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GEOLOGIC ASSESSMENT OF THE FOSSIL ENERGY POTENTIAL OF BANGLADESH

By

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U.S. Geological Survey

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GEOLOGIC ASSESSMENT OF THE FOSSIL ENERGY AND GEOTHERMAL POTENTIAL OF BANGLADESH

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INTRODUCTION

The purpose of this report is to provide geological input to the consideration of appropriate activities that can enhance the exploration and development of fossil-fuel and possible geothermal energy resources in Bangladesh. Information was obtained from: 1) review of published literature pertaining to the geology and energy resources of Bangladesh, 2) review of documents pertinent to current activities in the energy sector of Bangladesh, and 3) dicussions with government officials and scientists during a recent visit to Dacca. The literature that was reveiwed is listed as References Cited at the end of this report; the documents reviewed and the persons and agencies visited are listed in table 1.

This report was prepared under RSSA No.INT-USGS 1-80 for the Agency for International Development as a component of a broader study of prospective technical assistance to Bangladesh in the exploration and development of conventional energy resources. Some readers of this report may not necessarily have a geological background; therefore, a glossary of technical terms used herein is included as Appendix A.

Table 1. - Sources of information

DOCUMENTS

Bakhrabad Gas Development Project, World Bank Staff Appraisal Report 2956-BD.

Preliminary Version - Needs and Targets Study Bangladesh U.S. Geological Survey

Preliminary Version - Energy Issues and Prospects Energy Sector Assessment - World Bank

Loan Agreement (Geological Survey Project) Asian Development Bank, 5 August 1980.

Centre for Policy Research, University of Dacca, Scope of Study Topic, Natural Gas and Petroleum

Project Proforma, Accelerated Exploration for Mineral Resources and Modernization of Geological Survey of Bangladesh (1980-1985).

Technical Assistance to the Government of Bangladesh in the Fossil Energy Sector; C. Bliss. 1981.

VISITS

Government of Bangladesh Agencies

Joint Secretary, Ministry of Petroleum

Chairman and staff, Petrobangla

Former Joint Secretary, Ministry of Petroleum

Planning Commission Member

Director General, Bangladesh Geological Survey

OTHERS

Sunmark Exploration Company, Dacca

Geological Advisory Group, Federal Republic of Germany, Dacca.

Chairman, Department of Geology, Dacca University

The Government of Bangladesh has delegated the responsibility for the exploration and development of oil and gas resources to a state oil company, Petrobangla. The scientists and administrators of Petrobangla, supplied regional geologic and geophysical maps and reports, detailed studies of existing gas fields, and complete drilling histories. Various Russian, German, and American scientists working with Petrobangla provided valuable assistance. The staff of the Bangladesh Geological Survey was also most helpful in providing copies of their reports and maps.

Petrobangla's staff consists of 148 professionals, including 40 geologists and 40 geophysicists, backed by 375 support personnel. The staff is dispersed in 10 widely separated offices in Dacca. Geophysicists are segregated from geologists; sedimentologists, geochemists, and drilling personnel, are scattered. Coordinating activities of the various laboratories is difficult. On the whole, equipment is obsolete. Of four seismic field parties, only one was equipped with a digital recording system. The others had analog systems provided by the U.S.S.R. The sedimentology laboratory, the geochemistry facilities, and production testing equipment are inadequate. All drilling operations by Petrobangla are conducted with the assistance of Russian and Romanian advisors. The Federal Republic of Germany is conducting an exploration program that involves both government scientists and private industry. Training of Petrobangla's staff is a by-product of these cooperative efforts.

Bangladesh, in South Asia, has an area of 142,775 km^2, and is bordered by India on the west, east, and north, and by the Bay of Bengal to the south (fig. 1). It has a deltaic terrain with a complex river system susceptible to major flooding, particularly in the monsoon season. Two great river systems drain the highlands in the north. The Brahmaputra drains the north slope of the Himalayas and skirts the west end of the range to flow southward into Bangladesh. The Ganges drains the south slope of the Himalayas, flowing westward to join the Brahmaputra in the Ganges Delta. The combined system has been in operation since late Paleogene time and sediments deposited by the system have formed an eastward thickening wedge of deltaic sediment. Bangladesh is the most densely populated country in the world, having 85 million people, 2 million of whom live in the capital city of Dacca.

REGIONAL GEOLOGY AND STRUCTURAL FRAMEWORK

The geology and structural framework of Bangladesh is best interpreted in terms of the tectonic collision of the Indian plate on the south with the

-Figure 1. Index map of Bangladesh

Eurasian continent to the north during late Paleogene time, some 40 million years ago. Bangladesh is situated at the northeast corner of the Indian plate (fig. 2). To the north, the Himalayas are the expression of the pile up. On the east, the north end of the East Indies arc pushes west. To the south the Bay of Bengal opens into the Indian Ocean. On the west lies the Indian shield. The surface of Bangladesh is almost completely covered by sediments of Quaternary age that mask the underlying older rocks. Ideas about the distribution, geometry, and structure of the pre-Quaternary rocks are largely derived from drill-hole information, geophysical interpretation, rare outcrops, and geologic inferences based on the geology of adjoining parts of India and Burma.

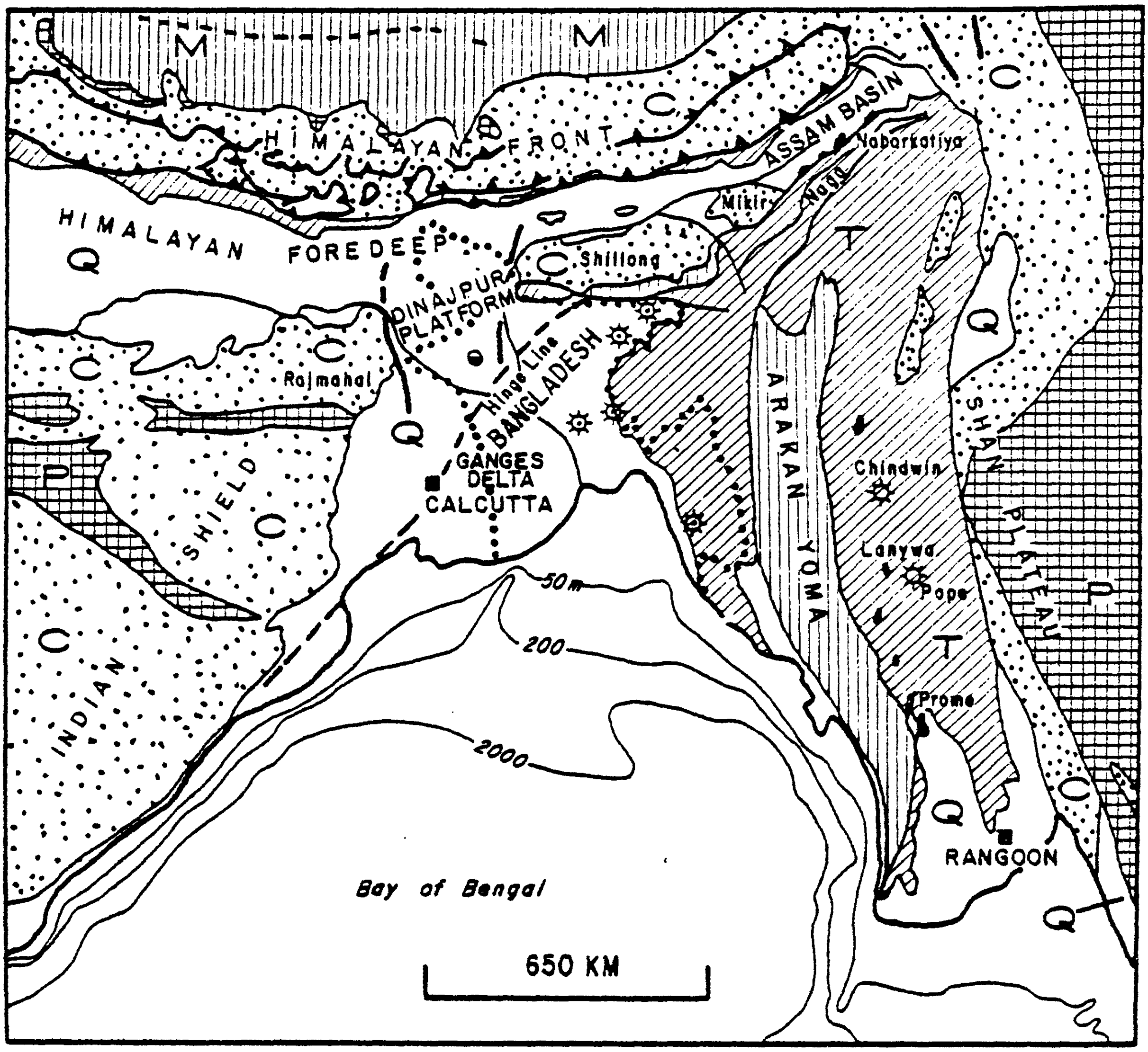
Brunnschweiler (1974) subdivided the Tertiary Orogen of the Indo-Burman ranges into three segments from north to south: Naga Hills, Chin Hills, and Arakan Yoma (fig. 3). He described the sedimentary sequences as becoming thicker and more complex southward through the segments.

Brunnschweiler (1974) described the following zones within the segments listed above (fig. 3).

1. Pegu-Sagaing Rise - a molasse basin resting on a mainly Paleozoic floor grading into the Central Burma Foredeep.

2. Central Burma Molasse Basin on which the post-Eocene molasse rests on flysch (partly allochthonous); the basin itself consists of folded neritic (Cretaceous/Eocene) and older metamorphics.

3. The Inner Thrust zone contains a similar sequence but in a more highly deformed state, as well as deeply exposed pre-Alpine metamorphics which include Cretaceous ophiolites.

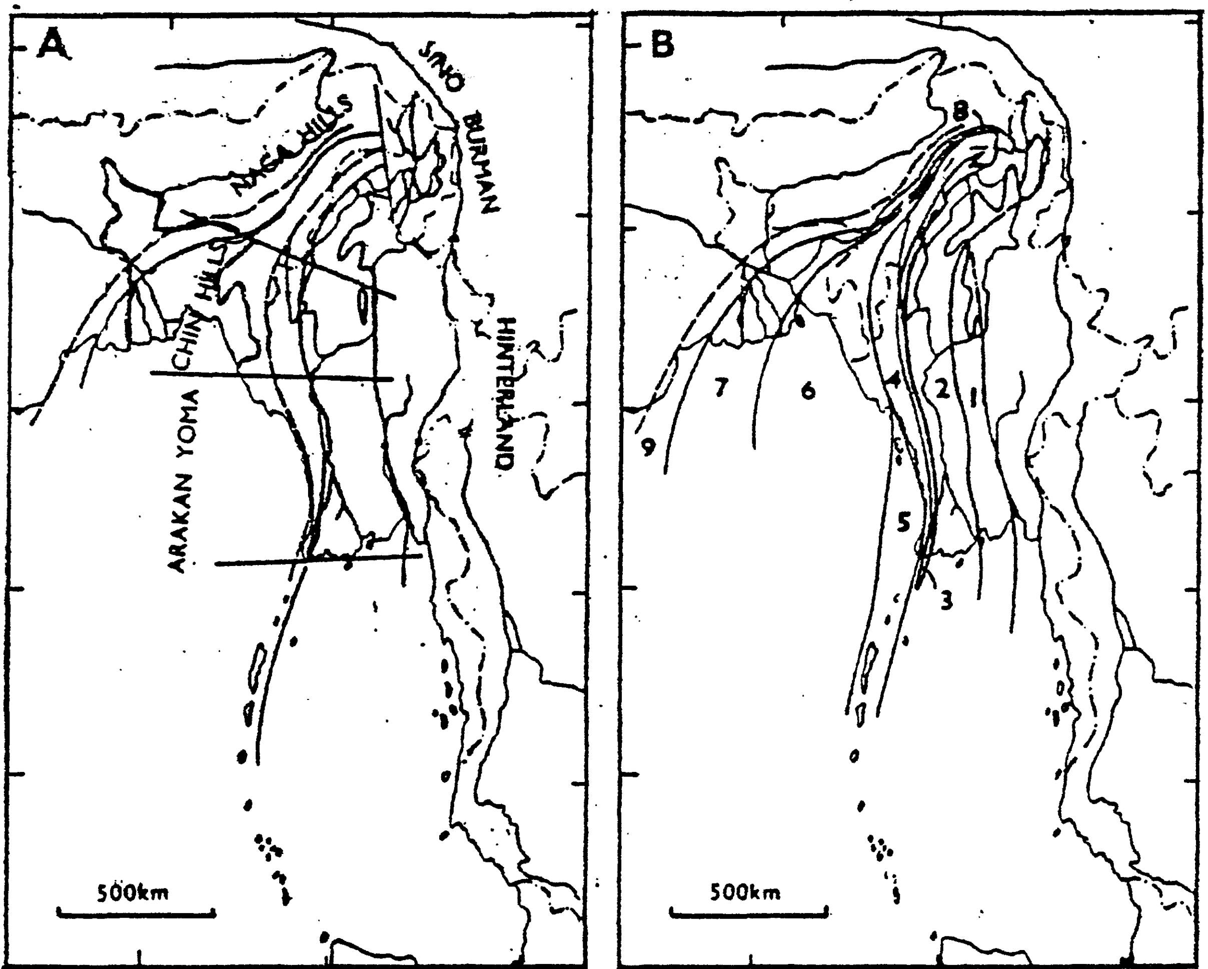


TECTONIC SKETCH MAP OF BANGLADESH
AND SURROUNDING AREAS
(Modified from Gansser, 1964)

LEGEND

Quaternary	Q	Volcano (recent to sub-recent)	☼
Tertiary	T	Faults and minor thrusts	—
Mesozoic	M	Major thrusts	▲▲
Paleozoic	P	Oilfields	●
Precambriam (Vindhyan)	C	Gasfields	☼
		Oil show (subsurface)	◒

Figure 2. Geologic and tectonic setting of Bangladesh. (After Anwar and Husain, 1980).



LEGEND

1. Pegu-Sagaing Rise
2. Central Burma Molasse Basin
3. Inner Thrust
4. Flysch Trough
5. Rami-Andaman Ridge
6. Outer Molasse Basin
7. Suma Foredeep
8. Outer Thrust
9. Bengal-Assam Pericraton

Figure 3. Structural segments (A) and zones (B) of the Indo-Burman Ranges (Source: Brunnschweiler, 1974)

4. The Flysch Trough is characterized by a great thickness of Upper Cretaceous to Miocene flysch resting on a thin Mesozoic section which includes abyssal Upper Cretaceous strata with ophiolites.

