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Geology and tectonics of Arakan Yoma - A reappraisal

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Abstract: The tectono-stratigraphic evolution of the Arakan Yoma Orogen with the Naga and the Chin Hills, positioned between the Sunda arc and the Himalayas, is vital in the framework of convergence of the Indian plate with Asia. The Orogen is flanked to the west by the Assam-Burma Cretaceous-Tertiary turbidite-molasse basin and further west by the Meghalaya (Shillong) Plateau; to the east by the Mesozoic-Cenozoic Central Burman molasse basin and the Shan-Tenasserim block east of the Shan Boundary Fault.

From the above tectono-stratigraphic setting it is surmised that the present site of Naga Hills - Arakan Yoma - Chin Hills has been marked by a meridionally trending spit of land projecting southward from the Angara land during Palaeozoic time forming Archipelagos of islands made of basement rocks, the western slope of which fell away into the Assam-Burma trough having oceanic floor in front of the subducting Indian Plate. On its eastern side, sediments were deposited over a submerged peneplained(?) Pre-Cambrian metamorphic basement volcanic line representing supra Benioff seismic zone volcanic front.

Continuous diastrophism, along a N-S arcuate axis, of the basinal sediments on either side of the Arakan Yoma and gradual upheaval of the same since Eocene indicate that this belt has been under constant and uneven E-W compressive stress due to eastward subduction of the India Plate. The peak of deformation and upheaval had been at the close of Oligocene shaping the mega fabric of the Arakan Yoma tectogene. The Bouguer gravity anomaly contours run parallel to the axis of the sedimentary basin and the fold belts. Maximum negative value contours running adjacent to the flysch trough and the ophiolite belt, O-anomally contour (positive by contrast) along the volcanic line and the eastward dip of the seismic zone also suggest that the Indian plate has been subducting eastward below the Shan-Tenasserim block since Eocene.

INTRODUCTION

In recent years the problems of tectonic evolution of the Indo-Burmese arc to which the Arakan Yoma is an important part, vis-a-vis the eastward subduction of the Indian Plate, has received much attention of the earth scientists who have put forward various models for its evolution based either on local geology or from interpretation of geophysical data. None has dealt with the details of the regional geology and palaeogeography and their correlation with available geophysical data. As such the present study aims at a reappraisal of the regional geology in detail and comparing the same with the siesmic and gravity data leading to a coherent picture of the geological and tectonic evolution of the Indo-Burmese arc.

GENERAL GEOLOGY

The Naga Hills-Arakan Yoma - Chin Hills Orogen is flanked to the west by the Assam-Burma turbidite-molasse basin and further west by the Shillong Plateau; to the east by the Mesozoic-Cenozoic Central Burman molasse basin and the Shan-Tenasserim block east of the Shan Boundary Fault (Nandy, 1983).

Naga Hills - Arakan Yoma - Chin Hills

The Naga Hills - Arakan Yoma - Chin Hills proper, the highest arcuate hill ranges, form the backbone for the development of the Indo-Burman tectogene. It consists of Proterozoic-Palaeozoic detached outcrops of metamorphics, Cretaceous-Eocene ophiolite suite with grit, conglomerate, cherts and foraminiferal limestone; crystalline limestone and Eocene flysch. At places they are intimately intermixed with the Disang flysch.

Exposures of metamorphic rocks occur along the eastern margin of the Arakan Yoma - Chin Hills as detached outcrops north of Kanpetlet (21°10´N: 94°02´E) and along the Myitha valley near Haka (23°N: 94°E). They are also exposed as a broad zone in Naga hills area astride the India-Burma border from Somra (25°22´N: 94°22´E) tract northeastward to Saramati Peak (25°44´N: 95°03´E) and further north-eastward up to 27°N latitude. The Naga metamorphics also continue southward beneath the Cindwin molasse and extends further south to form the basement ridge of igneous and metamorphic formations (Fig. 1).

