Geology of ASSAM

A.B. DAS GUPTA
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GEOLOGICAL SOCIETY OF INDIA
BANGALORE
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Foreword

The scheme of bringing out informative texts dealing with the geology and mineral resources of the States of the Indian union was launched in 1994 with the first issue of the book on the Geology of Karnataka. Since then it has been possible to cover the States of Arunachal Pradesh, Andhra Pradesh, Kerala, Maharashtra, Gujarat and Rajasthan. Books on other States are in the planning stage. For a long time it was not possible to identify persons who could write on the geology of Assam, Meghalaya, Nagaland, Mizoram and Tripura. These States located in the northeastern border of India, stratigraphically and structurally form a distinct unit. Several persons whom I approached in this connection did not favourably react to my request. While I was still on the look-out for a competent writer, a suggestion came that I should contact Sri A.B. Das Gupta, formerly of the Oil India Ltd. who had done considerable field work in Surma and Brahmaputra valleys and adjoining foot hills. I approached Sri Das Gupta in December, 1998, with my request. To my great relief he not only responded favourably but also took the trouble of approaching the ONGC and OIL and sought their assistance in the preparation of the text. The services of Dr. A.K. Biswas, ONGC's Deputy General Manager (Geology) was secured as a co-author. When once a commitment was made Sri Das Gupta lost no time and within a short period made ready the full text, eliciting the following encomium from Sri B.C. Bora, Chairman, ONGC:

> '..... I would like to place on record our deep sense of gratitude to you for bringing the book on the Geology of Assam to completion and making a landmark contribution to scientific work in the country. This endeavour of yours would no doubt inspire the younger generation to pursue such tasks that are beneficial to both academic and scientific community. It is a matter of genuine pride and honour for me and my exploration colleagues that ONGC could associate itself with you and could be of help to you in this venture.'

The speedy execution of the task undertaken is worthy of special mention. The draft of the text reached me in September and after a preliminary appraisal was handed over for composing and printing. I am glad to see the book has taken a final shape and it has become possible to release it before the end of the year 2000.

It is my duty now to place on record our deep sense of gratitude to Sri Das Gupta and Dr. Biswas for the extraordinary care taken in preparing the text and to Sri B.C. Bora, Chairman, ONGC for supporting and extending all assistance to the speedy execution of the project.

The book has been typeset by Sri B.R. Krishna and printed by Sri M. Nagaraju of Pragathi Graphics. Dr. Shivanna has helped in proof correction. My grateful thanks to all of them for their help in processing the matter for publication in record time.

Bangalore B.P. RADHAKRISHNA

Preface

This book is the outcome of a personal request made to me by Dr. B.P. Radhakrishna, President, Geological Society of India, Bangalore. If the readers find this book useful, then it is he who should receive the thanks.

To perform this task, I could to some extent fall back on my earlier papers, which gave a synthesised account of the regional geology, and also naturally on my memory banks. But to do this, I had to add a vast amount of new local information, re-interpret these in the light of advances in the basic concepts of geology and produce a fresh synthesis, illustrated with an adequate number of maps and figures. Since I no longer had the infrastructural support for this type of work, I asked Shri B.C. Bora, at that time the common Chairman-cum-Managing Director of ONGC and OIL, whether he would like one of these companies to collaborate in this venture. He readily agreed.

In the follow up process, Shri A.K. Biswas, ONGC's Deputy General Manager (Geology) working in Basin Studies Division in KDMIPE was drafted in as a co-author. KDMIPE (ONGC) and its Executive Director (R & D), Shri Kuldeep Chandra has provided all the organisational support and help necessary and OIL has come forward with their part of the information as and when called for, with Shri B. Bharali as the focal point in their assistance. Additionally, the Director General of GSI (Dr. S.K. Acharyya), the Director of the Anthropological Survey of India (Dr. R.K. Bhattacharya) and Director of Geology & Mining, Government of Assam (Shri B. Bhattacharya) helped in many ways in the data gathering process. Prof. Dhruba Mukhopadhyay of Calcutta University has helped by reading through the draft several times during its formative stages.

In Assam and its surrounding regions, the recording of geological information started with the arrival of the East India Company officials in 1826. Much of the area in those days had thick forest cover and hostile tribals. Access was poor. Even so, sporadic visits and expeditions had brought in reports of the presence of some oil seepages and coal, and, before the end of the 19th Century, both were under development in the northeast Assam. The main methodical geological work however started with the advent of The Burmah Oil Company (BOC) in 1914. They produced their first synthesis of the available information (including a geological map of Assam) and went on with well-planned investigations using the latest in geology and geophysics, as each new concept or technology became available.

With most of the ground surface covered by dense forests, outcrops of rock were primarily confined to stream courses. Visibility was poor and correlation of the data from one stream to another was difficult. Air photography and photogeology, geomorphology from Survey of India topographical maps and geophysical methods (where applicable) were extensively used to piece the information together. Study of heavy mineral assemblages (from 1927), micropalaeontology (from early 1940s) and a wide variety of other tools were used to support this work. The result was a series of individual area-wise internal reports by a large number of the BOC staff, and a number of overall synthesis prepared in the earlier years mainly by Percy Evans.

I myself became a part of the instrumentality of this process soon after I was inducted into the BOC in 1941. The BOC method of recording and preserving the field observations on 8 inches to a mile field sheets, and of preserving the rock samples and slides, came in very handy in reviewing all earlier information in the context of changing concepts in geology. The BOC era ended in 1962, when Oil India Limited (OIL) took over its operations. Oil and Natural Gas Corporation Limited (ONGC) activities commenced in Assam from 1957. I continued with OIL till 1976 and was concurrently also a Member of the ONGC from 1968-76. Later, my association with ONGC continued for some years as a member of its Chairman's Advisory Council for Exploration, and with the petroleum exploration and development activities in general, from 1993, as a Member of the Advisory Council of the Directorate General of Hydrocarbons (DGH). This has enabled me to remain in close touch with the geology of the northeastern region and also to express my views on its 4-dimensional aspects in a Presidential Address to GMMSI in 1977 and in two other papers to its journal in 1986 and 1997.

The present book has enabled me and my co-author to take these lines of thought much further, and to present a 4-dimensional picture of the geology of Assam and its surrounding regions in both space and time, which we hope will be found reasonably clear. In doing this, we have taken all the basic information we could get together and have fitted these in an overall frame, which we believe most satisfactorily matches up and produces a coherent picture. Some of these will be found to deviate from the earlier conclusions, and, to the extent possible, we have tried to explain the reasons in the text.

On the current lines of thinking, the geology of Assam is ultimately the product of an ancient landmass caught up in the collision zones of three other landmasses. These were originally its neighbours, but drifted apart with the break-up of the Gondwanaland. Later, they collided again to produce the present geological and continental framework. The geology is therefore very complex, and, in order to provide the reader with a reasonably clear picture, we have had to go into the overall geological processes that have affected not only the State of Assam, but also its surrounding lands. We have had further to integrate the geology with the many elements of Plate Tectonics, which have led to the formation of all the mountain belts and sedimentary basins in this area. The presentation therefore has had to be a little unorthodox, and the list of contents will give an idea about how the book has been structured. We hope the readers will find this satisfactory.

Lastly, in order to prevent burdening the reader, with a plethora of names, we have avoided using local geological names as much as possible in the text, but we have introduced a glossary of the more important of such terminology. In listing out references also, we have been selective. There are many publications, which have very local import, but are not equally essential for the understanding of the regional geology. There are also many important writings in the Oil company archives, which cannot be referred to anyway. The list we have given, we hope will be adequate in serving the readers' immediate requirements.

Calcutta A.B. Das Gupta

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Digboi Oil Field

1

Introduction

The Land

The State of Assam is located near the northeast corner of India between the latitudes of 24° and 28° North and longitudes 90° and 96° East (Fig.1). In the past, it has been the home of many important kingdoms – extending from the Pragjyotishpur of the Mahabharat times, to the Kamrup (where the famed Vashkarbarman ruled during the mid-7th Century) of medieval history, to that of the Ahom Kings (based in Sibsagar) from 1228 to 1826 AD. There were also a number of tribal kingdoms – each dominant in its own area – like that of the Cachari Kings, who ruled over an extensive area based in Dimapur during the pre-Ahom period. Later, with the advance of the Ahoms, they had to move their capital southwards, deeper into the North Cachar Hills, to Maibong in the Mupa Valley.

Eventually, the Ahoms extended their rule over greater part of the Assam Valley. They took to Hinduism in the 17th Century and progressively integrated themselves, as well as all the land and the people under their control, into a unified administrative and cultural set-up. Out of this assimilation process grew the Assamese language and the old language of the Ahoms lost popular contact.

By the 18th Century, the authority of the Ahom Kings had waned and there was near anarchy in the land. In 1792 (i.e. after only 33 years of the battle of Plassey), the ruling prince had to seek the help of the East India Company in restoring peace. Whilst this was happening in the Ahom heartland, a Myanmaresé King (Alaugpya) extended his domain to the eastern tip of the Brahmaputra Valley by taking over Mogaung (? Mangung in the Lohit valley) around the middle of the 18th Century.