5. The Rami-Andaman Ridge along the coast has a Cretaceous/Eocene rock section comparable to that of the Flysch Trough. The Cretaceous/Eocene section in the Rami-Andaman Ridge is strongly folded and largely allochthonous.

6. The Outer Molasse Basin includes 20,000 m of Tertiary molasse sediments that are folded and moderately thrust.

7. The Suma Foredeep is a molasse and flysch that is folded and thrust.

8. The Outer Thrust zone is similar to the Suma Foredeep.

9. The Bengal-Assam Pericraton Zone is a relatively undistrubed foreland which received a great thickness of Pliocene sediment.

Bangladesh contains parts of four regional structural elements (fig. 2, 4). The Bengal Foredeep or Basin to the southeast is separated from the Indian Platform (Shield) in the northwest along the Hinge Line (Zone). The Arakan meganticlinorium trends north-south along the eastern edge of the country, and the Sub-Himalayan Foredeep (South Shillong Shelf and Sylhet Trough) lies along the north and northeast boundaries. In Bangladesh the Indian Platform is, in turn, subdivided into: 1) the Dinajpur Slope, where rocks of Phanerozoic Age overlie the Precambrian basement complex, dip northward, and thicken toward the Himalayan Foredeep; 2) the Rangpur Saddle, a faulted area that is a possible structural connection between the Indian Platform and the Shillong Massif of northeastern India, and the basement core of which is overlain by as little as 422 ft (129 m) of Phanerozoic rock; 3) the Bogra Slope, containing rocks of Phanerozoic Age that dip gently to the southeast and also thicken in that direction; and 4) the Hinge Line (Zone), a transitional area some 15 to 20 miles wide in which the basement complex and overlying rocks plunge steeply south into the Bengal Foredeep, so that structural relief on rocks of Eocene Age such as the Sylhet Limestone attains as much as 7,000 ft (2,134 m).

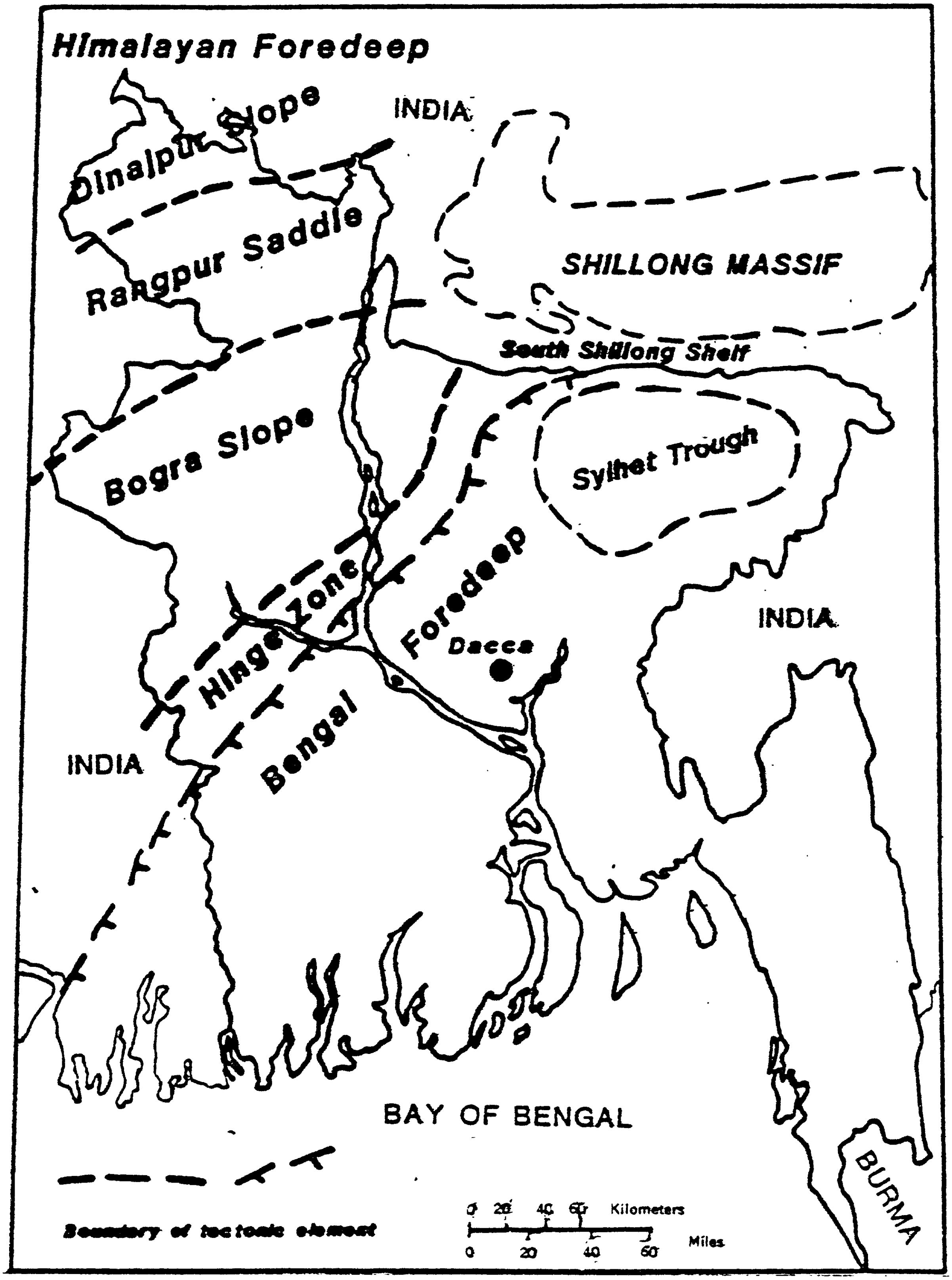


Figure 4. Tectonic elements of northern Bangladesh (from: Zaher and Rahman, 1980).

Only recently, when the Government of the Federal Republic of Germany, Prakla-Seismos (a German geophysical contractor under the Technical Aid Agreement with the Government of Bangladesh), and Petrobangla engaged in digital seismic exploration did the hinge line or transition zone become fully understood as to structural configuration and the interfingering of sediments.

The geology of Bangladesh is not yet adequately known. Nothing is known about the pre-Cretaceous geological history. The history of the Indo-Burman Orogen becomes discernible only from the Late Cretaceous (Senonian) onward. A comprehensive paleogeographic interpretation of the Indo-Burman Meszozoic-Cenozoic orogenic belt is presented by Brunnschweiler (1974) which is, in part, summarized here.

The earliest discernible sedimentary trough within Bangladesh is the Senonian abyssal series in the Arakan Yoma segment which was folded at the end of the Cretaceous to form the Rami-Andaman Ridge (fig. 2, zone 5 on fig. 3). Neither the areal extent nor thickness of sedimentation is known. Contemporaneous with the inital movement which created the Rami-Andaman Ridge, the earliest flysch trough developed in the north toward the end of Cretaceous time.

As the Indian plate approached the mainland during Late Cretaceous time, the subsiding area became a typical geosynclinorium that received terrigenous abyssal sediments in the south and flysch sediments in the north. A north-trending island arc developed at the beginning of Tertiary time to the east of Bangladesh. Subsequent to this island arc formation, flysch sedimentation from the north expanded southward. The Indo-Burma Ranges were paroxysmally elevated during the Oligocene, and the east and west flanking basins were compressed and narrowed in succeeding phases up to the present time.

Further uplift, but no folding of the ranges occurred during early Miocene; at the same time the flanking molasse basins were subsiding. These molasse basins, influenced by the late Miocene and Pliocene terminal folding, were rapidly filled and became areas of terrestrial fluvial sedimentation. Fluvial and deltaic deposition has since continued in the southern seaward regions of the flanking molasse basins of the Ganges delta.

Bangladesh was the site of vast delta buildups during Eocene to Pliocene time. Subsequent Pliocene-Pleistocene alluvial deposits of the Ganges-Brahmaputran Rivers system completely covered the earlier deltaic deposits. These Tertiary strata, below the Pleistocene, have become compressed into long and narrow, north-south oriented folds, produced during the Alpine Orogeny by the westward push of the East Indies island arc. The anticlines have gentle east- and steep west-flanks; thrust faluts are numerous. Deformation decreases westward, and in northern Bangladesh the fold and fault pattern becomes more easterly trending. Correlation of rock units by lithologic characteristics has proven to be unreliable; palynologic studies have proved more reliable.

Bengal Basin (Foredeep)

The Tertiary rock sequence within the Bengal Basin increases in thickness from west to east and from north to south to a maximum of about 35,000 feet. Four phases of folding and faulting during the Alpine Orogeny are recognized by unconformities in strata of the Bengal Foredeep: 1) Late Eocene to Aquitanina, 2) Early Miocene to early upper Miocene, 3) Middle to late Pliocene, and 4) Late Pliocene to early Pleistocene. A period of strong subsidence during Oliogocene time is reflected in 12,500 feet of fine to coarse clastics deposited in a marine environment. In the western part of the Bengal Basin these marine rocks overlie Cretaceous formations which in turn are underlain by the Permian Gondwana Basement complex. The Bengal Basin which covers most of Bangladesh is characterized by thick and monotonous unfossiliferous upper Tertiary sedimentary rocks consisting of sandstone, shale, siltstone, and conglomerate underlain by the Eocene Nummulitic Sylhet Limestone and poorly consolidated coarse-grained Eocene sandstone (fig. 5). The western and northwestern parts of the Bengal Basin are a stable shelf area where the sedimentary rock sequence is known to range in age from Permian to Pleistocene, deposited on a Precambrian basement complex.

Bogra Slope

The geology of the Bogra Slope in northwest Bangladesh has been interpreted from rock samples obtained from drilling and from reflections obtained during seismic surveys (fig. 6). The Eocene Sylhet Limestone is an excellent subsurface reflector. The sedimentary rock samples have been dated as ranging from Permian to Holocene in geologic age; they were deposited in a stable shelf environment on a basement complex (and equivalent Paharpur and Raniganj Formations) (fig. 7). The Late Permian Gondwana sandstone, shale and coal were deposited in faulted troughs of subsiding basins and were followed by Late Jurassic-Early Cretaceous lava flows. Subsequent deposition of the Paleocene to Eocene Tura Sandstone, Sylhet Limestone and Kopili Sandstone and Shale Formations reflect a marine transgression. The 535 feet of siltstone, carbonaceous shale, and fine grained sandstone collectively known as the Oligocene Bogra Formation was deposited in a deeper part of the Basin. This deposition was followed by 1,300 feet of fluvial and deltaic early Miocene deposit that is known as the Jamalganj Formation and the undifferentiated Surma Group.

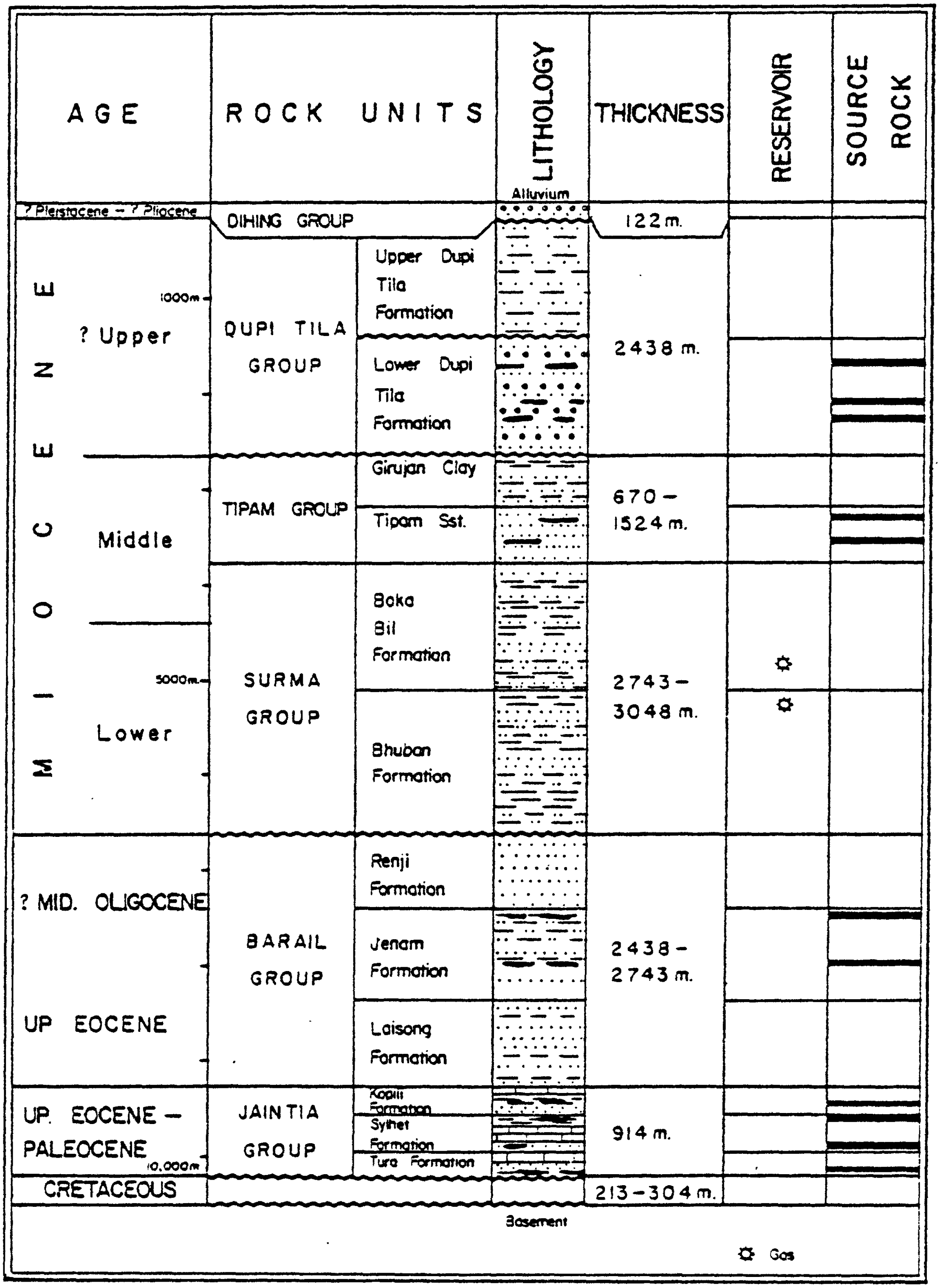


Figure 5. Stratigraphic sequence in the Bengal Basin
(Source: Grunau and Gruner, 1978)