In Nagaland the metamorphics consist of quartzite, phyllite, marble and their mylonitised equivalents occurring as thrust sheets over the ophiolites. In the Chin Hills they comprise schistose sandstone, slaty schist, crytalline limestone, talc schist, mica schist, green chlorite schist, quartzite and rubellite schist (Cotter, 1938).

All along the belt, wherever exposed, the metamorphics are steeply thrusted over to the ophiolite suite and/or the Yoma (Disang) flysch formation to the west. The ophiolite suite is represented by metaultramafites (serpentinite), ultramafic cumulates (dunite, harzburgite, lherzolite, olivine websterite, pyroxenite, wehrlite, etc.) gabbro, basalt, pillow lava, volcanic ash and volcanogenic sediments (Chattopadhyay *et al.*, 1983). They occur all along the Chin-Arakan Yoma hills as detached outcrops form Sidoktaya (20°27´N: 94°14´E) through Shauktaung, Kalemyo (23°12´N: 94°03´E), Webla Taung (23°03´N: 93°58´E), Nat Taung (23°51´N: 94°10´E) in Burma to the Manipur-Naga hills belt. In the Manipur-Naga hills area they occur in an almost continuous belt, about 15 km wide, from southeast of Manipur to Northeast of Nagaland (27 degree latitude). All along the ophiolite belt allochthonous, mostly upper Cretaceous fossiliferous limestone occur along with some Triassic and Eocene limestone beds (Nandy and Das Gupta, 1979). Ellipsoidal bodies of grit and conglomerate also occur as detached bodies in association with the limestone. The radiolarian cherts and tuffs occuring in association with the ophiolites contain Danian to Eocene fossils (Chatto padhyay *et al.*, 1983). The limestone contains microfossils ranging in age from Danian to Maestrichtian (Nandy and Das Gupta, 1979). In Nagaland there has been a report of a 25 m to 50 m wide blue schist in association with the ophiolites (Ghosh and Singh, 1981). Along the northern extension of the Shan Boundary Fault another belt of ophiolite occurs through the Bhamo-Mythkyina-Mandalay-Kalaw belt (Fig. 1).

Rocks of the above groups are highly crushed along their eastern boundary. Everywhere overfolds, faults and broken backed anticlines are seen. It seems obvious that rocks of very different ages are packed together in one metamorphosed complex. Both Cretaceous and Triassic rocks occur along with Tertiary rocks which have been folded into the Yomas (Clegg, 1941). According to Cotter (1938), conglomerate occuring north of Minbu is unconformably underlain by the metamorphics and the ophiolites. In Naga Hills three generations of fold movements have been deciphered in the Naga metamorphics (Chatto-

