sequences of the Bhuban Formation. The sandstone thickness map (Fig. 19) shows an increase in sandstone in the Rashidpur area. Low sandstone thickness is found near Bagumganj-Bakhrabad area. The sandstone percentage map (Fig. 20) indicates higher value towards the Beani Bazar area. Sandstone percentage decreases towards the northeastern and eastern part. Shale thickness map of Bhuban Formation (Fig. 21) shows lower contour values near Beani Bazar and Hazipur areas, whereas shale percentage (Fig. 22) is decreased near Rashidpur area. Sand-shale ratio map of Bhuban Formation (Fig. 23) shows higher value near Rashidpur-Beani Bazar area and lower value near Begumganj-Bakhrabad area. The ratio increases towards south.

Net sandstone thickness, sandstone percentage, net shale thickness, shale percentage and sand-shale ratio maps of the Boka Bil Formation are shown in figures 24 to 28. Sandstone thickness (Fig. 24)

WELL LOCATION	SAND THICKNESS (M)	SAND %	SHALE THICKNESS (M)	SHALE %	SAND-SHALE RATIO
HAZIPUR-1	218.3	24.5	474.3	53.2	0.46
CHHATAK-1	205.8	28.7	379.4	53.0	0.54
ATGRAM-1X	340.0	13.7	1404.9	56.7	0.24
BEANI BAZAR-1X	299.0	34.1	511.8	58.3	0.58
RASHIDPUR	468.9	27.9	773.2	46.0	0.61
TITAS-1	281.0	20.9	678.3	50.5	0.41
KAMTA-1	349.0	26.0	724.8	54.0	0.48
BAKHRABAD-1	187.9	17.8	692.6	65.6	0.27
BEGUMGANJ-1	119.9	11.0	646.0	60.8	0.19
SEMUTANG-1	353.5	21.0	1116.8	66.4	0.32

Table VI Net thickness, percentage and ratio of the sand-shale sequences in the Bhuban Formation (Lower to Middle Miocene).

WELL LOCATION	SAND THICKNESS (M)	SAND %	SHALE THICKNESS (M)	SHALE %	SAND-SHALE RATIO
HAZIPUR-1	123.5	10.6	714.1	61.4	0.17
CHHATAK-1	141.1	17.9	399.1	50.7	0.35
ATGRAM-1X	100.2	9.8	780.3	76.1	0.13
BEANI BAZAR-1X	286.3	48.5	125.3	21.2	2.28
RASHIDPUR	417.0	33.3	651.4	52.0	0.64
TITAS-1	474.3	30.8	878.7	57.1	0.54
KAMTA-1	302.5	24.8	796.4	57.8	0.38
BAKHRABAD-1	162.8	12.6	646.0	50.1	0.25
BEGUMGANJ-1	506.5	33.7	723.0	48.1	0.70
SEMUTANG-1	429.5	32.4	710.5	53.6	0.60

Table VII Net thickness, percentage and ratio of the sand-shale sequences in the Boka Bil Formation (Middle Miocene).

WELL LOCATION	SAND THICKNESS (M)	SAND %	SHALE THICKNESS (M)	SHALE %	SAND-SHALE RATIO
HAZIPUR-1	467.1	15.7	1687.7	56.7	0.28
CHHATAK-1	347.2	20.8	930.6	56.2	0.37
ATGRAM-1X	458.1	12.2	2292.6	61.1	0.20
BEANI BAZAR-1X	585.3	40.0	637.1	43.4	0.92
RASHIDPUR	885.9	26.1	1889.6	55.6	0.47
TITAS-1	755.3	25.3	1664.4	55.7	0.45
KAMTA-1	651.5	24.8	1521.2	57.8	0.43
BAKHRABAD-1	350.7	14.9	1338.6	57.1	o.26
BEGUMGANJ-1	626.4	24.1	1387.0	53.4	o.45
SEMUTANG-1	906.5	23.1	2523.0	64.7	0.36

Table VIII Net thickness, percentage and ratio of the sand-shale sequences in the Surma Group (Miocene) and upper part of Barail Group (Oligocene).

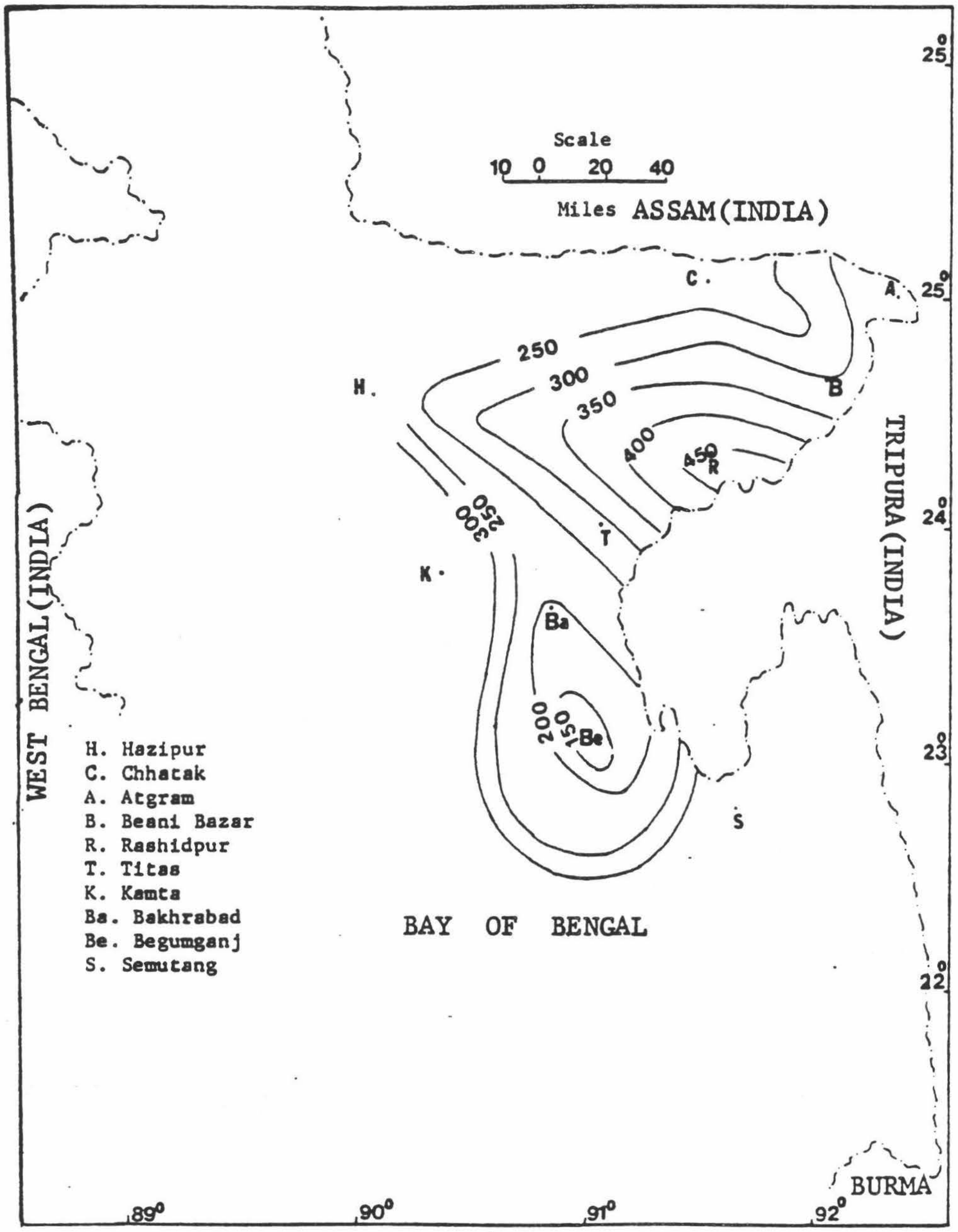

Figure 19. Sandstone thickness map of the Bhuban Formation.

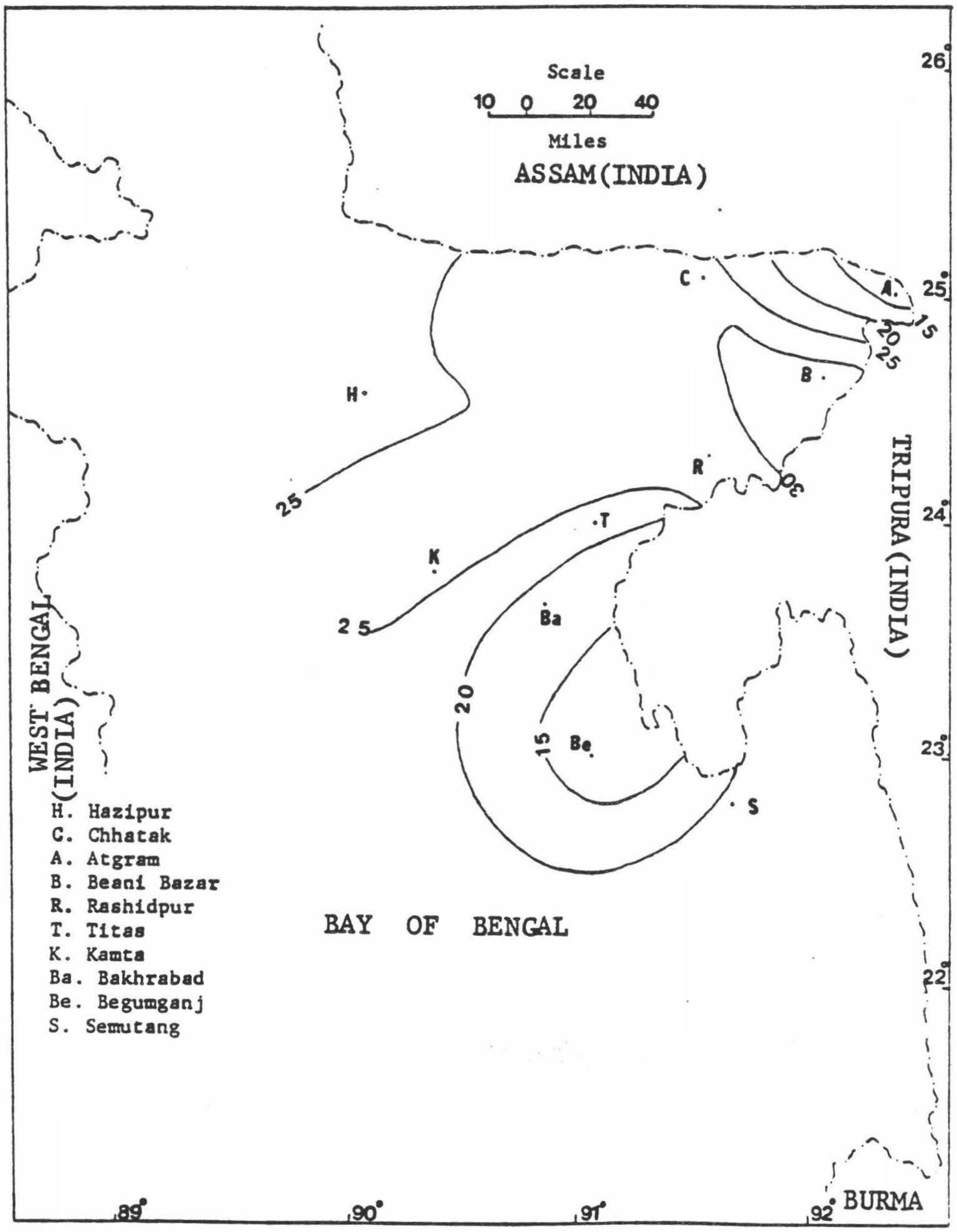

Figure 20. Sandstone percentage map of the Bhuban Formation.

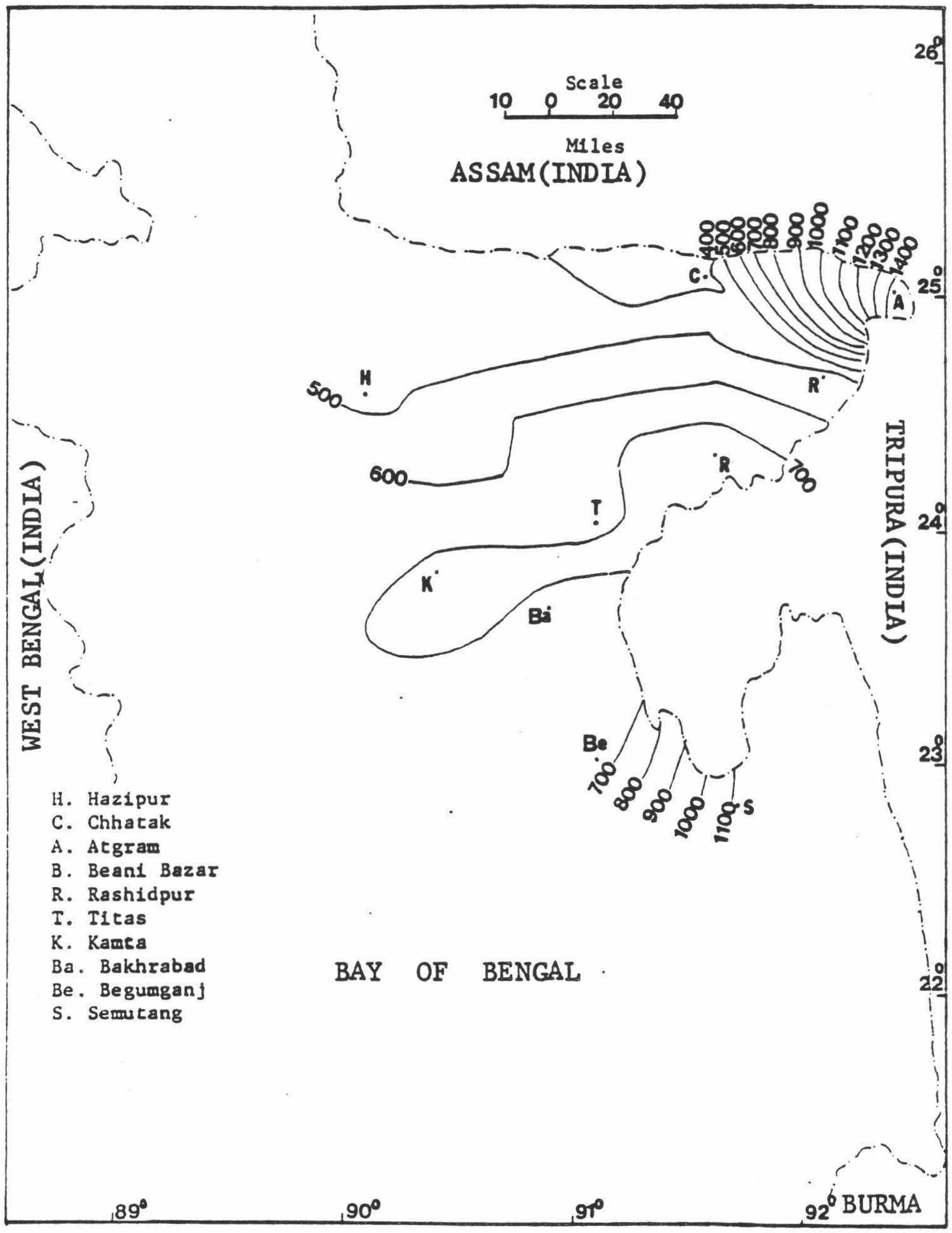

Figure 21. Shale thickness map of the Bhuban Formation.

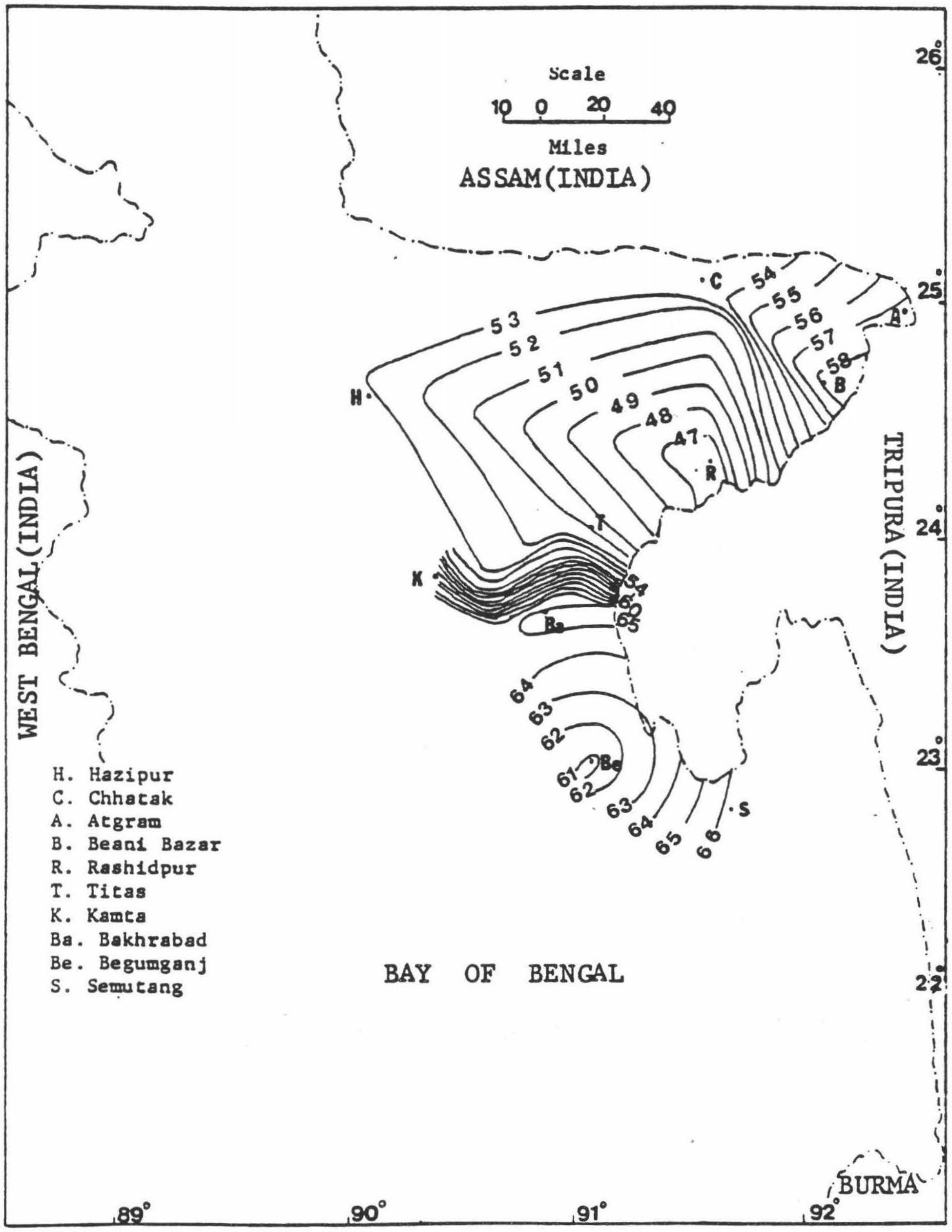

Figure 22. Shale percentage map of the Bhuban Formation.

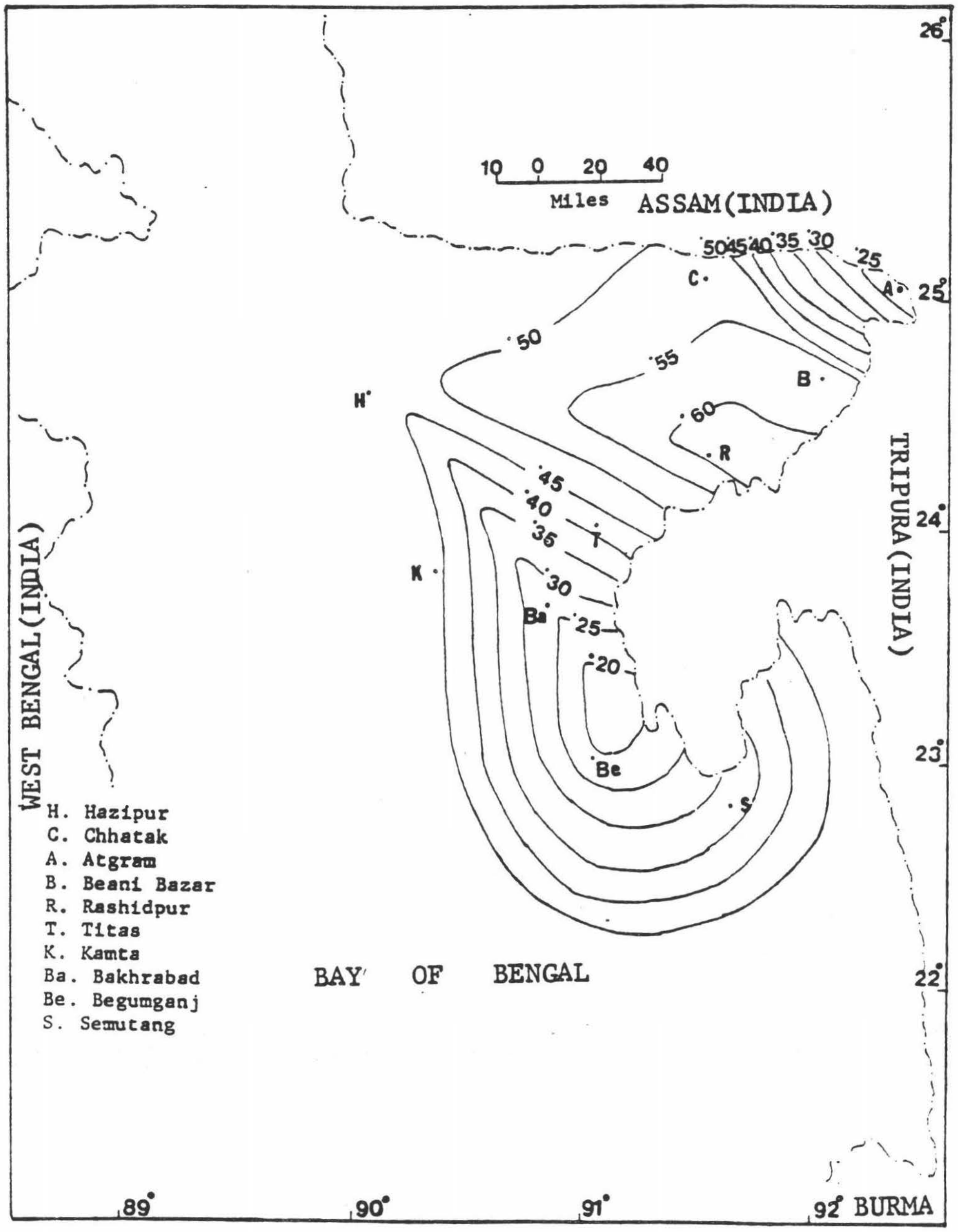

Figure 23. Sand-Shale ratio map of the Bhuban Formation.

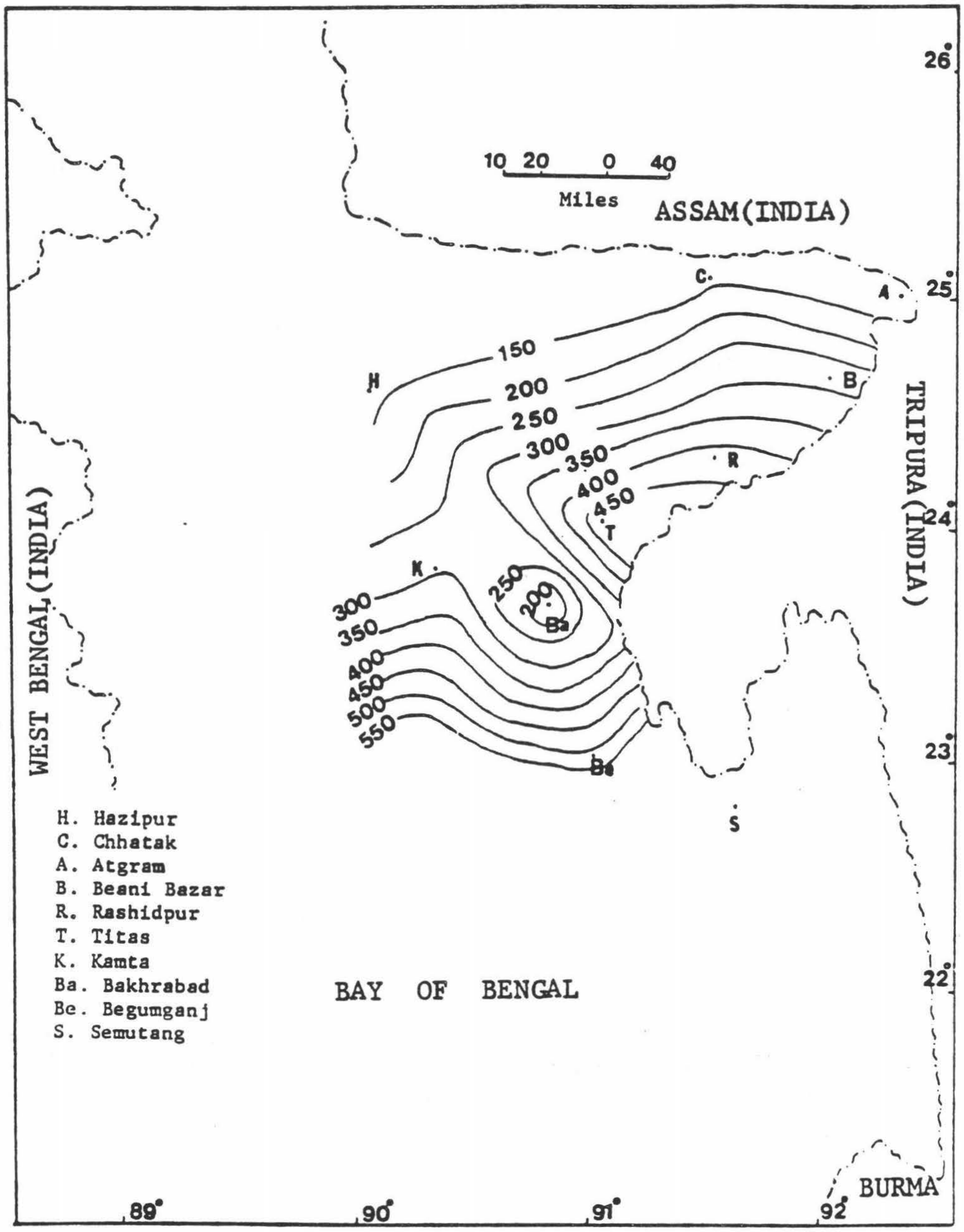

Figure 24. Sandstone thickness map of the Boka Bil Formation.

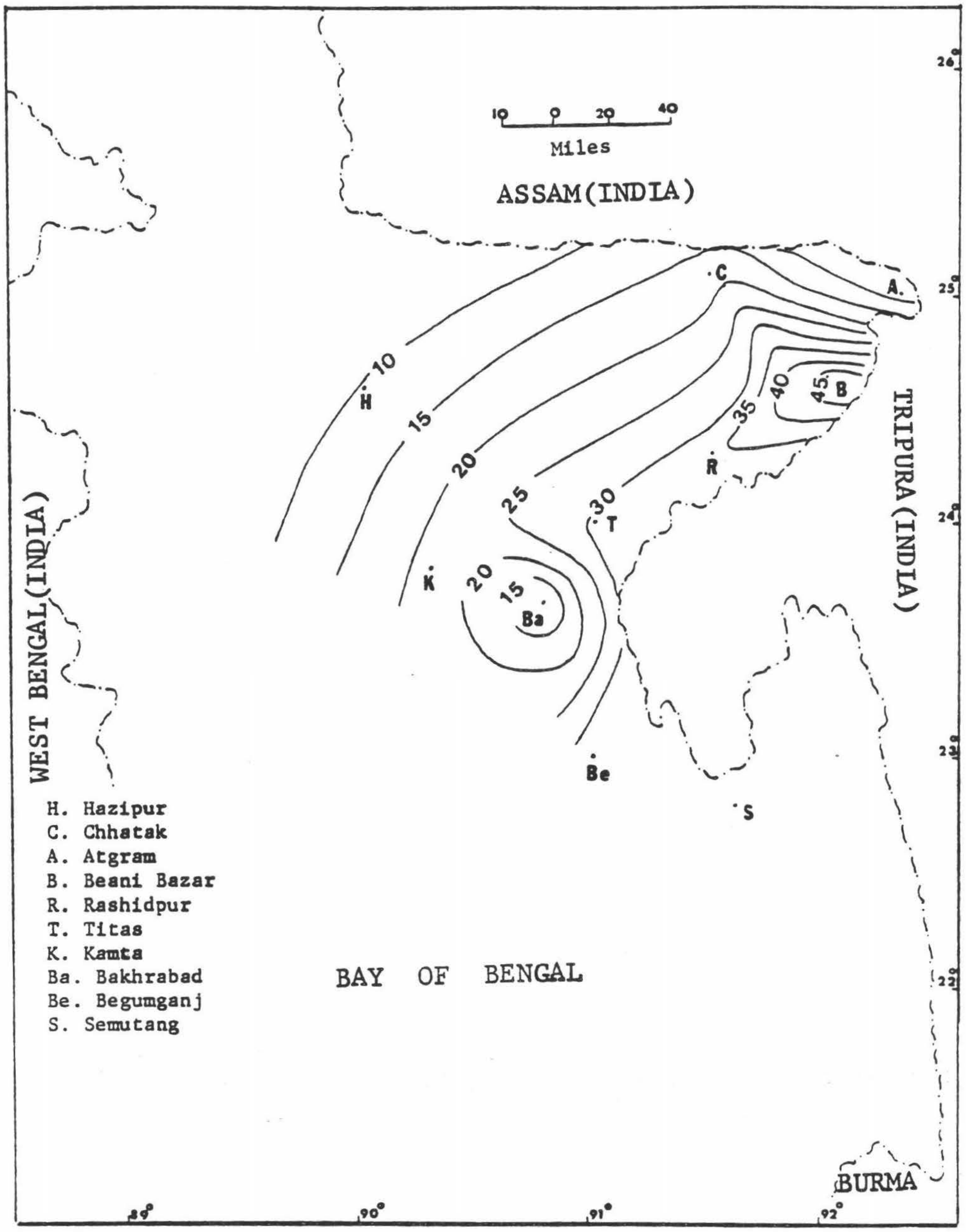

Figure 25. Sandstone percentage map of the Boka Bil Formation.