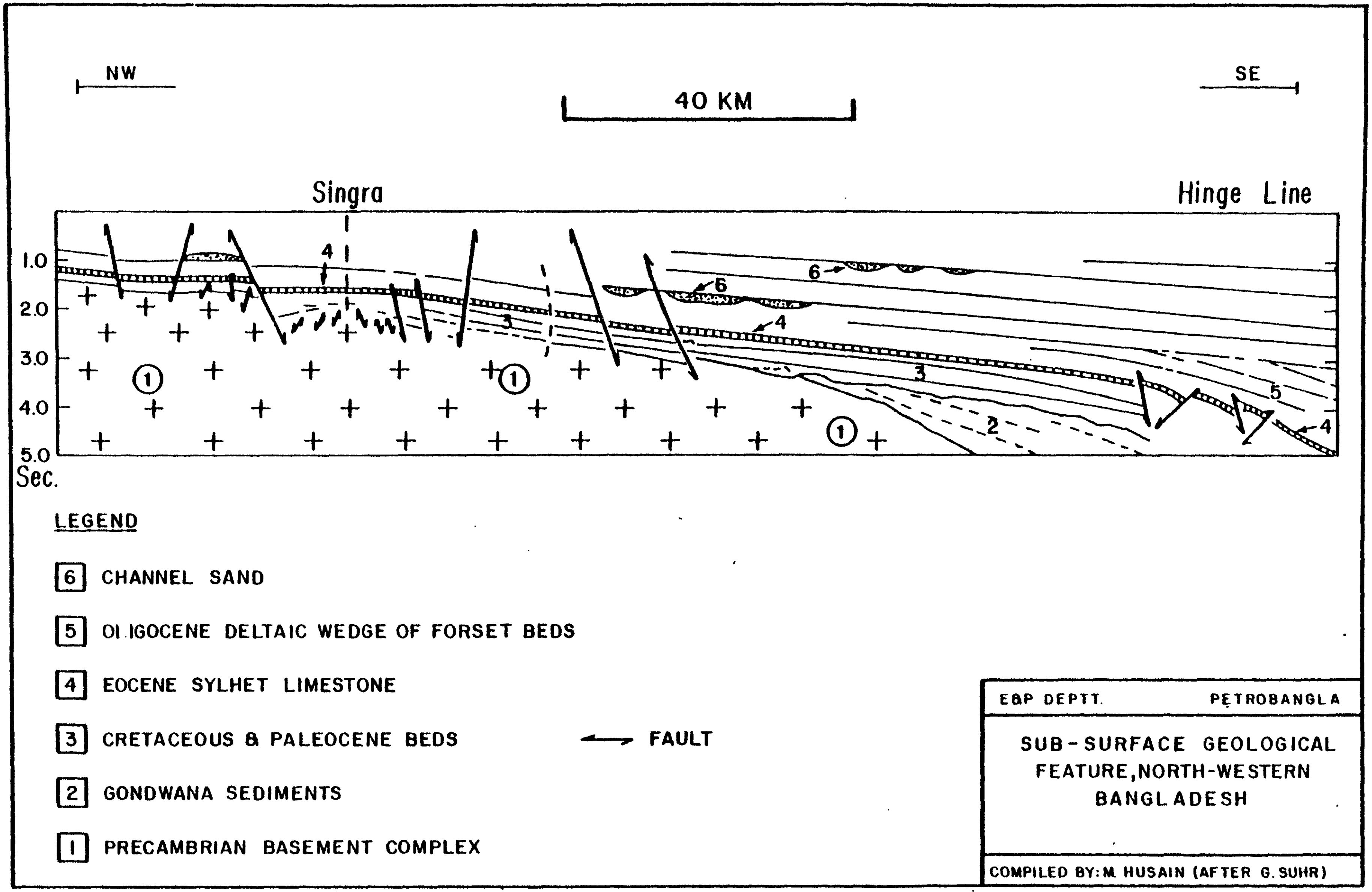


Figure 6. Regional cross section, northwest Bangladesh, based on reflection seismic section by Prakla-Seismos. (After Khan, 1980).

AGE	SHELF (BOGRA SLOPE) GROUP/FORMATION	RANGPUR SADDLE GROUP/FORMATION	LITHOLOGY
Recent to sub-recent	Alluvium (256')	Alluvium (173')	Sand, silt and clay
	unconformity	unconformity	
Pleistocene	Madhupur Clay (50')	Madhupur Clay (50')	Clay, and sandy clay; yellow-brown, sticky.
	unconformity	unconformity	
Middle Pliocene	Dupi Tila Formation (905')	Dupi Tila Formation(?) (560')	Sandstone with subordinate pebble bed, grit bed, and shale.
	unconformity	unconformity	
Early Miocene	Jamalganj Formation (Surma Group undiff.) (1355')	Surma Group undiff.(?) (410')	Fine to medium grained sandstone; sandy and silty shale; siltstone; shale.
	unconformity	unconformity	
Oligocene	Bogra Formation (535')		Siltstone; carbonaceous shale; fine-grained sandstone.
	unconformity		
Late Eocene	Kopili Formation (140')		Sandstone, locally glauconitic; highly fossiliferous shale with calcareous bands.
Middle to Late Eocene	Sylhet Limestone Formation (645')		Nummulitic limestone with interbedded sandstone.
Middle Eocene	Tura Sandstone Formation (340')	Tura sandstone (?) (420')	Gray and white sandstone with subordinate greenish gray shale and coal.
	unconformity	unconformity	
Late Cretaceous	(Sibganj Formation) Trapwash (430')		Coarse yellow brown sandstone; volcanic material; white clay.
	unconformity	unconformity	
Late Jurassic to Middle Cretaceous	Rajmahal Trapwash (1000')		Amygdaloidal basalt; serpentinized shale and agglomerate.
	unconformity	unconformity	
Late Permian	Paharpur Formation (1380') Raniganj Group	Gondwana sediments (560')	Feldspathic sandstone; shale; coal beds.
	Kuchma Formation (1020') Barakar Group		Sandstone and grit with subordinate shale and inter-bedded coal.
	unconformity	unconformity	
Precambrian	Basement Complex	Basement Complex	Gneiss; schist; grandodiorite; quartz diorite.

Figure 7. Stratigraphic succession of the northern part of Bangladesh. (Source: M.A. Zaher and A. Rahman, 1980).

Offshore

The sedimentary sequence offshore down to a depth of 15,500 feet can broadly be divided into three major intervals: two well stratified successions, the upper 4,900 feet thick and the lower 3,300 to 3,600 feet thick, representing sedimentation in a low-energy environment, and an intermediate sequence 1,000 to 1,200 feet thick, characterized by crossbedded and channel deposits in a high-energy environment. The lowermost interval shows that the source of the sediments came from the east and moved westward, whereas the uppermost crossbedded zone indicates that the sediments were transported in a north to south direction.

The absence of good seismic reflections over a wide area precludes drawing conclusions about the actual lithology of the rock sequence. Even between wells which are only a few miles apart, the sand/shale distribution varies greatly. Based on paleontology, the older sediments in the offshore are Late Miocene.

ENERGY RESOURCE INDENTIFICATION

Petroleum

Most of the hydrocarbons in the world are found in association with geologic basins. Sediments that were deposited in these basins lithified into shale, sandstone and limestone. The juxtaposition of source rock (shale) and potential reservoir rock (sandstone) are of great interest for exploration of oil and gas. As a generalization, the stable or moderately mobile parts of the basin are generally favorable for localization of hydrocarbons. Such an area in Bangladesh would include the Hinge Zone, i.e., the area between the Bogra Slope of the Rangpur Saddle and the Bengal Basin. A hinge zone is a boundary between a stable region and a region undergoing upward or downward movement. Hinge zones are characterized as zones of transition between two geologic regions that are indicated by rapid increases in thickness of individual formations and abrupt changes in rock facies. The hinge zone reflects the transition of shallow-water shelf facies to deep-water facies.

Gas and condensate were generated in the Bengal Basin where the source rocks are marine and nonmarine, the temperature gradients are average or slightly lower, and the depth of burial exceeds 10,000 to 20,000 feet. Good reservoir and cap-rock-seal conditions developed in shallow marine deltaic environments of deposition during late Eocene through middle Miocene geologic time. Gas accumulated in early Neogene sandstone on anticlines in a broad zone of more-or-less north-south oriented compressional folds in eastern Bangladesh. Reservoir porosities range from 20 to 30 percent and gas saturation averages 75 percent. Although the environment of deposition of the sedimentary rocks is deltaic, the gas fields have not been fully delineated so it is not yet possible to define the areal extent of any producing reservoir.

History of exploration

Table 2 presents the significant events in the history of petroleum exploration in Bangladesh. Table 3 summarizes the past exploration activities detailed in Table 2. Table 4 summarizes data from the past well-drilling activities in Bangladesh. Figure 8 presents a summary of potentially productive structures identified by Petrobangla from results of geophysical work and drilling activities.

Table 2. Significant events in the history of petroleum exploration in Bangladesh (Source: Khan, 1980; oral communication from World Bank, United Nations, and oil companies)

1908:	Structures in the Chittagong area were mapped by Burmah Oil Company (B.O.C.)
1914:	One dry hole was drilled on the Sitakund structure by B.O.C., Indian Prospecting Petroleum Company subsequently drilled three more holes on the same structure.
1922-33:	B.O.C. and the Whitehall Petroleum Company mapped the Patharia structure in the Sylhet District and parts of Chittagong. Oil shows were reported.
1933-51:	Due to World War II and the partition of India, no drilling activity occurred during this time period.
1950:	Standard Vacuum Oil Company [S.V.O.C.] conducted the first seismic Survey in the northwest part of the country. The contractor was Geophysical Services, Inc. (G.S.I.)
1950-64:	Pakistan Petroleum Limited (P.P.L.) and Pakistan Shell Oil Company (P.S.O.C.) carried out reflection seismic surveys in selected areas of the northwestern and middle-eastern regions of Bangladesh.
1951-64	Pakistan Petroleum Limited (P.P.L.) drilled 13 wells at Patharia, Patiya, Sylhet, Lalmai, Chhatak and Fenchuganj.
1952-53:	A reconnaisance aeromagnetic survey was carried out over the whole of Bangladesh by S.V.O.C. and the Pakistan Oil and Gas Development Corporation.
1955-56:	Gravity surveys were conducted over the whole country by P.P.L. and P.S.O.C. G.S.I. was the geophysical contractor.
1955:	P.P.L. discovered gas in the Hazipur region. P.S.O.C. also discovered gas in the Chhatak region.
1957:	P.S.O.C. discovered commercial gas at Titas, Habiganj, Kailas Tila and Bakhrabad. P.P.L. also discovered commercial gas in the Sylhet No. 3 well and at Chhatak in 1959.
1959-60:	S.V.O.C. drilled one well each at Lalmai, Bogra and Hazipur: all the wells were dry.
1960-69:	P.S.O.C. drilled 11 wells, 10 onshore and one in the Bay of Bengal. All these wells resulted in gas discoveries except for the wells drilled at Lalmai and Cox's Bazar.

Table 2. (continued)

1961:	The Government of Pakistan created the Oil and Gas Development Corporation (O.G.D.C.) with Soviet Technical Assistance mapped structures in Sylbet, Chittagong and Chittagong Hills tracts.
1963-present:	O.G.D.C. (later Petrobangla) conducted seismic surveys in selected area of the districts of Rangpur, Dianjpur, Mymensingh, Tangail, Decca, Comilla, Sylhet, Noakhali, Basrisal, Chittagong, and Chittagong Hill Tracts. These survey's covered over 6069 line kilometers. In addition gravity surveys were made.
1964-1971:	O.G.D.C. (later Petrobanla) with the help of Soviet built drilling rigs drilled 3 exploratory, 4 appraised and 3 stratigraphic tests in the area of Jaldi, Semutang, and Chittagong Hill Tracts. Two of the wells drilled in the Semutang area were reported to be gas producers. Gas shows in the Jaldi No. 2 well were depleted after two months.
1974-present:	Upon Bangladesh's independence from Pakistan, O.G.D.C. was absorbed into Petrobangla. Since its creation, Petrobangla geologists have mapped an area in the aggregate of over 4,435 square kilometers on a 1-50,000 scale in the districts of Sylhet, Chittagong and Chittagong Hill Tracts.
1974-77:	Six companies entered into production sharing contracts for oil and gas exploration in the offshore area of Bangladesh. The six companies covered 31,979 line kilometers of Seismic Survey's. Ina-Nafftaplin (BIVA) and the Union Oil of California (UNION) drilled two wells each and one well was drilled by Atlantic Richfield; Bengal Oil Development Corporation (BODC) drilled one hole. The BODC no. 1 well reached a total depth of 15,081 feet. All wells drilled except the UNION Kutubdia No. 1 well were dry. The Kutubdia No. 1 well tested 17.9 MMCFD from a 30 foot interval between 8,760-8,730 feet through a 3/4 inch choke.
1976:	A total depth 15,521 feet was reached in the Hijla-Muladi No. 1 well drilled by Petrobangla. Gas shows were encountered at the following depths: 1) 15,429 - 15,327 feet 2) 15,190 - 15,137 feet 3) 15,042 - 14,973 feet 4) 14,839 - 14,786 feet 5) 14,622 - 14,585 feet 6) 11,952 - 11,920 feet

Table 2. (continued)

The first two bottom zones would not flow on production tests. The next interval had to be plugged back for technical reasons. And the last three upper intervals could not be tested because the drill pipe stuck.

1977: The German Geological Advisory Group and Petrobangla geologists conducted sedimentological studies between Chandraghon and Kaptai in Chittagong Hill Tracts.

In addition geological reconnaissance was made between Paktanala and close to the Indian border in the Chittagong Hills Tracts as well as in area near Cox's Bazar, Sitakund, and Sandwip.

The Federal Insitute of Geoscience in Germany has made Carbon-isotope (13 c/12C) analyses on gas samples from all producing onshore gas fields and from natural gas seep.

1978: The Begumganj; No. 2 well, located about 4.5 km northwest from the Begumganj No. 1 well, along the anticlinal axis reached a total depth of 11,734.5 feet. Intervals were tested at the following depths from bottom to top:

1) 13,057 to 11,244 feet
2) 11,093 to 11,067 feet
3) 10,325 to 10,299 feet
4) 9,945 to 9,925 feet
5) 9,469 to 9,440 feet
6) 9,233 to 9,207 feet

No gas flowed from any of these six tested intervals [2]

2. The fact that none of tested intervals flowed gas necessitates reinterpretation and correlation by well log analysis. An appraisal of the potential deeper reservoirs is critical for increasing the gas potential in Bangladesh.