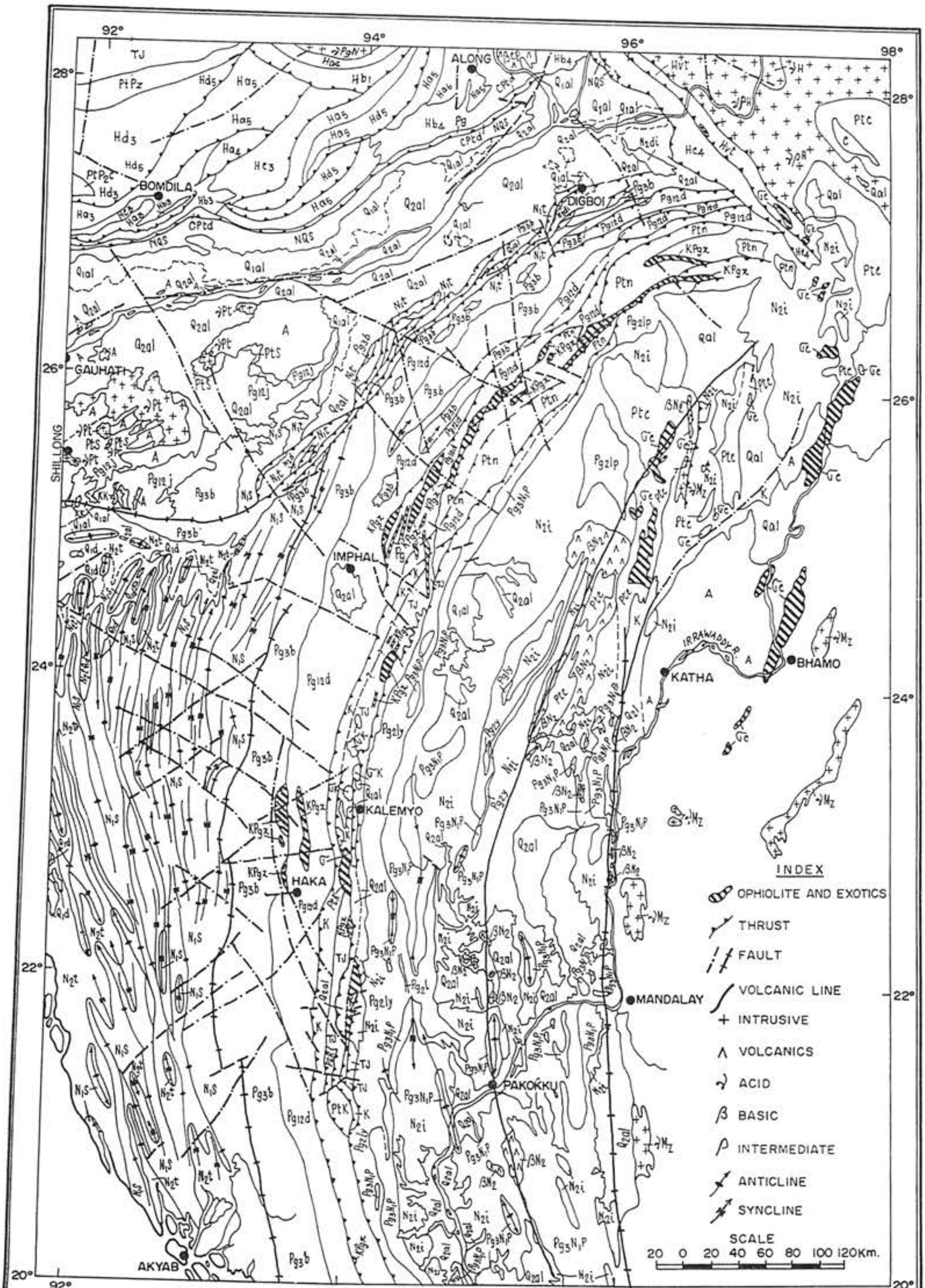

Fig. 1. Geological Map of Naga Hills – Arakan Yoma – Chin Hills and Adjoining Region: A – Archean gneiss and schist, TJ – Triassic-Jurassic Formation, K – Cretaceous Formation, Ptk – Proterozoic Kanpetlet schist, Ptn – Proterozoic Naga Metamorphics, Pts – Proterozoic Shillong Series, $Pg_{13}d$ – Palaeocene-Eocene Disang Group; $Pg_{12}J$ – Palaeocene-Eocene Jaintia Group; Pg_2ly – Eocene Laungshe, Tilin, Tabyin, Pondaung and Yaw Groups, Pg_2lp – Eocene Laungshe-Pondaung Groups, Pg_2y – Eocene Yaw Group, Pg_3b – Oligocene Barail Group; Pg_3N_1p – Oligocene-Miocene Pegu Series; NiS – Miocene Surma Group, N_1t – Miocene Tipam Group (Upper Assam); N_2t – Pliocene Tipam Group (Surma basin); N_2di – Pliocene Dihang Group, KP_{gx} – Ophiolites and exotics; σc – Pre-Tertiary serpentinite; σk – Cretaceous ultrabasics, NQS – Neogene-Quartenary Siwaliks, Q_1d Pleistocene Dupitile Formation, Q_1al – Pleistocene Older Alluvium, Q_2al – Holocene and Alluvium, H – Undated Himalayan formations, a – Lowgrade schists, b – quartzite and carbonate sequence, c – High grade schist; d – gneisses, CPtd – Carboniferous – Permian Talchir and Damuda Groups.

padhyay *et al.*, 1983). The first generation of fold trends N-S to NNE-SSW with axial plane steeply dipping towards east. The second generation folds have E-W axes and the third one trending N-S is a large scale drag fold with vertical axial plane. Within the ophiolite suite, the various members occur as fault bounded slices. As a whole this linear arcuate belt of metamorphics and ophiolite suite is bounded on either side by east dipping thrusts, at places assuming imbricate pattern (Fig. 1).