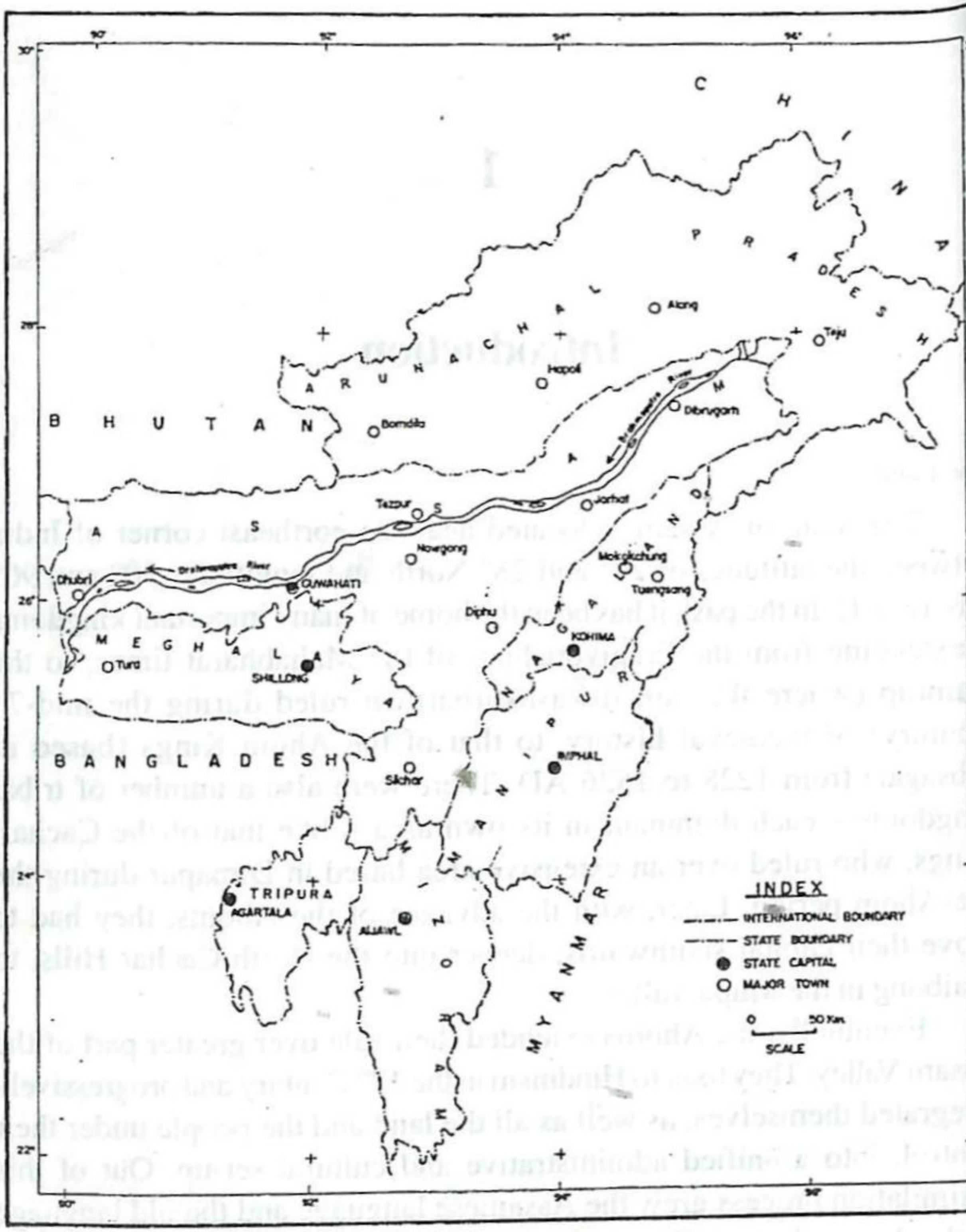

Fig.1. Political map of northeastern States.

By early 19th Century, he mounted a full-scale invasion. The ruling Aho Prince again sought the help of the East India Company. This led to th "First Burmese War" of 1824-26 at the end of which the Company force the Burmese (Myanmarese) to withdraw after signing the Yandab Treaty. Following this the Company also took over the administration (Arakan, Cachar and Assam. By 1842, the whole area and the adjoinir hills came under the East India Company's control and for some years they ruled these areas as newly acquired districts of their Province of Bengal. In 1874, the Government of India (then directly under the British Government) created a separate province of Assam, under the administrative control of a Chief Commissioner located at Shillong (now the capital of the Meghalaya State).

Several administrative changes followed. In 1905, the State was merged with the eastern districts of Bengal and constituted into a new province of Eastern Bengal and Assam, with headquarters in Dacca (now spelt as Dhaka). This arrangement was short-lived and the province was separated again in 1912. A number of Frontier Tracts (the North East Frontier Tracts or NEFA) were created in 1914, partially separating the Eastern Himalayan and Mishmi-Naga Hills mountainous areas from the Assam Administration.

After India attained independence in 1947, re-arrangements have continued. Over a period of time, the NEFA and the border hills districts have all been given the status of separate states under the name of Arunachal (NEFA), Nagaland (Naga Hills), Mizoram (Lushai Hills) and Meghalaya (Garo, Khasi and Jaintia Hills). Most of the large plains district of Sylhet (to the south of Meghalaya) had already gone to East Pakistan (now Bangladesh) as a part of the Independence process.

The political geography of Assam has thus seen many changes. The State was carved out of a number of earlier Kingdoms by the Britishers in mid-19th Century. By the beginning of the 20th Century, it covered the entire Brahmaputra and Barak-Surma valleys east of Bengal, and all the mountain and hill areas surrounding these valleys. In their reference to Assam, all the earlier geological literature refers to this much larger area.

In its present status, the State covers the plains areas of the Brahmaputra and Barak Valleys, the Mikir Hills Plateau (i.e., Karbi Anglong), the North Cachar Hills, the plains and the hilly areas of the Cachar district and some marginal plateau and hill areas adjoining the neighboring States. Its total area is now 78,438 km^2.

Physiography

In its present form, Assam is thus dominated by the alluvial plains of the Brahmaputra and the Barak - Surma rivers. Amongst these, Brahmaputra is much larger (Fig.2). It comes into being through the confluence of three major rivers as these emerge from the mountains near Sadiya. From the east to the west, these are Lohit, Dibang (including its tributary - Checheri) and Dihang.

The river Lohit has its source in China. It cuts through the Mishmi Hills (Arunachal) and emerges onto the plains near Parasuram or Brahmakund giving birth (according to local folklore) to the Brahmaputra

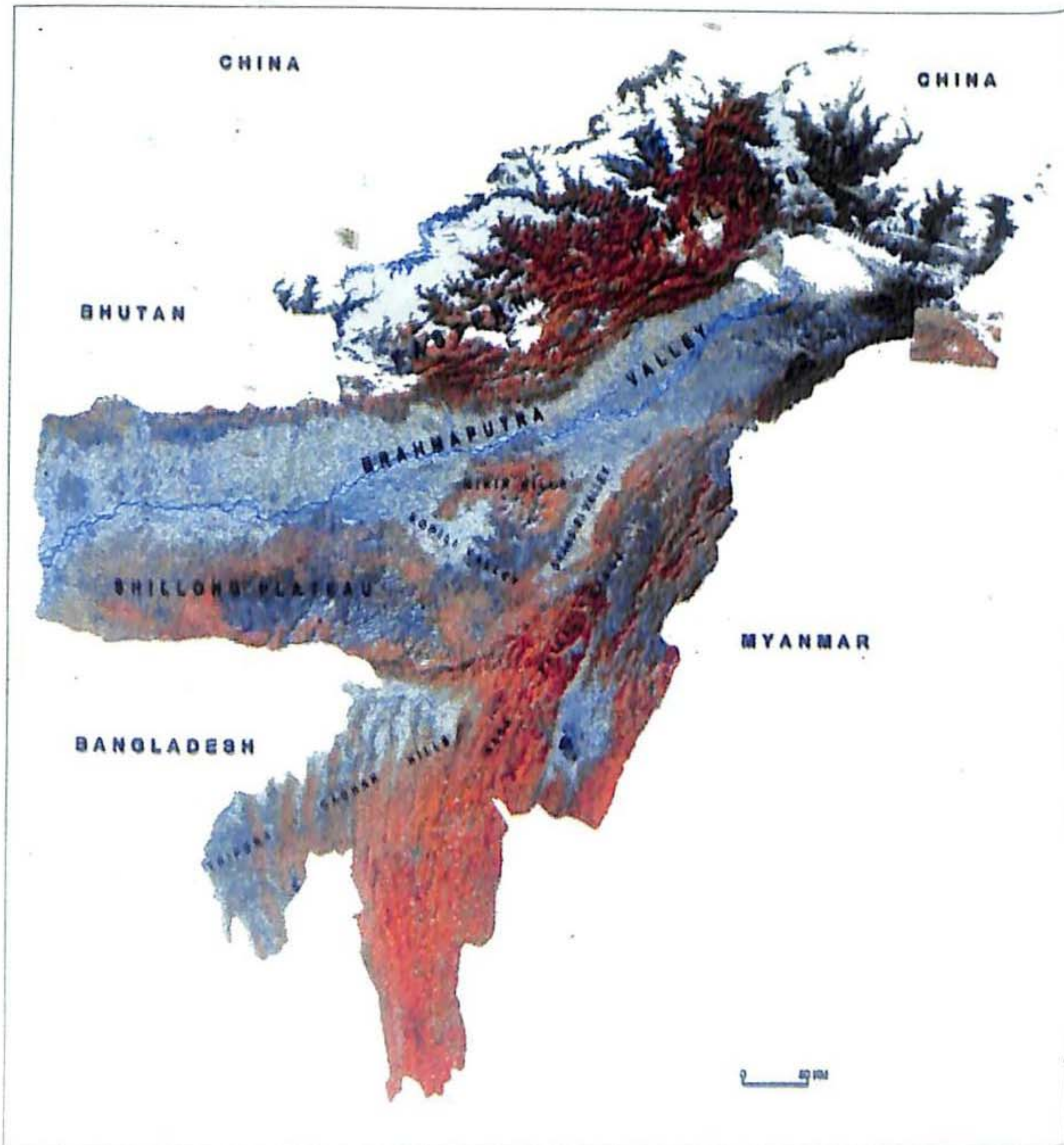

Fig.2. IRS-1C WIFS digital mosaic highlighting the physiography of northeastern States of India (Courtesy ONGC).

river. The pioneering explorers of the 19th and 20th Century have, however, demonstrated that the main flow of Brahmaputra comes via the Dihang river of Arunachal, about 100 km downstream from Brahmakund, and links it with the long Tsangpo river of Tibet. The Dibang and its important tributary, the 'Checheri', are primarily Mishmi Hills rivers.

To reconcile the folklore with the ground reality, one would have to assume that Dihang captured the Tsangpo through headward erosion during relatively recent times (in terms of human racial memory) and earlier to that Lohit had remained the main source of Brahmaputra.

Some of the southerly flowing Himalayan rivers do cut across the main mountain range, and one of the possible explanations offered has been river capture through headward erosion. The Subansiri and the Manas rivers – both north bank tributaries of the Brahmaputra in this 'region' are examples of this type of behaviour. Maybe, studies of the remote sensing imageries will some day provide clue as to whether this has indeed been the mechanism whereby rivers originating in Tibet at altitudes a little over 12,000 ft (3657 m) have cut through much higher mountain ranges before emerging onto the plains of India.

The Brahmaputra has many Himalayan tributaries in Assam, but most of these have only a short run in the plains before they join the main river. The larger of these, from east to west, are Subansiri, Bhareli, Manas and Sankosh.

There are many south bank tributaries as well. The larger amongst these (from east to west) are Lohit, Dihing (two channels, the Noa and the Burhi), Disang, Dikhu, Jhanzi, Dhansiri and Kopili. Amongst these, Dhansiri and Kopili have large alluvial plains of their own. Mikir Hills Plateau comes close to the Brahmaputra river between the longitudes 93°00' and 93°30' E and divides the region into an Upper Assam Valley to the east and a Lower Assam Valley to the west. This is reflected in literature as Upper and Lower Assam.

The Barak river originates from the 2995 m high (9827 ft) Barail Range south of Kohima. It emerges onto the plains near a place few kilometres south of Jiribam on the Manipur-Cachar border, receives discharges from many tributaries (both from the Barail Range to the north and the Mizoram hills to the south), before splitting into the Kusiyara and the Surma rivers near the Assam-Bangladesh border. Thereafter, the two rivers skirt round a depressed area with very large interlinked water bodies called *haors* (or *sagars*), receive reinforcements from a number of tributaries draining the Garo, Khasi and Tripura Hills and join up with an old channel of the Brahmaputra to form the Meghna river. The latter is the ultimate recipient of most of the Ganga-Brahmaputra drainage before the sea is reached. A little further to the south, Meghna has the dimensions of a residual sea or gulf itself. The total land area covered by the flood plains of these multitudes of rivers in the Barak-Surma-Kusiyara-Meghna system is quite large but the portion left within Assam is relatively small.