1981: Petrobangla discovered gas reserves of as much as 1.5 trillion cubic feet at Beani Bazar and Noakhai in the eastern part of the country.

Notes:

1. The discovery dates listed above do not always correspond to those listed elsewhere in this report. The date depends on whether the discovery is considered as the date the discovery well was completed, the first production test was successful, or commercial production commenced.

2. Prior to Bangladesh's independence all the geological, geophysical and drilling reports including maps were filed at the central office of the Pakistan Oil and Gas Development Corporation in Karachi, West Pakistan. No documents were kept in the regional office at Chittagong, East Pakistan. Included were data accumulated by foreign companies such as B.O.C., P.P.L., S.V.O.C. and P.S.O.C. Only a few reports of P.P.L. and P.S.D.C. are now available in Bangladesh; all other exploration and drilling records prior to independence are not available.

3. The quality of the geophysical data is good. Regional gravity and magnetic maps have been compiled and the gravity is useful in delineating the compressional anticlines of the fold belt. New seismic reflection data collected by Prakla Seismos have revealed the deep section beneath the Eocene Sylhet limestone on the western shelf and southward across the hinge line. The newer seismic data are useful in mapping the folds of eastern Bangladesh but steep dips and complex faults tend to preclude obtaining good data on the crests of anticlines. Older seismic data are also useful in mapping structure but depth of penetration is limited. Thirty two thousand kilometers of modern reflection seismic data are available for offshore areas together, with 16,000 km of gravity and magnetic coverage (see table 3). However, only 7,000 km of offshore reflection data are available, although the entire country of Bangladesh has been covered by geophysical survey; most of the results were kept in Pakistan when the countries divided. These data are not now available to Petrobangla for reinterpretation. The same is true of well logs, production records, and geologic reports made before the creation of the new nation.

Table 3. <u>Summary of petroleum exploration in Bangladesh</u>
(Source: Khan, 1980)

TYPE OF ACTIVITY	1910-1946	1947-1970	1971-1980 (June)	REMARKS
A. No. of Wells Drilled				
i) On-shore	6	38	6	
ii) Off-shore	—	1	8	
B. AREA SURVEYED				
On-shore (By Petrobangla)				
i) Geological (Field Investigation)	—	6555 L/Km. (6674 Sq. km)	2545 L/Km	
ii) Geological (Aerial Photo-interpretation)	—	Only Photogeological maps of part of Chittagong and Chittagong Hill Tracts Tracts are available	6069 L/Km	1024 L/Km by Prakla-Seismos
iii) Seismic Survey	—	1020 L/Km. (7351 Sq km.)		
iv) Gravity Survey	—	1605 L/Km (32,450 sq. km)	25718 Sq. km	
v) Magnetic Survey	—	Whole of Bangladesh (only aeromagnetic maps are available).		
OFF-SHORE (BY CONTRACTORS)				
i) Seismic Survey		600 Sq.km	31979 L/Km.	
ii) Gravity Survey		—	16684 L/Km.	
iii) Magnetic Survey		—	16684 L/km.	

Table 4. Summary of wells drilled in Bangladesh.
(after Khan and Badruddoja, 1980)

Field name on fig. 8 and well no.	Company 1/	Completion date	Total depth feet (meters)	Formation 2/ surface	Formation 2/ total depth	Remarks
ONSHORE WELLS						
Sitakund-1	IPPC	1914	2,500 (762)	Upper	Middle	Gas show in Upper
Sitakund -2	"	1914	" "	Bhuban	Bhuban	and middle Bhuban
Sitakund -3	"	1914	" (762)			
Sitakund -4	BOC	1914	3,350 (1,021)			
Patharia-1	BOC	1933	2,871 (875)	Upper Bhuban	Middle Bhuban	Oil and Gas show in Middle Bhuban
Patharia-2	BOC	1933	3,436 (1,047)	Upper Bhuban	Middle Bhuban	Oil show in Middle Bhuban
Patharia-3	PPL	10.12.51	5,411 (1,649)	Upper Bhuban	Lower Bhuban	Gas show in Middle Bhuban
Patharia-4	PPL	23.2.53	2,723 (830)	Upper Bhuban	Middle Bhuban	Dry hole
Patiya-1	PPL	14.9.53	10,176 (310)	Middle Boka-Bil	Middle Bhuban	Dry hole
Sylhet-1	PPL	12.5.55	7,800 (2,377)	Dupi Tila	Upper Bhuban	Gas shows in Boka Bil. Blow out with fire
Sylhet-2	PPL	7.10.56	9,245 (2,818)	Dupi Tila	Upper Bhuban	Gas show in Boka Bil.
Sylhet-3	PPL	19.7.57	5,497 (1,675)	Dupi Tila	Boka Bil.	Gas producer Boka Bil.
Lalmai-1	PPL	11.2.58	9,813 (2,991)	Dupi	Middle	Dry hole
Lalmai-2	PPL/PSOC	27.10.60	13,506 (4,116)	Dupi Tila	Lower Bhuban	Dry hole
Chhatak-1	PPL	14.4.59	7,000 (2,134)	Dupi Tila	Upper Bhuban	Gas producer Boka Bil. and Upper Bhuban

Table 4. (continued)

Field name on fig. 8 and well no.	Company 1/	Completion date	Total depth feet (meters)	Formation 2/ surface	Formation 2/ total depth	Remarks
			ONSHORE WELLS			
Kuchma-1	SVOC	21. 6.59	9,433 (2,875)	Alluvium	Lower Gondwana	Dry hole. Coal seams encountered
Bogra-1	SVOC	5. 9.60	12,521 (3,816)	Alluvian	Pre Cambrian	Dry hole. Gas show in Upper Bhuban. Coal seams encountered
Fenchuganj-1	PPL	18. 4.60	8,000 (2,438)	Dupi Tila	Upper Bhuban	Gas shows in Boka Bil
Hazipur-1	SVOC	5. 9.60	12,521 (3,816)	Alluvium	Barail ?	Dry hole
Rashidpur-1	PSOC	20. 7.60	12,663 (3,859)	Dupi Tila	Upper Bhuban	Potential Gas: Boka Bil and Upper Bhuban.
Rashidpur-2	PSOC	23. 6.61	15,071 (4,593)	Dupi Tila	Middle Bhuban	Potential Gas: Boka Bil and Upper Bhuban.
Kailas Tila-1	PSOC	22. 3.62	13,577 (4,138)	Dupi Tila	Upper Bhuban	Potential Gas: Boka Bil. and Upper Bhuban
Titas-1	PSOC	23. 8.62	12,325 (3,756)	Alluvium	Middle Bhuban	Gas Producer: Boka Bil and Upper Bhuban
Titas-2	PSOC	6. 1.63	10,574 (3,233)	Alluvium	Upper Bhuban	Gas Producer: Boka Bil and Upper Bhuban
Titas-3	PSOC	28. 8.62	9,315 (2,839)	Alluvium	Upper Bhuban	Gas Producer: Boka Bil and Upper Bhuban
Titas-4	PSOC	14. 10.69	9,350 (2,850)	Alluvium	Upper Bhuban	Gas Producer: Boka Bil and Upper Bhuban
Sylhet-4	PPL	15. 4.62	7,035 (315)	Dupi Tila	Tipam	Abandoned
Habiganj-1	PSOC	11. 5.63	11,500 (3,505)	Dupi Tila	Upper Bhuban	Gas Producer: Boka Bil and Upper Bhuban
Habiganj-2	PSOC	Oct. 63	5,100 (1,554)	Dupi Tila	Boka Bil	Gas Producer: Boka Bil
Sylhet-5	PPL	22. 3.63	1,885 (575)	Dupi Tila	Tipam	Gas shows in Tipam
Sylhet-6	PPL	3. 7.64	4,616 (1,407)	Dupi Tila	Boka Bil	Gas Producer: Boka Bil
Jaldi-1	OGDC	16. 3.69	7,546 (2,300)	Tipam	Upper Bhuban	Dry hole. Abandoned

Table 4. (continued)

Field name on fig. 8 and well no.	Company 1/	Completion date	Total depth feet (meters)	Formation 2/ surface	total depth	Remarks
			ONSHORE WELLS			
Jaldi-2	OGDC	27.11.66	11,024 93,360)	Tipam	Middle Bhuban	Gas shows in Upper and Middle Bhuban
Jaldi-3	OGDC	25.05.70	14,765 (4,500)	Tipam	Lower Bhuban	Abandoned
Semutang-1	OGDC	22. 5.69	13,413 (4,088)	Tipam	Lower Bhuban	Gas Well:Boka Bil
Semutang-2	OGDC	5. 5.70	5,036 (1,535)	Tipam	Boka Bil	Gas Well: Boka Bil
Semutang-3	OGDC	11.10.70	5,092 (1,552)	Tipam	Boka Bil	Dry hole
Semutang-4	OGDC	21. 1.71	4,803 (1,464)	Tipam	Boka Bil	Dry hole
Bakhrabad-1	PSOC	6. 6.69	9,310 (2,838)	Alluvium	Upper Bhuban	Potential Gas: Boka Bill & Upper Bhubam
Hijla-Muladi-1	T S	16.12.76	15,525 (4,732)	Alluvium	Late Miocene	Dry hole
Begumganj-1	T S	27. 1.77	11,995 (3,656	Alluvium	Late Miocene	Gas well
Begumganj-2	E D	29. 8.78	11,738 (3,578)	Alluvium	Late Miocene	Preparation for retesting
Hijla-Muladi-2	Petro-bangla	23. 7.80	14,948 (4,556)	Alluvium	Late Miocene	Production Testing is going on
Singra	Petro-bangla					Suspended due to drilling accidents 6/81
Feni	Petro-bangla					Gas discovery
Beani Bazar	FRG-PB					Gas discovery
			OFF-SHORE WELLS			
Cox's Bazar-1	PSOC	16.12.69	12,134 (3,698)	Alluvium	Upper Bhuban	Abandoned
B O D C-1	BODC	10. 3.76	15,086 (4,598)	Alluvium	Lower Bhuban	Abandoned
B O D C-2	BODC	17. 6.76	14,551 (4,435)	Alluvium	Lower Bhuban	Abandoned
ARCO	ARCO	4. 2.76	12,804 (3,902)	Alluvium	Boka Bil	Abandoned
BINA-1	INA-NAFTALIN	31. 5.76	13,436 (4,095)	Alluvium	Boka Bil	Abandoned
UNION 76-1	UNION	18. 3.76	7,65 (2,33)	Alluvium		Abandoned

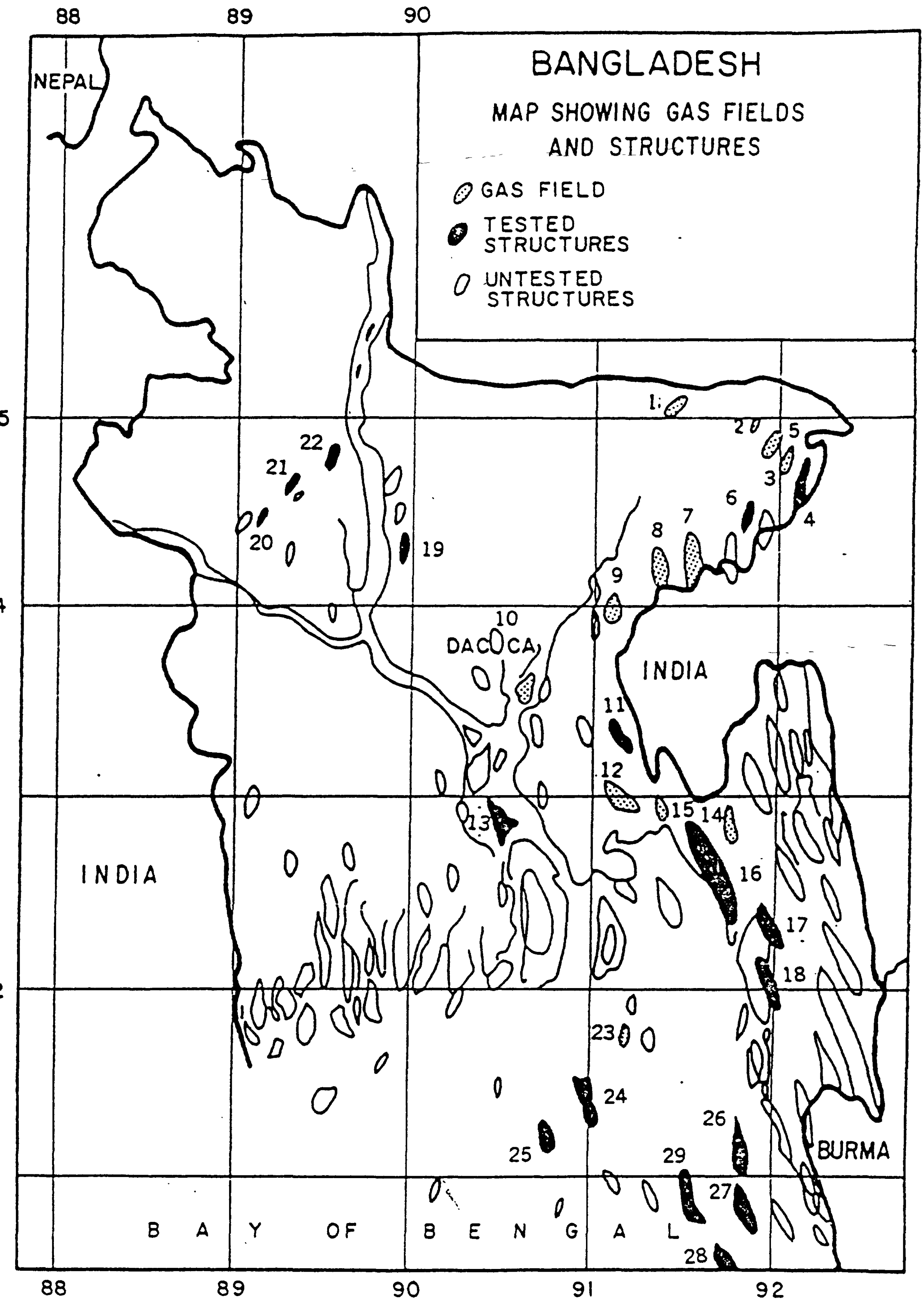
Table 4. (continued)

Field name on fig. 8 and well no.	Company 1/	Completion date	Total depth feet (meters)	Formation 2/ surface	Formation 2/ total depth	Remarks
Kutubdia-1	Union	28. 1.77	11,500 (3,505)	Alluvium	Middle Bhuban	Gas Well
BINA-2	INA-NAFTAPLIN	1. 3.76	14,089 (4,294)	Alluvium	Middle Bhuban	Dry hole
BODC-3	BODC	20. 3.78	14,784 (4,505)	Alluvium	Late Bhuban	Dry hole
			GEOLOGICAL INFORMATION BOREHOLES			
Sitakund core holes 1-25	BOC	1939	100-600	Upper Bhuban		Two major thrusts on the western flank
Sylhet GIB-1	PPL	1951		Dupi Tila		
Sylhet GIB-2	PPL	1952		Dupi Tila		
Jaldi GIB-1	OGDC	17. 3.65	4,429 (1,350)	Tipam	Boka Bil	Gas shows in Boka Bil
Jaldi GIB-2	OGDC	June 66	4,488 (1,368)	Tipam	Boka Bil	Gas shows in Boka Bil
Semutang GIB-1	OGDC	18. 9.68	1,109 (338)	Tipam	Boka Bil	Gas shows in Boka Bil Blow out

1/ Abbreviation:

IPPC	Indian Petroleum Prospecting Co.
BCC	Burmah Oil Co.
PPL	Pakistan Petroleum Ltd.
SVOC	Standard Vacuum Oil Co.
PSOC	Pakistan Shell Oil Co.
OGDC	Oil and Gas Development Corporation
TS-PB	Toila Sandhani
AMCO	Atlantic Richfield
BINA	Industrial Nafte
BODC	Bangal Oil Development Co.
ED	Exploration Division, Petrobangla
FRG-PB	West Germany-Petrobangla

2/ See figures 5 and 7 for stratigraphic sequence and correlations.