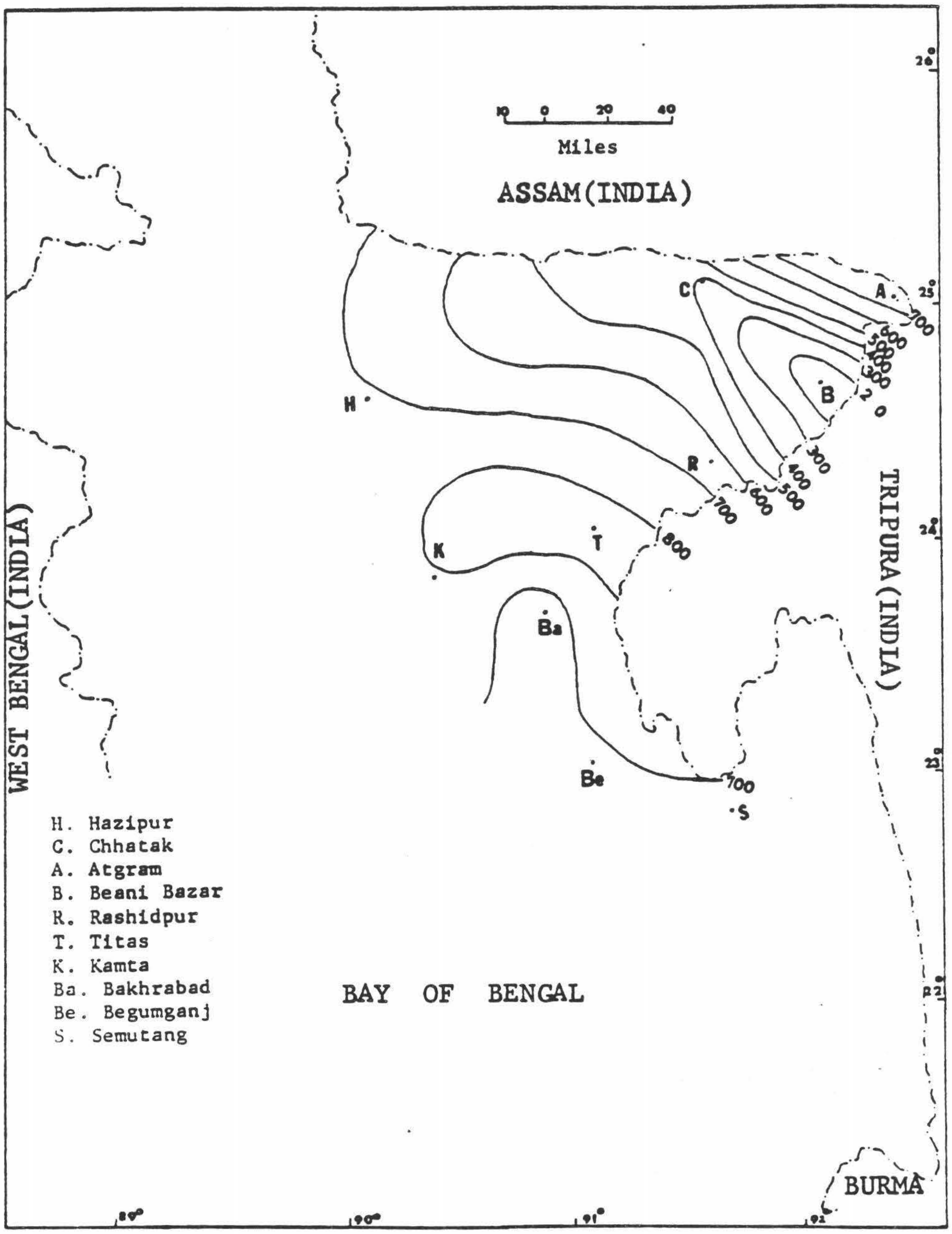

Figure 26. Shale thickness map of the Boka Bil Formation.

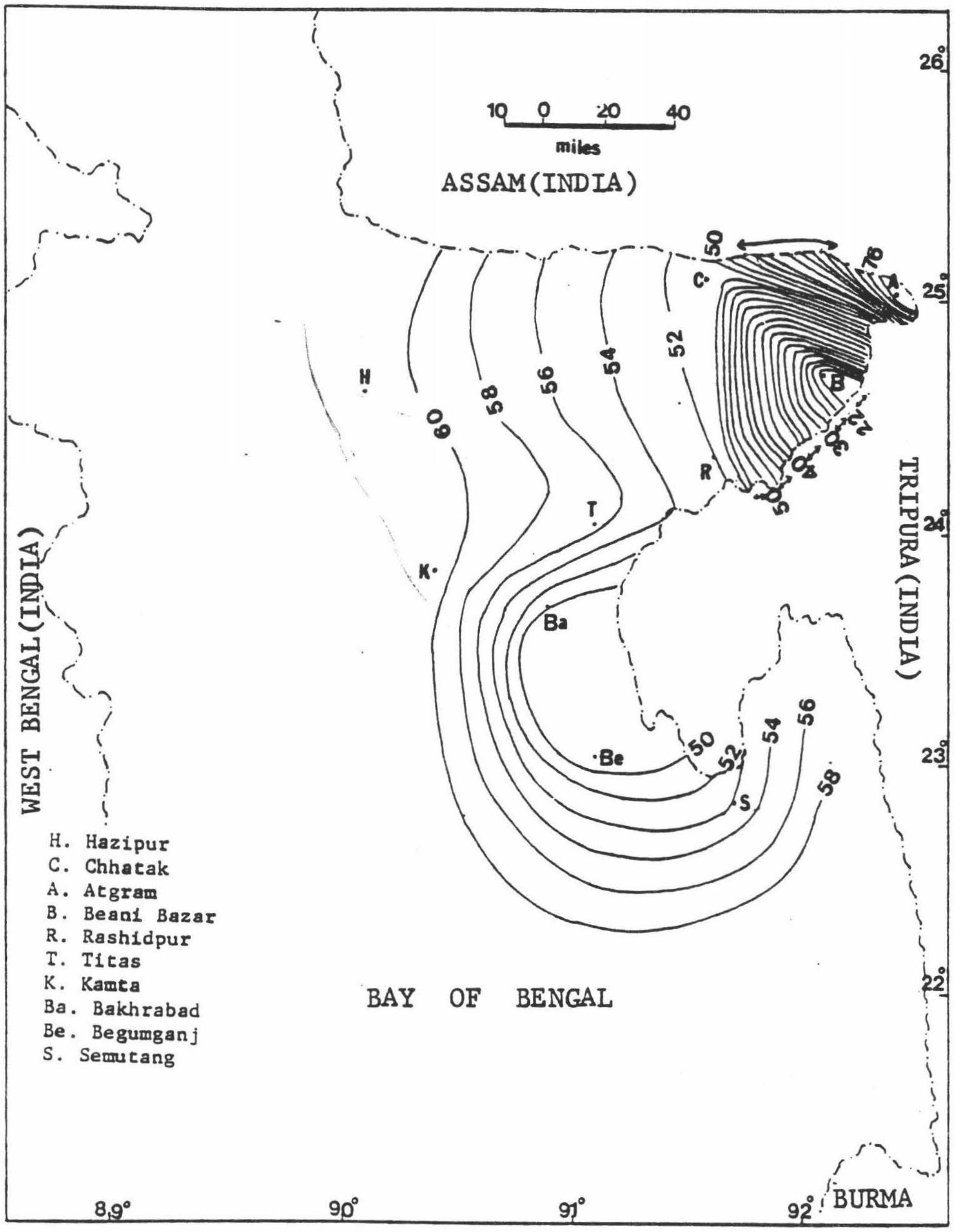

Figure 27. Formation Shale percentage map of the Boka Bil Formation.

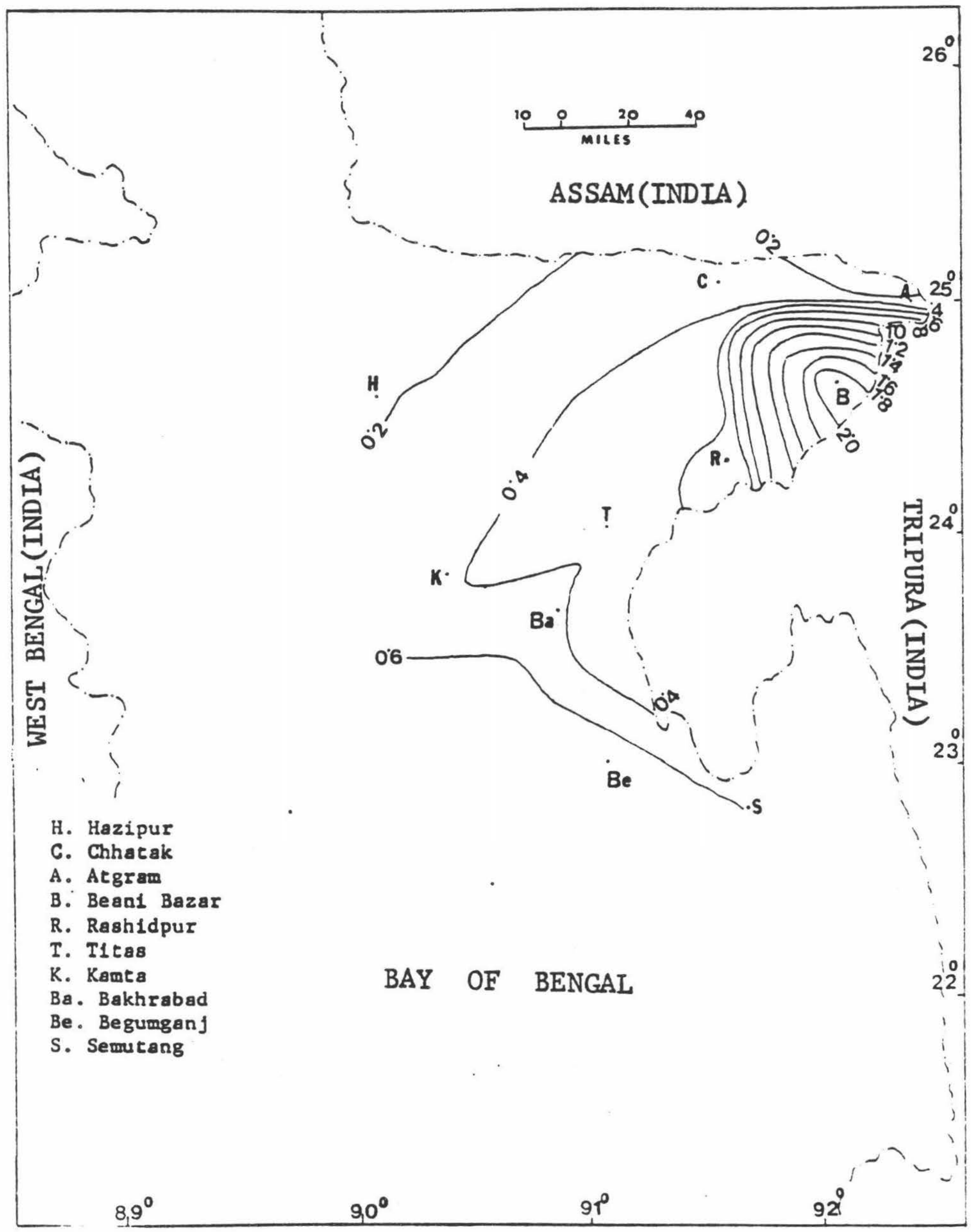

Figure 28. Sand-Shale ratio map of the Boka Bil Formation.

is increased near Titas-Rashidpur area and is decreased near Bakhrabad. Sandstone percentage is greatly increased in Beani Bazar (Fig. 25) which is decreased near Bakhrabad and towards north of Hazipur. Shale thickness is higher near Titas and lower near Beani Bazar (Fig. 26). Shale percentage is maximum in Atgram (Fig. 27). The shale percentage value has a sharp decrease from Atgram and Rashidpur area towards the Beani Bazar. Sand-shale ratio map (Fig. 28) shows decreasing values from Beani Bazar towards north, west and south.

Total sandstone thickness, sandstone percentage, total shale thickness, shale percentage and sand-shale ratio maps of the overall Surma Group and upper part of Barail Group are shown in figures 29 to 33. Like the sand-shale distribution pattern of the individual Bhuban and Boka Bil Formations, these figures also show the same trend. Sandstone is dominant in the Titas-Rashidpur-Beani Bazar region with gradual decrease in all the directions.

Lithologically, the Bhuban and the Boka Bil Formations are further subdivided into lower, middle and upper parts.

The Bhuban Formation is subdivided into a lower, 5800 feet (1768 m) of sandy; a middle 2700 feet (823 m) of shaly, and an upper 4000 feet (1220 m) of sandy units (Khan and Muminullah, 1980).

The Boka Bil Formation, 4260 feet (1300 m) thick, is also subdivided into three members: A lower shaly, a middle mostly sandy and an upper shale unit. Overall the Surma Group of rocks is a sequence of sandy at the base and changes to shaly in the near top member. The upper marine shale of the Boka Bil Formation is a marker bed in reflection seismology.

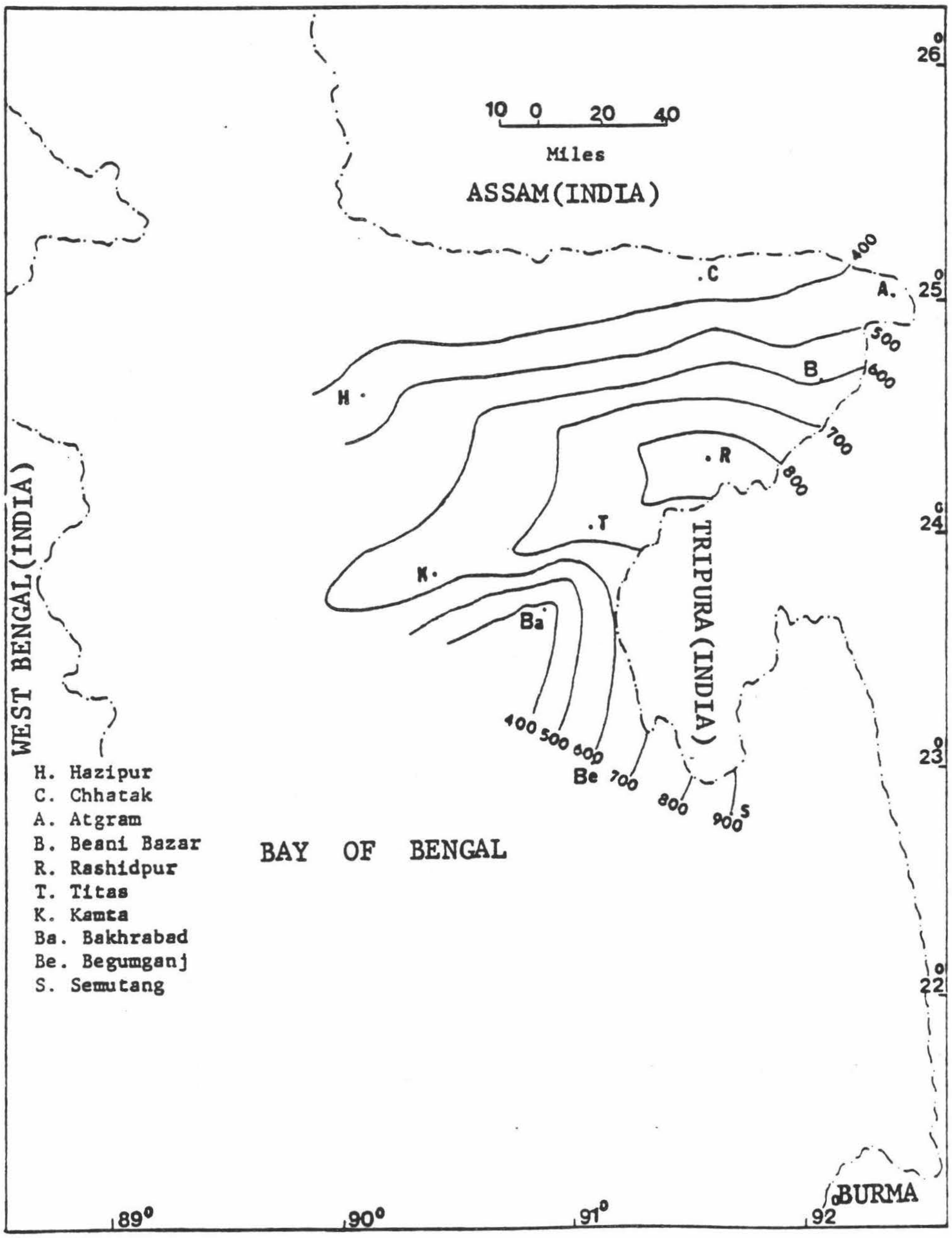

Figure 29. Sandstone thickness map of the Surma Group (Miocene) and part of the Barail Group (Oligocene).

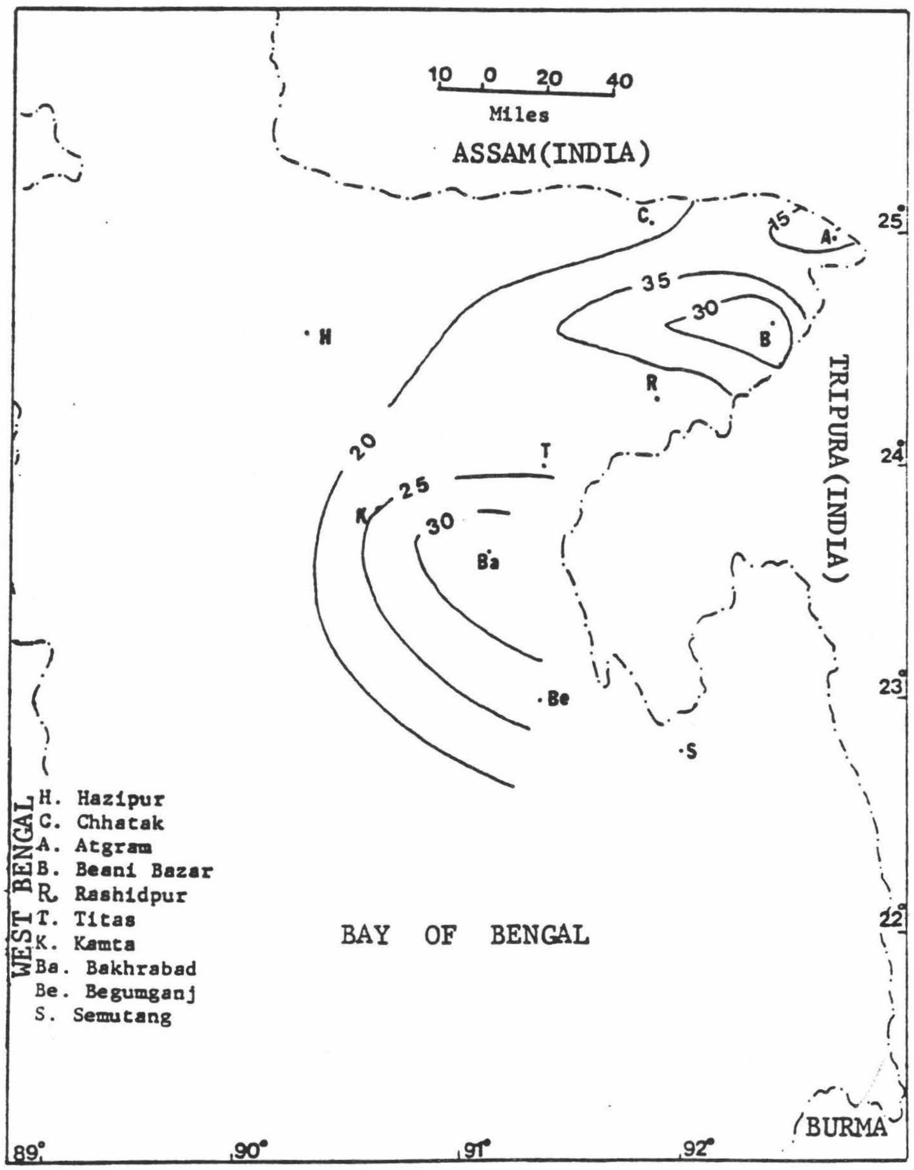

Figure 30. Sandstone percentage map of the Surma Group (Miocene) and part of the Barail Group (Oligocene).

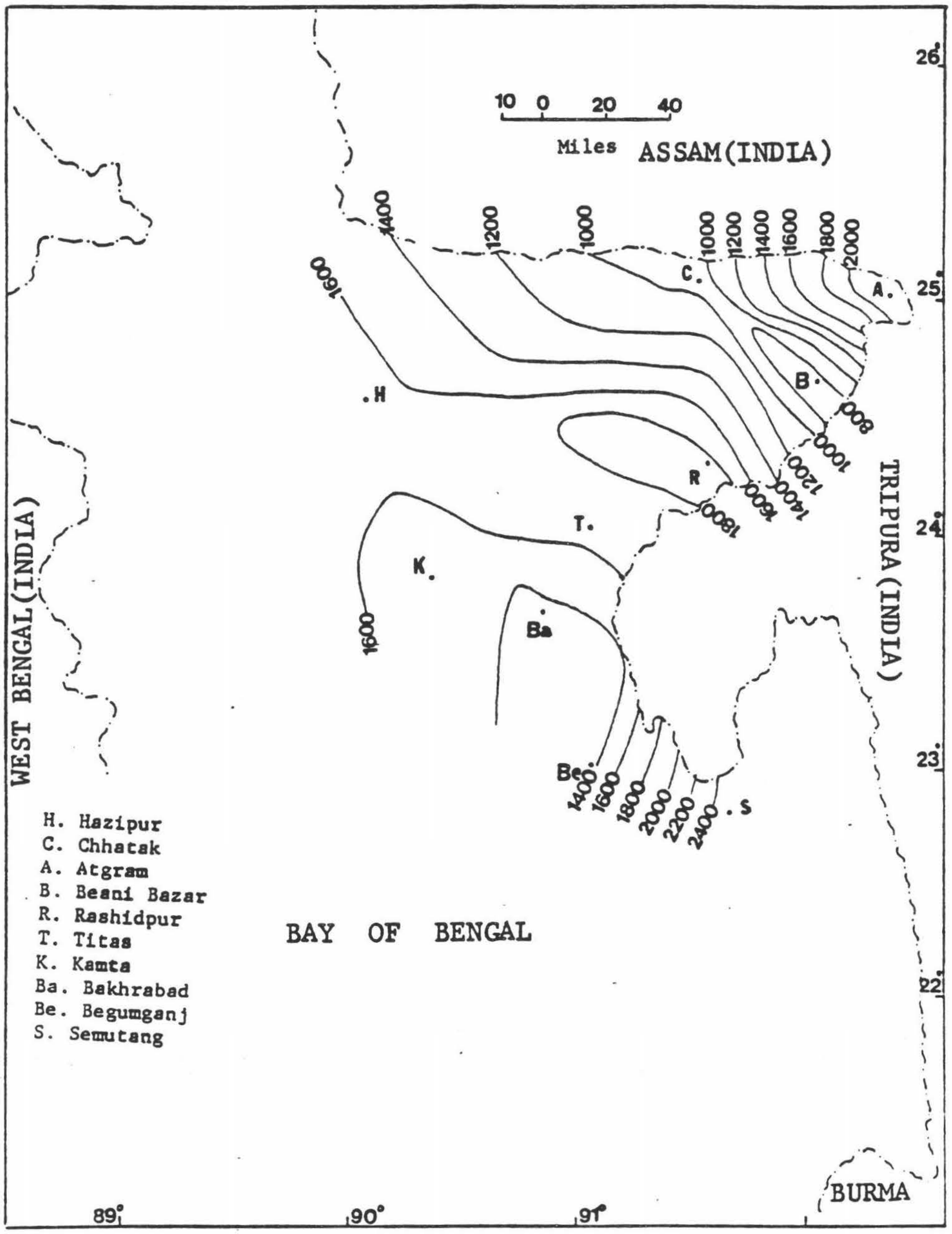

Figure 31. Shale thickness map of the Surma Group (Miocene) and part of the Barail Group (Oligocene).

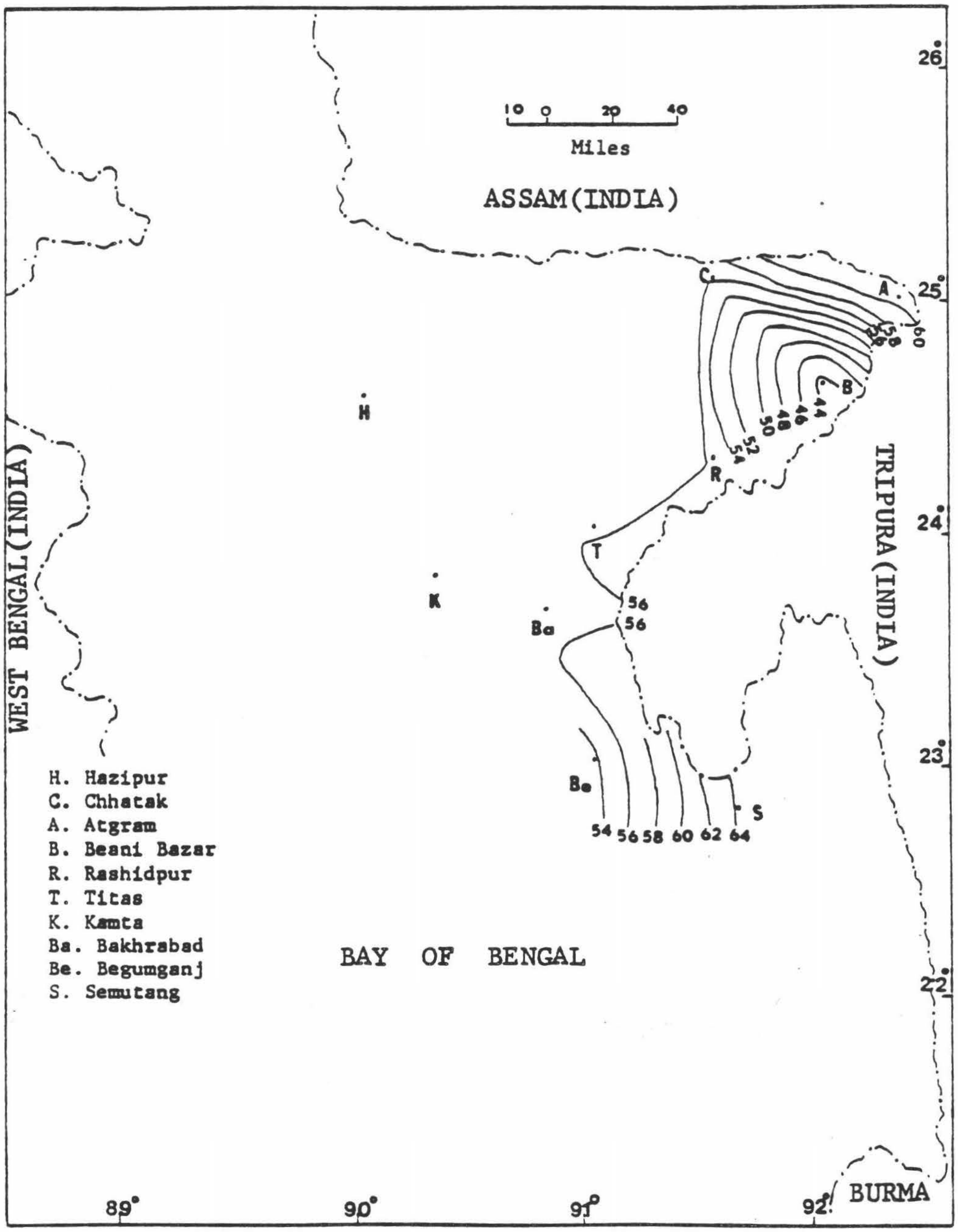

Figure 32. Shale percentage map of the Surma Group (Miocene) and part of the Barail Group (Oligocene).