Assam-Burma flysch trough

The flysch trough developed since Palaeocene time in a narrow arcuate belt from the Gulf of Martaban to the North-eastern corner of India along the western edge of the present day Arakan Yoma. The flysch consists of a massive sequence of shale, mudstone, clay and intercalated greywacks sometimes passing into slate and phyllite which together are 3000 m thick. Their eastern boundary is limited by the ophiolite suites and melange. The relation of this flysch group with the overlying Oliogene subflysch Barails (4000 m thick) is gradational. The flysch group of rocks are characterised by the primary sedimentary structures such as graded bedding, load cast, flute cast, ripple marks and ripple drift cross laminations reprensenting products of turbidity current. They include marine invertebrate fossils. The sequence is more arenaceous towards the top.

The presence of microforams and other invertebrate fossils suggest that deposition took place in a shallow marine syntectonic environment over an oceanic floor. In the Chin ?Hills and Arakan Yoma area the flysch group is inter-tongueing with the Lower Eocene Laungshe shale of the Central Burman basin.

Three generations of folding have been deciphered in the flysch group in Nagaland (Chattopadhyay *et al.*, 1983). The earlier folds are large folds with N-S to NNE-SSW trending axial plane having sub-horizontal to steep dip. The folds are flexural slip type giving rise to isoclinal, inclined and reclined styles often overturned towards west. The second generation movement is represented by broad N-S upright folds while the third one has E-W axial trend. In the Arakan Yoma-Chin Hills area exotic flysch blocks, transported for long distances towards west, are common.

The flysch trough gradually shallowed up during the Oligocene time with the deposition of subflysch 4000m to 6000m thick Barails (Raju, 1968) consisting mainly of sandstone with coal bearing horizons in upper Assam. This formation later got co-folded with Disang and Yoma flysch at the close of Oligicene to form the Arakan Yoma and Barail hill ranges.

Assam-Tripura-Bangladesh Molasse basin

During Miocene times Tipam molasse (4100 m) were deposited in the Upper Assam foredeep and Surmas (4000 m) subflysch/molasse were deposited in the Surma basin south of Shillong Plateau over a pronounced unconformity (a common feature in the Indo-Pacific region) in gradually closing basin conditions. The Tipams of Upper Assam is represented by arkosic sandstone and mottled clay and the Surmas are represented by siltstone, sandstone, shale-silt alterations (Nandy *et al.*,1983). While the Tipams of Upper Assam were thrusted and sliced in imbricate northwest directed thrust sheets (Belt of Schuppen; Evans, 1964), Surmas were folded and faulted into a series of long linear N-S trending arcuate synclines and anticlines subparallel to the arcuate flysch belt. Diastrophism in a E-W compressive field went hand in hand with sedimentation in these basins. Plio-Pleistocene period was witnessed by the deposition of coarse clastics in restricted basins in these peripheral areas.

Shillong Plateau

After the effusion of Jurassic-Cretaceous Sylhet traps along E-W Dauki fault and intrusion of Cretaceous Carbonatite-ultramafic complex right in the centre of the plateau, sediments of shelf and platform facies were deposited along the southern and eastern margin of the Shillong plateau and Mikir hills throughout the Tertiary period. Shillong Plateau and Mikir hills are separated by a tract of alluvium and the NW-SE trending deep seated Kopili fault (Das Gupta and Nandy, 1982) and both having continuous history of upheaval through the Cenozoic era.