1. Chhatak
2. Sylhet
3. Beani Bazar
4. Patharia
5. Kailas Tila
6. Fenchuganj
7. Rashidpur
8. Habiganj
9. Titas
10. Bakhrabad
11. Lalmai
12. Begumganj
13. Hijla-Muladi
14. Semutang
15. Feni
16. Sitakund
17. Patiya
18. Jaldi
19. Hazipur
20. Singra
21. Kuchma
22. Bogra
23. Kutubdia
24. Union 76-1
25. ARCO A-1
26. Cox's Bazar
27. BODC-1
28. BODC-2
29. BINA

Figure 8. Potentially productive structures identified by Petrobangla include known gas fields, tested structures, and untested structures. Numbered names refer to structures mentioned in the text. (After Khan and Badruddoja, 1980).

Reserves and production

Natural gas.—The proved gas reserves of some individual fields are given in table 5. Undiscovered gas resources for Bangladesh are estimated in table 6. The data for both tables were compiled from Petroconsultants (1978), Tiratsoo (1979), and the World Bank (1980).

Table 5. Proved gas reserves of Bangladesh

Field	Year of discovery	No. of wells drilled	Cumulative Production by 1979	Ultimate recoverable gas (10^{12} cu ft)	Condensate Recovery
Bakhrabad	1963	1	Not producing	2.78-3.70	0.30
Kailas Tila	1961	1	Not producing	0.6-1.3	trace
Habiganj	1962	2	0.038	1.28	0.05
Titas	1962	4	0.167	2.25	1.70
Rashidpur	1960	1	Not producing	1.06	0.30
Sylhet	1955	6	0.078	0.29-0.43	3.7
Chhatak	1959	1	0.017	0.04-0.2	trace
Jaldi		1	Not producing	unknown	unknown
Hijla-Muladi		1	Not producing	unknown	unknown
Semutang	1966	1	Not producing	0.03	trace
Kutubdia	1977	1	Not producing	1.0	trace
Begumganj	1977	1	Not producing	unknown	unknown
Beani Bazar	1981	1	Not producing	1.5	unknown

Table 6. Undiscovered gas resources of Bangladesh

Onshore, non-associated gas	10 to 15 Tcf
Probability that statement is true	0.5
Offshore (down to 200 m. water depth)	2 to 5 Tcf
Probability that statement is true	0.5
Total undiscovered gas resources	10 to 20 Tcf
Probability that statement is true	0.55
Total recoverable gas reserves:	8.5 to 9.2 Tcf

The total recoverable natural gas reserves are estimated at somewhere between 8 and 10 trillion cubic feet (Tcf). However, as many of the gas fields have not been delineated, the true extent of many gas reservoirs and reserves is not precisely known. The gas is essentially methane, practically sulfurfree, and has a high caloric value. Currently this gas is used in fertilizer and power plants as well as in the industrial, commercial, and domestic sectors. Only four fields were on production in 1979: 1. Titas (110 MMCFD); 2. Sylhet (16 MMCFD); 3. Habiganj (14 MMCFD); Chhatak (5 MMCFD). A summary of the oil and gas production in Bangladesh for the past three years is:

Year	Gas MMCFD	Oil B/D	Percent Change from 1978 Gas	Percent Change from 1978 Oil
1977	87.570	138		
1979	99.010	138		
1979	145.000	159	146	17

Source: Petroleum Developments in Far East, Am. Assoc. of Petrol. Geol. Bull., v. 64, no. 11, 1980, p. 1896, 1889
Note: The 1979 gas production reported here (145 MMCFD X 365 52,925 MMCF) is higher than the 47.6 MMCF 1979 production. The 5 MMCF difference in gas production is difficult to explain. Petrobangla must be aware of this difference. This difference must be understood and resolved as 5 MMCf of gas is too large an amount not to be unaccounted for.

The best prospects for discovery of additional hydrocarbons are probably in the easternmost part of Bangladesh as the degree of folding diminishes markedly in a westerly direction. The Bengal Basin undoubtedly contains growth faults and stratigraphic traps. It is reasonable to conclude that more gas remains to be found than has already been discovered. The area adjacent to the Hinge Zone may have stratigraphic traps which includes reefs, favorable for the entrapment of hydrocarbons. The results of the Singra No. 1 well, drilled in 1979, can clarify the hydrocarbon possibilities in this area. The central and western part of the Bay of Bengal were not affected by compressional folding. The stratigraphic sequence from Oligocene to Holocene represents a deltaic environment of deposition which may range from subaerial delta plain to abyssal marine prodelta. Major uncertainties exist as to the nature and size of the structures and development and thickness of the reservoir sandstones in the central and western parts of the Bay of Bengal.

Natural gas fields.--The descriptive data for the following fields are summarized from Khan (1980). Locations of the fields are shown on figure 8.

The Chhatak gas field discovery well was drilled to 7,000 feet. The structure is an east-trending faulted asymmetrical antiline. Six sandstone reservoirs range in depth from 1,850 to 5,436 feet. The two main sandstone reservoirs are at depth of 3,973-4,202 feet in sandstone of the Miocene Boka Bil Formation. Whereas approximately 42.5 percent of calculated recoverable reserves have been produced since 1960, there has been no significant decline in reservoir pressure. The lack of pressure decline is probably due to an active water drive which is maintaining the reservoir pressure. The reservoir porosity ranges from 25 to 30 percent and gas saturation is in the order of 70 percent. Of the six wells drilled in this field, two have been abandoned, two are producing, and two are shut-in.

In the Sylhet field the two main gas-bearing sandstone reservoir zones are at depths of 3,973 to 4,202 feet and at 4,290 to 5,430 feet whereas the range in depth of the producing reservoirs is from 1,665 to 6,300 feet. These sandstone reservoirs are in the Miocene Boka Bil Formation and are from 165 to 200 feet thick. Sylhet field reservoir parameters include: an average porosity of 25 percent, gas saturation of 70 percent, and typical characteristics of a water drive gas reservoir.

The Kailas Tila Field discovery well was drilled to a total depth of 13,577 feet and has yet to be put on production. The three principal gas-bearing reservoir zones are at the following depths:

7,670 to 7,985 feet

9,665 to 9,745 feet

9,808 to 9,900 feet

The estimated aggregate net sandstone thickness is 412 feet, porosity ranges from 20 to 28 percent and gas saturation from 70 to 80 percent.

The discovery well for the Rashidpur field was drilled to a total depth of 15,071 feet. The well was plugged back to gas reservoirs at shallower depths at 4,030 and 9,030 feet respectively in sandstone reservoirs of the Boka Bil and Bhuban Formations. Currently this gas field is not on production. The two main gas-bearing zones have the following characteristics:

Depth (feet)	Net sand (feet)	Gas saturation (percent)	Porosity (percent)
4,551-4,795	213	55	20
8,878-9,060	214	70	25

The Rashidpur structure is a narrow asymmetrical north trending anticline that is about 25 miles long and 3 miles wide. The structure plunges to both the north and the south.

The Habiganj gas field discovery well was drilled to a total depth of 15,000 feet. This gas field, consisting of two wells, is currently producing from two sandstone reservoir zones that are in the upper part of the Boka Bil Formation and that have the following characteristics:

Depth (feet)	Porosity (percent)	Gas Saturation (percent)
4,590-6,600	19 to 33	65-75
9,887-9,970	19 to 33	65-75

The Habiganj anticline on which this gas field is situated is the northerly continuation of the 80-mile-long Barmura anticline in India.

The depth of the producing wells in the Titas gas field range from 9,350 to 12,325 feet. The structure of the Titas field is a dome. This field contains ten sand reservoirs with an aggregate net sandstone thickness of 426 feet. Porosity ranges between 17 and 24 percent and gas saturation is between 55 and 70 percent.

The Bakhrabad gas field discovery well reached a total depth of 9,310 feet and then was plugged back to a depth of 7,098 feet. This one-well oil field is not yet producing. The Bakhrabad anticline is symmetrical, about 40 miles long, more than 4 miles wide, trends north, and has four culminations (fig. 9). The four main gas-bearing zones are sandstones in the Miocene Boka Bil Formation, at the following depths:

1. 5,990 to 6,080 feet
2. 6,406 to 6,590 feet
3. 6,853 to 6,990 feet
4. 7,032 to 7,308 feet

These reservoir zones contain net 768 feet of sandstone. The average porosity is 22.6 percent, whereas the average water saturation is 35 percent. The Bakhrabad field is one of the most promising gas discoveries in Bangladesh to date.

The Semutang field discovery well was drilled to a total depth of 13,413 feet. Gas-bearing zones are at the following depths in two wells.

Semutang No. 1	Semutang No. 2
3,212-3,258 feet	4,196-4,268 feet
4,196-4,208 feet	4,544-4,626 feet

Three dry holes were drilled after the discovery well. The Semutang gas field is not producing. The Semutang structure is an elongate anticline

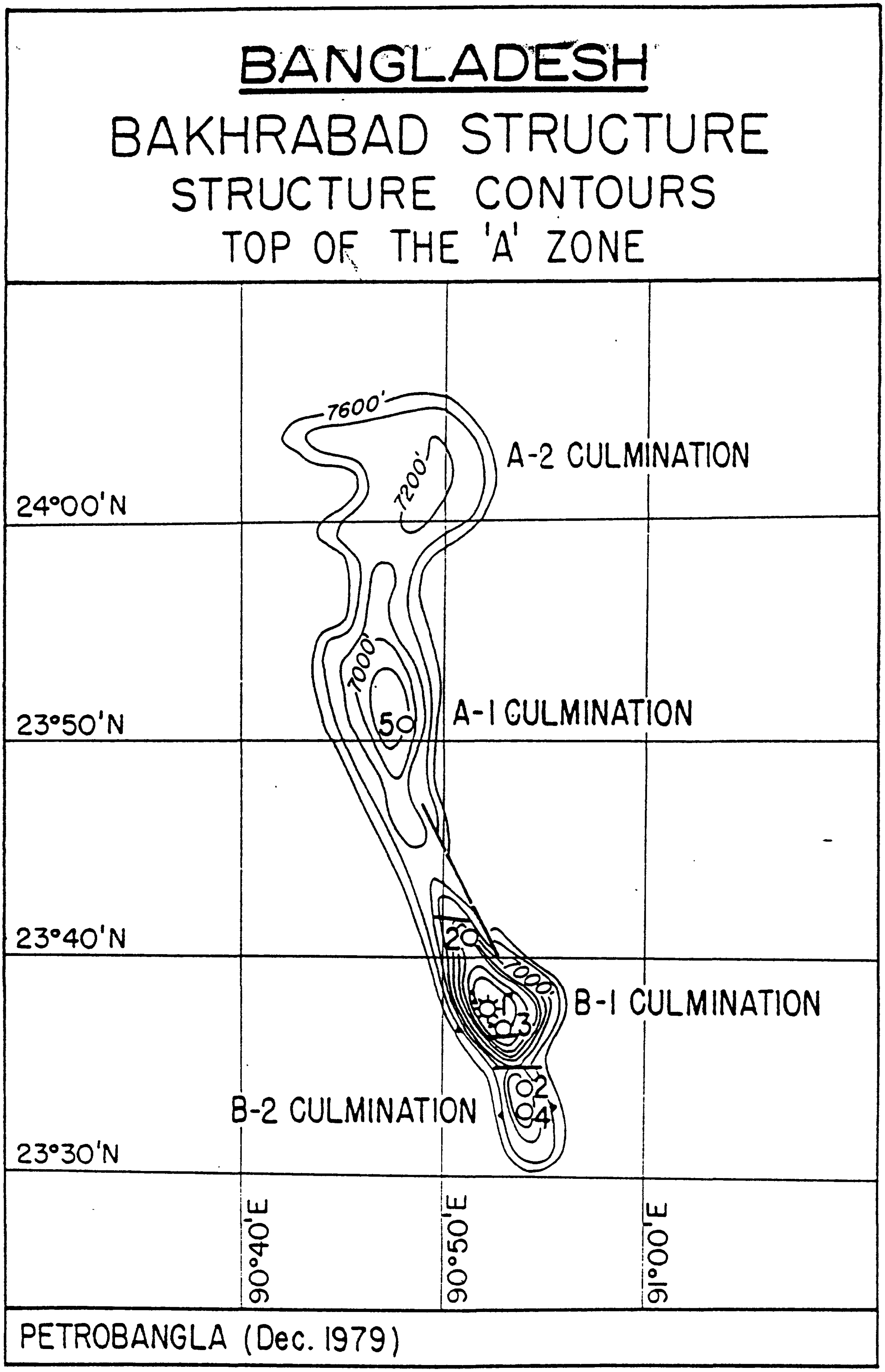


Figure 9. Bakhrabad structure as mapped by Petrobangla. (From Khan and Husain, 1980).

trending approximately north. Characteristics of the fine-grained, well-sorted feldspathic quartose sandstone reservoirs include:

Porosity (percent)	Permeability (millidarcies)	Water saturation (percent)
24-31	400-1,500	14-30

The Kutubdia offshore field discovery well was drilled to a total depth of 11,500 feet by Union Oil of California who relinguished this concession in 1978. This field is not producing. The gas (together with small amounts of condensate) is from upper Miocene-Pliocene siltstone having 17 percent porosity and a 35 percent water saturation at the 8,730 to 8,760 foot interval. Well log analysis suggests the possibility of two additional gas sands at depths of 9,573 to 9,638 feet and at depths of 10,457 to 10,488 feet. However, no tests were made to confirm the productivity of these zones. At the 8,730 to 8,760 foot interval the well tested 17.9 MMCFD. The preliminary estimated reserves for all sandstone reservoir zones in this field are almost one trillion cubic feet. The Kutubdia structure is a large culmination on a regional northwest trending anticline. The Kutubdia structure is well expressed at depth and is only slightly expressed in the shallow sedimentary rock sequence. Vertical closure on this structure is approximately 650 feet.