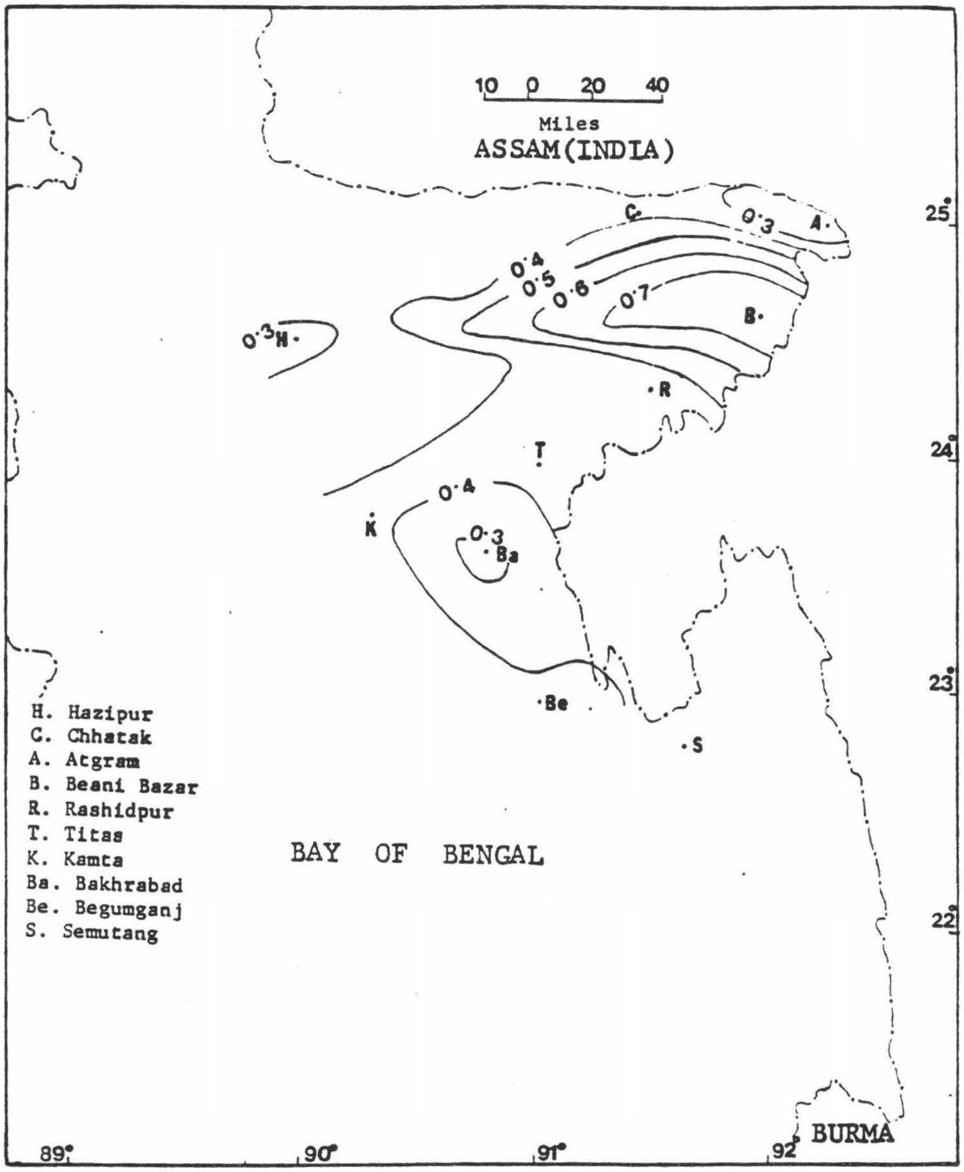

Figure 33. Sand-Shale ratio map for Surma Group (Miocene) and part of the Barail Group (Oligocene).

The Tipam Group of rocks both conformably and unconformably overlie the Surma Group. The Tipam Group is divided into a lower Tipam Sandstone Formation and the upper Girujan Clay Formation. Based on lithological characters the Tipam Sandstone can be divided into three members: a lower sandstone, 3798 feet (1150 m), a middle shale-siltstone, 1020 feet (310 m), and an upper sandstone, 634 feet (198 m). The sandstone is ferruginous, cross-bedded coarse grained and reported to be Early Miocene age (Khan and Muminullah, 1980). These sequences represent two transgressive and two regressive alternating phases. The Tipam Sandstone is overlein conformably by the Girujan Clay Formation, 1525 feet (465 m), which is believed to be of Middle Miocene age in Assam. This clay formation consists mostly of mottled clay with banded concretionary bodies. The Girujan clay is reported to be of Middle Miocene age in upper Assam (Lexa, Stra, 1956). The Girujan clay is missing elsewhere in the Chittagong (Holtrop and Keizer, 1970).

The Dupi Tila Formation which is 1540 feet (470 m) thick and unconformably overlies the Tipam Group, consists of massive sandstone with minor claystone of Mio-Pliocene age (Krishnan, 1960). The Dihing Formation unconformably overlies the Dupi Tila Formation. The Dihing Formation consists of pebble beds with lesser sandstone and clay and is probably of Pliocene Age (Krishnan, 1960). The Dihing is unconformably overlain by the Madhupur Clay Formation composed of oxidized mottled clays. The clay is predominately kaolinite with traces of montmorillonite (Alam and Khan, 1980). The Madhupur clay is believed to be of Pleistocene age. The Modhupur Clay is unconformably followed by a variable thickness of recent alluviums consisting of loose gravels, sand, silt and locally peat.

According to Brunnschweiler (1978), offshore marine seismic surveys indicate that the sedimentary sequence down to 4500-4800 m, can generally be subdivided into three major parts:

1. An upper 1500 m (4800 ft) thick unit of well stratified sediments deposited during a period of quiet sedimentation in a low-energy environment.

2. The next 1000-1200 m (3200 to 4000 ft) thick succession consists mostly of cross-bedded and channeled sediments (high energy environment). The submarine channels are 300-800 m (1000 to 2500 ft) deep and upto 8 km (5 mile) wide. The cross bedded zone points to north-south transport.

3. The channeled succession rests on a stratified sequence of 1500-1800 m (1500 to 6000 ft) thick.

Brunnschweiler (1978) noticed in some areas a still deeper fourth sequence of cross bedded and irregular, deeply channeled sediments, showing an east-west transport direction. The deepest offshore test (4598 m or 15000 ft), paleontologically has not gone below beds of Upper Miocene (top of well stratified 3rd subdivision of the seismic profiles). As no offshore test has gone deeper than the Tipam or perhaps the upper level of Boka Bil, the chaotic middle subdivision should be a part of Tipam/Girujan/Dupi Tila rocks while the top first layer should be a sequence of Pleistocene and Recent deposits.

Seismostratigraphy

Seismostratigraphy has become an important element of exploration in basins with limited well control (Brown and Fisher, 1977) and is highly useful in offshore areas. Stratigraphic interpretation involves two approaches 1) a physical approach, involving processing and synthetic modeling and 2) a stratigraphic facies approach involving interpretation and integratation of depositional system filling the basins.

In Bangladesh, since many of the important tectonic subzones and layers have not yet been drilled and therefore seismic sequences remain the only source of information upon which to interprete the internal stratigraphy of the region. Additionally depositional models can be created for each stratigraphic sequence which enables the hydrocarbon potential of each sequences to be evaluated.

Seismic studies in Bangladesh have been conducted for approximately two decades with more than 10,000 line kilometer of onshore and 31,000 line kilometer of offshore profiles now available. The onshore seismic surveys were mainly done in the northeastern Surma Basin and northwestern Stable Shelf/Hinge Zone areas. Although seismic studies have a long record in Bangladesh, seismostratigraphy, is a very recent activity (Lietz, 1982; Salt et al., 1986). Lietz (1982) attempted to establish a basin-wide seismostratigraphic correlation scheme and to compare its results with the established stratigraphic framework. Altogether, he picked seven major seismic sequences ranging from the Gondwana coal and Jurassic volcanics to the

"Upper Marine Shale" of Upper Miocene. The study determined a number of major erosional unconformities and revealed that the sedimentary sequences are most likely much younger than believed in the eastern-northeastern and southern Bangladesh (Fig. 34). Moreover, the total stratigraphy can be revealed by seismostratigraphy where there are problems with palynology. This can be seen in the well Atgram IX (Fig. 35).

Salt et al. (1986) have modified the seismostratigraphy proposed by Leitz (1982) for the Hinge Zone of southwestern Bangladesh (Fig. 36). Based entirely on reflection studies, the area is undrilled, Salt et al. (1986) have provided descriptions, depositional models and hydrocarbon prospectivity for each of specific seismic sequence. The left most column in the figure is that of Sengupta (1966) for the West Bengal, India. Salt et al. (1986) also provided description and depositional models for each specific seismic sequence along with its hydrocarbon prospectivity. They found eleven seismic sequences with seventeen reflector horizons, basement being the number 1 (R-1). Their S-D sequence begin with first prograding sequence in Upper Cretacious followed by a regression. In the Paleocene to Upper Eocene Sequence (S-F) a time-equivalent rock of foraminiferal limestone deposits were found. Moreover, marked thickness variation between Reflectors 7 and 8 has also been noticed (Fig. 37 and Fig. 38). The reflectors also conform the southward tilt of the stratigraphic layers within the Bengal Basin which was also determined by Sengupta (1966). A paleo-environmental reconstruction, on the basis of seismic results, also shown in figure 39. A number of curvilinear reflectors (Fig. 40)

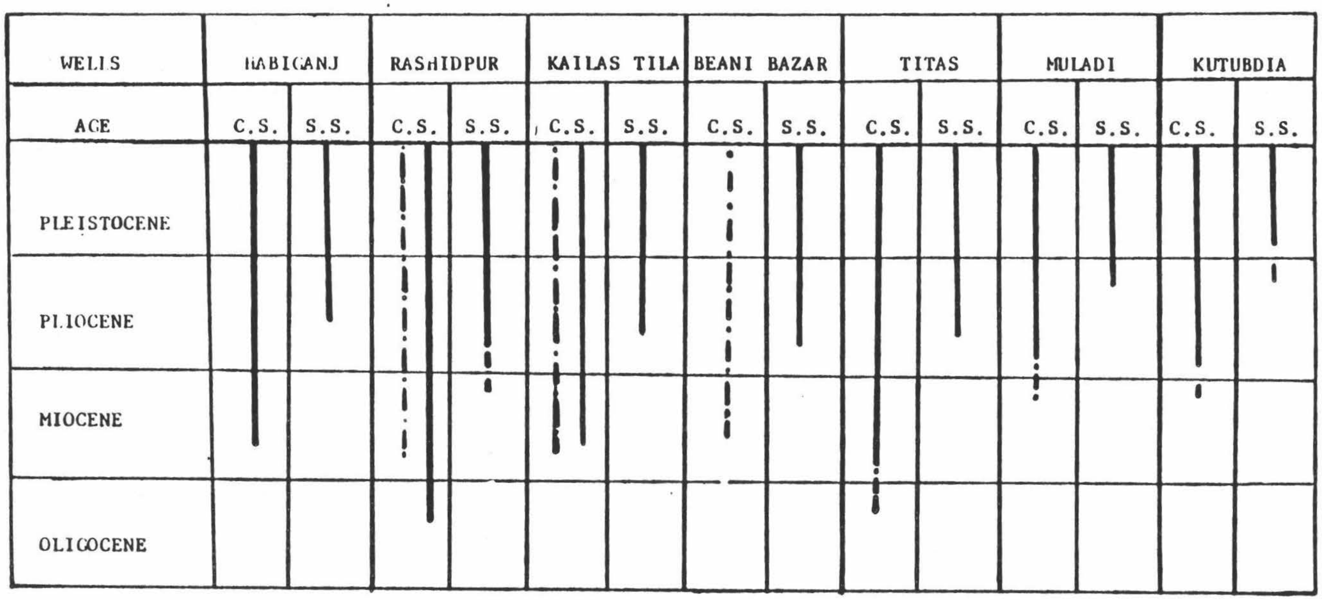

Figure 34. Comparison of stratigraphic age assignments from different wells in Bangladesh based on results of conventional stratigraphy (C.S.) and Seismic stratigraphy (S.S.).

source: Lietz (1982, cited in Ahmed, 1985)

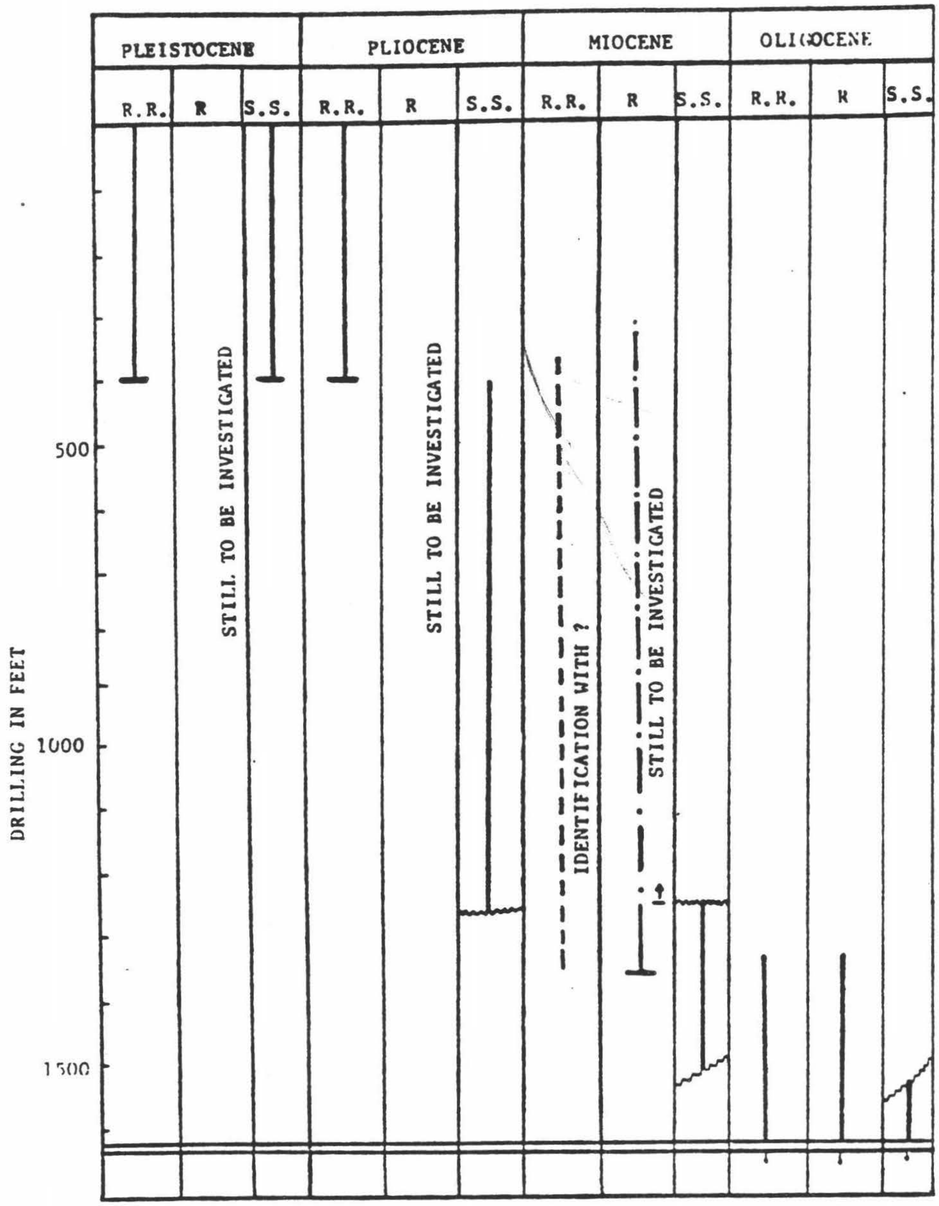

Figure 35. Comparison of Stratigraphic age assignments of the well Atgram-IX by Palynology (R.R=Robertson Research, R=Dr. Reimann, German Geol. Advisors Group) and Seismic Stratigraphy (S.S.).

source: Lietz (1982, cited in Ahmed, 1985)

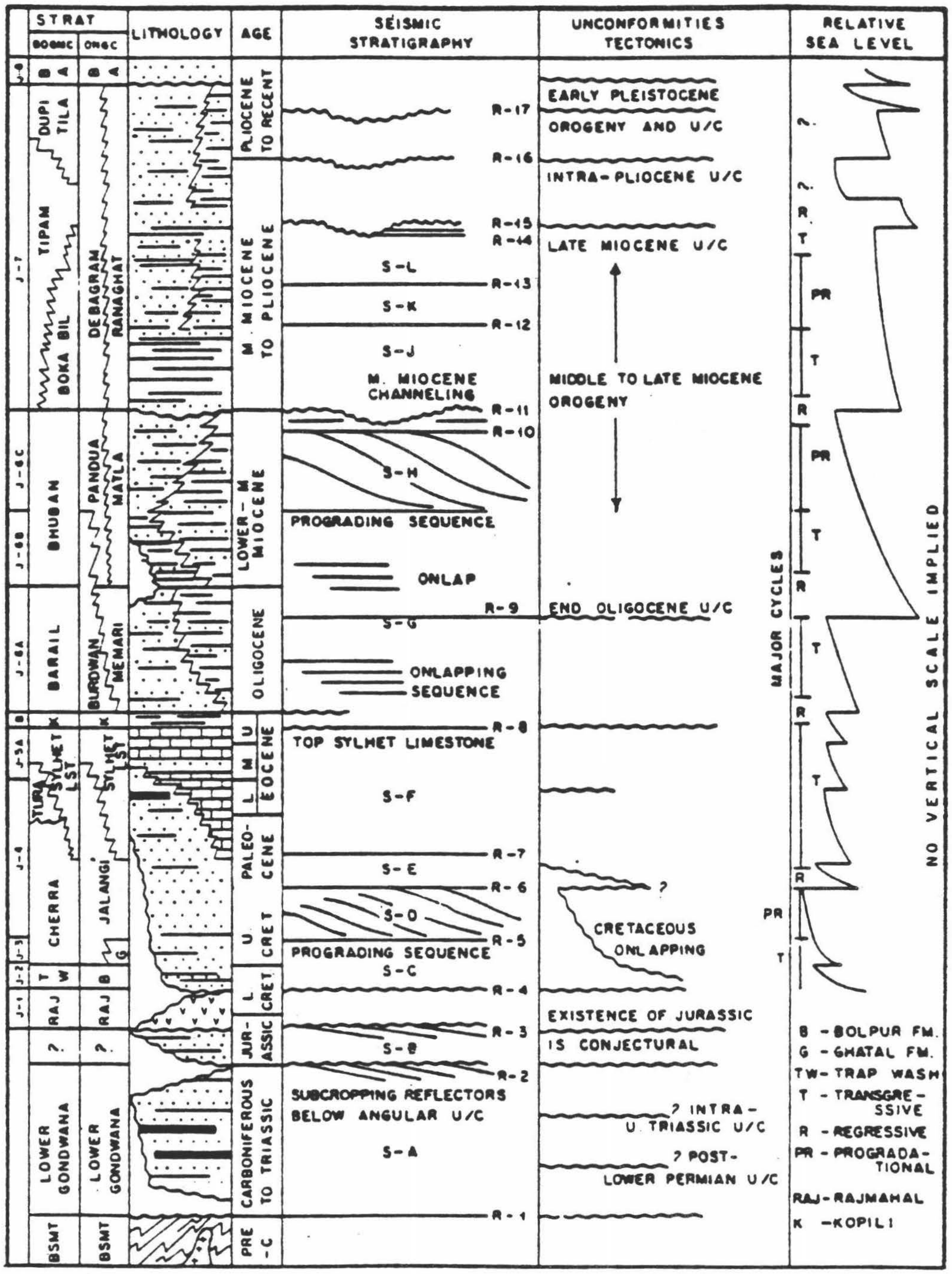

Figure 36. Seismic Stratigraphic Chart of the Bengal Basin 'Hinge Zone'.

source: Salt et al. (1986)

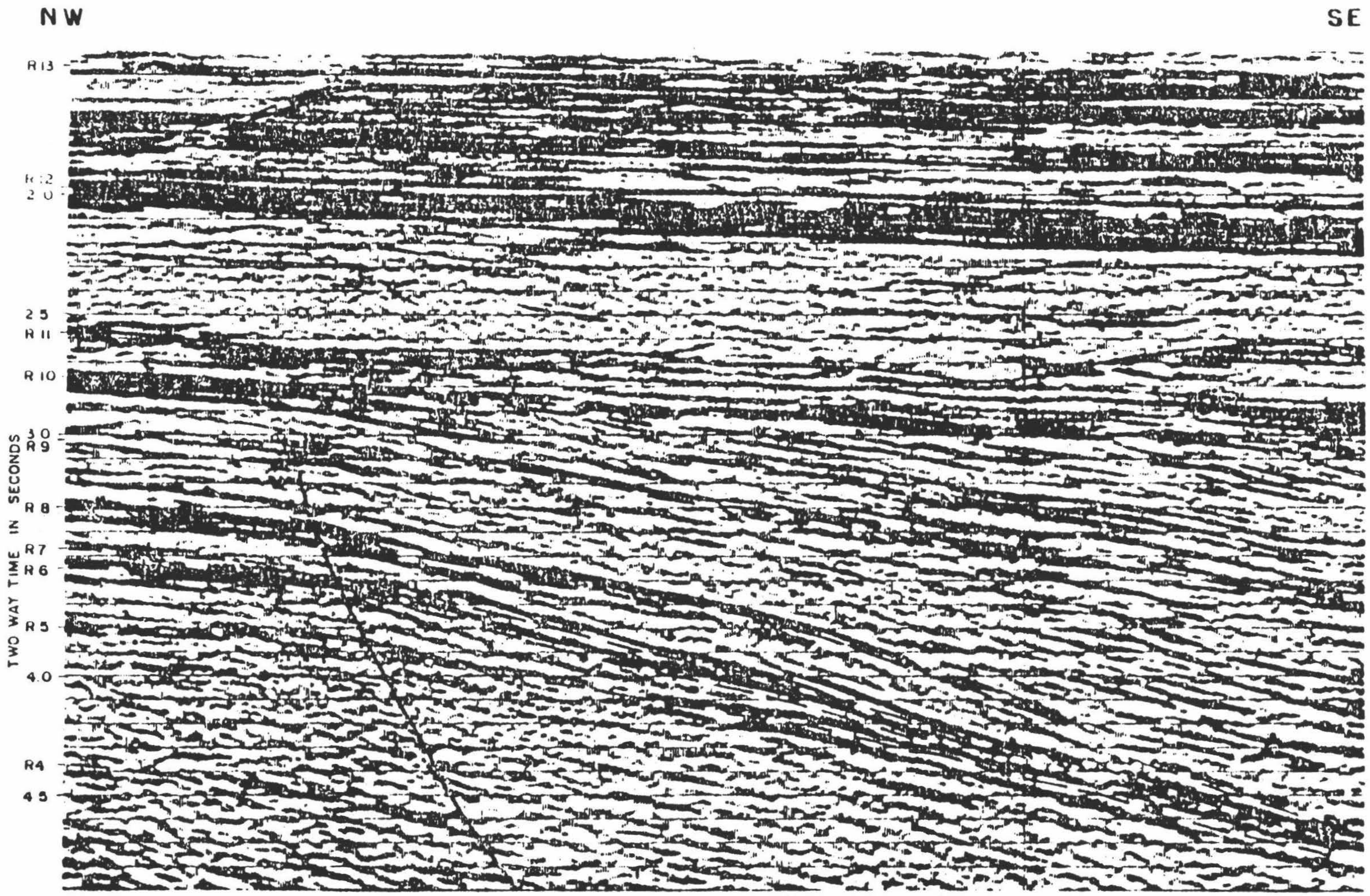

Figure 37. Seismic Section parallel to dip, across 'Hinge Slope'.

Scale 1: 50000

source: Salt et al. (1986)

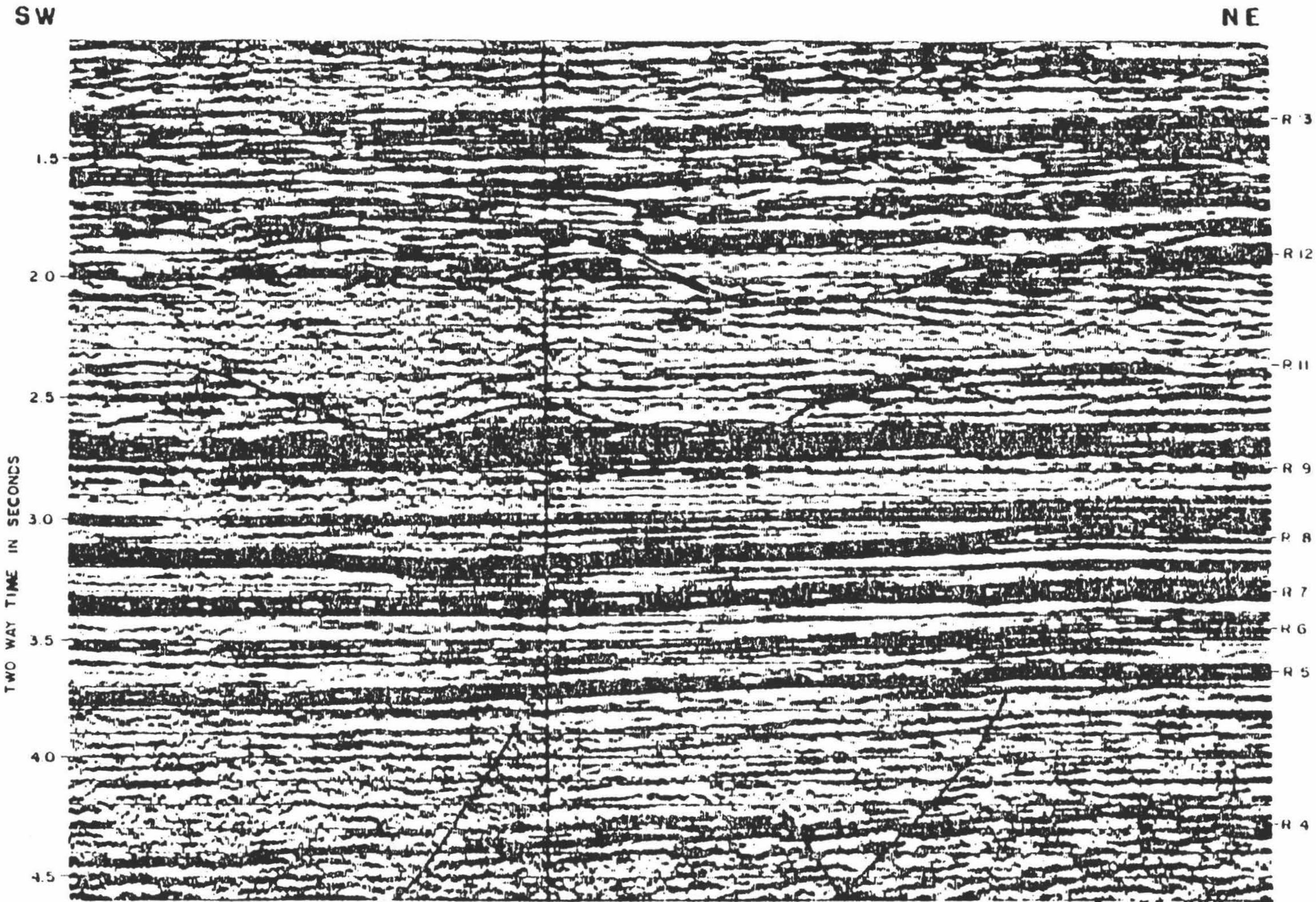

Figure 38. Seismic Section parallel to strike in lower shelf area.

source: Salt et al. (1986)

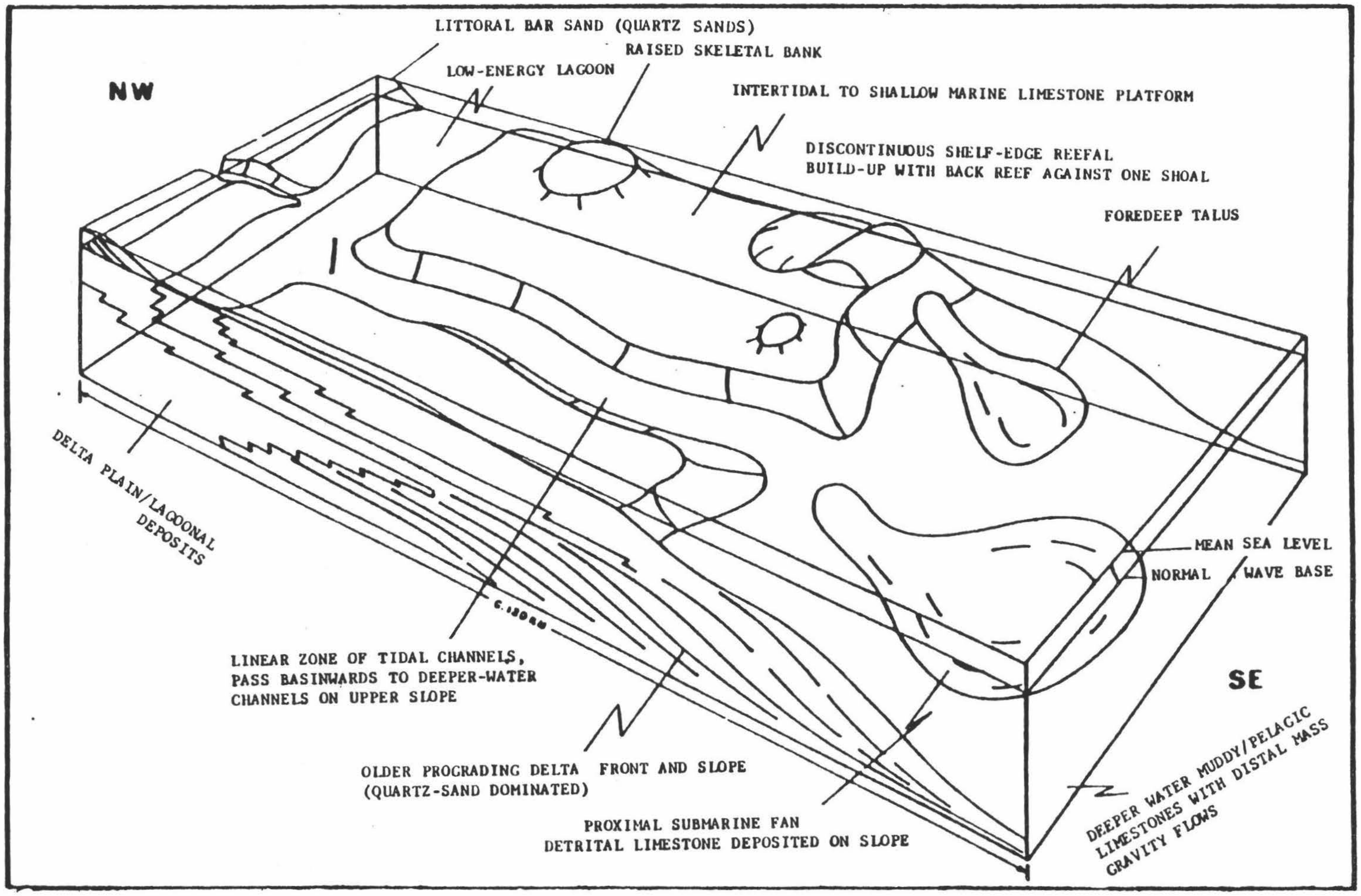

Figure 39. Diagrammatic paleo eviromental reconstruction of the Shelf and 'Hinge' areas of the western part of the Bengal Basin during the Paleocene-Eocene deposition.

source: Salt et al. (1986)

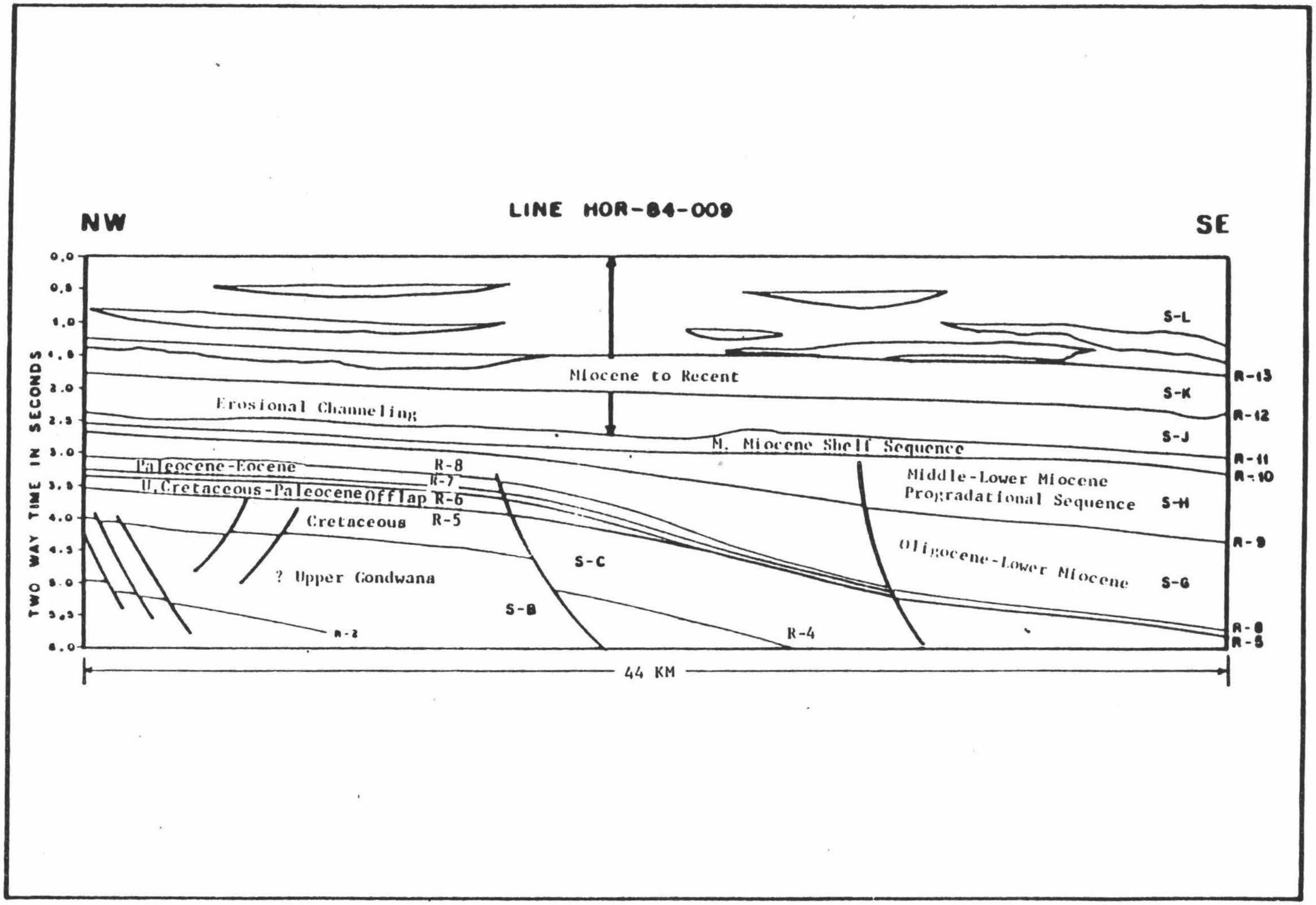

Figure 40. Reduced scale interpretation of Seismic line Hor-84-009, showing principal reflectors.

source: Salt et al. (1986)

mark the hiatuses after deposition of the Oligocene deposits. The post-Oligocene sequences have demonstrate deltaic structures including large scale cut and fill erosional channeling.