South of the Barak river, the overall morphology of the country consists of a series of north-south hills with intervening narrow as well as wide and flat valleys. These extend the Cachar plains as fingers in the southerly direction.

All these valleys receive their sustenance of water, sediments and nutrients from the high mountains, hills and plateau country, which surround them. The rainfall is particularly heavy near the mountain, hill and plateau fronts, and its run off brings with it much associated benefits to the valleys. The southern part of the Shillong Plateau, which drains into the Surma-Barak rivers, receives some of the heaviest annual rainfall in the world. The names of Cherrapunji and Mawsynram are famous in this connection.

The Eastern Himalayas, which feed the Brahmaputra Valley from the north, constitute the highest of these mountain ranges – rising to peaks ranging in height from 5000 to over 7000m (16400 to nearly 25000 ft). The Nyimo Chomo range in China, adjoining the Lohit Valley, comes next rising to a maximum of 6157m (20,000 ft). South of the Lohit river the Mishmi Hills rises to a maximum of 4571m (14997 ft) at Dapha Bum in Arunachal, enough to get covered with snow during the winter.

Southwest of the Mishmi Hills, the Assam-Arakan range starts with a lower elevation, but rises progressively to 3826m (12552 ft) at the Saramati Peak and to 3104m (10184 ft) at Mol Len, both near the Indo-Myanmar border. Thereafter, the highest feature shifts some 70km to the west to Japvo Peak at 2995m (9826 ft). It slowly loses its height further to the south.

The Shillong Plateau, which separates the Brahmaputra and Barak-Surma Valleys, rises to a maximum of 1961m (6433 ft) at Laitkor, south of Shillong. The Barail range towards its southeast varies from around 1500 to 1800m before rising to its highest point at Japvo (2995m). The

Mikir Hills plateau has a more modest height and rises to a maximum of only 1359m (4459 ft).

The combination of all these mountains, hills and valleys together with heavy to very heavy rainfall, thick forests, diverse vegetation and life forms, make the region very picturesque and endows it with a good deal of natural beauty. The forests were much more widespread and dense before but have been slowly decimated through the increase in human habitations and the advent of timber and tea industries particularly during the 20th century.

The People

As a country, India exhibits a wide diversity of ethnic groups and their admixture. Assam is no exception. There have been influx of people from both along the valleys as well as across the hills. The latter have brought in a large measure of the ethnic mongoloid groups; the former a wide mixture of North India population plus a liberal amount of mainland Indian tribals. A large section of the latter was brought in by the tea industry and has provided the backbone for their development and growth.

The Industries

The principal industries in Assam are based around the availability of petroleum, coal and timber. To this has been added a highly developed plantation industry, which is primarily tea. Deposits of limestone in Mikir Hills and the upper Kopili Valley remain a potential, but have not yet become a major source of industrial activity.

Most of the major deposits of coal occur in the northeastern corner of the State and extend from Margherita, through Ledo, into the adjoining Arunachal Pradesh. The total reserves are estimated to be 320 million tonnes, and the current production is about 1.0 million tonnes per annum (637,000 tonnes in 1998-99).

There are also some thin seams of coal in the Mikir Hills near Garampani, adjoining the Dhansiri Valley, as well as some thicker seams in the neighboring states of Nagaland and Meghalaya.

Petroleum is being produced primarily from the Upper Assam Valley with four refineries established at Digboi, Guwahati, Bongaigaon and

Numaligarh. There used to be a small oilfield near Badarpur in Cachar which was abandoned in 1933 after a total of only 0.321 million tonnes of cumulative production. Currently, there is a small amount of gas production from two fields, which have been discovered in this district during the last two decades.

Tea industry has found a favourable habitat on the slightly higher grounds formed by Older Alluvium and the rolling low hills in both Assam Valley and Cachar. It is therefore quite widespread in its distribution.

Two giant paper mills – one at Nagaon in Assam Valley and the other at Panchgram near Badarpur in Cachar – complete the tally of major industries. Besides, there is widespread small-scale industrial activity based on weaving fabrics of cotton and silk (including growing of silk-worms) and a wide variety of other handicrafts.

Communications

In the earlier days, the main entry into Assam from the Gangetic Plains was along the river valleys. The entry from the surrounding hills was by innumerable hill tracks. Within the plains, there were very few major roads except for the remarkable Dhodar Ali built by the Ahom Kings along the southeastern margin of the Upper Assam Plains, presumably for rapid deployment of troops. Otherwise, pathways with bamboo bridges, cart tracks and boats served the primary requirement of movement and communications.

The advent of the tea, timber, coal and petroleum industries saw the upgrading of a lot of these pathways and the opening up of many new ones into a large-scale road network. The riverine movement improved with the introduction of large river steamers and river ports along the Brahmaputra and the Barak-Surma-Kusiyara rivers. These provided the main link with the western mainland. Meanwhile, two railways set up as private sector enterprises by the Britishers (the East Bengal Railway and the Assam Bengal Railway) started to extend their metre gauge services into Assam.

It took many years for these two railways to link up the Surma and the Assam Valleys through the spectacular Badarpur-Lumding Hill Section and also extend the system northeastwards deep into Upper Assam. The tea, timber and coal industries had in the meantime gone head with the setting up of an Assam Railway and Trading Company Limited (AR & T Co.) and established a local metre gauge railway linking the Dibrugarh river port with Sadiya (now in Arunachal Pradesh) and Margherita-Ledo. In the process, they also discovered the Digboi oilfield. The main rail route into Assam eventually linked up with the Dibru-Sadiya Railway at Tinsukia, which is now a very important railway junction.

Today, this railway network stands much improved with large-scale conversion of the metre gauge into broad gauge. The road network has also improved considerably and there are now a number of major airports with regular services linking the State with Delhi, Bagdogra (Siliguri), Imphal, Agartala and Calcutta.

2

Geotectonic Evolution of Assam

The Backdrop of Plate Tectonics

Geologically, the rocks that make up Assam extend in age from very ancient Early Proterozoic to the present day Alluvium. Within the Brahmaputra Valley, the rocks at these extreme ends can be seen at the surface, but much of those of intermediate age are buried deep under the alluvium. To understand what rocks may be present in these areas and what sort of inter-relationships these may have with those exposed in the surrounding mountain belts, it is desirable to outline at this stage some of the basic geological processes which are believed to have affected the area.

According to the present day geological concepts, these processes revolve round a cyclic global geotectonic phenomenon - Plate Tectonics and Ocean Floor Spreading. The feeling is that, lasting over a cycle of approximately 500 million years or so, the continental masses of the crust fuse together to form one or more supercontinents, only to start rifting and breaking apart with ocean floor spreading to keep the breakaway continental fragments moving away from each other. Eventually, the drifting fragments or plates collide with other similar masses in their way and begin to form a new supercontinent. Along the line of junction, one plate gets subducted below the other with a lot of sedimentation and mountain building activity at the zone of collision.

At the beginning of the current Plate Tectonic cycle, Assam (together with the rest of India, Tibet, Australia, Antarctica, Africa and South America) was part of a supercontinent, which has been named the Gondwanaland (Fig.3). The landmass, within the area concerned, was

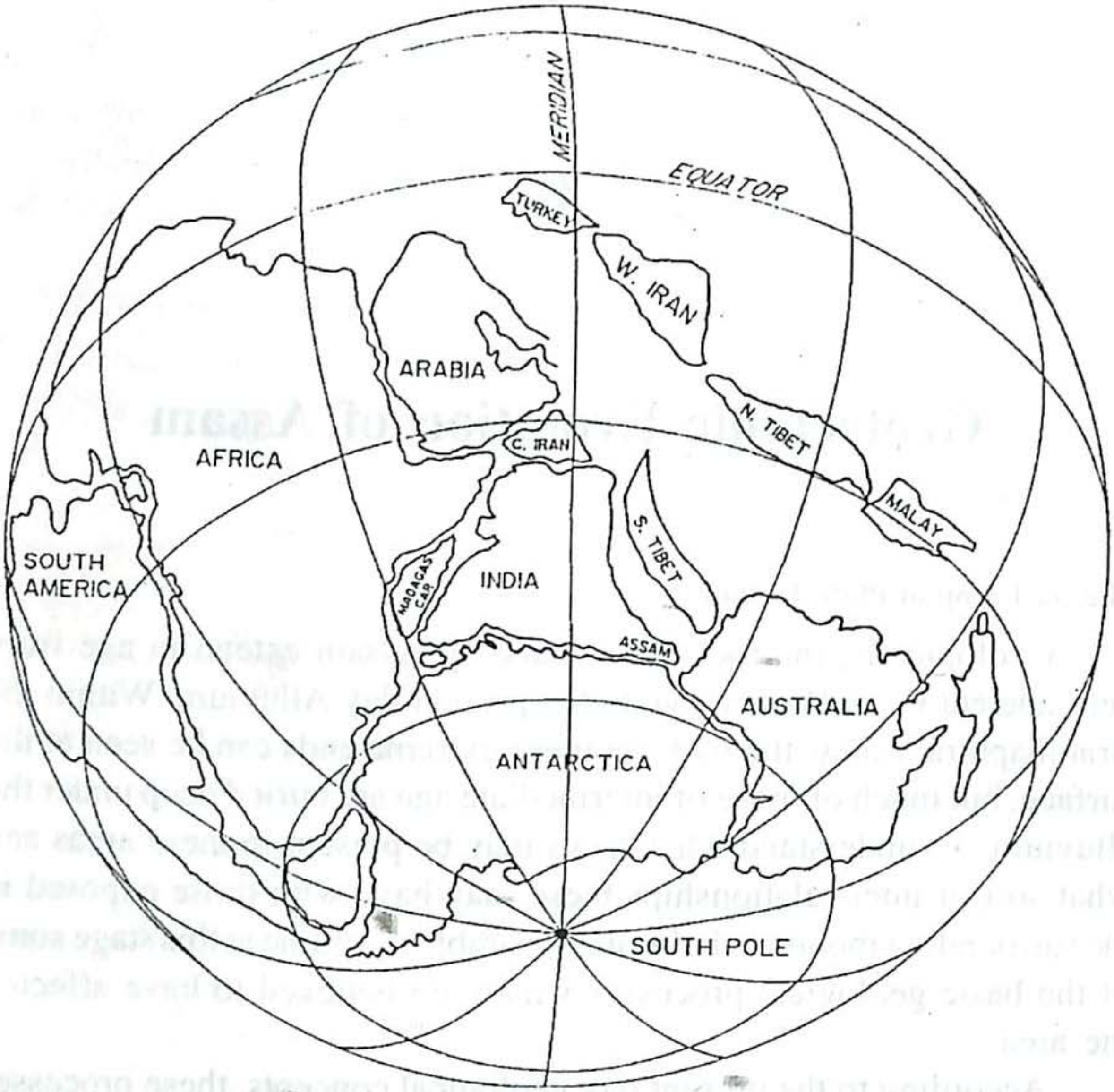

Fig.3. A schematic reconstruction of Gondwanaland around 250 mybp i.e., Late Permian (*after* British Petroleum - ONGC Report, 1991).

made up primarily of ancient metamorphics of Archaean to Early Proterozoic age with a variety of basic, ultrabasic and acidic intrusions. The land also included a number of younger Proterozoic sedimentary basins containing less metamorphosed sandstones, shales, limestones and quartzites, with some associated volcanics and intrusive igneous rocks. Within the rest of India, these younger Proterozoic rocks are represented by the Vindhyans, Cudappahs and their equivalents covering an age range of 1600 to 500 million years before present (mybp). In Assam, no clear representatives of these latter rock groups have been seen, but it is quite possible for some to be present within the basement complexes below the younger sediments.