Recent developments.—A new gas field was discovered at Feni in Comilla District. The discovery well was drilled to a total depth of 10,500 feet (3,200 m) and took about 12 months to complete. Gas reserves are estimated as 1 Tcf of gas and five million barrels of condensate. Reserves of gas in the following 12 fields in Bangladesh are now estimated to total 12 Tcf:

Sylhet	Kailas Tila	Titas
Chhatak	Bakhrabad	Jaldi
Rashidpur	Semutang	Kutubdia
Habiganj	Begumganj	Feni

Coal

The two known occurrences of coal in Bangladesh are in the northern part of the country, and any future discoveries of potential economic interest will almost certainly be in the northern part of the country, because potential coal-bearing rocks are at great depths in the central and southern parts. The coal is in rocks of Tertiary and Permian ages. Cenozoic rocks that contain peat deposits are present in the central and northeastern parts of Bangladesh (fig. 10.) (Ahmed, 1980).

Potentially coal bearing rocks of Tertiary and Permain ages are probably present on the Dinajpur Slope and on the Rangpur Saddle but coal has not been reported in either area. Coal bearing rocks of Permian age are present in the northern part of the Bogra Slope; and potentially coal-bearing rocks of Tertiary age are present on the slope, but coal has not been reported in them. No coal has been reported in strata of the Hinge Zone.

In most of Bangladesh that is included in the Bengal Foredeep, coal bearing rocks are at depths far and beyond the presently economically recoverable limits, and coal, if present, has not been reported. However, in northeastern Bangladesh and adjacent India, the rocks of the Bengal Foredeep are much shallower; they crop out along the southern edge of the Shillong Massif in India (fig. 4), and coal-bearing rocks of Eocene age that crop out in India at a depth of less than 500 feet (152) in one area of Bangladesh adjoining the Indian border. Other coal of Tertiary age in northeastern Bangadesh has been reported but its occurrence is poorly documented (Geological Survey of Pakistan, 1953); the report suggests the presence of coal over a larger area than can now be demonstrated.

The oldest known coal-bearing rocks of Bangladesh are the Paharpur Formation of Late Permian age (fig. 7), which is composed of feldspathic

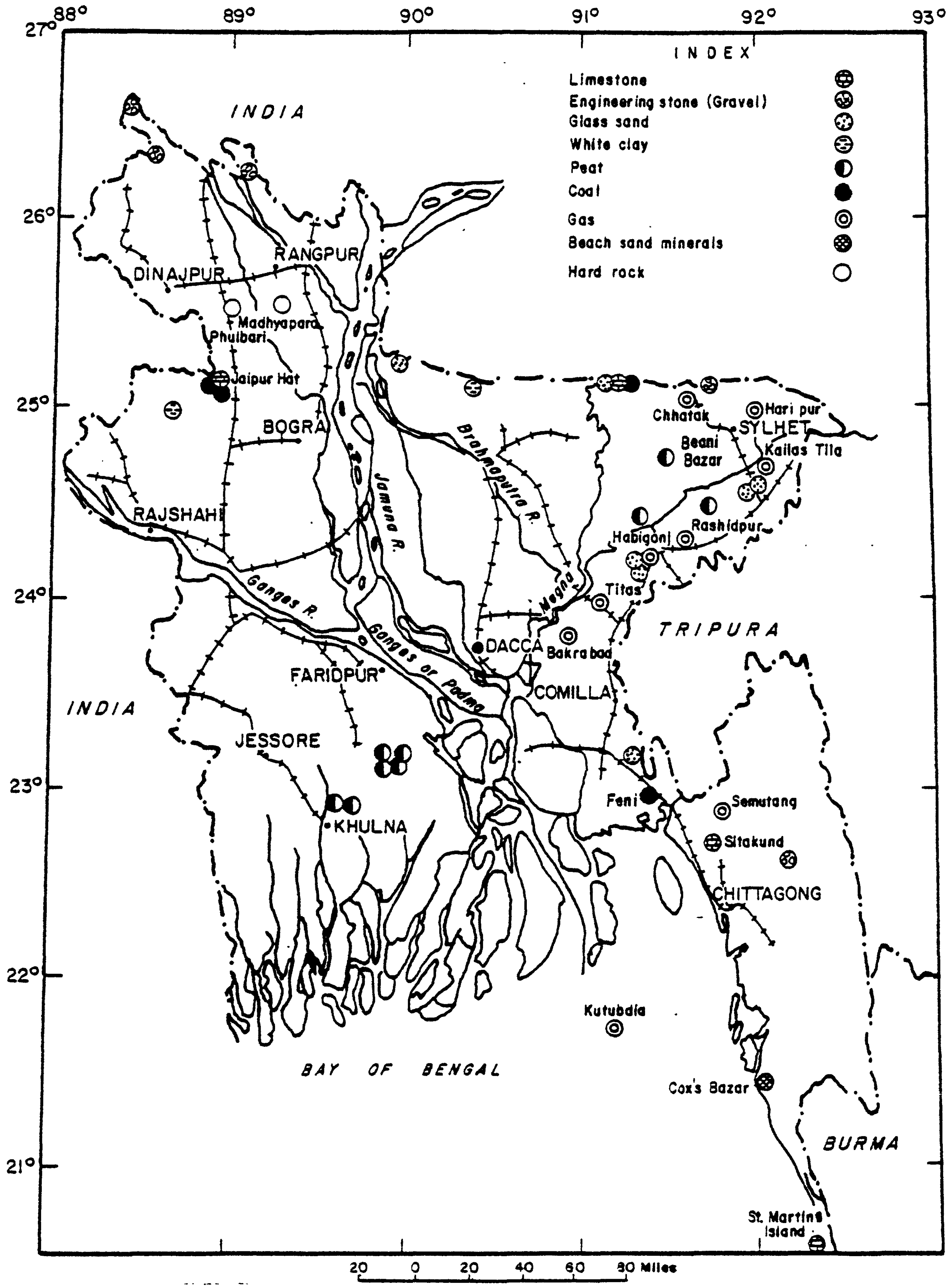


Figure 10. Mineral map of Bangladesh. (After Ahmed 1980).

sandstone, shale, and coal (Zaher and Rahman, 1980). The formation is more than 1,729 feet (527 m) thick in the Bogra Slope where it contains seven different coal beds that have an aggregate thickness of as much as 320 feet (98 m), and an individual bed thickness of as much as 154 feet (47 m) (Rahman and Zaher, 1980).

The Tura Formation of Paleocene (?) to middle Eocene age is coal bearing in northeastern Bangladesh (fig. 7). The Tura is more than 400 feet (122 m) thick in places (Zaher and Rahman, 1980) and is composed largely of sandstone, with lesser amounts of shale and coal in some areas.

Lignite and/or peat is reportedly present in rocks of Miocene, Pliocene, and Pleistocene age in several parts of Bangladesh (fig. 10), but information is incomplete.

Jamalganj area - Exploration and character

Northern Bangladesh has been known to contain coal of Permian age at depths in excess of 7,800 (2,375 m) since the sequence was penetrated in an oil and gas test well near the town of Bogra in 1959 (Rahman and Zaher, 1980). This discovery led to initiation of the United Nations - Pakistan (UN-PAK) Mineral Survey Project in 1961. The project's initial objective was to locate by geological and geophysical exploration, areas where the coal-bearing rocks were at minable depth.

Ten exploratory holes in the Jamalganj area in the northeastern part of the Rajshahi District and the adjoining part of the Bogra District established the presence of seven beds of high-volatile bituminous coal in the gently south dipping Paharpur Formation at depths of 2,200 to 3,800 feet (670 to 1,160 m). The coal-bearing rocks are part of the Gondwana Series which as yet have not been completely penetrated by drill holes in this part of Bangladesh. It is possible that more coal beds are present below those encountered to date.

Figure 11 shows the locations of some of the coal exploratory holes thickness of the seven coal beds penetrated by some of the drill holes (Rahman and Zaher, 1980). Whether the thickness shown represents coal alone, or coal plus interbedded noncoal material, cannot be determined from the available data.

Table 7. - Thickness of coal beds in drill holes in Jamalganj area (reported in feet and inches) 1/

Hole No.	Bed No. I	Bed No. II	Bed No. III	Bed No. IV	Bed No. V	Bed No. VI	Bed No. VII
5	5'	15'	64'6"	66'6"	7'9"	-	-
6	-	41'	14'	26'	17'	8'2"	10'6"
7	-	14'	67'	34'	45'	25'	49'6"
8	-	26'	68'	81'6"	69'	36'2"	-
9	-	17'	29'3"	15'	-	-	-
10	8'10"	8'5"	134'	17'2"	54'	20'	52'
11	-	10'6"	154'	29'6"	54'	20'	52'

1/ Conversion factors: meters = feet x 0.3048
millimeters= inches x 25.4

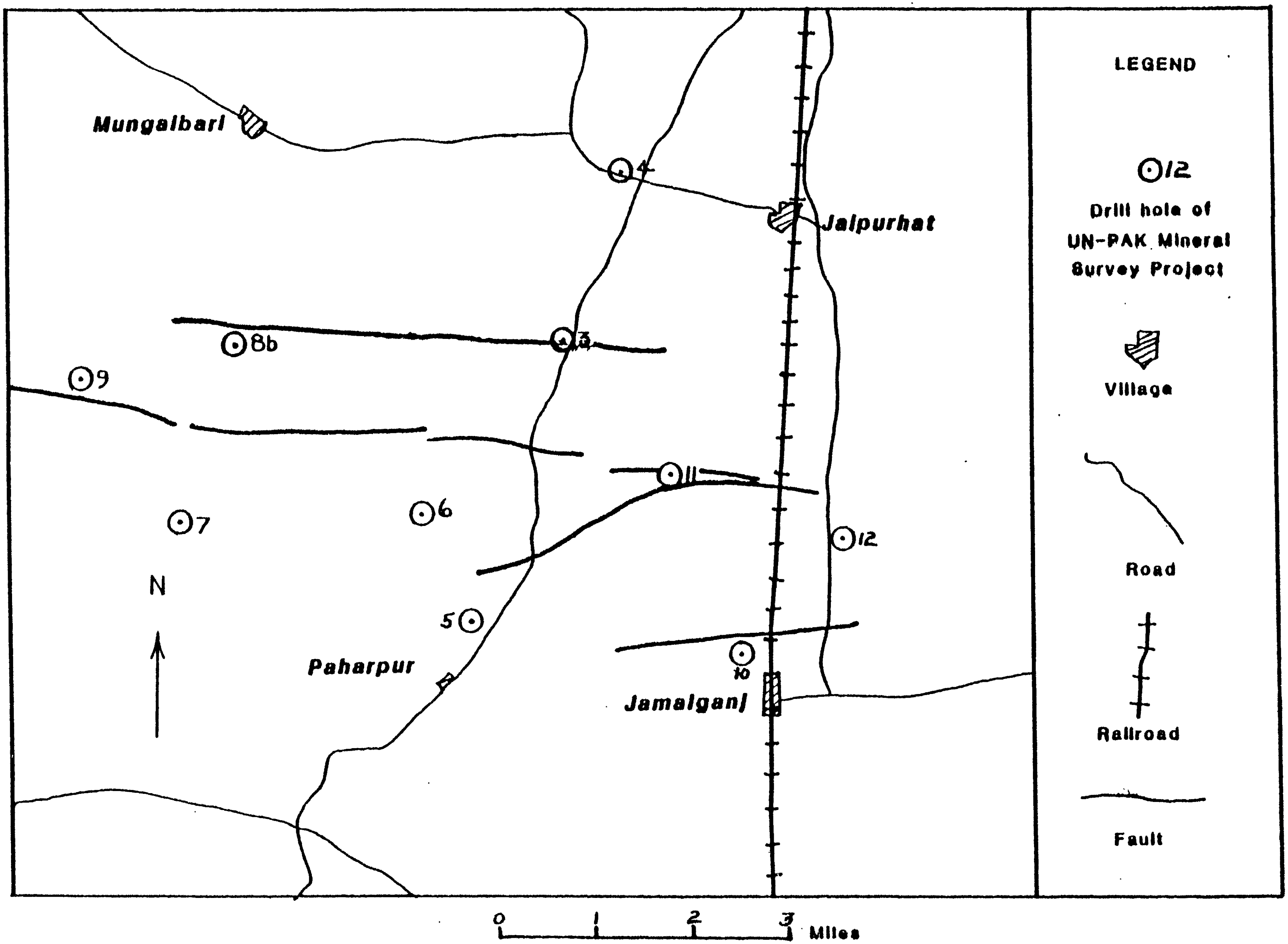


Figure 11. Jamalganj coal area (from: Rahman and Zaher, 1980).

Many analyses were made of samples from the holes shown on figure 11 (Rahman and Zaher, 1980). The coals appear to be largely of high-volatile C bituminous rank, with ash ranging from 10 to 60 percent and averaging perhaps 20 to 25 percent, and with sulfur content commonly less than 1 percent. Other tests indicate that some of the coal has very weak caking properties, so weak that they are probably not usable even in blends to make metallurgical coke. Washing tests indicate that a gravity separation at about 1.5 specific gravity would allow recovery of as much as 70 percent of the coal and reduce the ash content to about 13 percent (Fried Krupps Rohstoffe, 1964). All analyses and tests were conducted on drill-hole 1-hole core samples and are subject to uncertainties caused by small size of sample selection and handling problems. However, all tests to date indicate that the coal could be used as steam coal to generate electricity to bake bricks, and for other industrial purposes.