PALEOGEOGRAPHY AND GEOLOGICAL HISTORY

According to Paul and Lian (1975) the Bengal Basin, though almost a sedimentary basin, is the product of plate tectonics, reflecting both divergent and convergent episodes. The Pre-Cambrian history of Bangladesh is poorly known as no surface octcrops occur within the country. Limited data from drill holes in northwestern Bangladesh show that the Pre-Cambrian is represented by crystalline gneiss, granitoid pegmatites and metamorphic biotite-hornblende schists (Haque, 1974), indicating a complex sedimentology, metamorphic and igneous history.

Subsurface investigations in the platform region in Bangladesh (Stable Shelf or Pericraton-Raju, 1968) or West Bengal has not revealed the presence of any Cambrian, Ordovician, Silurian, Devonian, and Lower to Middle Carboniferous rocks, (Zaher and Rahman, 1980). They suggest that these rocks were not deposited in Bangladesh and the whole of Bangladesh was a uplifted craton area until the end of the middle Carboniferous.

During the Upper Carboniferous time regional tension caused by the initial splitting of the Indian block from Antarctica and the Gondwana Group was formed in the western portion of the Bengal Basin (Paul and Lian, 1975). The thick sequences of continental Gondwana sediments, consisting of cross-bedded arkosic sandstone, conglomerates, carboneceous shale (locally coal bearing), were deposited in a series of intracratonic, faulted graben type basins (Paul and Lian, 1975, and Zaher and Islam, 1975). The prevailing environment in the region was lacustrine to marshy environment (Haque, 1974). Ahmed (1961) suggests that the subsidence of the basin was epeirogenic in nature and sinking kept pace with the sedimentation. Warm humid climatic conditions favored the growth of luxuriant vegetation in this swampy land. Plant materials were buried by younger Mesozoic continental deposits and thus were protected from erosion. The plant materials were transformed into coal by the regional orogenic movements (Haque 1974). The coal, more precisely known as the Gondwana coal, is a high volatile, noncoking bituminous type similar to Raniganj coal of India (Ahmed, 1980). These coal deposits occur at a depth of 2800 to 3800 feet in Rajshahi (Northwest) district of Bangladesh.

Upper Jurassic and Early Cretaceous, and later Tertiary time in eastern India was characterized by regional crustal extension and rifting in association with a passive continental margin (Salt et al. 1986). A new oceanic basin was thus formed which provided a suitable area of late Mesozoic and Tertiary depocenters. The rifting and crustal extension were associated with a massive outpouring of basalts and andesites in the Rajmahal area of Bihar (Rajmahal Trap). Radiometric age (K/Ar) of the Rajmahal Trap basalt is 100-105 my (McDougall and McElhinny, 1970, cited in Paul & Lian 1975), which is about the time sea-floor spreading data indicate that India broke away from Antarctica (Sclater and Fisher, 1974). In Bangladesh, similar basalts have been detected in the bore holes of northwestern (Bogra and Rajshahi) Bangladesh. This suggests that at least the northwestern region of Bangladesh was included in the massive late Jurassic and Cretaceous volcanic activity that swept the entire Indian subcontinent during the periods (Haque, 1974).

It was during this time that the sea-floor of the Bay of Bengal disappeared beneath the Sunda area subduction zone (Curray and Moore, 1974). The Bay of Bengal is thus known as an example of remnant ocean basin (Reading, 1978 and Curray and Moore, 1974).

On the erosional surface of this Rajmahal Trap, the Shibganj Trapwash of early to middle Cretaceous age comprising coarse sand, volcanic materials and white clay, were deposited in a fresh water and lacustrine environment (Khan, 1980). The Bolapur Formation of West Bengal and the Langpur Formation of Assam are contemporary deposits (Haque, 1974). In the adjacent West Bengal and Assam, the Upper Cretaceous is represented by basin wide subsidence resulting in deposition in a transgressive sea.

Recent modern seismic surveys in northwestern Bengladesh reveal thick sediments below the Sylhet Limestone. Khan (1980) suggests that these sdeimentary sequences may be of Cretaceous age because similar Cretaceous sequences have been observed in Assam-Arakan Yoma regions of Bangladesh.

The Cenozoic Era is very important for Bangladesh, and as well as the entire Indian subcontinent, because it was during this period the present outline of the country was determined (Haque, 1974). During the Era the Himalayan orogeny resulted in change to the configuration of the Tethyan Sea, the Himalayan mountain chain was formed and several basins (Burma and Bengal) were formed.

The Tertiary period is also important because over 16km (50000 ft) thickness of sediments were deposited during this time (Paul and Lian, 1975). The land and sea distribution during various epochs of the Tertiary period are shown in Figures from 41A to 42B (Islam, 1975).

The Paleocene time began with strong repetitive submergence and emergence of the shelf areas. The sea entered beyond the Bengal and Assam Foredeeps to the deeper part of their respective shelves (Islam, 1975). The northwestern limit of extension was just southeast of the Burdwan well in West Bengal (Sengupta, 1966). In the Bangladesh portion the sea extended to near the Kuchma well in the Bogra district. The Tura or Cherra Sandstones, composed of impure limestones, sandstones and carbonaceous shales, represent epicontinental sedimentation of the Paleocene transgressive sea (Haque, 1974). Areas north of Rajshahi, Bogra, Sylhet were primarily continental, marshy or lagoonal as evidenced by the presence of coal and lignite (Islam, 1975). Palynological analysis revealed that a warm, humid, tropical to sub-tropical climate prevailed during this time (Biswas, 1963).

Widespread marine transgression, caused by basinwide subsidence, characterized middle to Late Eocene time (Fig. 41B). The shoreline in the north moved further north and the entire shelf zone of the Bengal Basin was the site of deposition of shallow, clear water, open marine

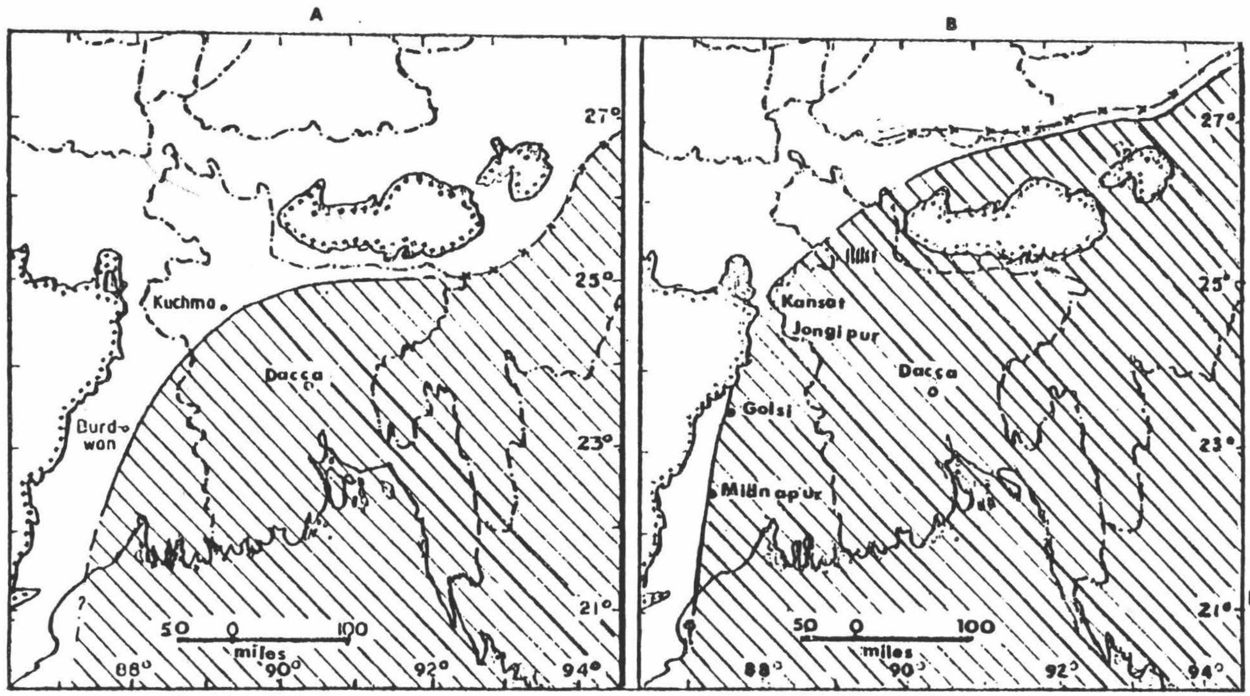

Figure 41A Distribution of land and sea during Paleocene to Early Middle Eocene time.

Figure 41B Distribution of land and sea during middle of late Eocene time showing maximum sea transgression.

source: Islam (1975)

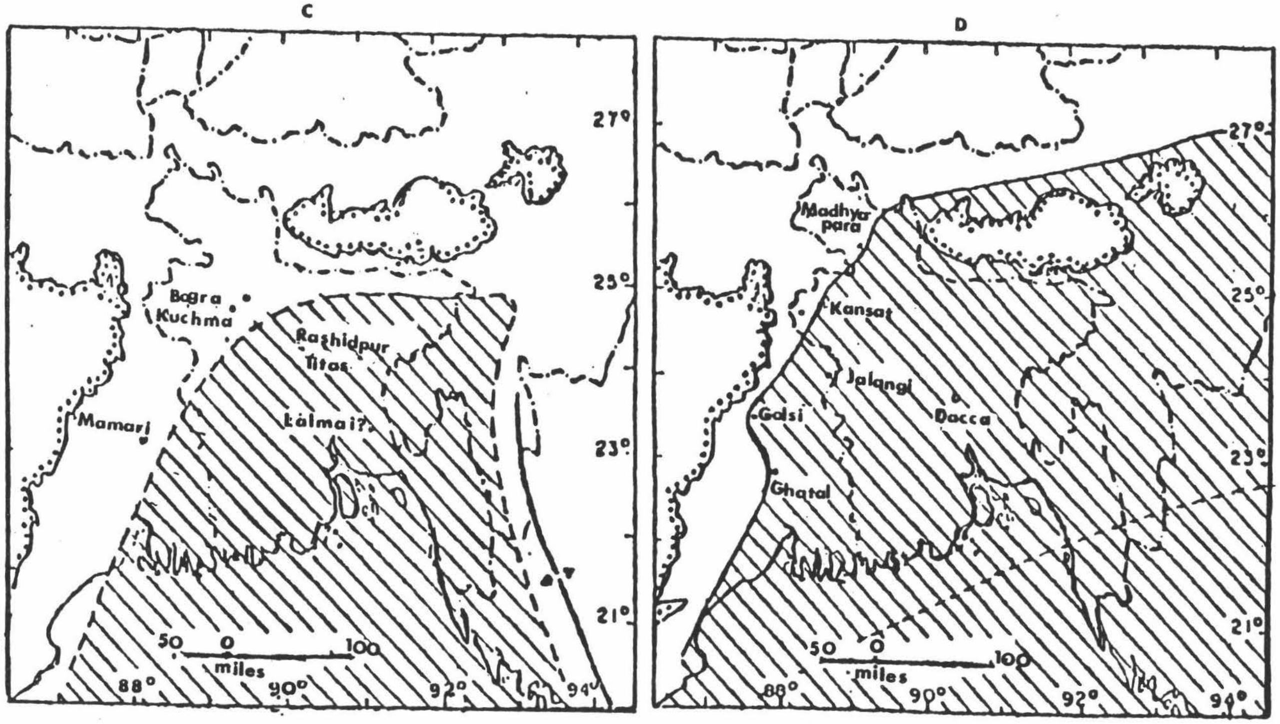

Figure 41C Probable distribution of land and sea during Oligocene time.

Figure 41D Partly generalized distribution of land and sea during Early to Middle Miocene time showing maximum sea transgression.

source: Islam (1978)

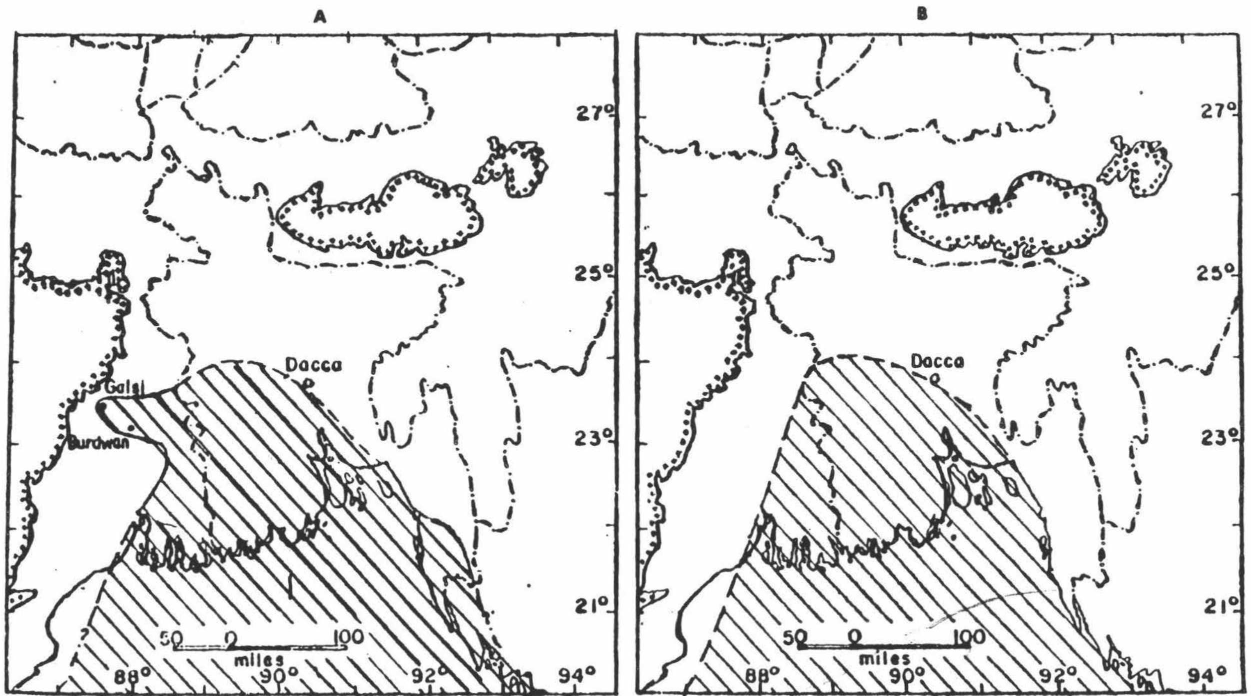

Figure 42A Distribution of land and sea during Late Miocene time.

Figure 42B Probable distribution of land and sea during Pleistocene time.

source: Islam (1975)

limestones. These limestones contain nummulitic fossils, commonly known as Sylhet Limestones, and are exposed in northern Sylhet and detected elsewhere in drill holes (Haque, 1974). In Bogra this limestone is known as the Bogra Limestone (Ismaïl, 1978). Sengupta (1966) suggested that the limestones of the shelf region are represented in the deeper basin by an argillaceons facies and should be noted. The change, as he mentioned, should be marked in the Hinge Zone which trends approximately N30E (in Calcutta to Mymensingh and further northeast). But Khan (1978) suggested that the Sylhet Limestone itself continues beyond the Hinge Zone south eastward. The Early to Middle Eocene is represented by sandstone, clay and shale sequence.

The Oligocene Epoch in the Bengal basin is represented by basinwide regression of the sea (Fig. 41C) and the collision of India with Eurasia (Paul and Lian, 1975). During this period the second diastrophic movement of the Himalaya took palce and the Bengal Basin was seperated from the Burma Basin by the Arakan Yoma uplifts (Khan, 1978). The collision event profoundly affected sedimentation as rivers began to supply a prograding delta complex in the northeast corner of the newly formed basin (Paul and Lian, 1975). The shoreline retreated southeast from northwestern Bangladesh, probably to the southeast of Bogra and the Kuchma well sites (Islam, 1975).

Oligocene rocks have been noted in the Rashidpur-2 and Cox's Bazar-1 deep wells. The presence of Bullimina-3 suggest a "holomarine" environment during this period (Holtrop and Keizer, 1970). Oligocene rocks were not reached by drilling in the north Bengal (NW) nor have they been found exposed anywhere in Bangladesh. Such an absence of Oligocene rocks suggest that Bangladesh was a land surface during Oligocene time with the exception of the Sylhet Trough and possibly the Chittagong Trough (Holtrop and Keizer, 1970) areas. In the Assam region the shaly Disang and Jaintia Series of Eocene age grade upwards into the sandy and coaly Barail Group of Oligocene Age. In the Sylhet region the Barail becomes more shaly (Paul and Lian, 1975). Barail coaly shales, siltstones and sandstones were deposited in these troughs. The close of Oligocene is marked by regional erosion of the land area (Islam, 1975).

The Miocene Epoch began with a marine transgression resulting from widespread basin subsidence (Fig. 42A). The sea advanced northwest up to the area of the Memari-Ghatal wells in the West Bengal (Sengupta, 1966). The northwestern portion of Bangladesh was also inundated but the sea remained to the east and south of the Madhyapara and Kansat (Islam, 1975). In the Surma Basin, the shoreline stretched along the Titas-Fenchuganj-Kailas Tila (Holtrop and Keizer, 1970). A distinct mobile belt (Tripura-Chittagong folded belt) was an integral part of the basin but was subjected to local and modest uplift while the basin was subsiding (Hoque, 1974). Brunnschweiler (1978) studied satellite photos (Fig. 43) and airphotos and found that the Neogene folding was highly plastic in nature and often associated with large scale listric thrusts formed under horizontal stress.

More than twenty thousand feet of molassic sediments were deposited in the subsiding basin. The sediments are represented by the

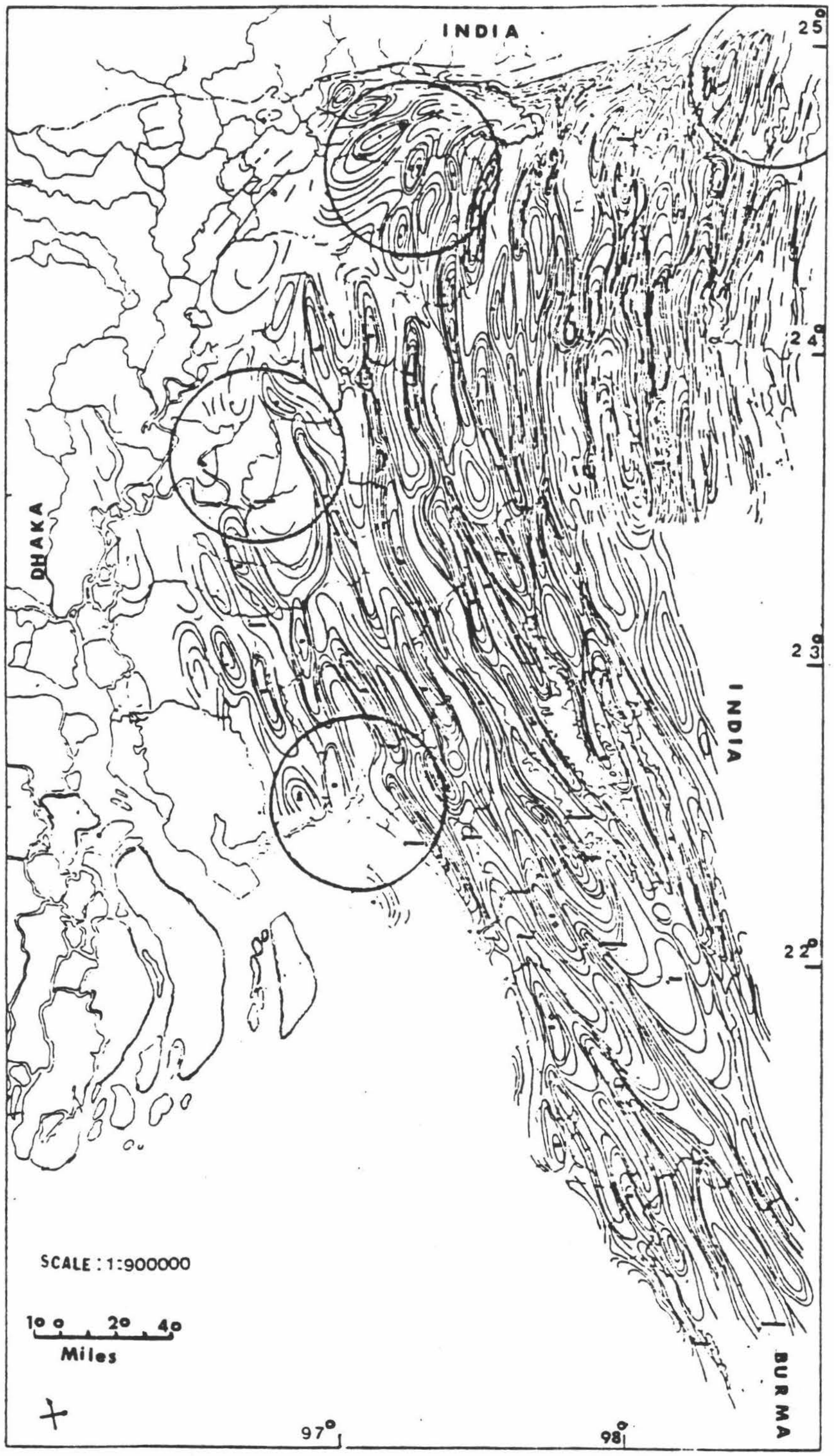

Figure 43. Fold pattern in the Arakan-Yoma Mountain ranges.

source: Brunnschweiler (1978)

Surma and Tipam groups which outcrop in the Chittagong and the Chittagong Hill Tracts and in the Sylhet districts (Fig. 2). These have been drilled at shallow depths in the northwestern region and at deeper depths elsewhere. The Surma Group is a sequence of alternating sand and shale thought to have been deposited under shallow marine to deltaic conditions (Hoque, 1974), whereas, the overlying Tipam Group of sediments were deposited under continental fluviatile condition as evidenced from its coarse grains and associated sedimentary features. Line M-6 (Fig. 44) and Figure 40 show abundant channels in the Surma Group and upper Barail Group equivalent. These channels tend to confirm a long-persisent deltaic environment of deposition, which may have ranged from subaerial delta plains to abyssal marine pro-delta plains to abyssal marine pro-delta (Paul and Lian, 1975).

During late Miocene-Pliocene time (Fig. 42A) the final phase of sea-withdrawl occurred as a result of orogenic movement in the eastern mobile belts, which were contemporaneous with the third and the most dynamic phase of the Himalayan uplift. The late Miocene-Pliocene is also represented by the deposition of fluviatile Dupi Tila sandstones distributed in the basinal area of Bangladesh. Curray and Moore (1971) "confidently traced" a widespread unconformity at the end of Pliocene over the entire Bengal Fan as far south as 10 degrees latitude. This indicates that the marine regression was not only from Bangladesh and adjoining regions but also from the entire Bay of Bengal and even the northeastern part of the Indian Ocean by late Miocene.

As the sea retreated from the Bengal Basin the only Pleistocene

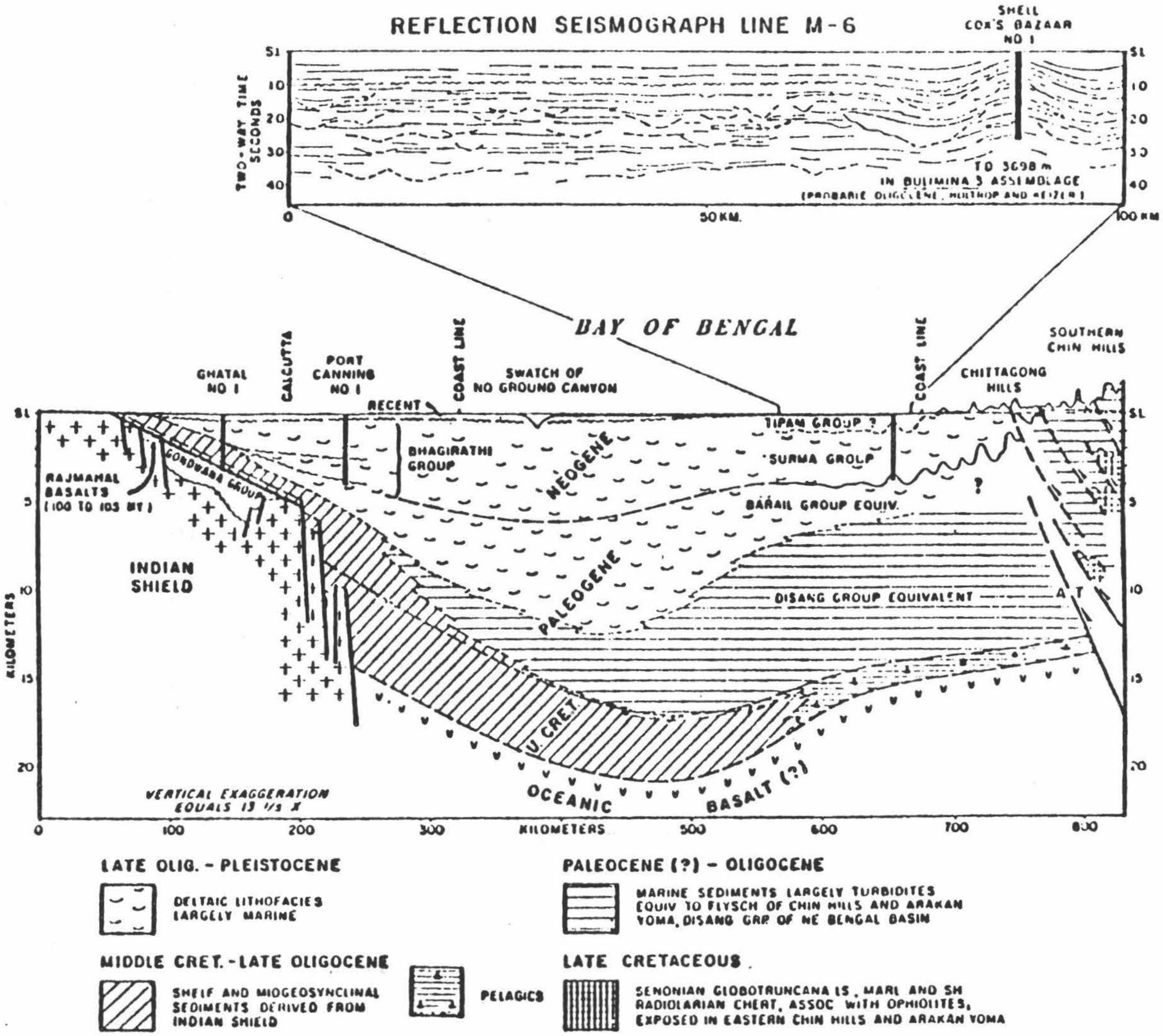

Figure 44. Regional cross section across Bengal Basin and reflection seismograph line M-6.

source: Paul and Lian (1975)

marine record has been found in the St. Martin's Island (Islam, 1975), south of the Cox's Bazar.