Around 250 million years ago, i.e., around the Permian period, this supercontinent started to develop a number of rift valleys in which were deposited the coal-bearing Gondwana (Assam itself has only a small area occupied by these formations exposed at the surface at Singrimari in the Goalpara district but some occurrences are present in the adjoining Bangladesh, Arunachal and Bhutan), possibly Lower Gondwana outcrops. The area falls north of Dolungmukh in Dhemaji district and it exposes Miri Formation of Lower to Middle Palaeozoic age (Anon, 1974). However, Gopendra Kumar (1997) has considered the formation under Lower Gondwana and has assigned it Lower Permian age.

This was a kind of precursor, and from around Late Palaeozoic to Early Cretaceous, the Gondwanaland itself started to break up in stages. With ocean floor spreading in between, large chunks of the erstwhile supercontinent moved away from the mainland with both lateral and rotational movement. During this journey, some of the chunks remained large (like Australia), some got fragmented, some joined together with accompanying collision tectonics to form larger landmasses. Eventually a large number of these fragments and composite chunks from northeastern Gondwanaland collided and fused with the Eurasian Plate. The final break up into Australia, Antarctica, India, Africa and South America is believed to have taken place in Late Jurassic to Early Cretaceous.

Amongst the earlier fragments, which broke away in Late Palaeozoic and joined up with Eurasia around Jurassic, are believed to be the cratonic nucleii of much of Iran, N. Tibet, Central and NE China, Indo-China and Eastern Thailand (Fig.4). Some more chunks got detached from the Gondwanaland around Late Triassic to Early Jurassic and eventually joined with Eurasia around the Middle to Late Cretaceous to form South Tibet, Myanmar, West Thailand, Malaya, Sumatra-Java and possibly Afghanistan (Fig.5). India and Australia broke apart later around Early Cretaceous and the continental part of the former seems to have reached its collision zone with South Tibet around Early Eocene (Fig.6).

As the continental fragments have broken apart and moved, their positions have changed vis-a-vis the earth's magnetic poles. They have also carried with them the imprint of their earlier geological and tectonic framework as well as their faunal and floral records. A vast amount of

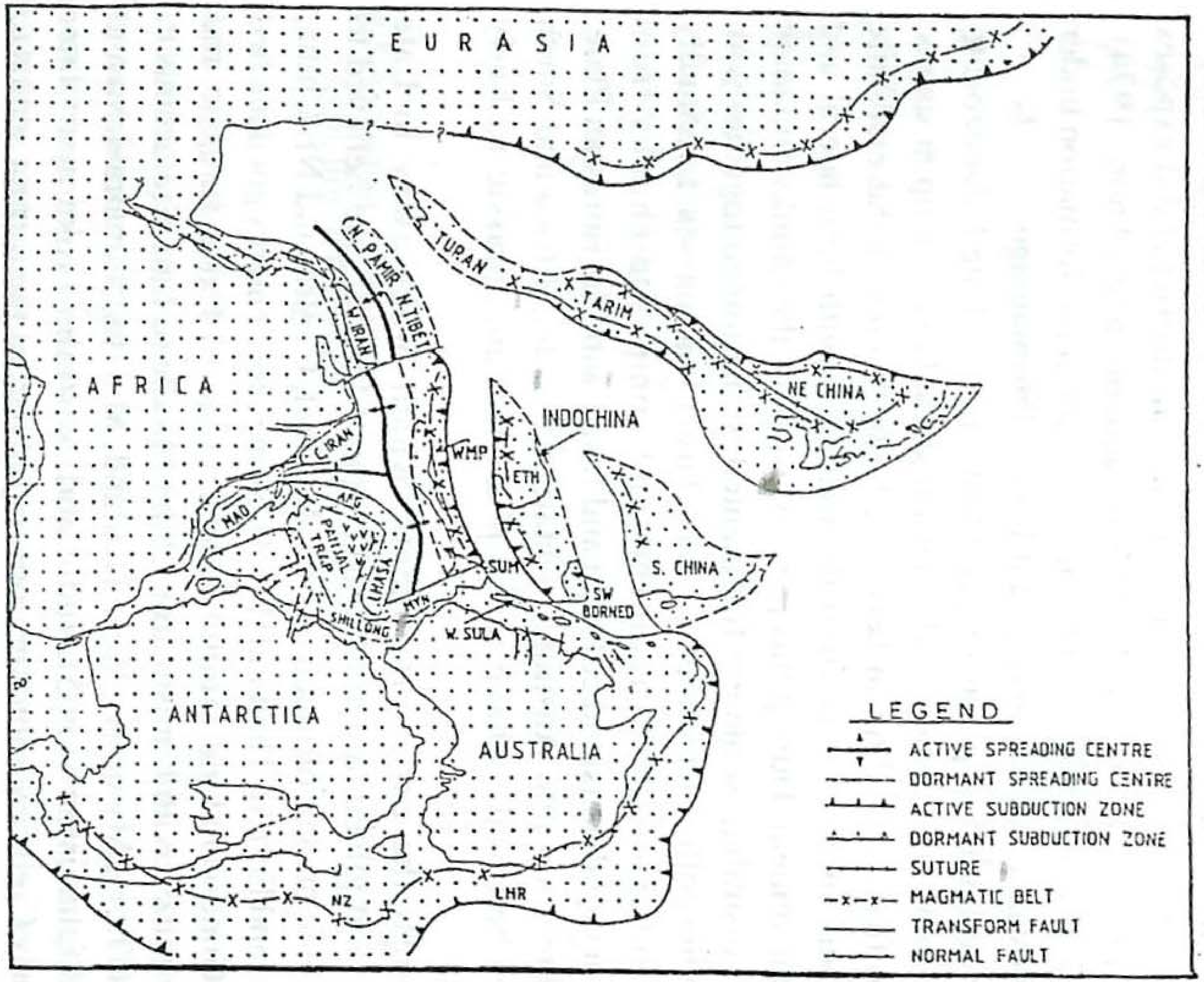

Fig.4. Plate reconstruction at end Permian (240 mybp). Stippled areas of the map are continental crust and blank areas are oceanic crust. WMP- West Malay Peninsula; MAD - Madagascar; AFG-Afghanistan; MYN - Myanmar; SUM - Sumatra; SU - Sulawesi; ETH - Eastern Thailand; NZ - New Zealand; LHR - Lord Howe Rise (Adapted from Parker and Gealey, 1985).

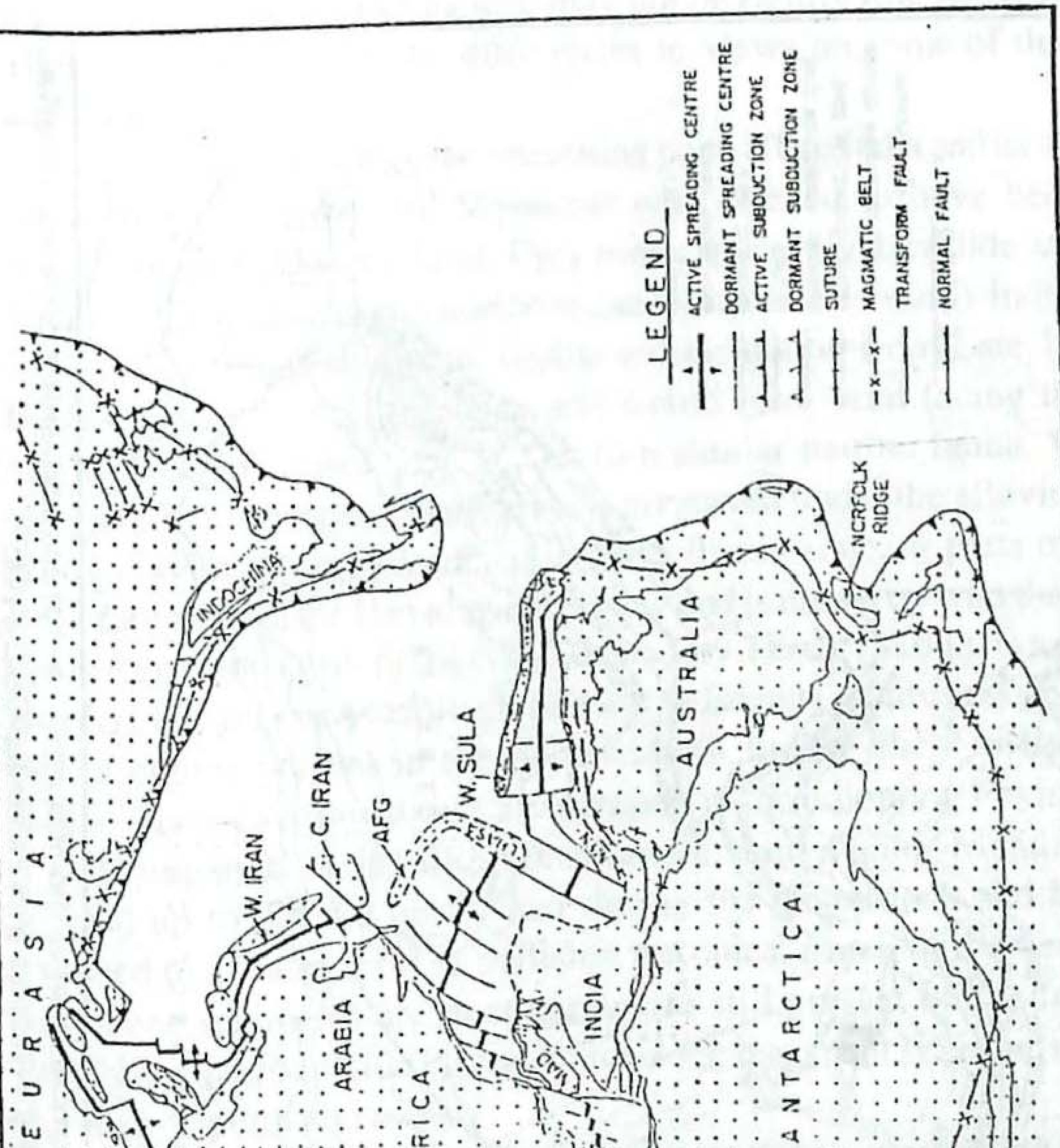

Fig.5. Plate reconstruction at Early Cretaceous (135 mybp). Explanation of symbols and abbreviations as in Fig.4 (Adapted from Parker and Gealey, 1985).