As shown on figure 11, a group of subparallel faults extends east across the Jamalganj coal area. The fault that passes near drill holes 3 and 8b is assumed to be the northern limit of coal-bearing rocks in the area. The effect of the remaining faults on the distribution of coal-bearing rocks in the area is very poorly understood. Obviously, a detailed understanding of the faulting pattern is necessary for evaluation of the quantity of coal in the area and its minability.

The coal beds in the Jamalganj area range in inclination from nearly flat to as much as 15°, with a possible average of between 2° and 5°.

Lamakata-Bhangarghat area.--this area is named for two villages about 2 miles apart between which drill holes encountered coal in two beds, 5.5 and 3 feet (1.7 and 1 m) thick, at depths between 400 to 430 feet (120-130 m) (Khan, 1963). The coal beds are in the Eocene Tura Formation, which crops out north of the Bangladesh-India boundary. The coal beds dip south 45° to 50° beneath the younger rocks of Bangladesh. The sparse available information, both descriptive and analytical, is sparse; however, that which is available suggests that most of the coal is lignite or subbituminous. Table 8 shows the results of seven analyses of the two coal beds (Khan, 1963).

Table 8. Proximate analyses of core samples of coal in the Lamakata-Bhangarghat area (from Khan, 1963).
(percent)

Bed		Moisture	Volatile matter	Fixed carbon	Ash	Sulfur
Top bed	1	0.62	39.44	26.88	33.06	1.30
	2	1.16	44.42	15.10	39.32	—
	3	0.56	45.58	24.16	29.70	—
Bottom bed	1	1.48	32.64	46.92	18.96	—
	2	0.80	44.42	17.06	37.72	—

Other areas.--Practically no information is available about other Cenozoic coals in eastern and northeastern Bangladesh. However, a table of analyses of coal samples collected from what appears to be 15 different localities (table 9) indicates that coal is present at other places in Bangladesh besides the Jamalganj and Lamakata-Bhangarghat areas (Geological Survey of Pakistan, 1953).

Analyses presented (table 9) indicates that the samples have high ash and low sulfur content but information is inadequate to indicate rank because heat-value determinations were not reported and because the moisture content seems deficient if, as assumed, the coal is lower rank. For comparison, 62 samples from 10 lignite mines in North Dakota and Montana have an average of 35 percent moisture, and 30 percent fixed carbon, as-received; whereas the 29 analyses shown in table 9 show an average of 13 percent moisture and 22 percent fixed carbon.

Table 9. Analyses of Cenozoic age coals

Source: Geological Survey of Pakistan, 1953

Locality	Moisture %	Ash %	Volat. mat. %	Total sulphur %	Fixed carbon %
Sylhet	17.42	17.82	43.24	0.69	21.54
Kadirpur	15.40	16.27	48.30	0.57	19.87
Salla	16.80	12.34	49.05	1.02	21.24
Madhabpur	13.39	9.28	51.49	1.57	24.24
Sunamgan	15.24	11.08	50.11	1.39	22.57
Modhumalaghat	10.76	21.08	32.02	0.18	33.14
Chahndhanaghat	12.47	28.86	36.81	1.80	21.86
Manikpur	13.80	23.96	34.14	0.33	28.10
Modhumalaghat (topmost layer) ..	11.26	25.60	37.24	1.08	24.86
Panchgaon	14.86	21.68	40.50	0.44	22.96
Baruathan	10.86	40.40	27.08	2.30	20.60
Sialuri	11.36	33.50	33.12	-	22.68
Panchgaon	11.34	30.50	35.92	0.32	22.24
Average	13.5	22.7	40.0	1.0	23.5

Locality	Specific gravity	Moisture %	Ash Color	Ash %	Volat. mat. %	Total sulphur %	Fixed carbon %
Shejamara							
Top most layer	1.43	8.32	Dirty yellow	43.40	30.45	.42	17.77
8 ft. from top	1.32	8.06	" "	40.20	32.95	.20	18.79
10 ft. " "	1.40	9.10	" "	31.20	38.90	.33	20.80
20 ft. " "	1.01	10.10	" "	30.82	33.87	.21	25.21
Chak Bajendrapur							
Top most layer (black clay)	1.68	7.22	" "	70.92	15.38	.14	6.48
5 ft. from top	1.41	13.28	Dirty orange	42.56	29.81	.21	14.35
10 ft. " "	1.48	15.02	" "	42.60	26.14	.17	16.24
12 ft. " "	1.32	10.01	" "	40.22	28.38	.19	21.40
Average	1.38	10.1	" "	42.7	29.5	.23	17.6

MUKUNDAPUR, TIPPERA DISTRICT	Moisture %	Ash %	Volat. mat. %	Fixed carbon %	Total sulphur %
(a) Selected samples					
Muk (3)	18.80	15.50	39.20	26.50	0.28
Muk (5)	16.10	17.56	40.64	25.70	0.28
Muk (7)	15.30	17.34	41.40	25.96	0.28
Muk (9)	14.44	20.40	39.26	25.90	0.28
(b) Average samples					
Muk (3)	15.10	21.24	39.10	24.56	0.28
Muk (5)	15.34	19.10	40.00	25.54	0.28
Muk (7)	14.16	22.30	38.84	24.67	0.28
Muk (9)	13.30	27.14	36.66	22.90	0.28
Average	15.3	20.1	39.4	25.2	0.28

(Swanson and others, 1974). Perhaps the Bangladesh samples dried out before they were analyzed.

Peat can form a significant part of the energy budget of various countries. It is used for generating electricity and heat for industrial purposes. Peat is present in several places in Bangladesh (fig. 10), and as the future energy needs of the country increase peat could become an energy source of local importance.

Resources and reserves

The U.S. Geological Survey and U.S. Bureau of Mines define resources as "A concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible." Identified resources are defined as "Resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence." Reserve base is "That part of an identified resource that meets specified minimum physical and chemical criteria related to current mining and production practices, including those for grade, quality, thickness, and depth." Reserves are "That part of the reserve base which could be economically extracted or produced at the time of determination." (USMB and USGS, 1980)

Several estimates of the quantity of coal in the Jamalganj area have been made. All have used different definitions, methods, procedures, and parameters and have derived considerably different noncomparable "reserve" estimates. In some cases the estimates include six coal beds (Bed 1 is excluded) and others concentrate on one bed. Fried Krupps Rohstoffe (1966) estimated 1,053,900,000 t of "proven" reserves in six beds in a 4.5 square mile (12 km^2) area bounded by five (5,6,10,11,12) of the UN-PAK drill holes. M/S Wahiduddin Ahmed and Zaher (1965) estimated that there were 760 million t in an area of 16 square miles (41 km^2). They also reported an estimate by

Savornin of the UN-PAk Mineral Survey Project in which he divided the area into three blocks, each bounded by three drill holes (9 and 12 excluded), and estimated "indicated" reserves of 716 million metric tons and "inferred" reserves of 847 million metric tons. Robertson Research International (1976) estimated "indicated" reserves of 58.35 million long tons in an area of 2.63 square miles and "assumed" reserves of 30.92 million long tons in an area of 8.08 square miles. The Robertson estimate was for Bed 3 and a combination of Beds 3 and 4. For comparison, an estimate of the identified resources of Bed 2 in the area was made by the author using the thicknesses reported in Table 7 and considering hole 12 as zero. The estimate followed procedures and methods standardized by the U.S. Geological Survey and Bureau of Mines. Demonstrated resources (all coal within 3/4 mile of an information point and all with a bed thickness of more than 3.5 feet) totalled about 225,300,000 t in an area of 12 square miles (31 km^2); inferred resources (no coal more than 3 miles from an information point, and contained in beds thicker than 3.5 feet) totalled about 328,400,000 t in an area of 25 square miles (6.5 km^2). The total identified resources in the 37-square mile (96 km^2) area are thus estimated to be about 553,700,000 t.

Powell Duffryn Technical Services, Ltd., (1969) apparently did not derive an independent estimate but summed up earlier estimates with the statement that "the very conservative conclusion may be fairly drawn, however, that the reserves are large and that they could be ample for a rate of extraction of 3 million tons/annum for over 30 years, even if the percentage of extraction were as low as 10 percent of the coal in sight." The very conservative estimate of Robertson Research International (1976) indicated that as much as 71 million long tons of coal was recoverable from Bed 3 in an area of less than 11 square miles.

With the at-hand information, no estimate of "reserve base" or "reserves" is possible. Though various investigators have derived a wide range of resource and reserve estimates, all seem to agree that the total resource potential of the Jamalganj area is very large.

On the basis of the small amount of data available from the Lamakata-Bhangarghat area an estimate of 3 million metric tons of coal in all reserve categories has been made (Khan, 1963). It was assumed that the beds continue for 1,000 feet (305 m) down the dip. Further drilling is needed to evaluate the coal potential of this area.

Geothermal

An active gas seep that is accompanied by a discharge of warm water in southeastern Bangladesh near Sitakund (fig. 10) is reported by Muminullah (1978). Other than this one report, no reference to geothermal energy sources in Bangladesh could be identified. Field and laboratory research beyond the scope of this report is needed to evaluate Bangladesh's geothermal energy resource potential.

EXPLORATION AND PRODUCTION PLANNING

Geophysical and drilling

Prospective planning for the oil and gas sector in the 1979-1985 Bangladesh national plan includes the geophysical and drilling activities shown in Table 10. The apparent technical assistance being received by the Government of Bangladesh is shown in Table 11. In addition, a Japanese oil company signed a contract in March 1981 with Petrobangla for the drilling of four new wells and the workover of an existing well at the Bakhrabad Gas Field. On May 14, 1981 the government of Bangladesh signed a production sharing exploration agreement with Shell Petroleum Development Company of the Netherlands. The

Table 10. Proposed Program for second five-year Plan oil and gas sector 1979-1985 (Source: World Bank, 1980)

(A) Survey

(i)	Geological:	Length	- 1,250 km
		Area	- 2,000 sq. km
(ii)	Gravity:	Length	- 6,000 km
		Area	- 17,500 sq. km of Semi-detailed or 7,500 sq. km of detailed.
(iii)	Seismic (Multifold):		
	Length of Profile (Reflection)		- 1,250 km. Regional
			- 2,750 km. Detailed
	Area (Detailed)		- 6,000 sq. km

Length of Profile (Refraction) - 4,375 km.

(iv) Vertical Seismic Profiles - 23 wells.

(B) Exploratory Wells - 20 wells.

(C) Production & Development of Gas Fields:

(i) Development Wells:

Field	No. of Wells
Titas	3
Habiganj	2
Chhatak	1
Kailas Tila	1
Bakhrabad (1st phase)	5
Titas/Bakhrabad (2nd phase)	3
Total	15

(ii) Natural Gas Liquids Processing Plant: 64,000 MT/yr. capacity

(D) Construction of Gas Lines

(a) Bakhrabad - Chittagong (24") - 110 miles.
(b) Parallel line from Titas to Ghorasal or a new line from Bakhrabad to Demra (14" & 16") - 30/40 miles.
(c) Ashunganj to East Bank of Jamuna via Kishorgonj, Mymensingh and Jamalpur (12") - 40 miles.
(d) Construction of Gas Lines

Table 11. Apparent technical assistance to Bangladesh for oil and gas development

A. The United Nations currently (1981) has a petroleum assistance team in Bangladesh.

B. The World Bank is providing financial assistance for the development of known gas fields.

C. The Asian Development Bank made a feasability study wherein they concluded that Bangladesh will need to spend $1 billion over the next decade to expand its power and gas production and to streamline the distribution system to meet its energy requirements by 2000 A.D.

D. The U.S.S.R. has intermittently provided petroleum technical assistance and drilling rigs.

E. Kuwait has made a $2 million loan for the purchase of the equipment.

F. Rumania has sold Bangladesh 2 drilling rigs on favorable terms.

G. West Germany has provided considerable technical assistance.

H. Sun Oil (Sunmark) has had 4-6 technical advisors in the country for the past eight years.

agreement covers a 5,178 square mile area in the Chittagong hill tracts. It provides 8 years for exploration, 2 years for development and 15 years of production. During the exploration period, Shell is committed to about $100 million expenditures with a minimum of three wells to be drilled during the first four years and six wells the following four years. Shell is planning to start seismic exploration October 1981 and would commence its first drilling operation before the end of June 1983.

Implementation

All implementation responsibilities in the oil and gas exploration and production sector are delegated to the Bangladesh government entity, Petrobangla. Table 12 lists and describes the current international agreements and negotiations of Petrobangla.

OBSERVATIONS

Potential for oil finds

Some authors (for example: Raju, 1968; Grunau and Gruner, 1978) conclude that the gas resources in Bangladesh were generated in an "overcooked, maturation environment". If so, then the prospects for significant future oil finds in Bangladesh are materially reduced. The generally accepted view that the source rocks in Bangladesh were terrestrial in origin reinforces the observation of minimal prospects for oil finds.

Current natural gas reserve estimate

Proved reserves of natural gas in Bangladesh have been reported as 8.5 to 9.2 trillion cubic feet (Tcf) but, these are reserves which have not been proven in the conventional sense. As none of the gas fields in Bandgladesh have been arealy defined (i.e. sufficient wells have not yet been drilled to define the areal limits of each field), the "proven" gas reserves have not yet been

Table 12. International agreements and negotiations of Petrobangla.

(1) The World Bank has provided a $85 million interest-free loan for workover of Bakhrabad Field and construction of a pipeline from that field to the coast at Chittagong. The Organization of Petroleum Exporting Countries has provided an additional $21 million interest-free loan for use on this project. Japex, a Japanese firm, has an initial $5 million contract to work over Bakhrabad-1 well and drill additional wells at that location. PLT of Houston is reportedly getting an $140 million contract to build the pipeline.

(2) The Asian Development Bank has loaned $46 million for development and workover of Titas and Sylhet Fields. British Petroleum under a technical assistance contract from British Overseas Aid is involved in the drilling at Titas. The Asian Development Bank has also granted a $6 million loan for the purpose of upgrading the Bangladesh Geological Survey. Of this loan, $780 thousand is earmarked for consultancies. The USGS is being considered as a source of consultants.