Central Burman Molasse Basin

The Central Burman molasse basin lying between the Chin - Arakan Yoma - Naga Hills and the Shan Boundary Fault in the east is characterised by the presence of marine to fresh water Palaeocene - Tertiary 10000 m thick sediments. The sediments have been grouped into Palaeocene basal conglomerate, Eocene Laungshe shale, Tilin sandstone, Tabyin clays, Pondaung and Yaw stage; Oligocene-Miocene Pegu Series consisting of Oligocene Kyaukpon, Swezetaw, Tiye, Padaung and Okmintaung formations and Miocene Pawbwes, Kyaukkok and Obogon formations. These are followed stratigraphically upward by the Pliocene Maw gravels and Irrawaddy formations over a marked unconformity.

Up to the upper Eocene period the eastern shore line of the basin was somewhere near the Wuntho-Medin-Popa volcanic trend and the deepest part of the basin lay westward along the Yenan-Myitha-Gangaw-Arakan Yoma trend with the basin shallowing eastward. The basin extended towards Shan Boundary Fault during Oligocene time.

The break in planktonic faunal sequence in the uppermost beds of Okmintaung formation suggest a break in deposition, probably a disconformity between Uppermost Oligocene and Lowermost Miocene, as in also the case in other parts of Indo-Pacific region (Maung, 1970).

The Laungshe, Tabyin and Yew formations were deposited in comparatively deeper water marine conditions whereas the Pondaung formation was deposited in shallow water fluviatile conditions. During the Oligocene period fluviatile/deltaic conditions prevailed in the north whereas there was prevalence of marine condition in the south (Maung, 1970).

The sediments are folded into 4 N-S trending anticlines between 20°N and 22°N latitudes. The sediments at the western margin completely overrides the eastern part of the Indo-Burma flysch. At places along the east dipping thrusts, the thrusts mechanism has sliced out substantial igneous and metamorphic rocks of the Chin-Arakan Yoma-Naga Hills.

Igneous rocks of the Central Burman Basin

They occur in an arcuate narrow belt and occupy a central position in the Central Tertiary basin of Burma which extends from the Gulf of Martaban in the south to the Hukuang valley in the north along the Wuntho-Medin-Popa volcanic line. They are represented by 10 to 11 explosion craters situated along both banks of the Chindwin river near Shwezaye (22°22´N: 95°0´E) and at Letpandaung (22°5´N: 95°5´E).

The igneous rocks include andesite, basalt, rhyolite, gabbro, rhyolite breccia, volcanic ash, coarse andesitic tuffs and bedded tuffs. The andesitic rocks occur at Maukthayet (27°7´N: 94°58´E), Salingyi (21°58´N: 95°5´N); West of Shinmadaung (21°34´N: 95°6´E), Ingyintaung (22°6´N: 94°58´E) and Linzagyet (21°51´N: 95°5´E).

The igneous rocks occuring at Taungbet, Taungshe, Taunghyngyi and Onebin lying west of Shinmadaung consists of lithic tuffs containing in addition to volcanic materials, feldspar crystals, splinters of quartz, fragments of andesite and partially kaolinised volcanic ash and numerous fragments of volcanic rocks (Barber, 1936). The area lying at the western foot of Taungtha in Shinmadaung area is strewn with large boulders and small fragments of metamorphic rocks probably brought up from the shallow crystalline floor by the paroxysmal activity of the volcanic vents from which other pyroclastic rocks were extruded (Barber, 1936).

The age of the igneous rocks extends from upper Eocene to Quaternary period.