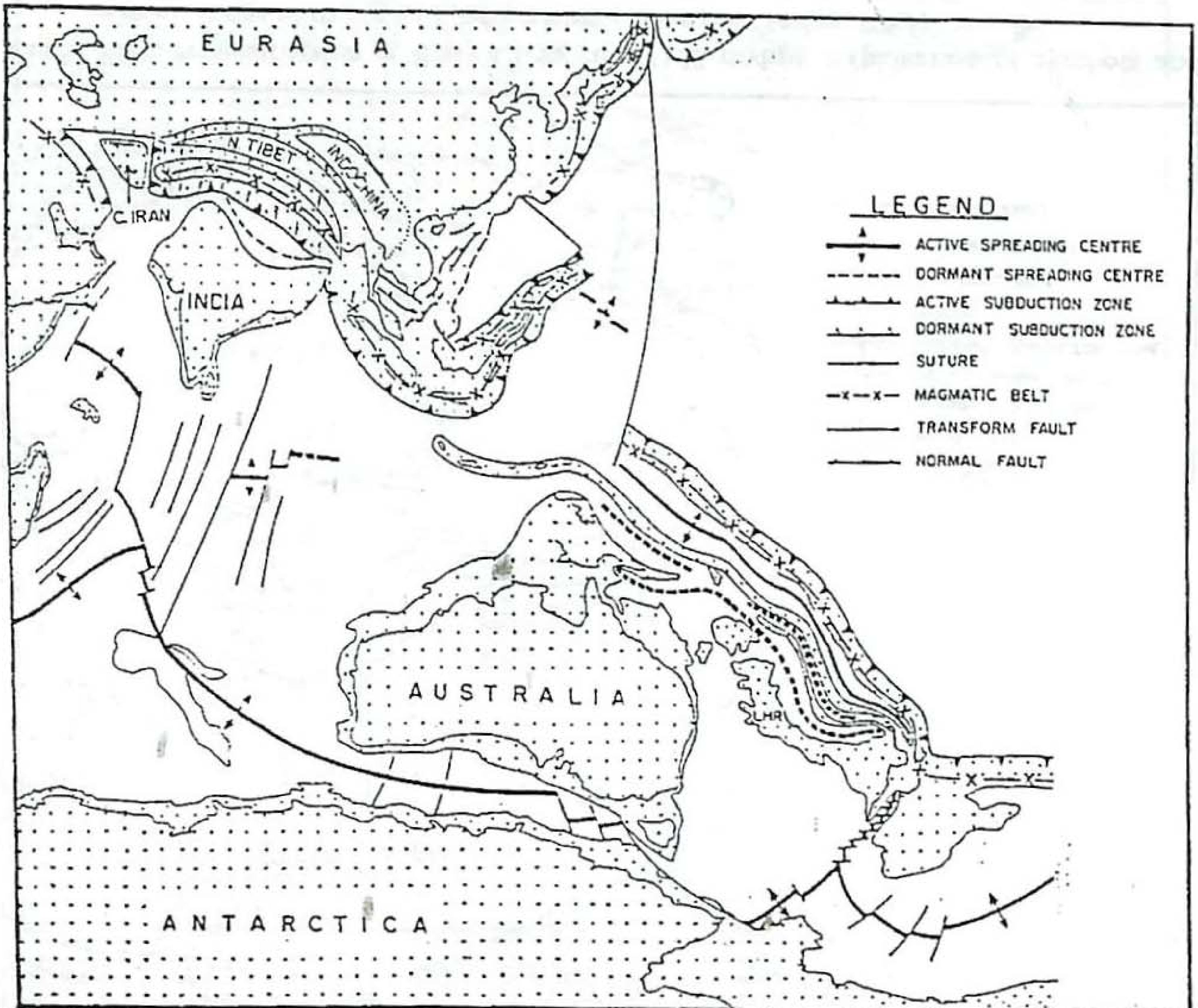

Fig.6. Plate reconstruction at Mid-Miocene (47 mybp). Explanation of symbols and abbreviations as in Fig.4 (adapted from Parker and Gealey, 1985).

palaeomagnetic data has had to be collected, analysed and matched with geology in arriving at the above picture of the breakup of Gondwanaland and the accretionary growth of Eurasia. Periodic reversals in polarity in the earth's magnetic field has helped within known spans of geochronology to fix the dates of some of these events. Even so, there are gaps in the database, and the overall picture may not be rigidly true in every detail. There are also likely to be differences in views on some of the events and their times.

Notwithstanding this, the interesting point is that India and its adjoining lands of South Tibet and Myanmar are believed to have been close neighbours in Gondwanaland. They broke apart only to collide and rejoin later. On this picture, the northern (and the northwestern) Indian shelf would have been exposed to marine sedimentation from Late Triassic - Early Jurassic to Early Eocene and would have been facing the same sea as Southern Tibet with access to a similar marine fauna. Whether any part of this northern shelf zone is preserved under the alluvium or its entire mass has been subducted in the collision zone, or parts of it have been caught up in the Himalayan orogeny and is mixed up with the Tibetan Zone formation north of the Main Boundary Thrust (MBT), is a problem that has not yet been resolved. Marine sediments from Jurassic onward are of course present in the northwestern Indian Shelf in Rajasthan. Some Triassic sediments are also present in the adjoining Pakistan.

Compared to this, the northeastern shelf facing Myanmar was opened up to the sea much later during the Cretaceous and has been exposed to a lower level of collision tectonics. Much of the Cretaceous to Eocene sediments are in consequence still present on the fringes of the Shillong-Mikir Hills Plateaux and in the basement ridge buried under the Brahmaputra alluvium.

When two parts of a continent break apart they open up to a common and expanding sea. The inland drainage pattern changes and sedimentation commences within the submerged continental edge or the shelf. The rate of sedimentation depends upon the extent and relief of the hinterland draining into the shelf. This in its turn is controlled by the uplift and erosion/peneplanation cycle that affects various regions of most cratonic masses and on the available rainfall. Marine fauna of the drifting fragments would be very similar, but the terrestrial flora and fauna could progressively change.

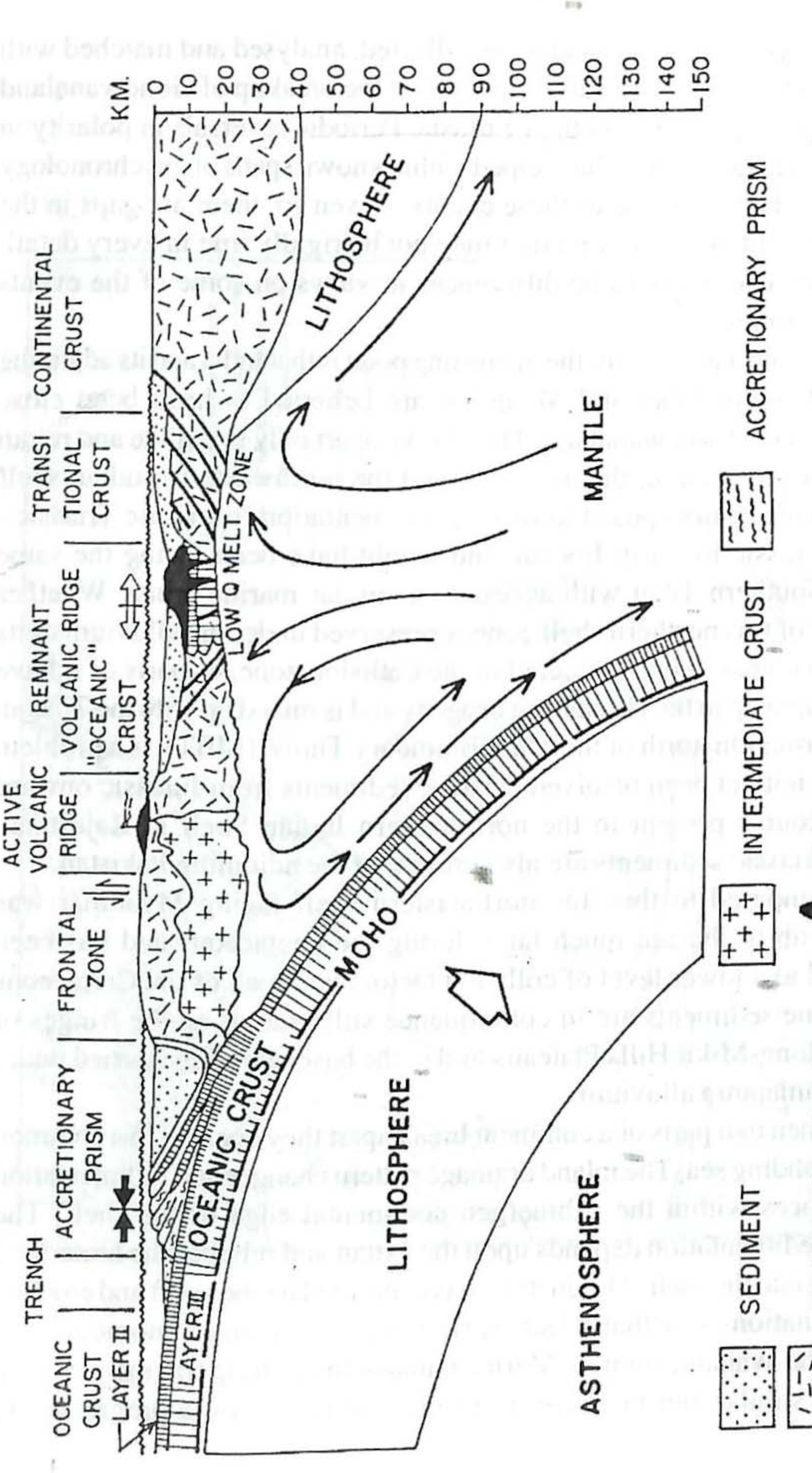

Fig.7. Morphology of a subduction zone. Figure depicts the stage of subduction which preceded the continental collision between Indian and Eurasian plates on the Indo-Myanmar front (adapted from Bally,1981).

The breakaway fragment would become part of a plate. This would initially get enlarged through ocean floor spreading till the beginning of the collision phase. After this, firstly the oceanic extension of the plate and later the continental margin of the underthrusting plate itself would start to get consumed in the zone of subduction (Fig.7). Faulting would raise the overthrusting plate and a deep trench or linear basin would develop in the subduction zone. Erosion of the upthrusting zone would fill up the trench but, as collisional forces continue, the compression would raise the basin-fill sediments as faulted and folded mountain masses, shifting the depositional trench or foredeep away from the growing mountain. This process is likely to be repeated a number of times resulting in a multiple phase of mountain building and shifting of its frontal basin of deposition. Alongside these, there can also be some emplacement of oceanic crust fragments as ophiolitic masses and igneous activity in various forms.