(3) The Federal Republic of Germany has provided a $50 million loan for drilling for exploration wells over a 2.5 year period. A team of six German government scientists oversees this operation. The team includes geologists, a geophysicist, a paleontologist and a geochemist. The Germans subcontract to private industry for geophysical data collection and drilling. Prakla-Seismos has conducted reflection seismic surveys for this project. Sunmark, a division of Sun Oil, manages the drilling operation and, in turn, hired Parker Drilling of Dallas to provide the drill crew. Logging and testing is done by Schlumberger. The first well drilled on this project at Beani Bazar in northeast Bangladesh was a new gas discovery.

(4) The United Nations Development Program is considering funding a Petroleum Institute.

(5) Royal Dutch Shell is embarked on a $120 x 10^6 exploration program in the Chittagong hills region of southeastern Bangladesh.

(6) USAID has a program underway offering scholarships that will lead to degrees at U.S. universities to provide technical training for Petrobangla scientists. Another USAID program will establish a Center for Policy Analysis at a cost of $280 thousand over three years. Analysis of exploration and production policies will be one of six studies undertaken at the center. Dr. Monirul Haque, Professor of Geology at Dacca University, will direct this analysis. Dr. Haque received his training at the University of Saskatchewan, Canada. Almost all of Petrobangla's geologic staff are Dr. Haque's former students.

(7) Russian and Romanian scientists have been assisting Petrobangla longer than anyone else. Russian scientists work alongside Petrobangla personnel in the various Petrobangla offices. Russian and Romanian equipment, ranging from drilling rigs through seismic systems to production testing equipment for determination of porosity and permeability, have been provided Petrobangla. While this equipment has undoubtedly been appreciated, it is inferior to that used by U.S. and Western European private industry. At Singra-1 well where a Romanian rig was used, drilling was suspended for at least the first 6 months of 1981 due to repeated drilling accidents.

(8) China is reportedly undertaking installation of a $120 million petrochemical facility in Dacca.

(9) India is reportedly purchasing a trillion cubic feet (10^{12}) of gas and will pay for construction of a 200-mile-long pipeline across western Bangladesh to be used to deliver the gas to India.

(10) The Jiddah-based Islamic Development Agency is lending Bangladesh $20 x 10^6 to finance oil imports from Saudi Arabia.

established with reasonable certainty. When these gas fields have been adequately drilled, the ultimately "proven" natural gas reserves could be established at less than the figure reported. For example:

1) The areal extent of the gas reservoir may be found less than previously assumed.

2) The sandstone reservoir properties, such as thickness, porosity, and permeability may not extend uniformly throughout the reservoir as indicated by the discovery well measurements.

3) Unforeseen geologic structures, such as faulting, may limit reservoir boundaries.

Potential natural gas resource

Bangladesh's undiscovered natural gas resource may be as large as 10-15 Tcf. A number of specific reasons support this observation.

1) Promising geological structures, perhaps 15-30 in number, have not yet been drilled.

2) The "hinge line" is one of the promising structures deserving priority attention.

3) The single offshore discovery (Kutubdia) promises other offshore discoveries in the Bay of Bengal. The potential for such discovery is greater eastward than westward where the sandstones gradually convert to shales.

Role of natural gas

Bangladesh's total potential gas resource of 20-25 Tcf can support an annual production of 2 - 2.5 Tcf. Such a level of production can permit the simultaneous export of natural gas through liquification or petrochemicals and domestic consumption by technologically feasible substitution for imported petroleum and coal.

Production constraints

A number of constraints can affect the optimization of the role of natural gas in the energy sector of Bangladesh.

1) The development of natural gas exports requires the inland transport of gas from the main production areas. For example, potential location for an export terminal is at Chittagong which is 180 miles from the producing areas. Such a difficulty would not apply to an offshore discovery nor to an onshore discovery such as in the areas of the still unevaluated coastal Jaldi field.

2) The national gas production suffers from inefficiencies arising from shortages in equipment and manpower. Petrobangla has been unable to obtain ready capital for modern equipment and necessary repairs. Manpower utilization could be improved by changes in management practices, better coordination among relevant government agencies, and the introduction of incentives to retain experienced staff.

3) The country could improve its gas production capability by a program of systemizing its geological data base to determine its national priorities in terms of promulgating policy for attracting needed capital.

Geological inputs for optimizing Bangladesh's indigeneous energy supply

Gas development options

Maximizing production from known gas fields versus exploring to discover new hydrocarbon fields, or any combination of these two options involves the allocation of available capital and human resources. The determination of such an allocation is a matter for consideration in broader gage national energy planning.

Coal development

Decision making regarding the further development of Bangladesh's known coal resource requires better delineation of the reserves so far identified in terms of a more precise knowledge of the geological environment defining the coal. The result would provide a better knowledge of the prospective mining techniques, the coal quality to be extracted, and the attractiveness of alternating capital and human resources to coal in lieu of gas.

Effectivness of available human resources

The skills and capabilities of human resources usually cannot be developed at a rate sufficiently rapid to meet the demand for these resources generated by exploration and development activities. The situation in Bangladesh is typical. Obviously, relief is available, given efforts to increase the skills and productivity of the professional staff of existing institutions engaged in the exploration and development activities.

Skills

Two simultaneous approaches toward increasing the skills of the professional staff may be considered. These are: (a) the conducting of structured workshop seminars in-country for selected geological topics relevant to the nation's exploration and development activities, and (b) providing the services of experienced professional advisors to work with selected professional staff on a daily basis.

Productivity

The areas to concentrate on to increase the productivity of the professional personnel are the facilitation of communication amoung the different exploration disciplines and improved access to data and techniques needed to discharge professional responsibilities.

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APPENDIX A

GLOSSARY OF TERMS USED IN THE REPORT

The following are definitions of terms used in this report. The definitions themselves are taken from Glossary of Geology, American Geological Institute, 1972.

abyssal: pertaining to the ocean environment or depth zone of 500 fathoms or deeper.

aeromagnetic: An applied geophysical means for mapping local spatial variations in total intensity or vertical intensity of the magnetic field. These measurements are interpreted as to the depth, size, shape and magnetization of geologic features.

Alpine: A geologic time period for mountain forming events that occurred in southern Europe and Asia. This mountain period of time is restricted to Tertiary geologic time period which included the time span between 65 and three to two million years ago. The intensity of these mountain forming events varied from place to place.

anticline: A fold, the core of which contains stratigraphically older rocks.

Aquitard: The lowermost time stage of the Miocene geologic time period.

basement: A complex of undifferentiated rocks that underlie the oldest identifiable rocks in the area. In many places the basement of the rocks are igneous and metamorphic and of Precambrian age, but in some places they are Paleozoic, Mesozoic or even Cenozoic.

basin: A general term for a depressed sediment-filled area.

biomass: Predominately animal dung as used in this report

cap rock: A impervious hard rock layer which overlies the top of pervious rock that may have reservoir potential.

carbonaceous: Rock or sediment that is rich in carbon, coaly.

conglomerate: A coarse-grained, classic sedimentary rock composed of rounded (to subangular) fragments larger than 2 mm in diameter set in a fine-grained matrix of sand silt, or any of the common cementing materials.

Cretaceous: A geologic time period that covered a span of time between 136 and 65 million years ago.

crossbedding: An internal arrangement of the layers in a stratified rock, characterized by minor beds or laminae inclined more or less regularly in straight sloping lines or concave forms at various angles to the original depositional surface or principal bedding plane.

deformation: A general term for the process of folding, faulting, shearing, compression, or extension of the rocks as a result of various Earth forces.

delta: The low, nearly flat, alluvial tract of land deposited at or near the mouth of a river prodelta: The part of a delta that is below the effective depth of wave erosion, lying beyond the delta front, and sloping gently down to the floor of the basin into which the delta is advancing and where clastic river sediments cease to be a significant part of the basin-floor deposits; it is entirely below the water level.

dip: The angle that a structured surface, e.g. a bedding or fault plane, makes with the horizontal measured perpendicular to the strike of the structure.

energy index: The inferred degree of water agitation in the sedimentary environment of deposition.

high energy environment: An aquous sedimentary environment characterized by a high energy level and by turbulent action (such as that created by waves, currents or surf) that prevents the settling and accumulation of fine-grained sediment.

low energy environment: Characterized by standing water or a general lack of current action, therby permitting very fine-grained sediment to settle and accumulate; e.g. a coastal lagoon or an alluvial swamp, containing shale.

Eocene: An epoch of the Tertiary time period, after the Paleocene and before the Oligocene.

facies: A term whose basic and original meaning signifies an aspect, appearance, or expression of something having two or more groups of attributes in different portions; e.g. such as overall appearance, composition, or conditions of formation of one part of a rock as contrasted with another or several other parts of the same rock, and the changes that may occur in these attributes over a geographic area.

The term facies has no significance except when it is used to contrast one or more other related facies and therefore implies variation, comparison, and differentiation, and also a certain degree of constancy and continuity with whatever rock mass is being compared or distinguished from others.

fault: A surface or zone of rock fracture along which there has been displacement, from a few centimeters to a few kilometers in scale.

foredeep: A elongate depression bordering an island arc or other orogenic belt. Cf: trench.

foreland: A stable area marginal to a mountain building belt, toward which the rocks of the belt were thrust and overturned. Generally the foreland is a continental part of the crust.

formation: The basic or fundamental rocks unit in the local classification of rocks consisting usually of sedimentary stratum or strata generally characterized by some degree of lithologic features such as chemical composition, structures, textures, or gross aspects of fossils.

geanticline: A mobile upwarping of the crust of the Earth, of regional extent. More specifically, an anticlinal structure that develops in geosynclinal sediments due to lateral compression.

geomorphic: Pertaining to the form of the earth or of its surface features.

geosyncline: A mobile downwarping of the crust of the Earth, either elongate or basin-like, measured in scores of kilometers or miles which is subsiding as sedimentary and volcanic rocks acumulative in thickness of thousands of feet or meters.

group: A major rock-straigraphic unit next higher in rank than "formation," consisting wholly of two or more (commonly two to five) contiguous or associated formations having significant lithologic features in common.

hinge line or zone: A line or boundary between a stable region and a region undergoing upward or downward movement.

Holocene: An epoch of the Quarternary period from the end of Pleistocene to the present time.

lithology: The description of rocks, especially sedimentary clastics usually in hand specimen and in outcrop on the basis of such characteristics as color, structure, mineralogic composition and grain size. In essence lithology is the physical character of the rock.

maturation: The act or process of organic material maturing and subsequent discharge from the source rock as hydrocarbons.

migration: The movement of liquid and gaseous hydrocarbons from their source or generating beds, through permeable formations into reservoir rocks.

Miocene: An epoch of the upper Tertiary geologic time period, after the Oligocene and before the Pliocene epochs.

molasse: A descriptive term for a paralic (partly marine, partly continental or deltaic) sedimentary facies consisting of a very thick sequence of soft, upgraded, cross bedded, fossiliferous conglomerates, sandstones, shales, and marls, characterized by primary sedimentary structures and sometimes by coal and carbonate deposits.

A molasse is a post mountain building sedimentary formation resulting from the wearing down of elevated mountain ranges during and immediately succeeding the main phase of mountain building.

nummulitic limestone: A foraminiferal limestone composed chiefly of nummulite shells. Specifically the "Nummulite Limestone" is a thick, distinctive, and widely distributed Eocene Formation stretching from the Alps and northern Africa to China and eastern and southern Asia.

Permian: The last geologic time period of the Paleozoic era (after the Carboniferous), thought to have covered the span of time between 280 and 225 million years ago.

platform: That part of a continent which is covered by flat-lying or gently tilted strata, mainly sedimentary, which are underlain at varying depth by a basement of rocks that were consolidated during earlier deformation that are a part of the Earth's crust that has attained stability and which has been little deformed for a prolonged period.

Pleistocene: An epoch of the Quaternary geologic time period, after the Pliocene epoch of the Tertiary period and before the Holocene epoch.

Pliocene: An epoch of the Tertiary geologic period after the Miocene and before the Pleistocene epoch.

Precambrian: All geologic time, and its corresponding rocks before the beginning of the Paleozoic geologic time era; it is equivalent to about 90 percent of geologic time.

Recent: See Holocene.

resource: May be grouped into the following categories:

economic resources: Those resources, both identified and undiscovered, which are estimated to be economically recoverable.

subeconomic resources: Identified and undiscovered resources that are not presently recoverable because of technological and economic factors but which may be recoverable in the future.

identified resources: Specific accumulations of economic resources whose location, quality, and quantity are estimated from geologic evidence supported in part by engineering measurements.

identified subeconomic resources: Known resources that may become recoverable as a result of changes in technological and economic conditions.

undiscovered resources: Quantities of a resource estimated to exist outside of known fields on the basis of broad geologic knowledge and theory.

undiscoverable recoverable resources: Those economic resources, yet undiscovered, which are estimated to exist in favorable geologic settings.
Source: U.S. Geological Survey Circular 725

saddle: A low point, sag, or depression along the surface axis or axial trend of an anticline.

shelf: As a sedimentary-tectonic feature, the part of a stable area of sedimentation, where it was bordered by a more rapidly subsiding, more mobile basin of sedimentation, generally a geosyncline. The edges of some shelves were unstable, resulting in more disturbed sedimentation and in slumps and slides of shield material into the basin.

shield: A large area of exposed basement rocks surrounded by sediment-covered platforms.

siltstone: A siltstone is a rock whose composition is intermediate between those of a sandstone and shale and of which at least two-thirds is material of silt size.

stratigraphy: The branch of geology that deals with the definition of major and minor natural divisions of rocks. This definition includes the arrangement of rock strata especially as to geographic position and chronologic order of sequence.

subaerial: Occurring in the open air; especially said of consition and processes, such as erosion that exist or operate on or immediately adjacent to the land surface.

Tertiary: The first geologic time period of the Cenzoic era after the Cretaceous of the Mesozoic era and before the Quaternary, thought to have covered a time span between 65 and three to two million years ago. The Tertiary is divided into five epochs: the Paleocene, Eocene, Oligocene, Miocene and Pliocene.

thrust fault: A fault with a dip of 45° or less in which the hanging wall appears to have moved upward relative to the footwall. Horizontal compression rather than vertical displacement is the characteristic feature. Syn: reverse fault, reverse slip fault.

transgression: The spread or extension of the sea over land areas, and the consequent evidence of such advance as rock strata deposited unconformably on older rocks.

turbidite: A sediment or rock deposited from a turbidity current. It is characteriz by graded bedding, moderate sorting, and well developed primary structures.

unconformity: A substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession, such as a interruption in the continuity of a depositional sequence of sedimentary rocks.

It results from a change that caused deposition to cease for a considerable span of time and implies erosion.