Towards the onshore, Pleistocene rocks are exposed in the form of several inliers (Fig. 2). These inliers were studied by Morgan and McIntyre (1959) to assess the structural forces affecting the Bengal Basin (Fig 45). According to Morgan and McIntyre (1959) the area between the Barind and the Madhupur tracts is the approximate location of a "Zone of Weakness", which may either be a subsurface major fault or a subsiding trough. They also suggested that the en-echelon fault at the edge of the terrace are due to crustal torsion.

Brunnschweiler (1978) studied the different aspects of the geology of Bangladesh and suggested that neotectonic forces are actively operating to create and reform the various structural and geomorphic settings of Bangladesh.. Some of these modifications are: a) the formation of the Modhupur tract due to continuing pressure from the side of the Indo-Burma Orogene into and through the Surma Basin (NE), b) elevation and subsidence of "large tracts of lands" in the Indo-Burma resulting in deep and major change of the course of the river Brahamputra, and c) thinning of domes and anticlines in the western half of the Bay of Bengal, where tectonic activity has died down. Although the eastern half shows the entire sequence up to near the Sea floor, there is no obvious thinning of beds and wedge-outs on their flanks. This suggests that there is continued neotectonic movements towards the fold belt. Matin et al. (1986) also indicated neotectonic activity in the region.

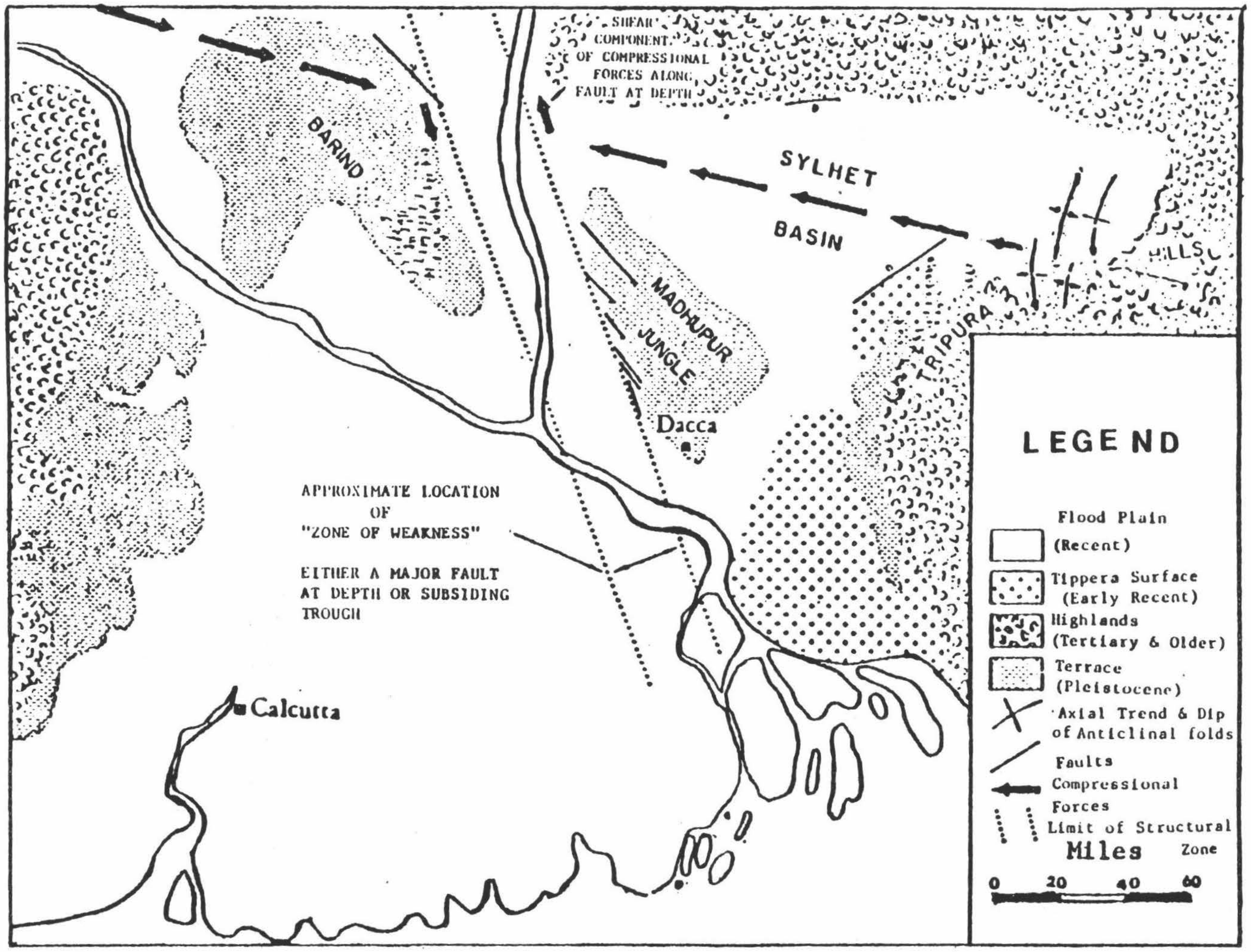

Figure 45. Compressional and shear forces in the Bengal Basin.

source: Morgan and McIntyre (1959)

PRESSURE AND TEMPERATURE DISTRIBUTION

Subsurface pressure and temperature distributions of Bangladesh are available from drilling logs (Fig. 46 and Fig. 47). These figures show a minimum depth of 25m (82 ft) for the rise of 1 ^{o}C of temperature in the more compressed and uplifted eastern zone of the country (4 ^{o}C/100m or 2.2 ^{o}F/100 ft). A similar trend, but with steeper gradients, is observed in the northwest part of Bangladesh where the basement is at a minimum depth of around 450 ft (150 m). The gradient curves show higher values (45 m)/ ^{o}C; 2.22 ^{o}C/100 m or 1.22 ^{o}F/100 ft) for the portion of the Surma Basin where the sedimentary thickness is the thickest. Thus the geothermal gradient empirically seems to show an inverse relation with depth to the basement.

Matin et al. (1982) prepared a vertical profile for the temperature depth distribution (Fig. 48). There are three zones for the profile:

Zone 1 is from surface to 1000 m (3280 ft.) where the temperature gradient is 1 ^{o}C/55 m (1.82 ^{o}C/100 m or 1.0 ^{o}F/100 ft.).

Zone 2 ranges from 1000 m (3280 ft.) to 3000 m (9840 ft.) in depth and the suggested temperature gradient is 1 ^{o}C/41 m (2.43 ^{o}C/100 m or 1.33 ^{o}F/100 ft.).

Zone 3, magma from 3000 m (9840 ft.) to 5000 m (16400 ft) where the temperature gradient is 1 ^{o}C/30 m (3.33 ^{o}C/100 m or 1.83 ^{o}F/100 ft.).

The three zones are again subdivided on the basis of the temperature differences into 3 parts : 0 - 50 ^{o}C, 50 - 100 ^{o}C and 100 - 160 ^{o}C from left to right. It can be seen that the wells in the Zones 2 and 3 are mostly situated on the eastern folded belt of the Bengal

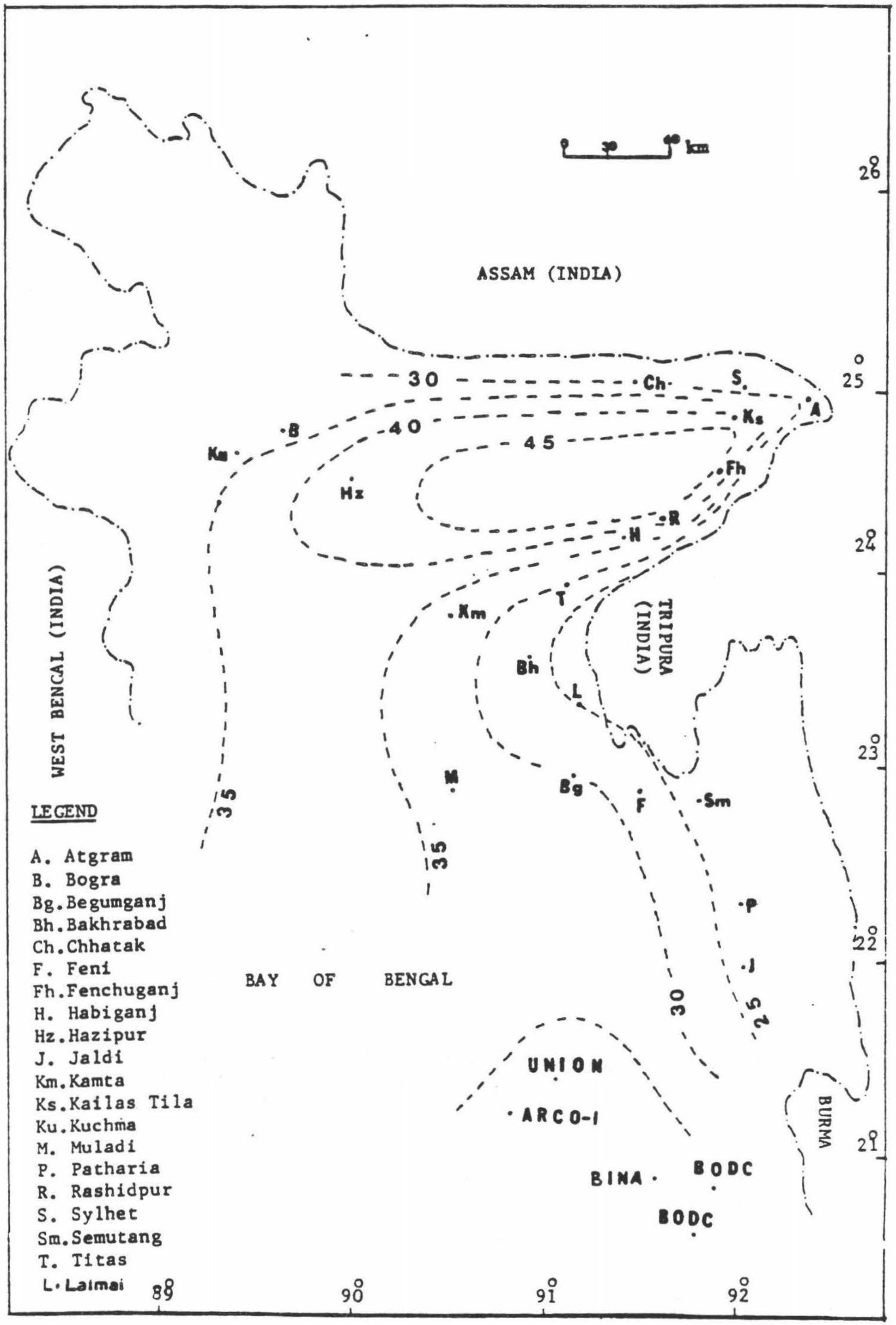

Figure 46. Sketch map of geothermal gradient in Bangladesh (in M/degree C).

source: Matin et al. (1982)

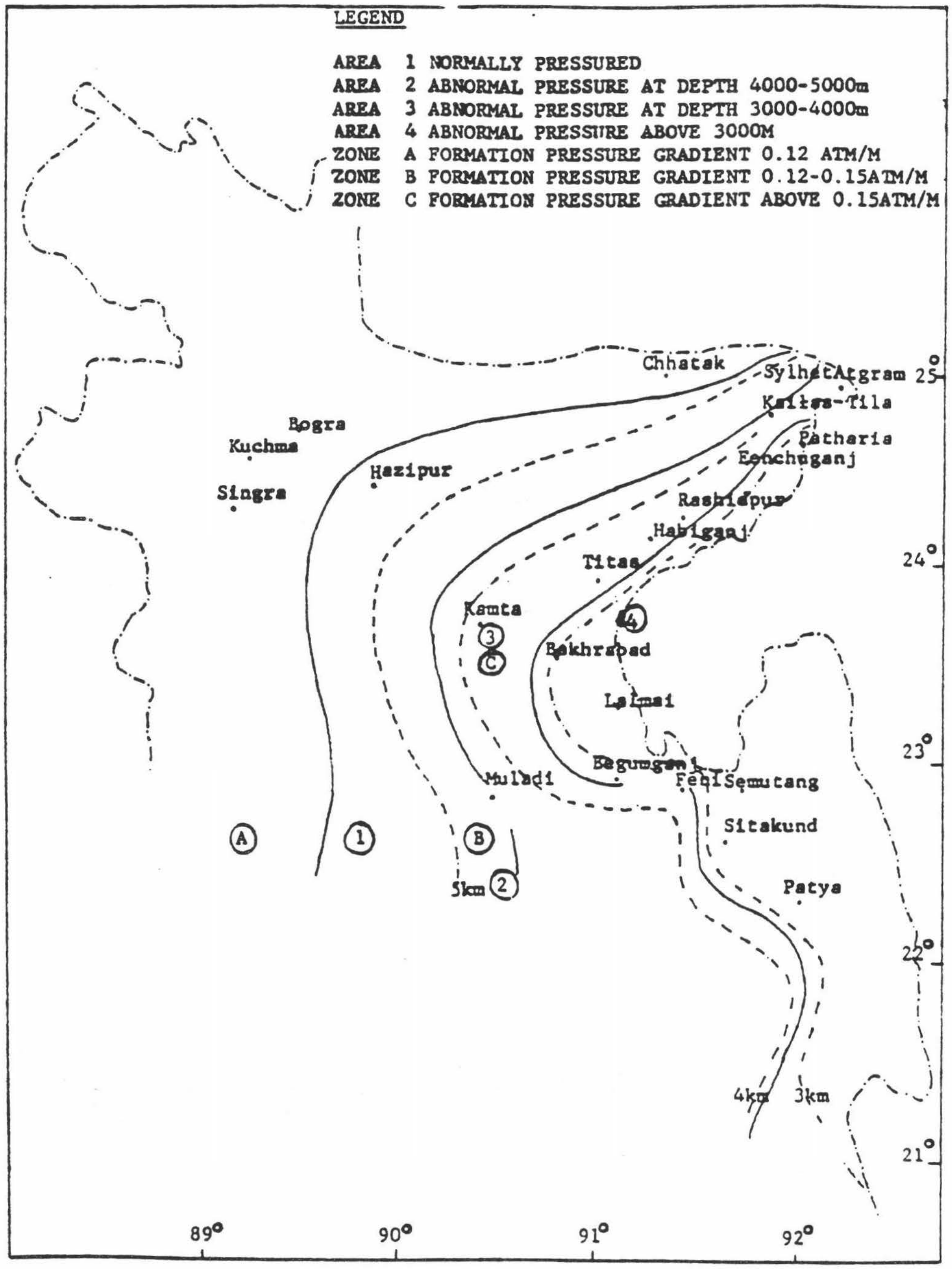

Figure 47. Sketch map of Formation change at 3000 m and presumed depth of Abnormal pressure zones.

source: Matin et al. (1982)

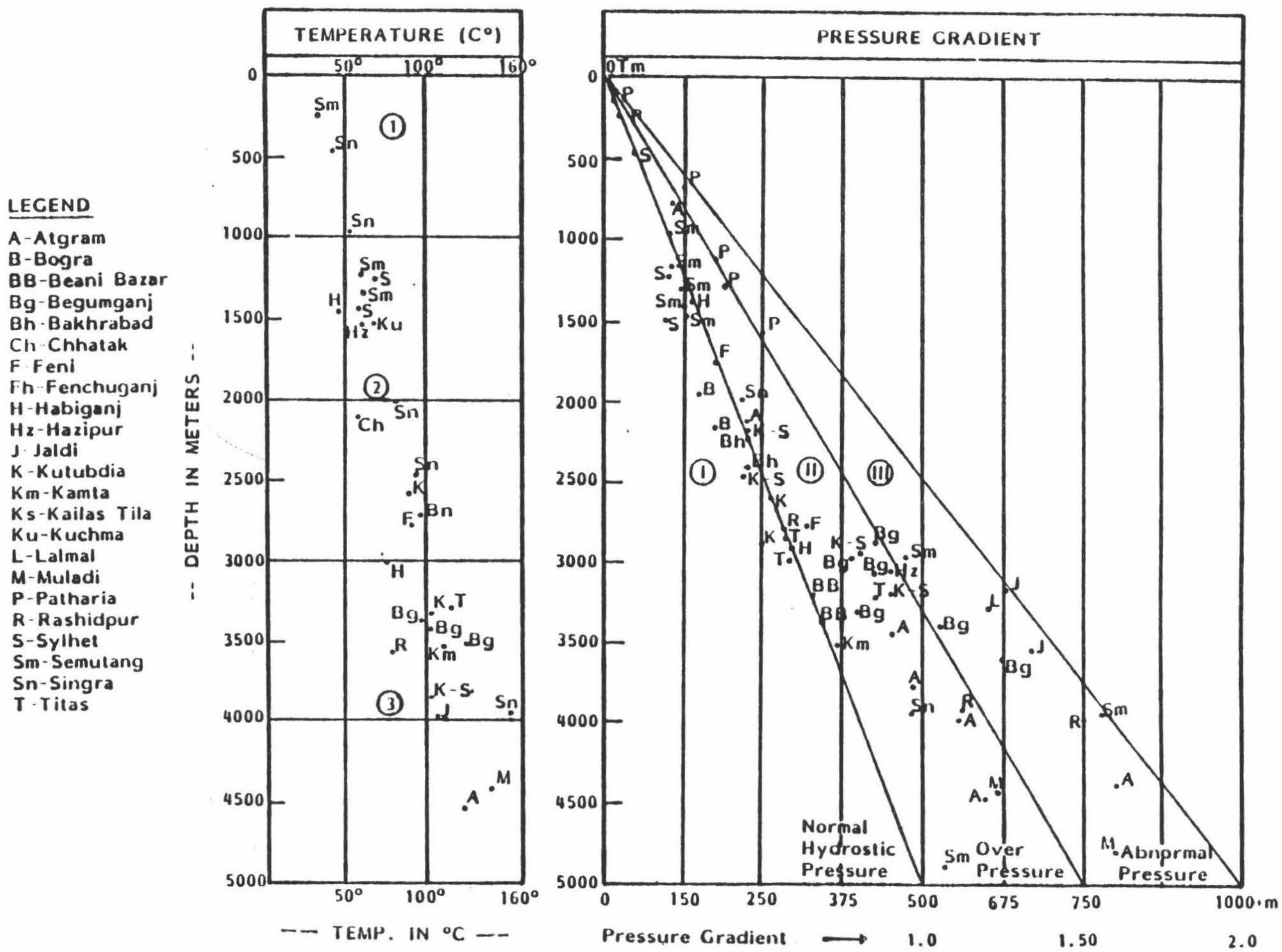

Figure 48. Change of Formation pressure and Temperature at depth.

source: Matin et al. (1982)

Basin. In zone 2 the wells lie within the temperature division of 50 - 100 °C and in the Zone 3, 100 -160 °C.

Figure 48 shows the formation pressure change at depth in different well (Matin et al., 1982). The scatter plots mostly fall in the overpressure zone (500-750 atm. pressure). With the highest pressure occuring within Zone 3, situated mostly on the eastern folded belt. Wells situated on the Begumganj, Rashidpur, Titas, Lalmai, Jaldi structures of eastern side show 750-1000 atm. The intensly uplifted Patharia structure shows a variable (normal to abnormal) pressure gradient within the shallower (1000-1500 m/3200-4800 ft) depth. In Figure 47 the different zones (based on the pressure gradient) and areas (normal or abnormal) of formation pressure are shown. Similar to the temperature distributions the formation pressures also occur at shallow depth of 3 km (1.5 mile) in the more compressed in the uplifted eastern and southeastern folded belt. The formation pressure depths in the eastern zone, particularly in the Sitakund area, give anomalous value. The computed depth based on sonic and resistivity logs and chloride ion concentration in formation water is 1.1 km (Ahmed, 1985) but the depth curve is shown as 3 km (Fig. 48). The formation pressure gradient also increased from 0.12 atm./m at the west and north to over 0.15 atm./m at the east and southeast. Ahmed (1985) studied the above mentioned over-pressure phenomenon in the Sitakund well and his study revealed the followings:

1) There is no record of abnormal high pressure in the NW shelf area, in the Hinge Zone area or in some small structures in the platform area.

2) Over pressure zones in Bangladesh have linear relationship with the amplitude of the structure and the depth to the top of the Bhuban Formation (Fig. 49).

3) Depth of the over pressure zone is shallower where the amplitude of the structure and the depth to the top of the Bhuban Formation are shallower.

4) Diagenesis of clay minerals (dewatering of montmorillonite while changing to illite resulting in compaction and hence overpressured to support the overburden) and tectonic compression of sedimentary deposits (because the overpressure zone lies near the folded flank zone and no overpressure in tectonically less disturbed shelf and hinge zone) seem to be the possible geologic controls of overpressure in Bangladesh.

5) As evidenced by the extensive fissility in shale the diagenesis of clay minerals seems to be the dominant geologic controls of overpressure in the Sitakund structure. The exposure of the core Bhuban Shale as well as shale diapirism evidenced by mud volcanoes, gas seepages, low resistivity and low sonic velocity all indicate rapid and sharp uplift which may have increased the pressure gradient sharply.

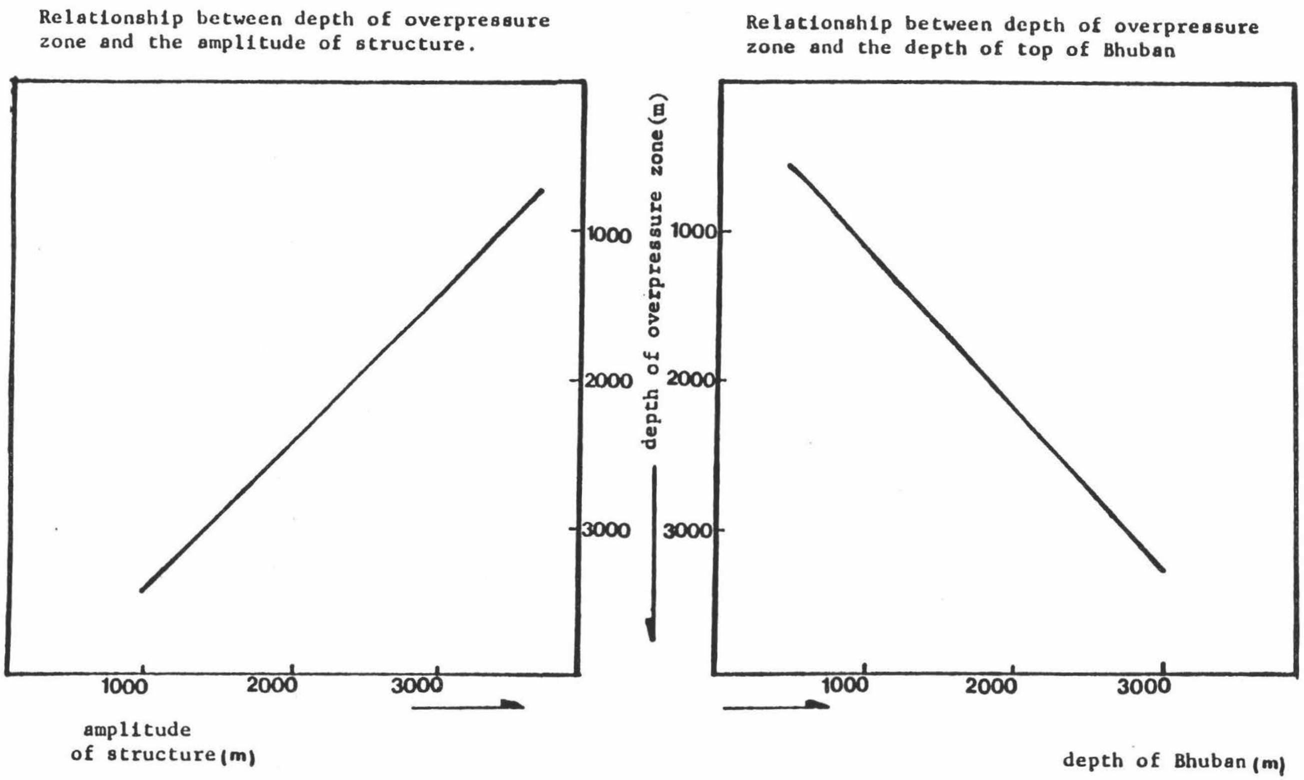

Figure 49. Relationship of overpressure zones with structure amplitude and the depth of top of Bhuban Formation.

source: Ahmed (1985)

CHAPTER II

HYDROCARBON POTENTIAL

Worldwide deltas are considered as highly prospective for the generation and accumulation of hydrocarbon deposits, and as a result the search for oil has a long history in the Bengal Delta.

The first exploratory well, in what is now Bangladesh, was drilled in 1910 on the Sitakund Structure by the Indian Petroleum Prospecting Company (Khan, 1980). It was however, not until the late 1950's that successes were recorded in the exploration for Hydrocarbons in Bangladesh. While searching for oil, the Standard Vaccuum Oil Company (SVOC or StanVac) found Gondwana coal deposits at Kuchma in 1959. Soon after this discovery, the Pakistan Shell Oil Company (PSOC) drilled 12 wells, including one offshore, and successfully discovered five gas fields. These early success led to further exploration by the Oil and Gas Development Corporation (OGDC), The Taila Shandhani Company, Canadian Supperior and Petrobangla all of which had some success drilling in the area.

To date, a total of 74 wells have been drilled in Bangladesh (Fig. 50). Out of this number 47 are exploratory (38 onshore and 9 offshore), 10 are appraisal and 11 are development wells.

The success rate of discovery is 1 in 3.6 for the onshore and 1 in 9 for the offshore (Khan and Husain, 1980). The ratio for onshore is high although the wells were drilled mainly on the crest of the anticlines, without knowing fully hydrocarbon formation and occurrence (Anwar and Husain, 1980).

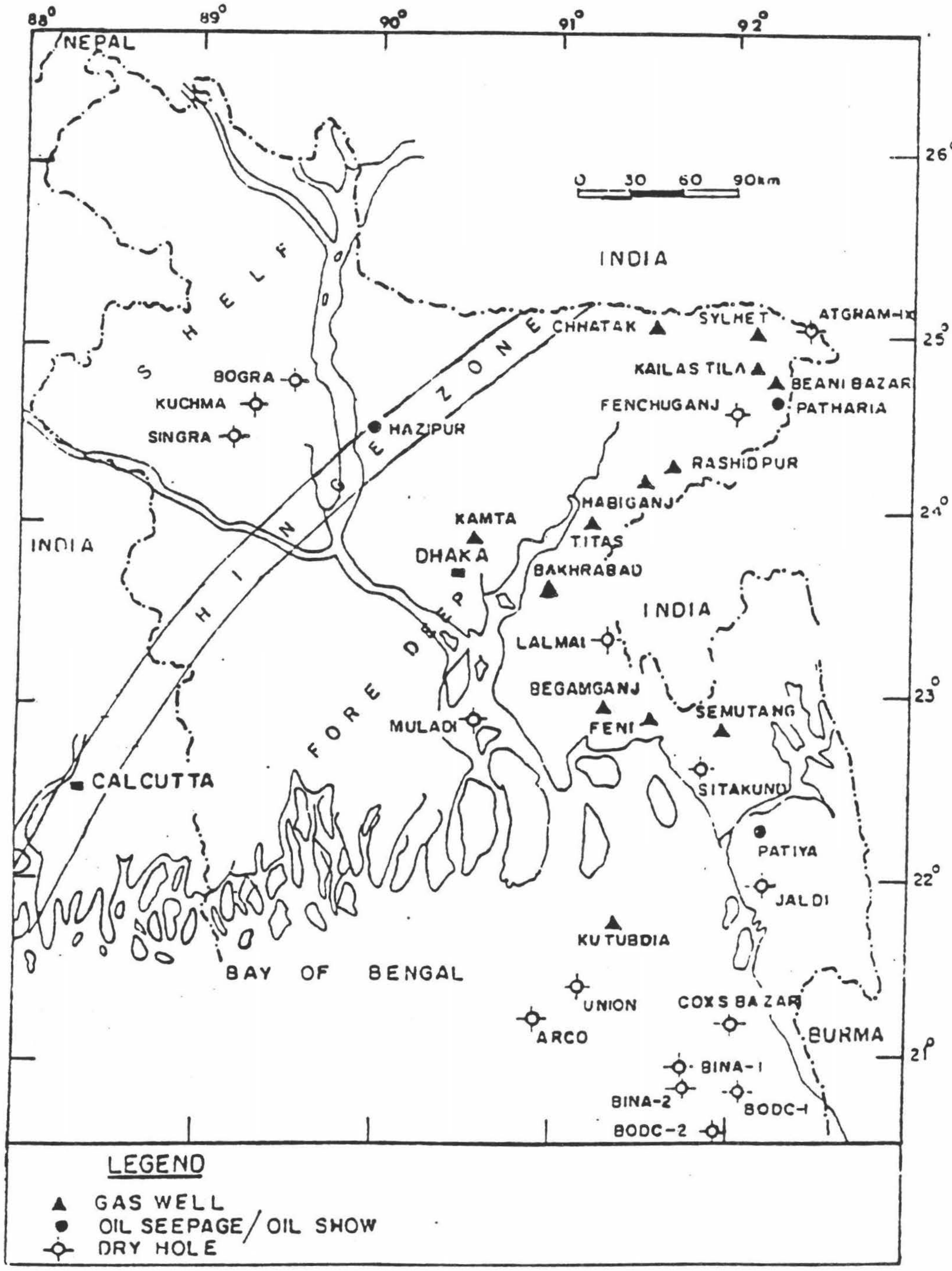

Figure 50. Wells drilled in Bangladesh.

source: Hayder (1985)

At present, Bangladesh has 13 gas or gas condensate fields which include 27 gas wells with an estimated reserve of 12.45 trillion cubic feet of gas (Hayder, 1985). The 13 gas or gas condensate fields are located mostly in the anticlinal traps of thick terrigenous Miocene sediments (Kononov et al., 1983).