Assam's geological history seems to follow this overall pattern. The drifting phase seems to have started during the Late Jurassic - Early Cretaceous. The collision of the continental masses seems to have commenced around the Early Eocene or say 40-50 mybp and multiple phases of mountain building and mountain-front basin formation has continued since then. The present-day basins are reflected by the Brahmaputra, Kopili, Dhansiri and Surma-Barak alluvial plains. Much of the earlier continental crust is buried deep under these basins, some have been elevated as the Shillong and Mikir Hills Plateaux and their associated isolated hills. Parts of the northern continental margin could have been either subducted or caught up in the faulting and folding activity of Indo-Tibetan Collision Zone. If so, these could be represented in the Proterozoics and Gondwanas of the Arunachal-Bhutan mountain belt.

The Different Tectonic Phases, Sedimentation and Stratigraphy

In the course of its geological history, Assam has thus passed through five important phases. The first of these relates to when it was a part of the Gondwana Supercontinent. The second phase came in the Permo-Carboniferous, when its adjoining areas were rifted and the coal-bearing Gondwana was deposited. This phase seems to have been accompanied locally by some volcanic activity and the area was still a part of the

Gondwanaland. The third phase came in Late Triassic/Early Jurassic when, with the drifting away of Southern Tibet, the northern fringe of India including the part that is now Assam became open to marine sedimentation. The Sung Valley Carbonatite intrusion took place during this period. The fourth phase started when the eastern boundary also broke apart in Late Jurassic-Early Cretaceous and the southern and eastern shores of Assam became open to marine sedimentation. This phase also saw the beginning of some igneous activity with the outpouring of Garo Hills, Sylhet, and Mikir Hills Traps (basalts), and the formation of a number of basic and ultrabasic intrusives.

The fifth phase started with its collision with Myanmar to the east and Tibet to the north around Early Eocene and continued with all the stages of collision tectonics thereafter. During this phase, the entire land was caught up, as in a vice, between the two collision zones. The Mishmi Hills added a third compressional force from the northeast and subsequently a major uplift of the Shillong-Mikir Hills Plateaux also contributed.

In descending order, we have thus in Assam a sequence of events:

Recent	Young and Old Alluvium
Unconformity	
Pleistocene Pliocene Miocene Oligocene	Sedimentation during the collision period with several tectonic interruptions and depositional breaks.
Eocene Cretaceous	Sedimentation and carbonate formation, partly in the collision zone and partly on the stable shelf. Some igneous activity in Cretaceous as reflected by Sylhet Trap and other intrusives.
Unconformity	
Gondwana Formation (Permo-Carboniferous to Jurassic)	Only a small development recorded from Assam proper, but thicker development may be present in the Basement complex below the alluvial areas.
Unconformity	
Precambrian Basement Complex	Representing a part of the Gondwanaland crust. Primarily of Proterozoic age in Assam.

3

Pre-Tertiary Stratigraphy

Precambrian

The crustal material of the Pre-Gondwana landmass outcrops in Assam in the Mikir Hills Plateau, at the fringes of the Shillong Plateau (including its main body which lies in the adjoining Meghalaya State) and in the Mishmi Hills, most of which lies outside Assam. It also forms isolated hill clusters straddling both sides of the Brahmaputra river in the Lower Assam Valley (Fig.8). Elsewhere, the surface of this Pre-Gondwana landmass slopes down into basinal depressions and constitutes the basement for their sedimentary cover (Fig.9). Some of these are very minor and are filled with recent alluvium; the others are major features covered by sediments ranging in age from the Cretaceous to the present day Alluvium.

The rocks have been studied primarily in the Shillong Plateau where the oldest material seems to consist mainly of granitoid gneiss, hornblende-biotite gneiss and biotite-cordierite gneiss of early Proterozoic age (i.e., less than 2.5 billion years before present). Over a 50 km wide and 200 km long belt extending from the eastern Shillong to the Mikir Hills, these metamorphics are overlain unconformably in a number of places by a group of younger Proterozoic sediments, called the Shillong Series. Both of these rock groups are intruded by some basic and ultrabasic rocks, some of which (from their radiometric age) belong to the much younger Cretaceous period. There is also a report of a carbonatite intrusion from the Sung Valley (Meghalaya) of Late Jurassic age.

Intruding the Shillong Series, south of Shillong, there is a large mass of young looking granite – the Mylliem Granite. Elsewhere, there are also a number of smaller masses of similar granites. Radiometrically, these range in age from 480 - 885 mybp, but clustering mainly around 500 - 700 mybp i.e., within the geological range of Late Proterozoic to Cambrian.

The Mikir Hills and the isolated hill masses have not been studied to the same extent, but these also seem to be predominantly granitoid gneisses. The geographical position of Mishmi Hills has prevented any intensive study. It has been briefly described as a granodiorite complex with a frontal belt of high-grade schists and migmatites, and an inner belt of actinolite-tremolite schists with crystalline limestone and serpentine lenses. The predominance of granitoid gneiss material in the massive deposits of Dihing and alluvial boulder beds in the Manabum anticline and other areas near the Mishmi Hills front also gives an indication that its main mass may not be much unlike that of the Shillong Plateau.

Possibility of Palaeozoics Being Present

Between the Proterozoic - Early Cambrian to the Gondwana period, the Indo-Pakistan peninsular landmass did not receive much sediment, except in the Salt Range, where representatives covering most of the Palaeozoic are present. Some Palaeozoics are present in the Himalayan fault belts in Arunachal and Bhutan, but it is not clear whether these represent developments on the southern edge of the Tibetan Plate or on the northern edge of India. In any case, the two plates did not apparently break apart till late in the Triassic, and any Palaeozoic sediments could easily have been common to both. It follows that one cannot rule out the possibility of some non-Gondwana Palaeozoics as well being present within the buried basement features of Assam.

Gondwanas

Although, only a minor patch of Gondwanas have been reported so far from Assam itself (as discussed earlier in Chapter 2), some NW - SE trending developments have been encountered under their Tertiary cover during drilling in Bangladesh. Some are also present all along the Himalayan foothills, from Arunachal to North Bengal, in the thrust belt north of the Siwaliks, and their equivalents. Some Gondwanas could therefore be easily present in Assam in block-faulted troughs within the basement areas buried under the Upper Mesozoic to Recent sediments. The 135m of continental Permian sediments encountered below 1598m in ONGC's Barpathar Well in the Dhansiri Valley probably represent an occurrence of this class (Fig.10).

The Gondwanas reported from the surrounding regions are primarily Permo-Carboniferous with their typical coal-shale-sand sequence, but in Singrimari, near the Garo Hills border some poorly preserved plant impressions resembling those in the Jurassic Rajmahal have also been reported. There is thus no reason why any buried Gondwana found in the Assam Valley basins should not include some younger Triassic and Jurassic developments as well. In the context of the Abor Volcanics, some of which are associated with the Lower Gondwanas in Arunachal, one cannot also rule out the possibility of some similar manifestations being present.

Cretaceous Lava Flows and Igneous Intrusives

India is believed to have started to break out of Gondwanaland in Early Cretaceous. Around the same time a lot of volcanism (basaltic lava flows and intrusives) commenced in eastern India. Here again direct evidence from Assam itself is limited to the Mikir Hills area, but other groups of such rocks are known from the neighbouring lands.

To the west, we have the Rajmahal lava flows, which extend and cover a very large area under the Gangetic Alluvium and the Tertiaries of Bengal. To the south, there are the Sylhet (and Garo Hills) Traps, which are well exposed in the Um Sohringknew and a number of other rivers at the southern margin of the Shillong Plateau (Meghalaya). These underlie Upper Cretaceous sediments and are believed to be of Early to Middle Cretaceous in age (110 to 133 mybp).

In Assam itself a small thickness (about 21m) of basaltic lava flows are present in Koilajan and its neighbourhood, and in the Puja Nala, in the Mikir Hills area. About 67m of lava flows, with a thin inter-trappean bed has also been encountered in ONGC's Barpathar Well in the adjoining Dhansiri Valley in the interval 1326 to 1393m (Fig.10). From its stratigraphic position, the Barpathar Trap is younger than Albian but older than the unconformably overlying Palaeocene. This would place it at

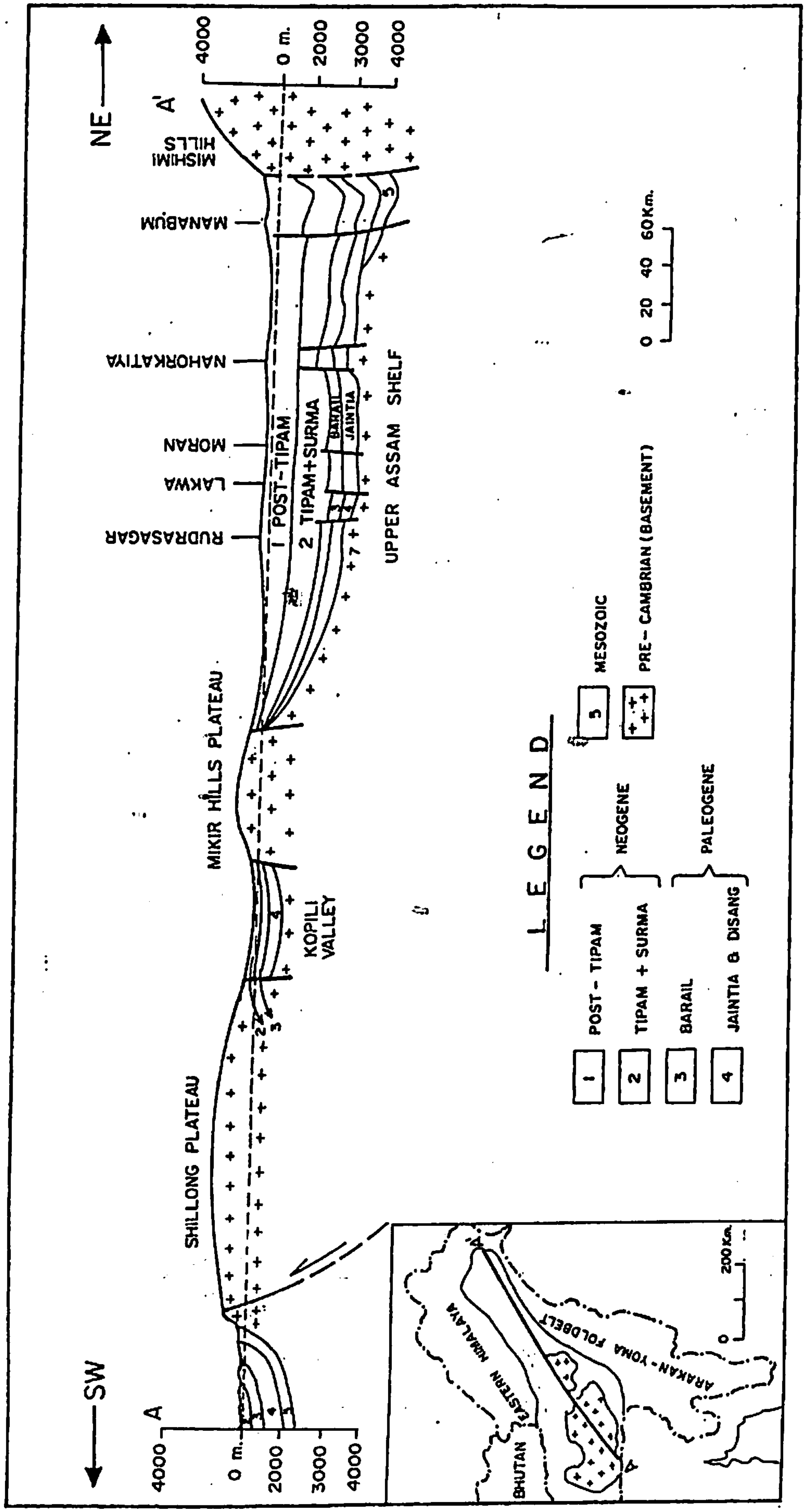

Fig.9. Schematic geological section along Shillong and Assam shelf (modified after Deshpande et al. 1993).