Numerous factors combine to indicate Bangladesh has a large gas and oil potential. Firstly, Bangladesh, along with its position in a vast delta, is also located in a stable, or only moderately mobile, shield area of the geosyncline. The stable shield position is highly favorable for occurrence of hydrocarbon (Knable and Roderiquez, 1956). Secondly, since the evolution and formation of the delta is related to the subsidence, deposition, uplift and erosion of the Himalaya (part of the Tethyan cordilerra), petroleum generation and accumulation is considered likely. In particular because elsewhere in the world the major petroleum accumulations are concentrated in the Tethyan belt (Anwar and Husain, 1980). Third, since most of the worlds production and reserves of hydrocarbon are in Tertiary rocks (Levorsen, 1954), and Bangladesh is composed mostly of Tertiary rocks, hence hydrocarbon potential should be very high.

To assess the hydrocarbon potential of the Bengal Delta, emphasis must be placed on the structural geology, source rock of hydrocarbons, sediment maturation, traps, reservoirs and cap rocks, and migration phenomena of the hydrocarbon deposits of the country.

Structural Setup

The structure and tectonic history of Bangladesh have been described in the previous chapter and are summarized here as a basis for subsequent discussion. The Bangladesh Basin is composed of a thick sedimentary sequence (50,000 ft) of sediments range from Gondwana (carboniferous) age to Recent. The Basin is surrounded by Pre-Cambrian and Tertiary exposures of India on the east, north and west and on the south is open to the Bay of Bengal for an unknown distance (Fig. 2). Geophysical and drilling records reveal two broad subdivisions of the Bengal Basin, a northwest Shelf and a southeast Geosynclinal area. The Indian platform in the west and the Arakan Yoma area in the east can also be considered as two Tectonic divisions adjacent to the Bengal Basin.

Overall the Bengal Delta is one of the major deltas in the world characterized by thick sedimentation resulting from concomitant sedimentation and subsidence for a long period of time. In the northeast Shelf area the sediment thickness is considerably less than the southeast geosynclinal area. The zone of transition, known as the Hinge Zone between the two regions appears to be characterized by a relatively rapid increase in thickness of individual formation along with the facies change from the shallow shelf facies sediments in the north to deeper basin sediments in the south. The geosynclinal area is further subdivided into troughs and highs (Table II). The mobile belt lies to the east.

<u>Source Rock</u>

Rocks that are able to generate petroleum are commonly called source rocks. The presence of insoluble organic matter, Kerogen, the fraction of the organic matter in sedimentary rocks which is insoluble in organic solvents, is a primary requisite for a potential source rock. Kerogen is a macro molecule made of condensed cyclic nuclei linked by hetero atomic bonds or aliphatic chains (Tissot and Welte, 1978).

Kerogen is transformed toward thermodynamic equilibrium through the stages of diagenesis, catagenesis and metagenesis, due to the continued sedimentation and subsidence resulting in temperature and pressure increase. During diagenesis, as the depth of burial increases, oxygen is decreased with a resultant increase of carbon content. At the end of diagenesis, organic matter remains as Kerogen. Catagenesis causes a decrease of hydrogen content and of the H/C ratio, due to generation and release of hydrocarbons. Temperature here ranges from 50-150 ^{o}C and geostatic pressure due to overburden may vary from 300-1500 bars. In catagenesis, thermal degradation of Kerogen is responsible for the generation of most hydrocarbons, i.e. oil and gas. Metagenesis of Kerogen can be observed in very deep samples. The begining of metagenesis corresponds to a vitrinite reflectance of 2% indicating the begining of the last stage of evolution of organic matter. The last hydrocarbons, generally methane, are expelled in this phase. The hydrogen-carbon ratio declines until only carbon is left in the form of graphite. Porosity and permeability are important. Kerogen is finely dispersed and intimately mixed with the mineral matrix in petroleum source beds. Kerogen of petroleum source beds is generally derived from by marine plankton, lower plants and bacteria.

The two terms mostly used in describing the characters of source rocks are: Total Organic Carbon (TOC) and Extractable Organic Matter

(EOM). The TOC percentage and its source rock quality are shown below. (North, 1985)

TOC (Weight Percent)	Quality
0.0-0.5	poor
0.5-1.0	fair
1.0-2.0	Good
2.0-4.0	Very Good
4.0 upwards	Excellent

The minimum value of organic carbon for potential source rock - 0.3% for carbonate and 0.5% shales. There is an empirical relationship between vitrinite reflectance (Ro) (a measure of the degree of reflectivity by reflecting light microscope) and hydrocarbon generation. Crude oil generation occurs for Ro values between 0.6 and 1.5. Gas generation takes place between 1.5 and 3.0; at values above 3.0 the rocks are essentially graphite and are devoid of hydrocarbon.

Generally fine grained, permeable non-porous rocks like shale, limestone, coal are good source rocks. In Bangladesh the TOC values of the Neogene and Quaternary deltaic formations are very low; TOC below 1% and EOM less than 200 ppm (Brunnschweiler, 1978). The Ro values are in the average between 0.2 and 0.5% (Khan and Husain, 1980). All the gas deposits in Bangladesh are essentially methane (94-99%) (Table IX) with nil or very low sulfur content.

The potential source rocks of hydrocarbon in the Bengal Delta are the subject of considerable debate. Geochemical source rock

FIELD	RASHIDPUR	KAILAS TILA	TITAS	HABIGANJ	BAKHRABAD	SYLHET	CHHATAK	SEMUTANG	KUTUBDIA
Methane	98.2	95.7	96.27	97.8	94.3	96.26	99.05	96.94	94.41
Ethane	1.2	2.6	1.82	1.5	3.4	1.99	0.24	1.70	2.83
Butane & Higher	0.1	0.4	0.67	Nil	0.6	0.32	Nil	0.14	0.30
Propane	0.2	0.9	0.43	Trace	0.8	0.14	Trace	0.01	0.66
Nitrogen	0.25	0.2	0.35	0.7	0.4	0.95	0.67	0.86	1.40
Carbon-di-oxide	0.05	0.2	0.46	Trace-0.5	0.54	0.54	0.04	0.35	0.06
Total Sulphur Grain/100 SCF	Nil	Nil	Nil	Nil	Nil	0.298	0.298	--	--
SP.GR.(AIR -1)	0.569	0.586	0.589	0.578	0.575	.557	0.557	0.571	0.586

Gas Analysis: Mol-%

Table IX Results of the Chemical Analysis of the Natural Gas in Bangladesh.

source: Khan and Husain (1980)

evaluations of the drilled Neogene and Quaternary sediments both offshore and onshore as well as surface samples of the southern Chittagong Hill tracts, do not show any source rock potential (Khan and Husain, 1980). The reason however, was not clearly discussed.

There is a suggestion (Kehrer, 1977, cited in Brunnschweiler, 1978) that the gas might be derived from Gondwana coal of Permo-Carboniferous age which underlie the gas horizons (Miocene). This implies extensive upward migration through many kilometers of Tertiary, and probably Mesozoic, rocks. This proposition has been questioned because:

a) only oil is found in the adjacent Assam which is believed to sit on the Gondwana Shillong Spur. Gas deposits are not present there. Since coal cannot be the source rock for the oil (Tissot and Welte, 1978) and as gas is not found there, Gondwana coal cannot be considered as a source rock in the region.

b) in the West Bengal and Bangladesh Pericraton, where Gondwana coal measures occur at depth, there are no significant gas deposits (only minor gas show in Miocene beds in Bogra-1).

c) the Tertiary lignites in the Pericraton present in Tipam and Dupi Tila (Pliocene) lie much higher than the present gas deposits and are not considered responsible for the gas accumulation thousands of feet below them (in the Miocene Surma Group). Moreover, these are shallowly buried and not matured enough to generate hydrocarbon.
The isotope study (13C/12C) of the Bangladesh gases (Table X) from the Chhatak, Sylhet, Titas, Habiganj and Semutang area indicated that the

LOCATION	WELL NO	DEPTH OF RESERVIOR	N_2%	CO_2%	C_2/C_1	C_1/C_n	$iC_4/-C_4$	$iC_5/n-C_5$	$13CH_4$	$13C_2H_6$	$13C_3H_8$
SYLHET	3	1675(M)	2.79	0.42	0.0201	0.9733	---	---	-42.2	-34.1	---
SYLHET	6	1405	1.49	0.55	0.0207	0.9602	3.0123	3.9376	-42.3	-35.2	-32.0
CHHATAK	1	2134	5.92	---	0.0024	0.9976	---	---	-45.2	-41.7	---
TITAS	1+2+3	3756	---	0.97	0.0632	0.9092	1.6066	1.6108	-42.3	-33.8	-30.2
HABIGANJ	1	3505	2.17	---	0.0156	0.9846	---	---	-44.5	-38.1	---
SEMUTANG	---	300(?)	5.24	0.01	0.0001	0.9999	---	---	-44.5	---	---
SYLHET	3 + 6	---	1.34	0.39	0.0195	0.9792	---	---	-42.3	-34.5	-33.9
TITAS	1+2+3	3756	7.21	0.80	0.0499	0.9285	1.1157	1.6108	-42.2	-33.4	-30.2

Sample taken before Scrubber Unit. Analyst: Dr. W. Stahl, FRG Geosci.Nat.Resour.Hannover.

Table X Isotope analysis results of Bangladesh gas deposits.

source: Brunnschweiler (1978)

gases are derived from marine source rocks (Lietz and Kabir, 1978). The study further revealed that the gases are formed within the "Oil Window" of the maturation range and they are neither immatured (swamp) nor over-matured (dry) gases. The isotope ratios of Chhatak and Sylhet gas fields point to lateral migration distance of the gas between 2 and 5 Km (Lietz and Kabir, 1978).

After studying all the drilling data, well logs and seismic sections Kononov et.al. (1983) suggested that the Eocene sedimentary sequences particularly the Disang Shales (Kopili Shale equivalent) are possibly the source rocks for the hydrocarbon generation. Khan (1980) also suggested the same shaly rock type (Kopili Formation) as the source rock for Bangladesh gas deposits because this is the source rock for lower Oligocene oil fields at Assam, India. On the basis of the geochemical studies by BOGMC (Petrobangla) they excluded the lower Miocene Bhuban Formation as the source rock because these sediments are predominately humic organic matter and paleotemperature and paleopressure environment were too mild for generation of hydrocarbons.

In summary, the gas deposits in Bangladesh: 1) appear to have a marine origin with a considerable lateral migration, 2) an Eocene sedminetary sequence (Disang/Kopili shale) is considered as the probable source rocks and 3) isotope study suggested that the gas deposits occurred within "Oil Window."

Maturation

During the phase of Catagenesis, Kerogen matures and yields oil and gas. When Kerogen is immature, no petroleum has been generated; with increasing maturity, first oil and then gas are expelled; when the Kerogen is overmature, neither oil nor gas remains. Pusey (1973) has shown that significant oil generation occurs between 60 and 120 ^{o}C, and significant gas generation between 120 and 225 ^{o}C. Above 225 ^{o}C the Kerogen is inert, having expelled all hydrocarbons; only carbon remains as graphite. Oil occurs in a liquid window of between 65 and 150 ^{o}C, which extends from shallow depth with high thermal gradients to deep basins with lower gradients.

One commonly used maturation study is the Thermal Maturity Index (TTI) proposed by Lopatin (1971) and developed by Waples (1980). The thermal maturity index is calculated from a formula that integrates temperature with the time spent in each temperature (in increments of 10 ^{o}C) as a source rock is buried.

Maturation studies of surface and drill hole material of middle/late Miocene samples, both onshore and offshore, indicated that the Neogene succession in the Bengal Basin conforms to the norm in terms of the relation between paleotemperatures and the depth of burial (Anwar and Husain, 1980). Ahmed and Karim (1983) modeled the principal phase of hydrocarbon formation based on catagenesis of Neogene clastic sediments of the Bengal Basin and Time-Temperature Index (TTI) values for Atgram and Muladi wells. They concluded that the present Bhuban sediments are partly located in the Principal Phase of Oil Formation (PPOF) (Oil Window) and their bottom sections have already entered the Principal Phase of Gas Formation (PPGF). But the Boka Bil sedimentation has entered the Principal Phase of Oil Formation (PPOF) only at Muladi. The PPOF is located at a depth of 2.6-4.6 Km (paleodepth 4.5 to 5.4 Km) in Muladi section and at 2.6 - 3.9 Km (paleodepth 2.7-4.0 Km) at the Atgram section.

The temperature history, as evidenced from different boreholes (Fig. 46) and gas deposits of Bangladesh, is mature. Isotope study have indicated that the gases are within the "Oil Window". Particularly, the Bhuban Formation is located mostly within the PPOF and partly within the PPGF.

Reservoir and Cap Rocks

The deltaic environment with its associated close interaction of sediment and compressional tectonics provide good reservoir and cap rocks in the Bengal Basin. After evaluation of well logs and tests, paleontology and seismic data it appears that the sand layers of Miocene Surma Group of rocks constituts the pay zones of the Bangladesh Gas Fields.

The depth of the sand layers of the gas horizon ranges from 979 meters in the semutang to 3425 meters for the Kailas Tila (Fig. 51). Aggregate net pay of the sand thickness of the discovered gas fields range from 11 meters at Chhatak to 104 meters at Sylhet. The thickest net pay sequence occurs at Bakhrabad (225 meters).

The pay zones occur mostly in the Boka Bil Formation (Chhatak, Sylhet, Kailas Tila, Habiganj, Titas, Bakhrabad, and Semutang). Gas in Rashidpur occurs both in the Bhuban and the Boka Bil Formations

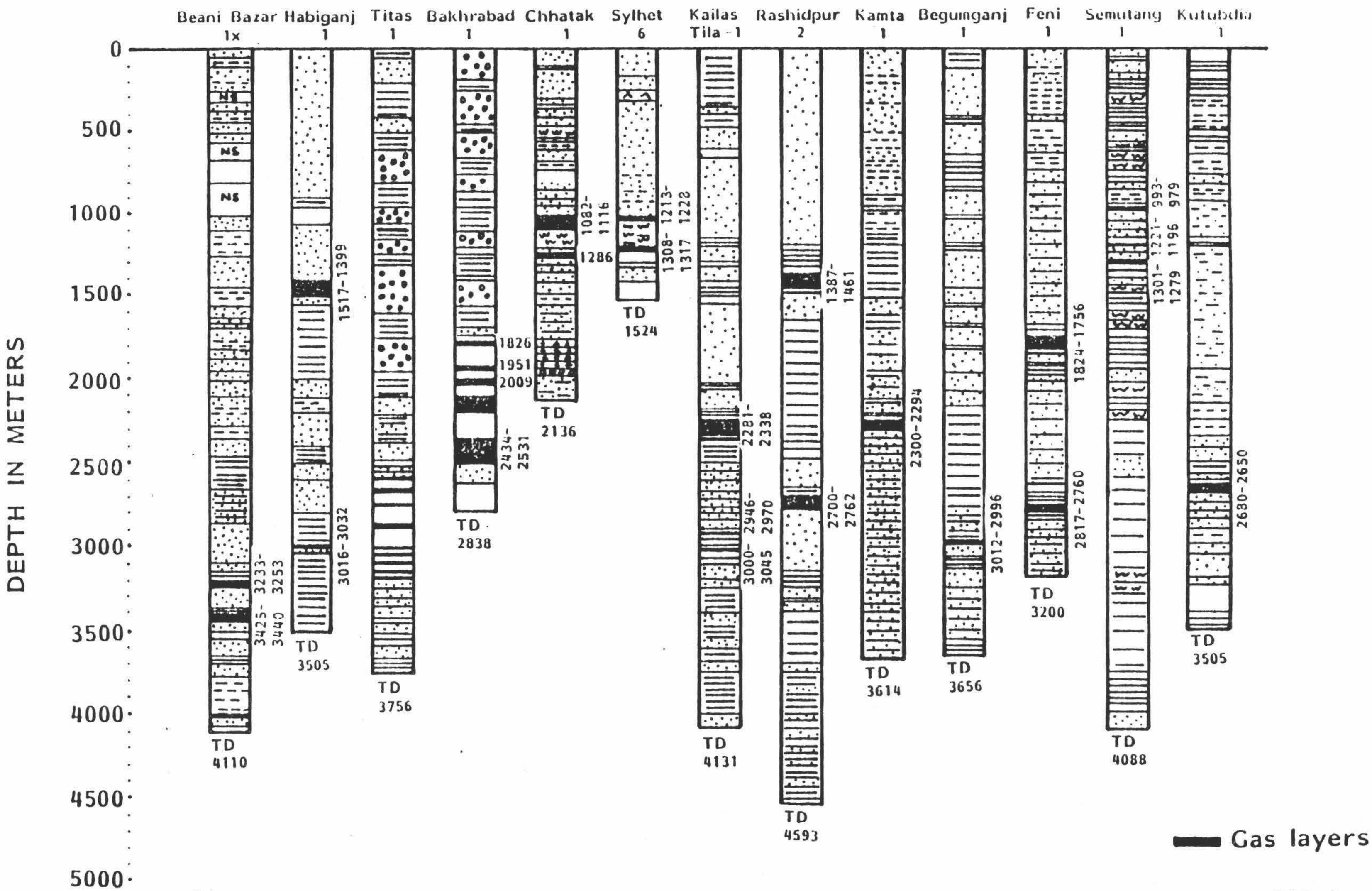

Figure 51. Gas bearing zones of Bangladesh Gas Feilds.

source: BOGMC

(Khan and Husain, 1980). Anwar and Husain (1980) proposed that reservoir rocks ranged from Paleocene to Pliocene and in the shelf area the thick pre-Eocene sediments (likely to be Cretaceous) may also be good reservoir rocks. Khan and Husain (1980) similarly proposed that deltaic Paleocene and Oligocene sandstone and the intermittent sandstone of the Sylhet Limestone are good reservoir rocks.

The cap rock for Bangladesh gas deposits are not known precisely however, Anwar and Husain (1980) have suggested that the distinct fine grained, low permeability layers, including the Eocene Sylhet limestone, Kopili Shale, Upper Marine Shale of Boka Bil and Girujan Clay, can be good cap rock.

Traps

From the discussion of the basin tectonics of the Bengal Delta, it is evident that two principal types of structural traps occur in Bangladesh (Brunnschweiler, 1978, Anwar and Husain, 1980):

A) Monoclinal: A few large scale, regional, monoclinal structures due to vertical crustal movements are likely to occur in the Hinge Zone, Shillong Monocline and Madhupur High (Fig. 8) and

B) Anticlinal: Many smaller scale (though at times upto 100 KM long) anticlinal structures due to compressional orogenetic folding on decollement surface on and well above the basement. Structures are found as low amplitude domal features in a zone extending from the Central Bay and Delta through the Dhaka area into the western part of the Surma Basin. They also occur in the tight, rarely thrust fractured, in places even diaperic folds of the Chittagong Hill, Mizo Hills and Tripura area. The majority of Bangladesh gas fields are located in these anticlinal traps.

All the gas deposits in Bangladesh occur in anticlinal traps except the Titas, which occurs in domal structure (Khan and Husain, 1980).

Potential stratigraphic traps occur throughtout the delatic sequence of Bangladesh. In particular in the southern slope of the Rangpur Saddle (Bogra Slope) and the Hinge Zone (Fig. 8) stratigraphic traps associated with buried reefs and pinch outs (Guha, 1978). Drilling of five wells on these structures, Bogra and Kuchma, (on the Bogra Slope) and Hazipur (on the Hinge Zone) have, however, proved unsuccessful to date (Brunnschweiler, 1978). A later well also drilled on the Bogra slope (Singra-1) was dry. Stains of oil in Bhuban-Barail rocks were found in the Hazipur well. The Tura sandstone of the Bogra well and Sylhet limestone in Kuchma well also showed oil stains (Guha, 1978). Brunnshweiler (1978) explained the lack of commercial hydrocarbon concentration in the basin by asserting, that the Bogra and Kutchma were too far updip and the Hazipur too far downdip (it failed to reach the Eocene Sylhet Limestone) on the structure.

Other stratigraphic trap situations, within the fault closure, are likely to occur along the Shillong Monocline, south of the Shillong Massif (Anwar and Husian, 1980). To date the area has not been drilled.

The third type of trap, the Combination Trap, may occur in the fold belt region (Brunnshweiler, 1978). The pay zone of Begunganj well No.1 is a "Bar Finger Sand" of deltaic environment and is reclassified as a structural - stratigraphic trap (Anwar et al., 1980).

Migration

Geochemical and isotope (13C/12C) data reveal that the gas deposits of Bangladesh originated in a marine environment. The isotope study further indicated that the gases occurred within the "Oil Window" of the maturation range. They are neither immatured (swamp) nor over-matured (dry) gases. The isotope study of the samples of gas deposits of the northern fields, especially the Chhatak and the Sylhet (Fig. 50) indicate long distance migration (2 to 5 Km) (Leitz and Kabir, 1978).

The gases having once been associated with oil, appear thus to have been separated by a barrier which allowed only the lighest hydrocarbon fractions through (Brunnchweiler, 1978) during an early stage of the migration process. To explain the lack of accumulation of gas in the crestal part of the anticline, Brunnschweiler (1978) suggests that the 1) migration might have been lateral rather than vertical, 2) oil might be held back in the synclinal down flank situations behind a migration barrier, and 3) the barrier may be casually related to the growth of the various structures.

Geochemical studies of the Patharia oil samples suggest that the oil is mature and could have undergone extensive migration (Khan and Husain, 1980). Anwar and Husain (1980) proposed that due to their position at the required depth of burial Cretaceous and Paleogene beds may also produce hydrocarbon late migration and accumulation could have been controlled by Neogene tectonics and faulting or it may be that vertical oil migration was not possible due to a barrier.

Kononov et al. (1983), after constructing the Miocene thickness maps and analyzing the Paleo Tectonic features, suggested that the general path of oil migration was towards the Tripura and Surma high (East and Northeast) where considerable amount of gas with condensate has already been discovered in the Titas, Bakhrabad, Feni, Chhatak, Sylhet, Beani Bazar and Kailas Tila wells. But Ahmed and Karim (1983) indicated that oil migration was towards the west, because of the oil traces in the Bogra, Kuchma and Hazipur wells. They however, did not refute the suggestion of oil migration towards north and east.

Petrophysical data of the producing gas fields of eastern and northeastern Bangladesh yield pay porosities from 19% to 30% with up to 70% gas saturation (Khan and Husain, 1980).

Regional Hydrocarbon Potential

A. Surma Basin

The Surma Basin, also known as the Sylhet Trough, in the northeast of Bangladesh (Fig. 8) is characterized by an increasing thickness of sediments, north dipping anticlines and widespread occurrences of thrust and fault planes. The basin forms a portion of the late to post-geosynclinal Bengal Basin covering an area of 2.5 million acres. Several local and foreign oil companies have worked extensively in the Surma Basin and have produced seismic, gravity, aeromagnetic maps and profiles. Drilling and surface geological records have also been prepared. The basin has a long history of subsidence beginning from Oligocene, or earlier, onwards (Holtrop and Keizer, 1970) with its peak of subsidence since the Pliocene (Hiller and Elahi, 1984).

Subsidence is evidened by a negative gravity anomaly of over 80 mgl. which is the lowest gravity value in Bangladesh (Fig. 11). At the deepest sub-basins or troughs, Plio - Pleistocene sediments have cumulative thickness of up to 22200 ft (at Goyain and Kushiara Trough). This is equivalent to a rate of subsidence and subsequent fill of 1.4 mm/year. Drilling (Guha, 1975) and seismic surveys (Hiller and Elahi, 1984) indicate that the cumulative post-Eocene sediment thickness in the Surma Basin is greater than 57,000 ft.

Most of the anticlines in the Surma Basin are N-S oriented and analogous to the N-S Indo-Burman Fold Belt. These structure were all existing in early Pliocene time (Hiller and Elahi, 1984) (Fig. 52). The structures were contemporaneously formed by the interaction of two major tectonic movements, i.e. the emerging Shillong Massif in the north and the west-prograding mobile Indo-Burman Fold Belt. Summarizing the various tectonic features Hiller and Elahi (1984) stated that the structural configuration of the Surma Basin has an age of about 3-6 millions years. Holtrop and Keizer (1970) emphasized that the uplifting is still continuing.

Early Pliocene structures trend north (northern structures: Chhatak, Atgram) and south (southern structures: Habigonj Rashidpur, Maulavi Bazar etc.). As a result of the structural deformation the drainage pattern changed and the present time most of the drainage is

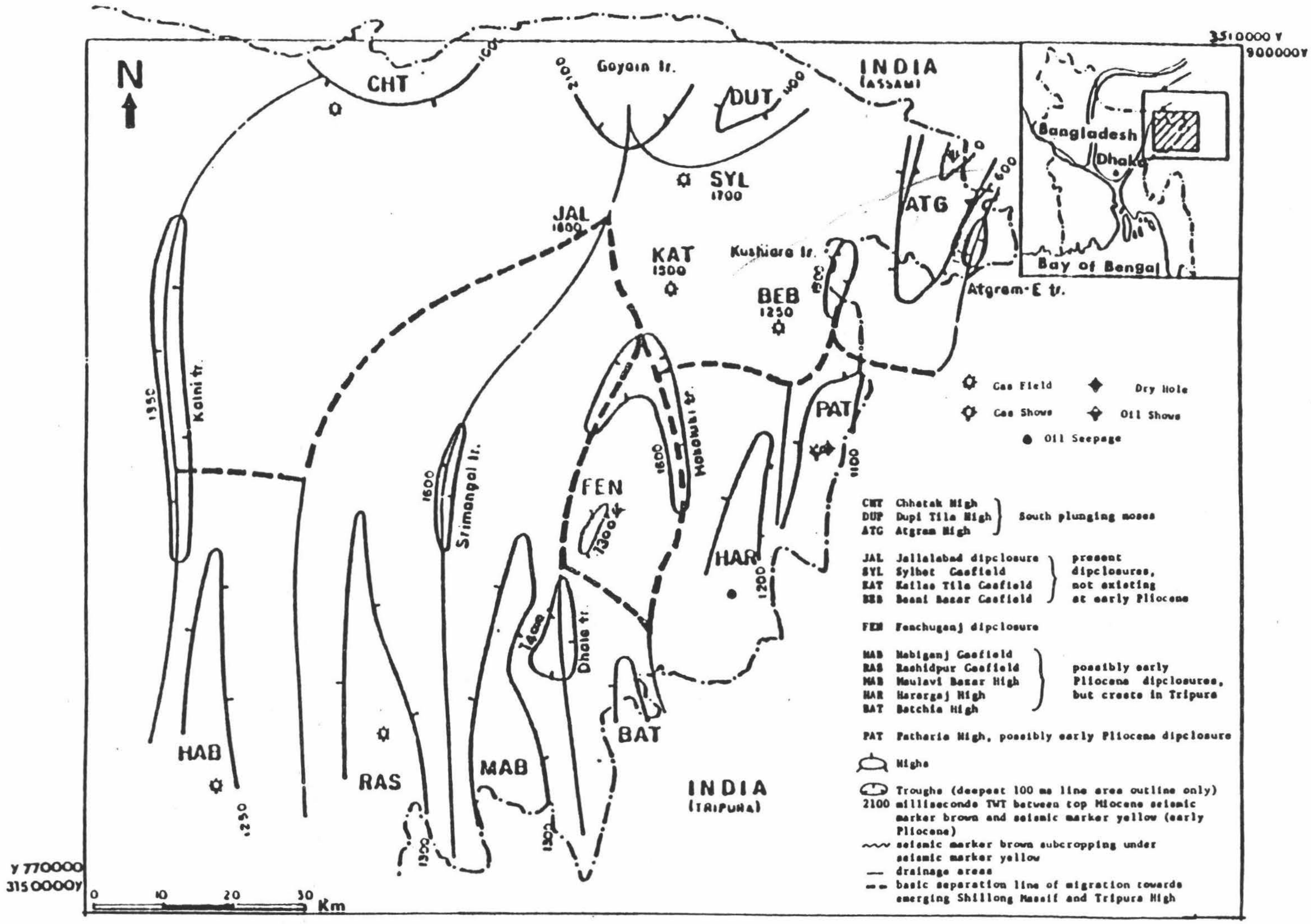

Figure 52. Structural situation and drainage pattern at the Surma Basin in Early Pliocene.

source: Hiller and Elahi (1984)

within the basin (closed structure) (Fig. 53).

The Surma Basin and its adjoining areas are rich in hydrocarbon deposits. In the northeast in Assam there are oil deposits in Nahar Katiya, Moran, Rudrasagar, Lakwa and Geleki. The nearest Assam oil field to Bangladesh is approximately 25 Km to the southeast of Atgram IX, which was discovered in late 1920's. The oil is associated with Upper Oligocene Renji sands and has produced about 20,000 bbls cumulative of heavy oil until completion (Hiller and Elahi, 1984). Subsequently oil (28^{o} API gravity) was found on the nearby Masimpur Patharia structure (Fig. 53) of Bangladesh but no commercial production has been obtained. At Harargoj there is an oil seepage known to occur at the Upper Bhuban beds.