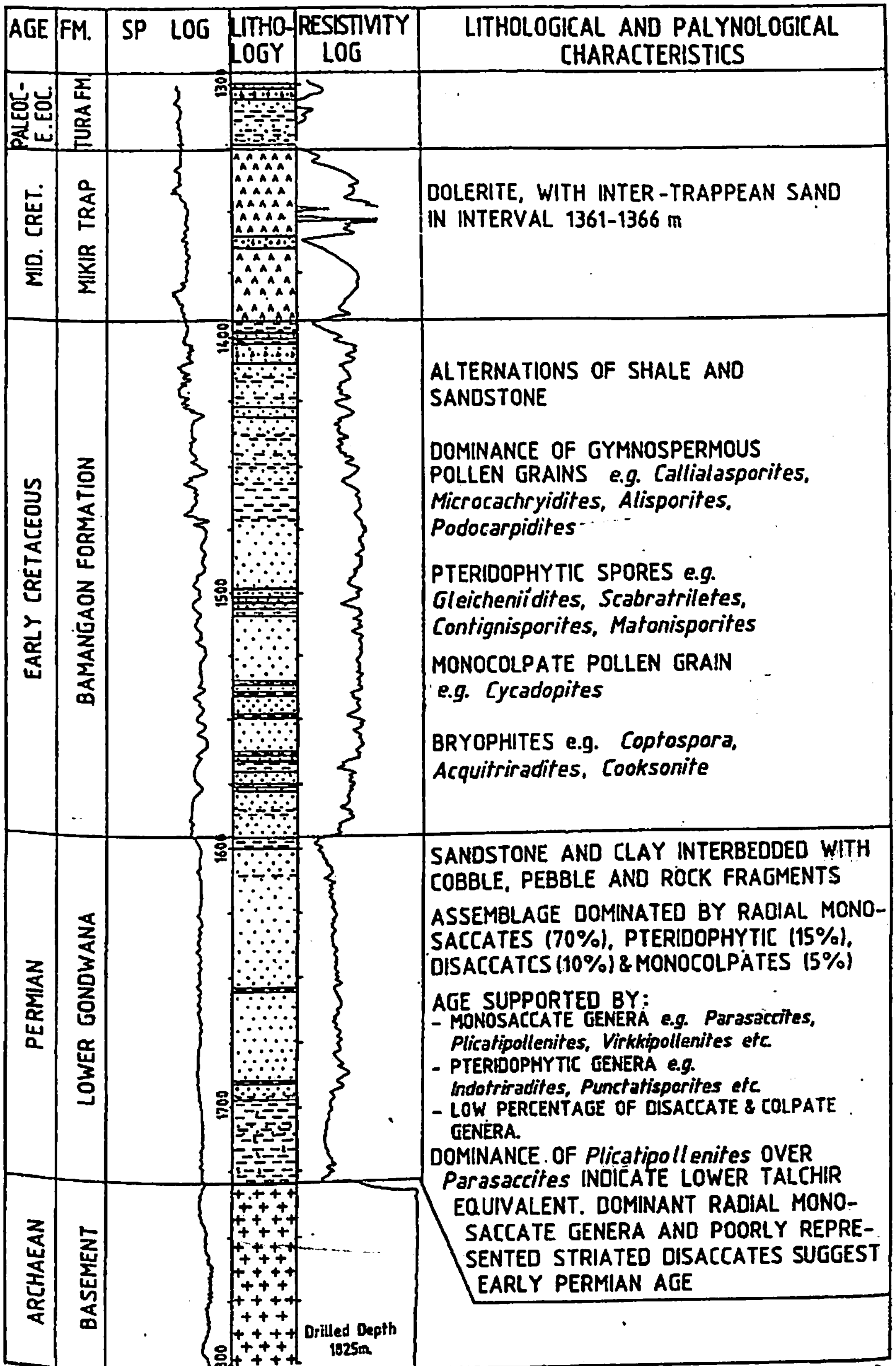

Fig.10. Log character, lithology, and palynology of Barpathar well (courtesy ONGC).

more than 66 million years and less than 112 million years in age. The older limit would take it close to the Sylhet and Rajmahal Traps in age. The younger will bring it closer to the Deccan Trap. The presence of an unconformity at the top naturally makes it more likely to be closer to the former.

In western Meghalaya (Garo Hills), there is an alkaline lamprophyre dyke intruding the granite gneiss, which has been radiometrically dated at 107 mybp (Mid Cretaceous) and is therefore within the Sylhet Trap activity time span.

There are a number of basaltic lava flows and other volcanic manifestations to the north in Arunachal Pradesh as well. These have long been known under the collective name of Abor Volcanics. The more recent work summarised in Gopendra Kumar's Geology of Arunachal Pradesh indicate that these include representatives of volcanism during three widely differing periods – Proterozoic, Early Permian and Palaeocene, Early Eocene. Perhaps these now need to be described, named and shown separately on geological maps. As a matter of fact, GSI in its 'Geological Map of India' published in 1998 have split Abor Volcanics into two – a 'younger phase' of Palaeocene-Eocene and an 'older phase' of Permain age. In any case, none of these times quite match up with India's breaking apart from the Gondwanaland. Petrographically also, the Arunachal volcanics reportedly comprise of basalts (including pillow lavas) and andesites, with some acidic tuffs, lapilli, and volcanic agglomerates – an assemblage that does not altogether match up with either the Sylhet or the Mikir Hills Traps.

4

Mesozoic-Cenozoic Tectono-Stratigraphy

Basement Complex

So far, we have thus the picture of a crustal fragment of the ancient Gondwanaland, made up of metamorphosed igneous rocks and sediments of the Archaean to Early Proterozoic age, with some embedded less metamorphosed sediments of younger Proterozoic to Early Cambrian age. The whole sequence is intruded by some granitic, basic and ultra-basic igneous rocks. This crustal mass was further repeatedly block faulted and peneplaned with the deposition of some Gondwana sediments ranging in age from Permian to Early Cretaceous. Very locally, some of the basins received even some non-Gondwana Palaeozoic sediments as well, but whether any of these extended to the region near Assam is not certain.

The composite crustal mass, briefly described above, forms the Basement Complex for the next phase in the geology of Assam. The exposed parts of this complex show a number of important features. Firstly, as seen from the Shillong and Mikir Hills Plateaux, it is criss-crossed by a large number of nearly rectilinear lines (Fig. 11) along which rivers and streams have cut straight valleys. Some of these may reflect major joints, but some others are obviously faults. Whilst their primary origin may have been in the Archaean - Proterozoic past, some of the faults have clearly been reactivated from time to time. Even during 1897 earthquake, the two sides of the Chidrang Fault is known to have moved by over 11m against each other.

The second set of important features are the Dauki and the Disang faults which determine the southern limit of the Shillong Plateau (Fig.12). The Dauki Fault not only provides a magnificent morphological

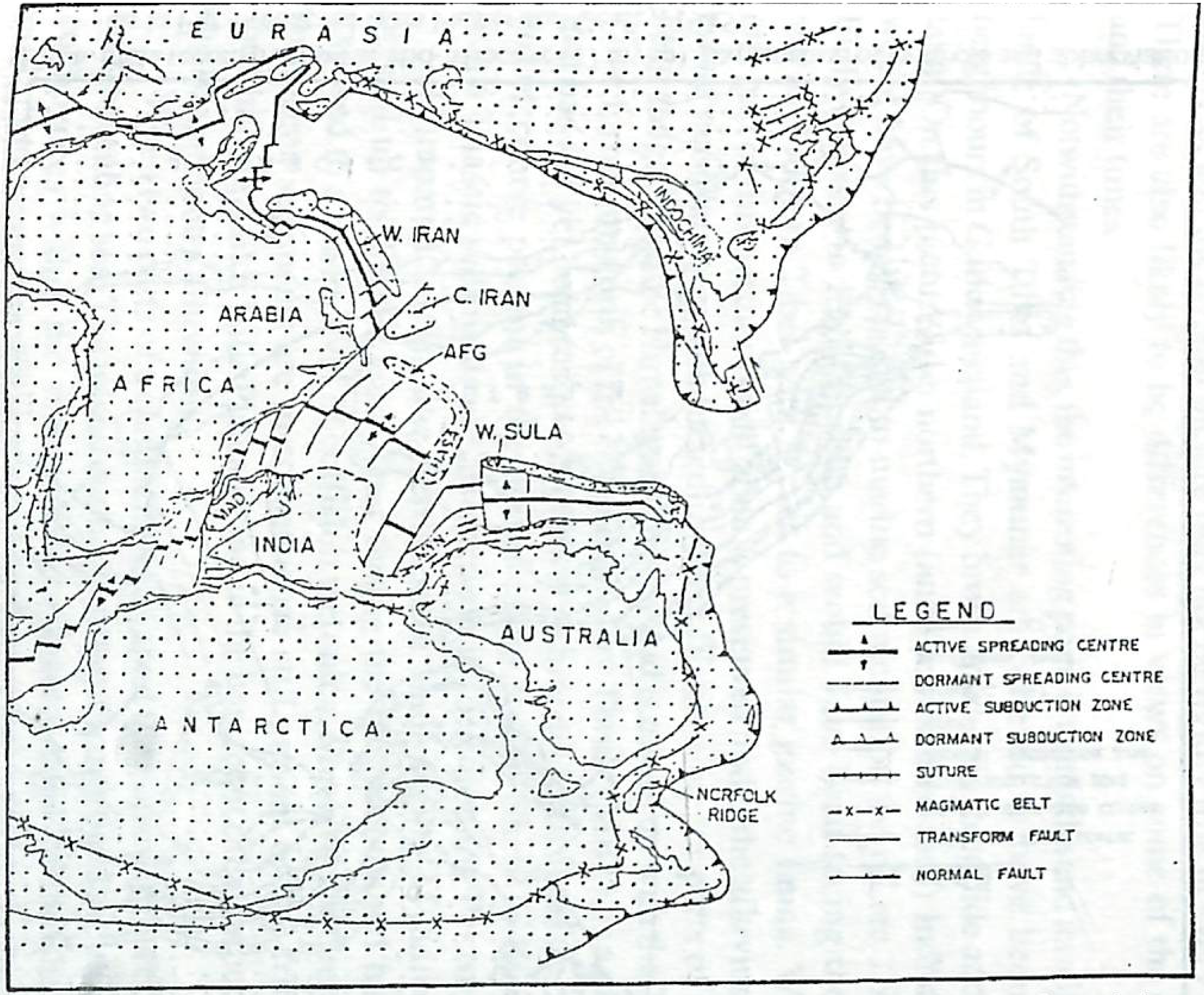

Fig.5. Plate reconstruction at Early Cretaceous (135 mybp). Explanation of symbols and abbreviations as in Fig.4 (Adapted from Parker and Gealey, 1985).