Economic gas discoveries have been made in less disturbed anticlines in the marginal parts of the Surma Basin (Chhatak, Sylhet, Kailas Tila, Rashidpur, Beani Bazar, Habiganj, Titas and Bakhrabad) at depths of about 3500-11700 ft. in the Boka Bil to Middle Bhaban (Upper and Middle Miocene) Formations. The gases are dry and are composed mostly of methane (CH4) ranging from 94-99% with nil or very low sulphur and only trace of carbon-dioxide and nitrogen. The delta $13C_1$ isotope values - a measure for thermal maturity of gas range from 45.2% to 40.0% which corresponds to a vitrinite reflectance spectrum of Ro of 0.7-1.2%, equivalent in maturity to the "Oil Window" (Hiller and Elahi, 1984). The TOC values of the cores or cuttings of the Surma group on an average range from 0.8-0.9% which indicate that these are marginal and gas prone source rocks. Assuming that the Mid-Oligocene Jenan Shales are the dominant oil source rock, Atgram IX was

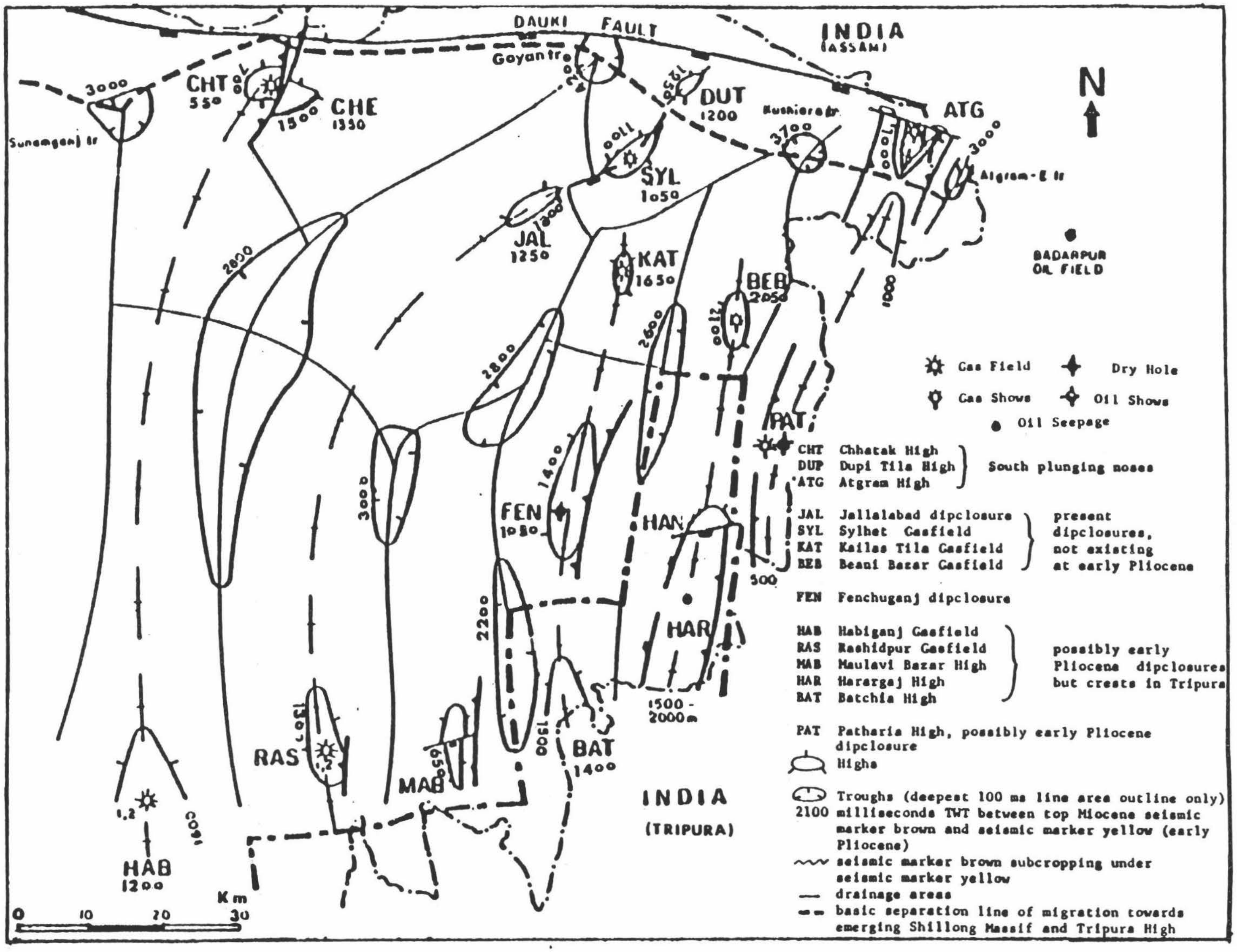

Figure 53. Present Structural situation and drainage pattern at the Surma Basin. source: Hiller and Elahi (1984)

drilled 16,276 ft. penetrating about 850 feet of Jenam formation. Drilling was discontinued due to poor test results. This was the deepest drill hole in Bangladesh.

As in Assam, the Upper Eocene Kopili Shales are considered to be the oil source rock in the Surma Basin. The geothermal gradient varies from 1-8 to 2.2^{o}/100m.

The low vitrinite reflectance value and low temperature gradient suggest that other than the Fenchuganj dipclosure, none of the present traps was capable of holding hydrocarbons in the Surma Basin. Moreover, the Kopili shales with a temperature regime of 160^{o}C or more have passed almost entirely through the oil window. Thus oil has migrated out towards the east and the north (Hiller and Elahi, 1984). On the basis of the post Pliocene drainage pattern of the Surma Basin (Fig. 52), Hiller and Elahi (1984) have suggested that oil has not migrated out of the Basin in total. As a result, the uplifted anticlines of Patharia and Harargaj may contain liquid hydrocarbon. Moreover, there are possibilities of occurrence of Jenan shales in the more basinward portion of the area as seen from Atgram IX (Fig. 52). In this context, Fenchuganj and Maulavi Bazar are promising structures. Currently drilling is going on at Fenchuganj, results are not known yet.

Out of 13 existing gas fields of the country, 8 are in the Surma Basin having a reserve of about 9.0 trillion cft. Thus, the Surma Basin occupies a very important position in the Petroleum Geology of Bangladesh.

B. Stable Shelf and Hinge Zone

Hydrocarbon potential of northwest Bangladesh is regarded as good based on its structural history. The standard Vaccuum Oil Company (StanVac) has drilled three wells (Kuchma, Bogra and Hazipur) in the region but all the 3 wells were declared as dry holes with minor oil stains. The region recieved renewed interest after it was interpreted as a Transition Zone between two different facies. Petrobangla drilled at Singra in Rajshahi, but this was found as a dry well. In West Bengal of India with 25 drilled wells completed, there has been no success in finding hydrocarbons (Raman, Kumar and Neogi, 1986). Continuous subsidence with little orogenic disruption in the western part of the basin, has provided a suitable environment for the generation of stratigraphic traps but structural traps are largely absent (Salt et al., 1986).

Salt et al. (1986) evaluated (chapter I, this study) the hydrocarbon prospectivity of each seismic sequence of the hinge zone region based on interpreted seismostratigraphy. The area is not drilled yet. The different seismic sequences and their deposition models have been described in the seismostratigraphy part of the first chapter of this research. The different seismic sequences are shown in figure 36. Here only the Hydrocarbon prospectives will be discussed (Salt et al., 1986):

Sequence S-B (Jurassic-Lowar Cretaceous): This comprises a series of sub-aerial basaltic lava flow.

Prospectivity is negligable for this sequence because reservoir properties are reduced due to depth related diagenesis and seals may be ineffective due to overlying sandy beds.

Sequence S-C (Lower to Up Cretaceous): The sequence represents the trap wash deposits.

Here too, potential reservoir rocks are of poor quality because of textural immaturity.

Sequence S-D and S-E (Upper cretaceouss to Paleocene): S-D and S-E sequence represent high energy delta front and deltaic plain deposits.

Potential exists here for stratigraphic traps. The best potential is offered in the updip Lithofacies change from the delta front sequence S-D, to lagoonal or delta plain sequence of S-E. High sand-shale ratio may diminish the trapping potential.

Sequence S-F (Paleocene to Upper Eocene): This is a regional marker reflection sequence given by Sylhet Limestone deposits.

Potential plays have been identified in : 1) Coastal Deltaic Facies; 2) Shelf Carbonates and 3) Slope Carbonates.

The Coastal deltaic facies is likely to contain excellent reservoir rocks in distributary-mouth bar, distributary channel and littoral-shelf sands however, updip seal may be lacking. Lower part of S-F contains thick porous reservoir sandstones in Singra, Kuchma, and Bogra wells (oil stains).

Shelf carbonates constitute a potential play. The sealing to carbonate reservoirs is likely to be mainly stratigraphic by lithofacies change. Potential source beds are offered by Kopili Shales.

The slope carbonate facies offers speculative deep gas play in carbonate debris flow and turbidite reservoirs.

Sequence S-G (Up Eocene-Oligocene): It represents a regressive event during the Late Oligocene.

The potential play here is associated with coastal onlap as evident by reflectors at the base of sequence S-G against the unconformable upper surface of the Eocene Limestone. The onlapping seismic facies is predicted here to include high energy transgressive coastal sandstone reservoir (Barail Group) and sealing mudstones.

Sequence S-H (Lower-Middle Miocene): This event shows marked differential thickenning from the shelf to the deeper basin as a result of continued regression of the sea. This represents the Bhuban Formation.

This sequence offers potential plays in both shelf and slope facies. Deltaic to shallow marine shelf snadstones are encountered in the upper part of sequence S-H. Here reservoir properties are excellent. Sequence S-J acts as the seal rock.

Sequence S-J (Upper Miocene to Recent) and Above: The sequence represents the termination of progradation of the shelf-slope system by a prominent erosional channeling event.

Prospectivity for hydrocarbon is not of much importance here and hence not discussed.

Although there is higher than average exploration risk, stratigraphic traps may be encountered during any future drilling in the region.

C. Southern and Southeastern Bangladesh

The folded belt and the deeper basin too have potentialities for hydrocarbon exploration. Tectonically and stratigrpahically, the folded belt zone can become a hydrocarbon province.

Gas deposits have been located at shallow depth at Semutang (Fig. 51) and oil show has been detected in the Patiya structure; the folded belt also shows high formation pressure at a shallow depth (3 Km). The folded belt zone of the Chittagong Hill Tracts offers the best chances for vertical hydrocarbon migration. Tectonic activity, which continued into the Pleistocene, probably played a role in the separation of fluid and gaseous hydrocarbons. Pressure changes during different tectonic phases may have led to a separation migration through different traps leaving the oil stepwise and residually behind while the gas became concentrated.

On the basis of structural complexities, the folded belt is classified into three zones: a more complex eastern zone, a moderate middle zone and a gentle western zone. Tectonic studies have established that the anticlines of the western zone are most favorable traps for hydrocarbon as regards their structural forms. It should be noted that structures lying within the southern portion of this same zone are more prospective.

As regards the closures of the structure, both the Boka Bil and the Lower Bhuban Formations are of insterest in the western zone. For structure of the middle zone, due to the middle Bhubans having been exposed, the prospects are confined to the Lower Bhuban and still older sediments of the Barail Group. Stratigraphically sediments from the Boka Bil to the top of the Lower Bhuban, contain considerable amount of sandy sediments, for instance, the Middle part of the Boka Bil Formation contains 50 to 250 m of sandstones having high permeability and porosity. The top of the Boka Bil contain a thick band of shales (Upper Marine Shales) which reliably seals these sandstone. The Middle Bhuban Formation is mainly a shaly succession which should be considered as a reliable cap for the Lower Bhuban Sediments.

Only the upper portion of the Lower Bhuban sediments are exposed on the surface within the region. Hence, the important Barail rock was drilled at shallow depth on structures such as the Inani, Olahtung, Dakhin Nila, in the western zone, and the large Matamuhuri and Bandarban and possibly the Gilasari structures in the middle zone Presently drilling is underway·on in the Sitakund structure. The sturcutre shows shale diaperism and abnormal formation pressure. Ahmed (1985) studied the economic potential of the Sitakund structure on the basis of Shale Resistivity Ratio (SRR) and concluded that the structure is not a prospective zone for oil unless a major unconformity is drilled.

The deeper basin with its enormous sediment thickness and concurrent subsidence is also a highly prospective area for hydrocarbon occurrences. A number of structures have been drilled in the foredeep area and in the Bay of Bengal and hydrocarbon deposits have been found at: Kamta, in the Dhaka Uplifted Zone, at Begumganj and

Feni in the Foredeep and at Kutubdia in the Bay of Bengal (Fig. 50). The Bay of Bengal has been proven to have less hydrocarbon potential. The success ratio is 1 in 9 in Bangladesh. In Indian part of the Bay of Bengal, 25 offshore drills were found to be dry (Raman, Kumar and Neogi, 1986).

The 74 wells drilled to date in Bangladesh have yielded a reserve of 13 trillion cft. of gas and condensate but no oil.

Lietz and Kabir (1978) studied the oil potential of Bangladesh. They defined the Bangladesh gas deposits as:

a) an immature marsh or swamp gas with a maturity rank above the so called "Oil Window". This would imply no chance for the generation of oil;

b) generated together with oil but became separated during migration. This would still give the chance of finding oil;

c) an overmature gas with a maturity rank below the "oil window". This would mean that intensive cracking processes have destroyed liquid hydrocarbons;

d) derived from woody kerogen. This would exclude the joint generation with oil.

Kononov et al. (1983) and Hoque (1982, cited in Ahmed, 1985) discussed the possibilities of "shale diapirism" in Bangladesh. Kononov and Fariduddin (1983, cited in Kononov et al., 1983) suggested possible shale diapirism in Chhatak, Sylhet, Patharia, possibly Fenchuganj (the northeastern part and Sitakund), Patia and possibly Semutang (southern part) of the region. Reasons they have described in favor of shale diapirism are: a) absence of persistent seismic reflectors or appearence of chaotic short flat spots of questionable character in the crest of the folds; b) steep rock dip angles (70-80 degrees) in the flank parts of the folds, even reversed dip angles and an abrupt flattening of dip angles in depth almost to horizontal; c) multiple surface gas shows (Sitakund structure), and sometimes, oil shows in shallow wells (e.g. in Patharia) located in crestal or disturbed parts of the folds and d) formation of high pressure zones due to the consequence of plastic deformations.

Based on the Miocene (the Boka Bil and the Bhuban Formations) and the Oligocene (Barail) thicknesses and shale diapirism Kononov et al. (1983) recommended that a) like the oil bearing areas of India and Burma the sediments of Lower Paleogene, mainly Paleocene and Eocene (Disang Series) and possibly also Oligocene (Barail Series) are oil generating layers; b) oil bearing sediments may be the Lower Oligocene Liasong Series and Lower Miocene Bhuban Formation; c) potential zones of maximum oil accumulation are in the old structures of Chhatak-Sitakund-Semutang area and d) the depth of oil prospecting would be between 4300-4700 m (13000-14000 ft).

Growth Faults, structural features common to many deltas, have not yet been identified in Bangladesh.

CHAPTER III

GEOLOGIC ANALOG STUDY

Tertiary hydrocarbons occur in many of the deltas of the world. Liquid hydrocarbon however, are produced from only four deltas: the Mississippi, in the Gulf Coast of USA; the Niger, in Nigeria; the Mckenzie, in Canada and the Mahakam, in Indonesia. Among all these, the Mississippi has been the most extensively studied delta. The Niger Delta has been locally studied in detail and the Mahakam and the Mckenzie Deltas are now being studied. Because of the presence of oil in only these four deltas, there arises a consideration that deltas are different in geologic character and in having the potential to generate and produce hydrocarbons. The petroleum aspects of two major deltas, the Niger and the Mississippi are discussed below:

Niger Delta

The Niger Delta, arcuate in nature, is one of the largest in the world and formed by the Niger River and its distributaries in West Africa . The Delta has built seaward with symmetrically concentric sediment facies. The braided Niger River has a group of distributaries which are each tide dominated. They appear to build forward into the Gulf of Guinea at about the same rate and to have advanced the margin of the continential shelf so that it conforms with that of the Delta margin (Fig. 54). The search for hydrocarbon in Nigeria since 1910's (Weber and Daukoru, 1975) has led to a great increase in the knowledge of the geology of the coastal sedimentary basin. Most of studies have been concentrated in the southern deltaic region after a commercial discovery in this region (Oloibiri field) in

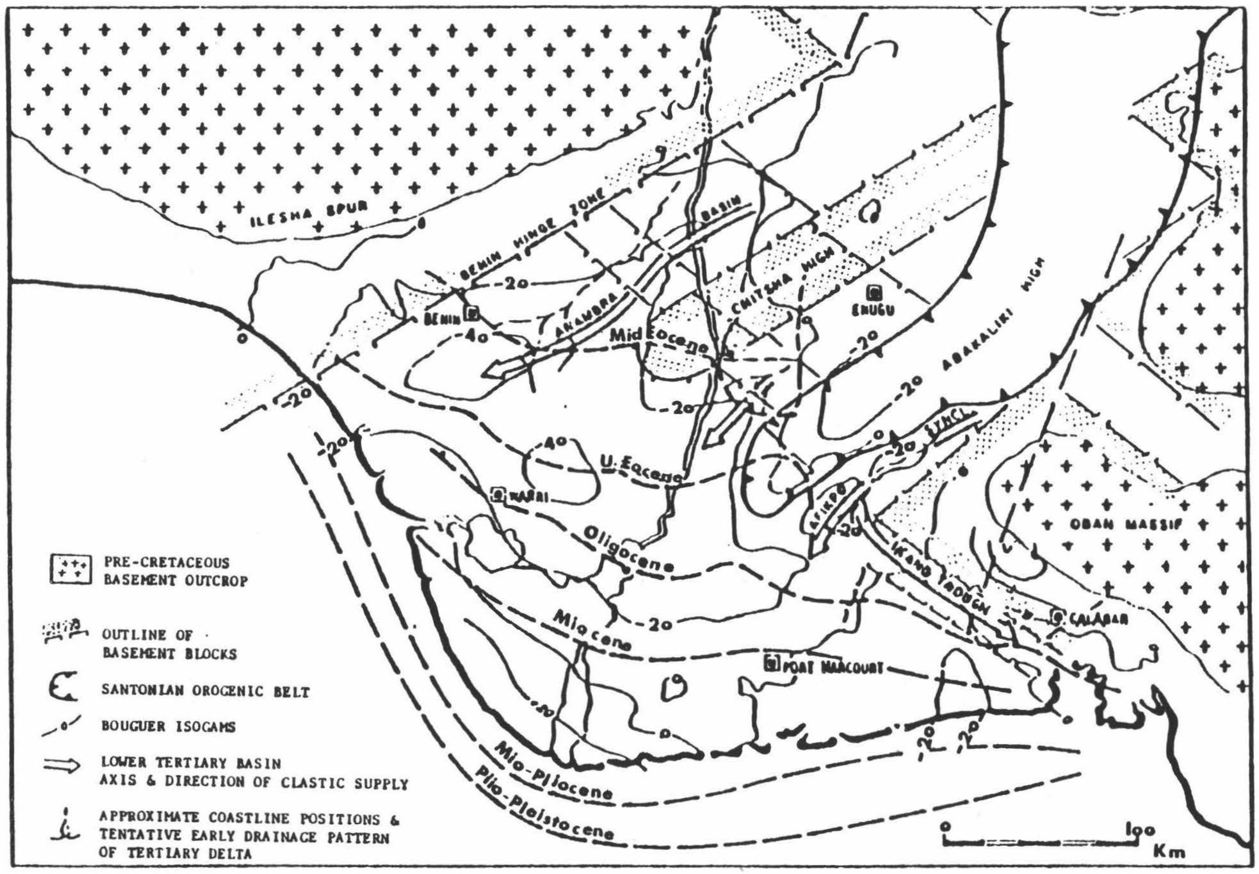

Figure 54. Megatectonic frame and stages of Tertiary delta growth in Nigeria.

source: Weber and Daukoru (1975)

1955.

The Tertiary Niger Delta covers an area of about 75,000 sq. Km (29000 sq. mile) and is composed of an overall regressive clastic sequence which reaches a maximum thickness of 30,000 to 40,000 ft (9,000 to 12,000 m) (Evamy et al., 1978).

The coastal sedimentary basin of Nigeria has been the scene of three depositional cycles: the first began with a marine incursion in the Middle Cretaceous and was terminated by a mild folding phase in Santonian (Middle Upper Cretaceous) time (Short and Stauble, 1967). However, the regional tectonics started earlier in Aptian/Albian when Africa started to separate from South America and as a result Benue Trough was formed. The second depositional cycle included the growth of a proto-Niger Delta during late Cretaceous and ended in a major Paleocene marine transgression. The development of Cretaceous proto-deltas was terminated in the Paleocene by a major transgression, represented by the Imo Shale. This was followed by the regressive phase and the third cycle, from the Eocene to the Recent, marked the continuous growth of the main Niger delta.

Stratigraphic horizons of as far back as Albian (base of Upper Cretaceous) are found in the northern Nigeria (Table XI). In the deltaic part however, the thick sequence of sediments are considered to consist of three units: the bottom, marine, Akata Formation; the middle, sandy Agbada Formation; and the top, shaly Benin Formation.

The Akata Formation is characterized by a uniform shale development. The pro-delta shales are medium to dark gray, sandy or silty undercompacted, and may contain lense of abnormally high a pressured siltstone or fine grained sandstone. This formation was

SUBSURFACE			SURFACE OUTCROPS		
YOUNGEST KNOWN AGE		OLDEST KNOWN AGE	YOUNGEST KNOWN AGE		OLDEST KNOWN AGE
RECENT	BENIN FORMATION (Afam/Qua Iboe)	OLIGOCENE	PLIO. PLEISTOCENE	BENIN FORMATION	MIOCENE?
RECENT	AGBADA FORMATION	EOCENE	MIOCENE	OGWASHI-ASABA FORMATION	OLIGOCENE
			EOCENE	AMEKI FORMATION	EOCENE
RECENT	AKATA FORMATION	EOCENE	L. EOCENE	IMO FORMATION	PALEOCENE
EQUIVALENTS NOT KNOWN			PALEOCENE	NSUKKA FM.	MAESTRICHTIAN
			MAESTRICHTIAN	AJALI FORMATION	MAESTRICHTIAN
			CAMPANIAN	MAMU FORMATION	CAMPANIAN
			CAMP./MAEST.	NKPORO SHALE	SANTONIAN
			CONIACIAN/ SANTONIAN	AWGU SHALE	TURONIAN
			TURONIAN	EZE AKU SHALE	TURONIAN
			ALBIAN	ASU RIVER GROUP	ALBIAN

Table XI Stratigraphy of the Niger Delta.

source: Avbovbo (1978)

deposited in front of an advancing delta front. The estimated thickness of the Akata Formation which is extended across the entire delta and which is considered as the source rock of the Niger delta oil province is over 18000 feet (550 m). The age of the Formation ranges from Eocene to Recent (Short and Stauble, 1967).

The Agbada Formation consists of alternating sandstone and shales of delta front, distributary-channel and deltaic plain origin (Weber and Daukoru, 1975). The alternating sequence of sandstone and shales of this formation are of cyclic sequences of marine and fluvial deposits. Thickness of this Formation is of about 12,000 ft. (3650 m). The age of this Formation ranges from Eocene to Recent. This Formation is the main objective in the exploration for oil in southern Nigeria because hydrocarbons have been found in the sand intervals.

The Benin Formation consists of predominately massive, highly porous freshwater bearing sandstone locally interbedded with thin shale beds. The total age of this Formation is from Miocene to Recent. The Formation produces mostly freshwater and hydrocarbon production is very low.

The Niger Delta began to build seaward over the edge of the African continent in middle to late Eocene time. The Oligocene and younger delta sediments are very thick beyond the continental edge. Rapid sand deposition along the delta edge on top of undercompacted clay has resulted in the development of a large number of synsedimentary gravitational faults. Much of the resultant fault movements are contemporaneous with deposition, producing a thickening of the sedimentary section across the fault plane on the down thrown blocks. These are known as "growth faults" (Fig. 55) and in Nigeria the ratio of the thickness of a given stratigraphical unit in the downthrown block over that of the corresponding unit in the upthrown block is 2.5 (Weber and Daukoru, 1975). Growth fault causes a rotational movement which tilts the beds towards the fault. In this way anticlinal so called "rollover" structures are formed along the faults. Hydorcarbons in the Niger Delta are mostly trapped in the growth faults.

Growth faults also acted as the migration pathway of hydrocarbon from the lower Akata Formation to the reservoirs in the Agbada Formations. Shale diaperic structures also occur in the Niger Delta (Weber and Daukoru, 1975).

The patterns of sedimentation in the Delta is probably typical for the Miocene to Recent Delta. The pre-Miocene delta was probably less smoothly arcuate in shape because of the smaller influence of the longshore currents. The reservoir quality of the sand is strongly dependent on the depositional environment and the depth.

Overpressures are encountered in the Tertiary Niger Delta as a result of rapid loading of the undercompacted shales of the Akata Formation by the Sandy Agbada and Benin Formations (Weber and Daukoru, 1975). Moreover, whenever Akata Shale is juxtaposed with paralic Agbada Sand, fluids may "inflate" into the Agbada sand and hence overpressure are often encountered before the Akata Shale was reached.

The geothermal records of the Niger Delta suggest that the

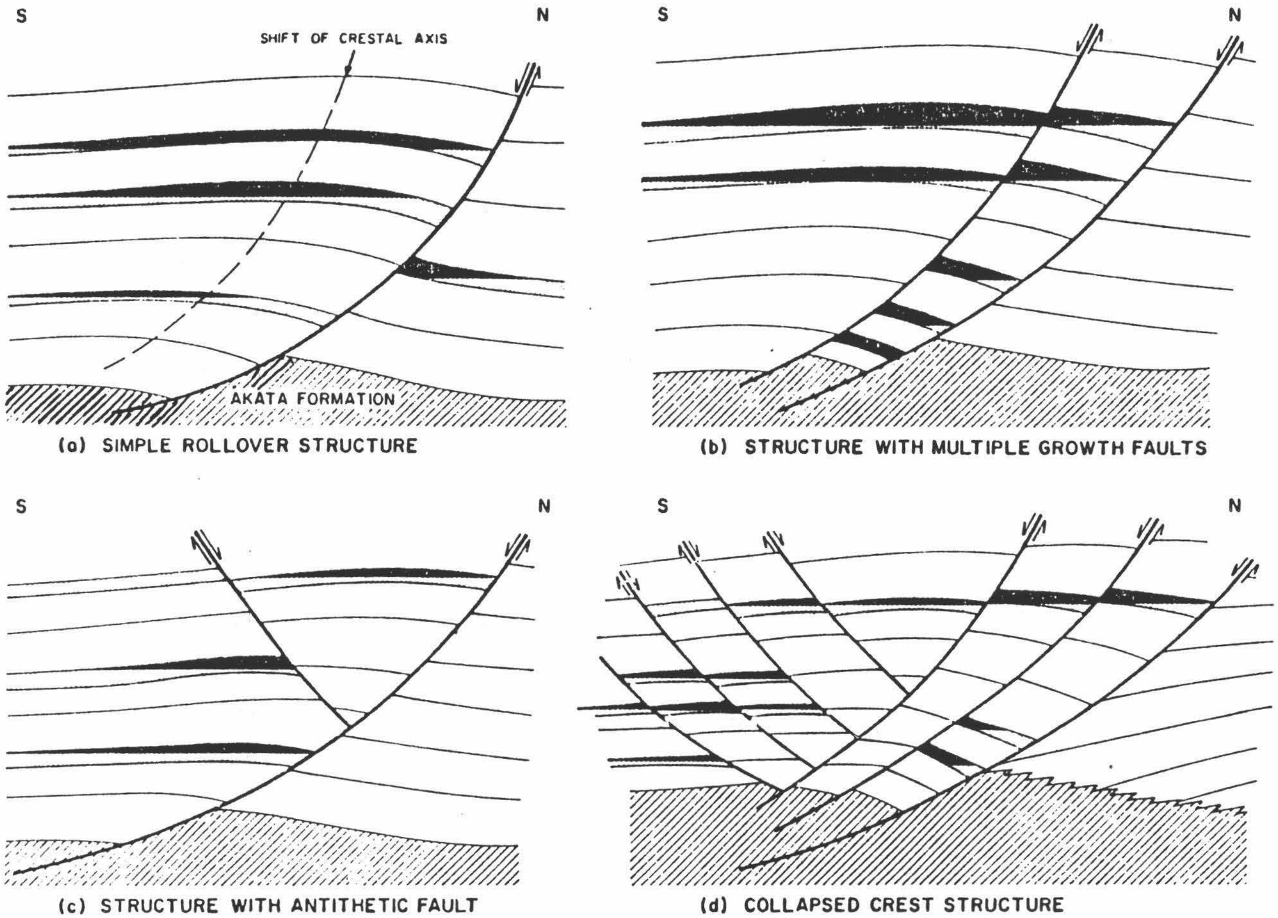

Figure 55. Principal types of oil field Structures in the Niger Delta with schematical indications of common trapping configuration.

source: Weber and Daukoru (1975)

temperature values are lowest over the center of the Niger Delta (Fig. 56) approximately 0.7 to 1.0 ^{o}F/100 ft and they increase to about 3 ^{o}F/100 ft in the cretaceous rocks on the north (Nwachukwu, 1976). These temperatures have high potential for hydrocarbon generation.

The upper part of the Akata Formation can be considered as a mature source rock (Weber and Daukoru, 1975) because this Formation was deposited under anoxic conditions on the continental slope where the nutrient supply for planktonic organisms must have been plentiful.

In Nigeria the best evidence for the vertical migration of the oil is the occurrence of hydrocarbon at the spill points (Weber and Daukoru, 1975). It is thought likely that these spill points are also the entry points of the reservoir of the hydrocarbon from the fault zone into the reservoir. Aother major migration pathway may be the orverpressured shale through the fault zone. From the conductive fault zones the hydrocarbons appear to flow into the downthrown blocks only. Below a throw of more than 150 m there is no vertical migration.

Hydrocarbon in Nigeria occurs in anticlinal structures, mostly faulted and bordered on one side by growth faulting. Growth faults act as sealing on the upthrown side of the fault. The larger the shale percentage, the larger the trapping capacity of the faults. Reservoir can also occur for their location at juxtaposition with the shale.

Minor stratigraphic trapping also occurs in Nigeria in clay filled gullies.

In conclusion, the following points can be mentioned:

1. The Nigeri Delta began to form from Cretaceous but the present delta was outlined in Eocene.

2. The Delta has a thickness of about 11,000 m.

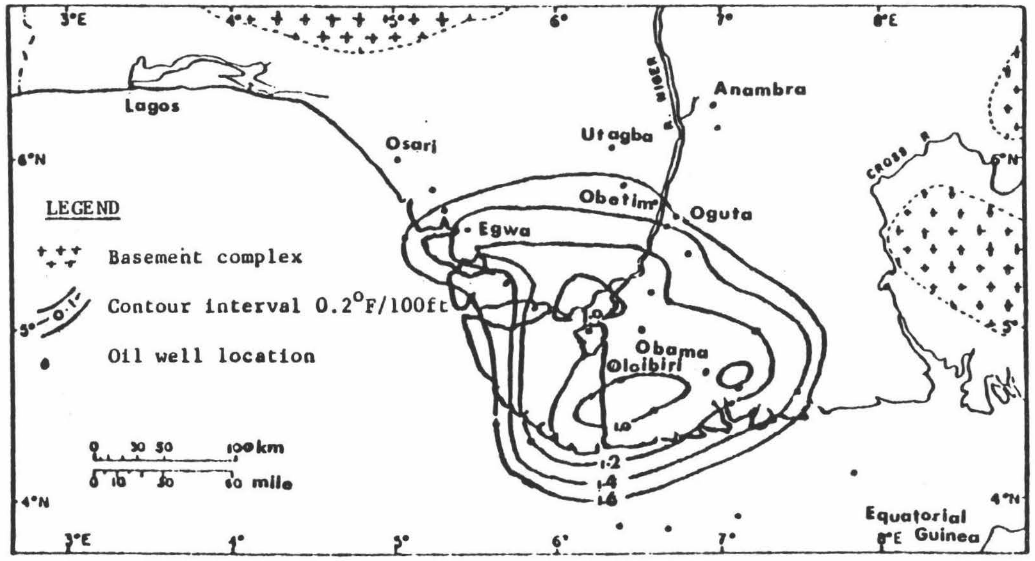

Figure 56. Geothermal gradient map of the Niger Delta.

source: Nwachukwu (1976)

3. There are three zones for hydrocarbon occurrence. a)lower Turonian and Senonian to Lower Maestrichtian sandstone; b) Maestrichtian bitumen; c) Eocene - Pliocene and Plio-Pleistocene sands (Avbovbo and Ogbe, 1978).

4. Hydrocarbon migration to the reservoir took place after sedimentation reached the present stage.

5. Both oil and gas are produced in the Basin.

Mississippi Delta

The Mississippi delta complex is one of the largest and probably best known of the worlds' major delta systems. The delta has an area of 11,000 sq. miles (18,000sq. km.). The exposed delta plain is dominated by a small number of large distributaries and a host of minor ones. The "Bird's Foot" morphology of the delta results from these distribution, with the 'claws' marked by channels and the 'webbed' connections marked by interdistributary bays. Over the past few thousand years the active parts of the Mississippi delta have undergone periodic shifts along the coast of Louisiana as successive channels searched for gradient advantages over their precursors. There is a mechanism in switching deltas in the Mississippi for producing deltaic 'cycles', so long as the coastal plain is located in an area of net tectonic subsidence. This fluvial dominated delta has undergone surface tectonics of density contrast and gravity instability resulting in regressive basin filling sedimentation (Curtis, 1970). The Gulf Coastal region is a Mesozoic-Cenozoic coastal geosyncline. Deposits of the northern Gulf Coastal element possess an overall homoclinal dip toward the Gulf of Mexico. Piercement salt domes, deviced from a thick bed of salt, are present in the salt basins of the Gulf Coast.

Deltaic sedimentation predominated in the provinces during the Cenozoic. Thickness exceeding 25,000 feet (8000 m) accumulated in coastal Louisiana and Texas during the Tertiary. The predominantly clastic nature of these deposits reflects continuing orogeny in these Cordillera of wastern North America.

A well established generalization in Gulf Coast petroleum geology is that the occurrence of oil and gas is controlled regionally with depositional facies that contain optimum reservoirs. Hydrocarbon in the Mississippi Delta occurs in the Eocene Wilcox Formation and Frio Formation of the Miocene.

The Tertiary record in the Gulf Coast is dominated by deltaic systems recognized using vertical sequences and sandstone body Characteristics derived largely from electric logs (Fisher, 1969).

In the Eocene Lower Wilcox Group, the fluvial dominated Rockdale delta system extends over 6000 sq. km and has a maximum thickness of 1500m (Fisher and McGowen, 1967). The Wilcox Group (early Eocene) is a thick sequence of predominantly ferrugenous clastic sedimentary rocks. Facies pattern in the Upper Wilcox Group differ radically from the Lower Wilcox Group, the Lower is an example of Highly Constructive Delta Systems whereas the Upper Wilcox is a example of High Destructive Delta Systems (Fisher, 1969). Electric log profiles present distributary mouth bar sequences in the delta front. Growth Faults and diaperic structures are associated with zones of deposition.

The Frio Formation of Oligocene and Miocene age is one of the major progradational wedges of the Texas Gulf Coast- Tertiary Basin (Galloway et al., 1982). The Formation consists of seven principal depositional systems.

The structural elements include regional growth fault zones, salt diapirs and interdiapiric salt-withdrawl basin and shale diapirs and ridges. These are the product of depositional loading of undercompacted slope and basinal muds or of bedded salt.

Integration of structural, stratigraphic and production data defines ten producing plays within the Frio Formation. Hydrocarbons productivity in the Frio Formation varies widely from play to play and among the various depositional systems. The geologic and geochemical considerations suggest that the hydrocarbons in this Formation originated far below (Galloway et al., 1982). Vertical distribution of the oil reservoirs relative to the oil generation window suggests upward migration of about 3000-4000 ft (900-1200 m). Oil production significantly overlaps both wet and dry gas production. The average depth of oil reservoirs ranges from about 55000 ft (1700 m) in the Rio Grande embayment to 7300 ft (2300 m) in the Houston embayment and the deepest oil occurrence are from 9000 ft (2800 m) to about 12,000 ft (3700 m).

CHAPTER IV

DISCUSSION

Bangladesh is a nation surrounded by India on the north, east and west and open only to the south to the Bay of Bengal. The landmass of Bangladesh is composed of sediments of the Bengal Delta, also known as the Ganges Delta, one of the largest Delta in the world.

The Bengal Delta is formed by three major rivers, the Ganges, the Brahmaputra and the Meghna which carry enormous amounts of sediment from the Himalayan mountain region to the Bay of Bengal. The Delta, arcuate in nature, has built from the point where the Ganges enters the Bengal Basin from west to east. The Delta is divided into moribund (or dead), mature and active parts from northwest to the southeast.

Physiographically, Bangladesh is divided into 3 broad parts, viz: 1) Tertiary Uplands in the northeast and southeast, 2) Pleistocene Terraces distributed in three different blocks, at the northwest, central and eastern part, and 3) Recent floodplains, Piedmont Plains, swamps, levees and coastal deposits in the south. The Tertiary uplands mostly trend NNW-SSE while a few structures in the northeastern portion trends E-W.

Tectonically, the Bengal Delta is divided into two broad parts, a northwestern Stable Shelf portion with reduced thickness of sediments and a southeastern deeper basin (foredeep) with sediment thickness reaching more than 50000 feet. Within the Hinge Zone (22-70 miles), the boundary between the shelf and the deeper basin, the thickness of the Eocene Sylhet Limestone varies from 6000 ft. in the north to 13000 ft. in the south with an inclination change between 2^{o} to 12^{o} (Salt et al., 1986). At the northwestern part of Bangladesh basement dips northwest (Ruhea Flank) which is followed at the south by an area of nondipping basement known as Rangpur saddle where the basement occurs at shallow depth in Bangladesh. Rangpur saddle is followed at the south by the southeast dipping of basement (Bogra Flank). The deeper basin can be divided into a number of troughs, highs and elongated fold patterns. In the folded flank of the Foredeep folds are steeper in the eastern than in the western portion.

The origin and classification of the Bengal Delta has been the subject of considerable debate. Alam (1972) designated the Bengal Delta as an exogeosyncline between the Naga-Lusai Miogeosynchline on the east and the Indian Shield, acting as a craton, on the west side. The Bengal Basin would therefore be a continuation of the sub-Himalayan Foredeep.

The origin of the Bengal Basin has also been explained in the concept of "Plate Tectonics" by which Desikachar (1974) suggested that the Bengal Basin is associated with a subduction zone between the Indian Plate at the west and the Burmese Plate at the east. The later overriding the former during the Miocene. The Basin has also been suggested to have originated as a rift valley on the crest of the Ninety East seismic ridge (Faruqee, 1975). Bengal Basin is an asymmetrical basin. Basin thickness increases from west to east and from north to south. The stratigraphy of Bangladesh is based on the nomenclature and classification of Assam area of India. Although Tertiary rocks are the oldest exposure sequences in Bangladesh Permo-Carboniferous Gondwana Coal measures have been drilled in northwest (Bogra, Kuchma, Singra, Jamalganj) areas of Bangladesh. The Gondwana Coal is a high volatile, noncoking bituminous type similar to Raniganj Coal of India (Ahmed, 1980) and occurs at a depth of 2800 (850m) to 3800 ft (1150m). The coal sequence is overlain by Cretaceous volcanic trap deposits. The Rajmahal Trap and the Shibganj Trapwash are also detected at the northwestern part of the country. The Tertiary Tura Sandstone formation of Paleo-Eocene overlies the trap deposits and is in turn overlain by the Eocene Sylhet Limestone containing Globorotalia Cocoensis which represents a marker horizon in the country. This sequence is overlain by the Oligocene Barail rocks of both continental and marine facies. Barail rocks however, have only been drilled locally within Bangladesh. The Bengal Delta is dominantly characterized by thick, monotonous and mostly unfossiliferous Neogene sediments consisting of sandstone, shale, siltstone, claystone and conglomerate of the Surma Group, the Tipam Group and the Dupi Tila Formation. The Surma Group is further divided into lower Bhuban Formation and an upper Boka Bil Formation. The Tipam Group is similarly divided into a lower Tipam Sandstone Formation and an upper Girujan Clay Formation. The Boka Bil is bounded at the top by the "Upper Marine Shale" which is a marker horizon representing a regional marine transgression. The overlying rocks: Tipam Sandstone, Girujan Clay, Dupi Tila Formation, Dihing Formation and Madhupar Clay are all continental deposits.

Tertiary deposition in the Basin is related to tectonic activity in the Himalaya, the first phase of which begun in late Cretaceous. In the offshore, three sedimentary sequences have been recognized which represent an ideal deltaic deposit.

Detailed studies of the Surma Group, based on reports and data of the Bangladesh Oil, Gas and Mineral Corporation, have been conducted, which hosts all the gas and condensate reservoirs in Bangladesh. The Surma group has a thickness of 590m, in the Stable Shelf portion, to 3645m in the Hatiya Trough (Muladi) portion of the Bengal Foredeep. The Bhuban Formation, which comprises the lower part of the Surma Group, has a thickness ranging from 280m to over 1970m and is overlain by the Boka Bil Formation with a thickness ranging from 310m to over 1840m. It is thus evident that thickness for the Miocene Surma Group is greatly reduced in the Stable Shelf region compared to the foredeep. The isopachs drawn for the Surma Group show a number of depocenters, four in the Bhuban sediments and three in the Boka Bil sediments. Location of the major depocenter has shifted to the central part of the Basin in the Boka Bil Formation. Comparison of the Miocene Bhuban and Boka Bil Formation with the bouguer anomaly map of Bangladesh suggests that subsidence of the Surma Basin, which has the lowest gravity value, did not take place only in the Miocene. As there are no depocenter represented in the Miocene isopachs of the Surma Basin, subsidence must have taken place before and after the Miocene. On the otherhand, in and around Singra, on the Stable Shelf, a Miocene depocenter coincides with the bouguer anomaly of closed contour. Isopachs show a broad opening to the south with increasing sediment thickness.

The net sandstone and shale thickness, sandstone and shale percentage and sandstone ratio of the Bhuban and the Boka Bil Formations have been calculated and several isolith maps have been drawn for those. The isoliths of the upper part of the Oligocene Barail rocks have also been drawn along with the Miocene Bhuban and Boka Bil Formations. The lower part of the Barail rocks have not been drilled in Bangladesh.

The overall sand-shale distribution suggests that the major Tertiary sequences are dominated by shale. Increased sandstone is only seen in the Boka Bil Formation of the Beani Bazar area.

The sandstone thickness map of the Bhuban Formation suggest a higher value in the Rashidpur area (469m). The sandstone percentage map shows an increasing value towards the southeast of Beani Bazar area (34.1%). The sand-shale ratio map also suggests sandstone dominance in the same region. The percentage of sandstone decreases on or near the Begumganj. Since the Tertiary sequences in Bangladesh are an alternation of sand and shale, whereever sand decreases, the shale values increases and vice versa. The shale percentage increases (66.4%) in the Begumganj- Bakhrabad-Semutang areas.

The Boka Bil Formation also shows a trend of sandstone prevalence, in the Titas-Rashidpur-Beani Bazar areas, with sandstone thickness showing there lowest closed contour near Bakhrabad. Sandstone percentages show increasing values in the Beani Bazar area and reduced values in the Bakhrabad and Hazipur areas. Shale thickness map shows a highest value (878m) near Titas and lowest (125m) in the Beani Bazar area where the shale percentages are sharply decreasing. In Titas, however, the shale value is coincidently high with the sandstone value. The shale percentage value increases in all direction.

Sandstone thickness map of overall Surma Group and part of Barail Group shows increasing value in the Rashidpur-Titas area. Other than in Semutang, the sandstone thickness decreases in all directions. Sandstone percentage has highest value in Beani Bazar area. Shale thickness map yields higher values in Semutang (2523m), Atgram (2292m) and Rashidpur (1889m) areas and greatly reduced in Beani Bazar area. Shale percentage maps depict a gradual decreasing value towards the Beani Bazar area. Sand-shale ratio map also shows larger values towards Beani Bazar area and a decreasing value in Atgram, Hazipur and Bakhrabad areas.

From the above individual analyses it is concluded that the thickest sand contents in all the Miocene and Oligocene layers are in the Titas-Rashidpur-Beani Bazar areas. Particularly the Beani Bazar is an area where sand percentages are considerably larger than the shale percentages, and shale percentages increase in all directions away from Beani Bazar. The general distribution of the sand-shale sequences indicate that sediments in the region began to be distributed from an area east of Titas-Rashidpur-Beani Bazar of Bangladesh. The grain size distribution (dominance of large grain in the above area and followed by finer deposits distributed in all directions) points to the deltaic outbuilding from the positive uplifted areas in the east towards the west, north and south. The uplift of the Arakan-Yoma Ridge in Oligocene and a deltaic outbuilding from east to west have also been indicated by Holtrop and Keizer (1970).

Analyses of the hydrocarbon potential of the Bengal Basin showed the Miocene Bhuban and Boka Bil Formations as the major producers of gaseous hydrocarbons. Oil shows have also been detected in few wells. The source rock for the gaseous hydrocarbon is still in controversy. There were suggestions that the Gondwana (Permian) coal deposits were the source rock. However, this is not considered true because a) in the adjacent Assam area of India experimental results found that coal is not the source rock for overlying oil deposit and b) gas is not found in the West Bengal (India) and Bangladesh pericraton where Gondwana Coal measures occur at depth. The Eocene Sylhet Limestone and the Eocene Disang Shale are now considered as the probable source rocks for Bangladesh gas deposits with the majority of current opinions favoring the Eocene Disang Shale.

The isotope study of some of the gas deposits of Bangladesh provided the information that: 1) the gas has a marine origin, 2) the gas occurred within the so called "Oil Window", and 3) few gas deposits in northeastern Bangladesh show a lateral migration between 2 to 5 Km.

Geochemical study of Bangladesh gases suggested that the gases are composed mostly of methane (94 to 99%) with little or no sulphur content. The overall total organic carbon (TOC), Extractable Organic Matter (EOM) and the reflectance value (Ro) of the Bangladesh gas deposits are below 1%, 200 ppm and 0.2 to 0.5% respectively. The Ro value of Surma Basin samples vary from 0.7-1.2% which is equivalent in maturity to the "Oil Window" (Hiller and Elahi, 1984). Works on the catagenesis of the Atgram and the Muladi wells indicated that the present Bhuban sediments are partly located in the Principal Phase of Oil Formation (PPOF) ("Oil Window") and their bottom sections have already entered the Principal Phase of Gas Formation (PPGF). The underlying Boka Bil Formation entered into the PPOF only at Muladi.

The temperature record of the Bangladesh gas wells indicates an increased value in the Surma Basin towards the northwest of Bangladesh. The highest temperature in the area is 160 ^{o}C. Geothermal gradient varies from 1 ^{o}C/30m to 1 ^{o}C/55m and pressure records of different wells show a distribution of normal to highly abnormal pressures. The abnormal pressure gradient occurs at a depth from 3000m to 5000m, the shallowest one being near the eastern folded belt. The Formation pressure gradient varies from 0.12 Atm/m in the west to 0.15 Atm/m in the east. The higher formation pressure also occurs in the areas where Bhuban rocks are shallower. Thus, over pressure zones in Bangladesh have linear relationship with the amplitude of the structure and the depth of the Miocene Bhuban Formation.

The Miocene Surma Group (the Bhuban and the Boka Bil Formations) of rocks act as reservoir rocks in Bangladesh. The sandstone of the Surma Group is classified as lithic arenite. Most of the gas deposits are contained within the sand layer of Boka Bil Formation.

The porosity of the producing gas fields of Bangladesh varies from 19% to 30% with up to 70% gas saturation. The Eocene Sylhet Limestone, and Kopili Shale, Upper Marine Shale of Boka Bil (Upper Miocene) and the Girujan Clay of Mio-Pliocene are considered as the probable cap rocks of Bangladesh.

The gas in Bangladesh occurs mostly in anticlinal traps with or without faulting. Monoclinal structures are also expected to be found in the Hinge Zone, Shillong Monocline (south of Shillong Plateau) and Madhupur High (Dhaka Uplifted Zone). It is postulated that stratigraphic traps are likely to occur in the Hinge Zone and Shillong Monocline.

There are two suggestions on the migration of hydrocarbon in Bangladesh. One idea is that gas migrated towards the west whereas another suggests migration towards east. The later group also suggested the occurrence of shale diapiric structures in Bangladesh.

Oil stains have been found in a number of wells; Hazipur, Patharia and Patya and there are a number of oil shows in Bangladesh. However, absence of liquid hydrocarbons in this large delta is also a subject of controversy. The lack of hydrocarbon being attributed to the fact that, 1) the gases are immature marsh gas and formed above the "Oil Window", 2) the gases are overmatured suggesting that the liquid hydrocarbon was subjected to thermal cracking, 3) the gases are generated together but became separated during migration and 4) the gases are divided from woody kerogen.

The Surma Basin or the Sylhet Trough is the prime area of regional hydrocarbon potential as out of 13 existing gas fields in the country, 8 are in the Surma Basin. The total reserve is about 9.0 trillion cft. Seismic records indicate a post-Eocene sediment thickness of more than 57000 ft. The Basin has the lowest gravity value and highest formation temperature value in the country. The Basin started to be forming and subsiding since Oilgocene to present.

A number of oil deposits have been found in both the Miocene Bhuban and Upper Oligocene Renji sands of Assam in India, near the Surma Basin. The nearest oil field to Bangladesh is approximately 25 Km to the southeast of Atgram IX and oil seepage was found in the Patharia, Harargaj and Masimpur structures. The Stable Shelf and Hinge Zone may also have important hydrocarbon potential as the Stan Vac Oil Company has drilled three wells in the region and found oil stains although no commercial quantity of oil or gas were found there. Subsequently the region has received renewed interest after it was intrepreted as a transition zone between two different facies. Additionally, the area is considered very suitable for the occurrence of stratigraphic traps because of its continuous subsidence with little orogenic movement. Several important seismostratigraphic sequences (S-G, S-H) show good indication for hydrocarbon potential. Nevertheless, drilling by Petrobangla, at Singra in Rajshahi, resulted in dry wells as did the 25 wells drilled in the West Bengal part of India also were dry.

Tectonically and stratigraphically, the western and southern portion of the fold belt zone is likely to be a hydrocarbon province because of the presence of the Barail, Lower Bhuban and the Middle

Boka Bil reservoir rocks that are sandy and have good porosity and permeability. High pressure occuring, at shallow depths (3 Km), provide an ideal mechanism for vertical hydrocarbon migration and tectonic activity, which was continued into the Pleistocene, probably played a role in the separation of the fluid from the gaseous hydrocarbons.

The offshore of Bangladesh has not yet proven to be very rich in hydrocarbon occurrence as gas was found only in Kutubdia out of drilling a total of 9 wells drilled.

Current research on the Miocene and Oligocene thicknesses and on the shale diapirism suggests that like the oil bearing areas of India and Burma the sediments of lower Paleogene and also Oligocene may be oil generating layers. The lower Miocene Bhuban Formation may also be considered as prospective. The depth of oil prospecting would be between 4300-4700m (13000-14000 ft.).

Growth Faults, typical delta features elsewhere in the world form during marine regressive phase when strong sandy deposits lie over undercompacted shale of low shear strength, have not yet been identified in Bangladesh. Their absence is due not to lithological plasticity, but seems to be the result of the combination of plasticity and compressional tectonics (subsidence in the east-west compression). Elsewhere in the world, particularly in the Mississippi and the Niger Deltas the tectonics are tensional where growth faults have developed.

The results of the isotope analysis carried out on the Chhatak, Sylhet and Titas have indicated that the Chhatak and Sylhet gas have undergone long distance migration whereas the gas from the Titas field shows no such characteristics. The oil from which the gases are separated therefore must lies near the Titas field. Brunnschweiler (1978) suggested that oil could be found in the same stratigraphic level where gases are found but downslope, not vertically below the gas. He further recommended that oil accumulations may be found in the older Paleogene or even Pre-Tertiary beds in the Hinge Zone or Shillong Monocline. Kononov et al. (1983) suggested the eastern Paleo Highs (near Assam - Tripura of India) are the probable areas for oil accumulation.

Geological analog studies were completed on the Mississippi and the Niger Deltas which have been extensively studied. The Niger Delta is a wave dominated arcuate delta which started forming in the Eocene. Broadly distributed sedimentary sequences are deposited in the basinal part of the Niger Delta. The bottom unit is the Akata Formation which is shaly and acts as source rock. Age of this ranges from Eocene to Recent. The central lithological unit is the sandy Agbada Formation. The Agbada Formation holds most of the hydrocarbon in Nigeria and the age ranges from Eocene to Recent. The upper sequence is the freshwater Benin Formation which acts as the cap rock. The age range for this formation is from Miocene to Recent. Growth Faults and rollover anticlines are the major structures present in the Niger Delta which accumulates hydrocarbons. The geothermal gradient values are lower near the center of the delta where bouguer gravity values are also low. The Delta progradation is analogous to the advancement of the continental shelf. The total vertical thickness of the sediment is 11 Km.

The Mississippi is a fluvial dominated Bird's Foot Delta which also began forming in the Eocene. The delta demonstrates piercement salt domes and distribution mouth bars, primarily in the Eocene Wilcox and Miocene Frio Formation which are prolific areas for hydrocarbon occurrences. Growth faults are frequently distributed.

A brief comparative study of the Bengal Delta with that of the Niger and the Mississippi Deltas is shown in Table XII.

Tertiary geology of Bangladesh is very complex (Khan, 1980). It does not simply represent a classic delta formation like that of the Mississippi and the Niger. The Bengal Delta also displays certain characters of the flysch facies.

Table XII Comparison of the three Deltas, the Mississippi, the Ganges and the Niger.

Mississippi	Ganges	Niger
Fluvial dominated. Building in local estuaries.	Tide dominated. Not building in closed estuaries. Located at the head of broad embayments.	Both tide and wave dominated. Not building in closed estuaries. Located at the head of broad embayments.
The delta developed as a result of overlapping and laterally displaced sediment lobes that are slowly subsiding.	Have a broad tidal plain as a result of hightides at the Bay of Bengal.	Does not have various subdelta lobes. Has a single symmetric arc with concentric sediment facies.
Entire mass of the Delta is retreating more than advancing.	Not growing appreciably and probably most of the sediment is being carried into the Bay of Bengal by the major rivers.	The distributaries are advancing at the same rate as the Continental Shelf advancing conforming with that of the Niger Delta.
Local lobes are built across and which are pouring sediment onto the continental shelf. Rivers are meandering.	Rivers are mostly of braided pattern.	Inbcluded both braided (Niger) and meandering rivers.

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Mississippi	Ganges	Niger
Deltaic 'cycles are produced because the coastal plain is an area of net tectonic subsidence.	Delta progradation causes a gradual convergence of the tidal current ridges and the tidal channels turn to be fluvial channels as progradation continues.	Continued delta progradation might result in reworking and destruction of facies at the expense of the upper deltaic plain facies.
Bird's Foot type Delta.	Arcuate type.	Arcuate type Delta.
There are records of Jurassic and Cretaceous deltas.	Proto delta begun in Early Paleocene but present day delta got outline in Mio-Pliocene.	Proto delta started in late Cretaceous, present delta formed in Eocene time.
Formed in "Atlantic Type" margin.	Formed in "Atlantic Type"margin.	Formed in "Atlantic Type" margin.
Basement depth above 9000 m (27000 ft).	Basement depth is more than 19000 m (57000 ft).	Basement depth at the deepest is 11000 m (35000 ft).

continued......

Mississippi	Ganges	Niger
Delta shows salt diapirism .	Delta possibly shows shale diapirism.	Delta shows shale diapirism.
Growth fault and roll over anticlines are found.	No trace of Growth faults.	Growth faults, rollover anticlines are abundant.
Vertical migration of Frio Formation is 3000-4000ft.	Lateral migration of 2-5 km.	Information not available.
Information not available.	Bouguer gravity low coincides with the temperature high in the subsided Surma Basin.	Temperature low coincides with bouguer gravity low in the subsided basins.
Develops molasse facies.	Develops molasse and flysch facies.	Develops molasse facies.

continued......

Mississippi	Ganges	Niger
Eocene and Miocene produces hydrocarbon.	Hydrocarbon occurs in Mio-Pliocene rocks.	Hydrocarbon occurs in in Pre, Post Cretaceous and Eocene-Pliocene rocks.
The 'oil window' for the Frio sandstone is between 100-300 F isotherm.	Geothermal gradient range from 1.22 F/100 ft to 2.2 F/100 ft at the southeastern part of the country. The value decreases in the Surma Basin where sediment thickness is more.	Geothermal gradient range from 0.7 to 1.0 F/100 ft and sometimes 3 F/100 ft towards Cretaceous rocks. The lower temperature is at the deeper part of the basin (Inverse relation relation of Temperature with depth).
The depocenter of the Tertiary isopach maps show scattered depocenters. The values are more in the south.	Isopach maps of Tertiary reservoir rocks show depocenter in different parts of the delta, however, there is one at the deeper part, in the south of Delta. Isopach maps of Miocene rocks suggest subsedence did not take place only in Miocene.	Isopach maps of Tertiary source and reservoir rocks show depocenter at the south of the delta. Isopach maps show subsedence stared from the Eocene and continued later.
Oil producing Wilcox and Frio Formation are trapped growth faults and diaperic structures.	Gas producing Boka Bil Formation is found in anticlinal traps.	Oil producing Agbada Formation is trapped mostly in rollover anticlines formed by growth faults.

SUMMARY

The Bengal Basin began forming in the Oligocene, following separation from the Burma Basin, as a result of tectonic events closely associated with the formation of the Himalayan mountain chain. Delta formation in the Bengal Basin has continued until the present with the major delta growth occurring in the Miocene. To date over 13 trillion cft. of natural gas has been discovered in the Miocene Surma Group.

Isopach maps of the Miocene sediments in the Bengal Basin indicate that the Surma Group sediments formed in a number of depocenters. Sediment thickness are greater in the southern foredeep portion of the Basin and considerable thinner on the northernmost stable shelf areas. Subsidence of the Basin has continued from the Oligocene to the recent.

Sand-shale ratios within the Bhuban and the Boka Bil Formations of the Surma Group show a dominance of shale in most areas but with significant sand in the eastern portion of the Basin; particularly in the Titas, Rashidpur and Beani Bazar areas of exploration drilling.

Gas deposits in the Bengal Basin are of marine origin having a composition of 94-99% methane. Several studies have indicated that the gas deposits formed within the "oil window" and therefore hydrocarbons, other than gas may be present.

Most gas deposits occur in structural traps and indications of diapiric structures, which may also be traps, have been recorded. Another type of trap which may occur, but has not been recognized, are

those associated with the growth faults.

Unlike other petroleum producing deltas (Mississippi and Niger) oil has not been found in the Bengal Basin. Nevertheless, future exploration for oil should be directed toward the eastern paleohigh (Rashidpur-Titas-Bakhrabad) and stratigraphically downdip of sequences where gas deposits have been discovered.

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