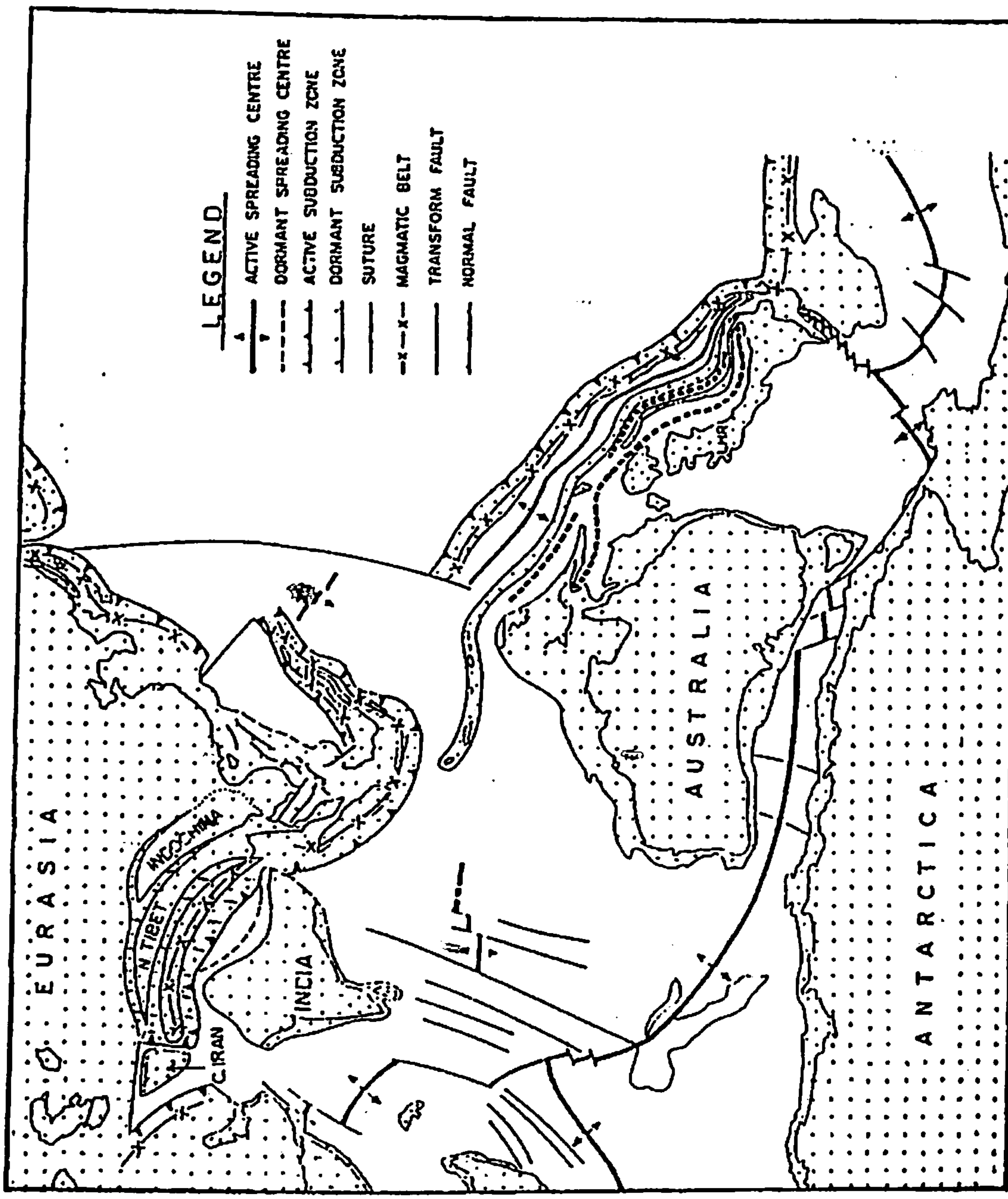

Fig.6. Plate reconstruction at Mid-Miocene (47 mybp). Explanation of symbols and abbreviations

palaeomagnetic data has had to be collected, analysed and matched with geology in arriving at the above picture of the breakup of Gondwanaland and the accretionary growth of Eurasia. Periodic reversals in polarity in the earth's magnetic field has helped within known spans of geochronology to fix the dates of some of these events. Even so, there are gaps in the database, and the overall picture may not be rigidly true in every detail. There are also likely to be differences in views on some of the events and their times.

Notwithstanding this, the interesting point is that India and its adjoining lands of South Tibet and Myanmar are believed to have been close neighbours in Gondwanaland. They broke apart only to collide and rejoin later. On this picture, the northern (and the northwestern) Indian shelf would have been exposed to marine sedimentation from Late Triassic - Early Jurassic to Early Eocene and would have been facing the same sea as Southern Tibet with access to a similar marine fauna. Whether any part of this northern shelf zone is preserved under the alluvium or its entire mass has been subducted in the collision zone, or parts of it have been caught up in the Himalayan orogeny and is mixed up with the Tibetan Zone formation north of the Main Boundary Thrust (MBT), is a problem that has not yet been resolved. Marine sediments from Jurassic onward are of course present in the northwestern Indian Shelf in Rajasthan. Some Triassic sediments are also present in the adjoining Pakistan.

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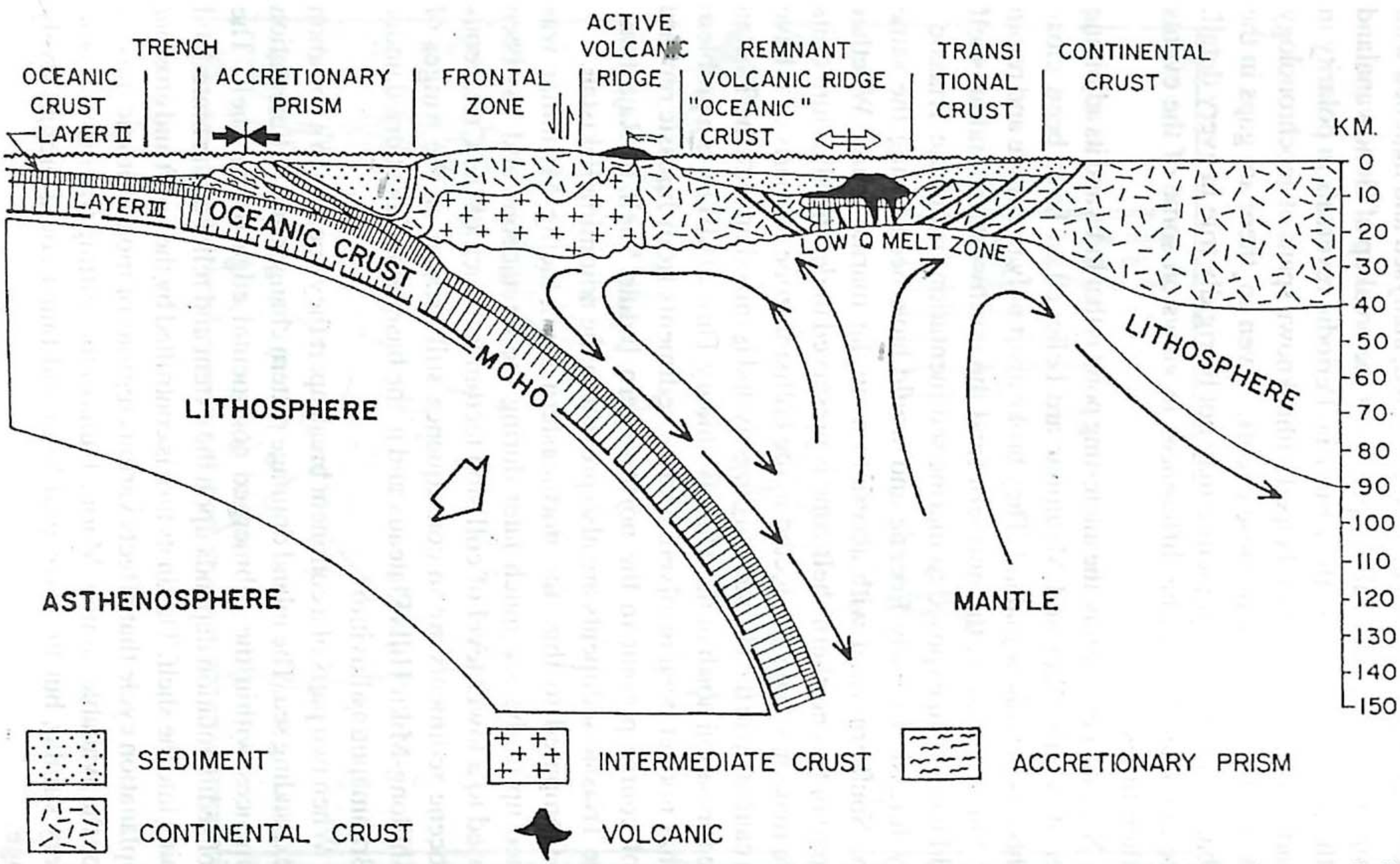

Fig.7. Morphology of a subduction zone. Figure depicts the stage of subduction which preceded the continental collision between Indian

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The Different Tectonic Phases, Sedimentation and Stratigraphy

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In descending order, we have thus in Assam a sequence of even

Recent	Young and Old Alluvium
---------- *Unconformity* ----------	
Pleistocene Pliocene Miocene Oligocene	Sedimentation during the collision period with sever tectonic interruptions and depositional breaks.
Eocene Cretaceous	Sedimentation and carbonate formation, partly in th collision zone and partly on the stable shelf. Some igne activity in Cretaceous as reflected by Sylhet Trap a other intrusives.
---------- *Unconformity* ----------	
Gondwana Formation (Permo-Carboniferous to Jurassic)	Only a small development recorded from Assam pro but thicker development may be present in the Basem complex below the alluvial areas.
---------- *Unconformity* ----------	
Precambrian Basement Complex	Representing a part of the Gondwanaland crust. Prima of Proterozoic age in Assam.