PALAEOGEOGRAPHY OF THE REGION

From the available geological record it is difficult to decipher the pre-Mesozoic history of the Indo-Burma region. However, during the late Mesozoic period the eastern gulf, greater part of the Central Burmese area as well as the eastern margin of the Assam, Manipur and eastern fringe of Bengal, became split longitudinally into two separate basins at first by an archipelago of islands formed of basement rocks, and then eventually by a long ridge of land over what now exists the Arakan Yoma and its northward and southward continuation (Threshold belt of Brunnschweiller, 1966). This projected southward as a narrow land from the Angara Landmass (Pascoe, 1973). The western slope of the ridge fell away into the Assam-Burma flysch trough having oceanic floor while on its eastern side shallow marine and fluviatile (shelf and molasse) sediments were deposited in the epicontinental central Burman basin. On the shoulder of this projected ridge Triassic sediments and Cretaceous foraminiferal limestone, grit and conglomerate were deposited. During Palaeocene-Eocene times Disang and Yoma flysch were deposited in a long narrow arcuate gradually subsiding western Assam-Burma basin (flysch trough) while shallow marine and fluviatile sedimentation continued in the eastern Central Burman basin in an epicontinental back arc oscillating basin environment. The basin was filled up gradually both in transgressive marine and regressive fluviatile conditions with a general north-south slope during Eocene and early part of Oligocene (Maung, 1970). During Eocene time the western part of the Basin was relatively deeper than the eastern part.

During the Lower Eocene, the whole of the Pegu Yomas was land, as present basement studies show that it is a very shallow Oligocene-Miocene basin. The shore line was somewhere west of Wuntho-Medin-Popa volcanic trend (Khin and Win,1968). The onset of upper Eocene was marked by widespread continental condition over the whole Burma Tertiary, except probably the deepest part of the previous sea. It also marked the gradual emergence of Arakan Yoma. In the eastern border this phase was marked by volcanic activity all along the Wuntho-Medin-Popa line (Khin and Win, 1968). The activity continued through the Oligocene to Quatenary period.

During Oligocene the Assam-Burma basin gradually shallowed up with the gradual uplift of the Arakan Yoma to receive the Barail subflysch with restricted basin conditions towards north which was favourable for formation of coal deposits. During this time the Central Burman basin got extended towards east up to the Shan Boundary Fault with deposition of the shallow water Pegu series (Kyaukpon, Shwezetaw, Tyio, Padaung and Okmintaung formations).

At the close of Oligocene the whole of the Chin Hills - Arakan Yoma - Naga hills along with the Disangs and Yoma flysch and Barail subflysch suddenly got uplifted with a break in sedimentation in both the basins on either side of it.

The break in planktonic faunal sequence in the uppermost beds of Okmintaung formation suggest a break in deposition probably a disconformity between uppermost Oligocene and lowermost Miocene (Maung, 1970).

During this time the Assam-Burma basin in the west got separated into the Upper Assam Tipam molasse basin in the north and the Surma basin to the south of the Shillong Plateau having its opening towards the present day Bay of Bengal. Thus the Miocene Tipams of Upper Assam and the Surmas of the Surma basin were deposited to the west of the Arakan Yoma over a marked unconformity in a fluviatile to deltaic environment in front of the rising Barail ranges. Sedimentation went hand in hand with diastrophic movements in a E-W compressive stress field giving rise NNW-SSE, N-S and NNE-SSW trending along arcuate folds, faults and imbricate thrusts. The polarity of these basins migrated further west during Plio-Pleistocene time depositing coarser clastics in restricted basin conditions along the western periphery of the Oregon. During Pliocene time fresh water fluviatile conditions prevailed all over the Central Burman Basin.

Shillong Plateau and the Mikir hills proper remained a positive landmass through the Mesozoic-Cenozoic era with deposition of shelf and platform sediments in the south and eastern margin of the Plateau.

SEISMICITY AND GRAVITY ANOMALY OF THE REGION

The region falls in the highly seismic zone of the world. 252 earthquake events have been plotted on the generalised tectonic map of the region (Fig. 2). Earthquake data have been obtained from the National Geophysical and Solar Terrestrial Data Centre, U.S.A. through request and from the available published literature for the period from 1845 to 1980.

From scrutiny of these data it can be seen that out of 252 earthquake incidents 104 have focal depth varying from 70 to 200 km and most of them are located in between the Chin Hills - Arakan Yoma - Naga Hills thrusts zone and ophiolite belt and the Central Burman volcanic line (Fig. 2). A few of which are also located along the Kopili fault in between the Shillong

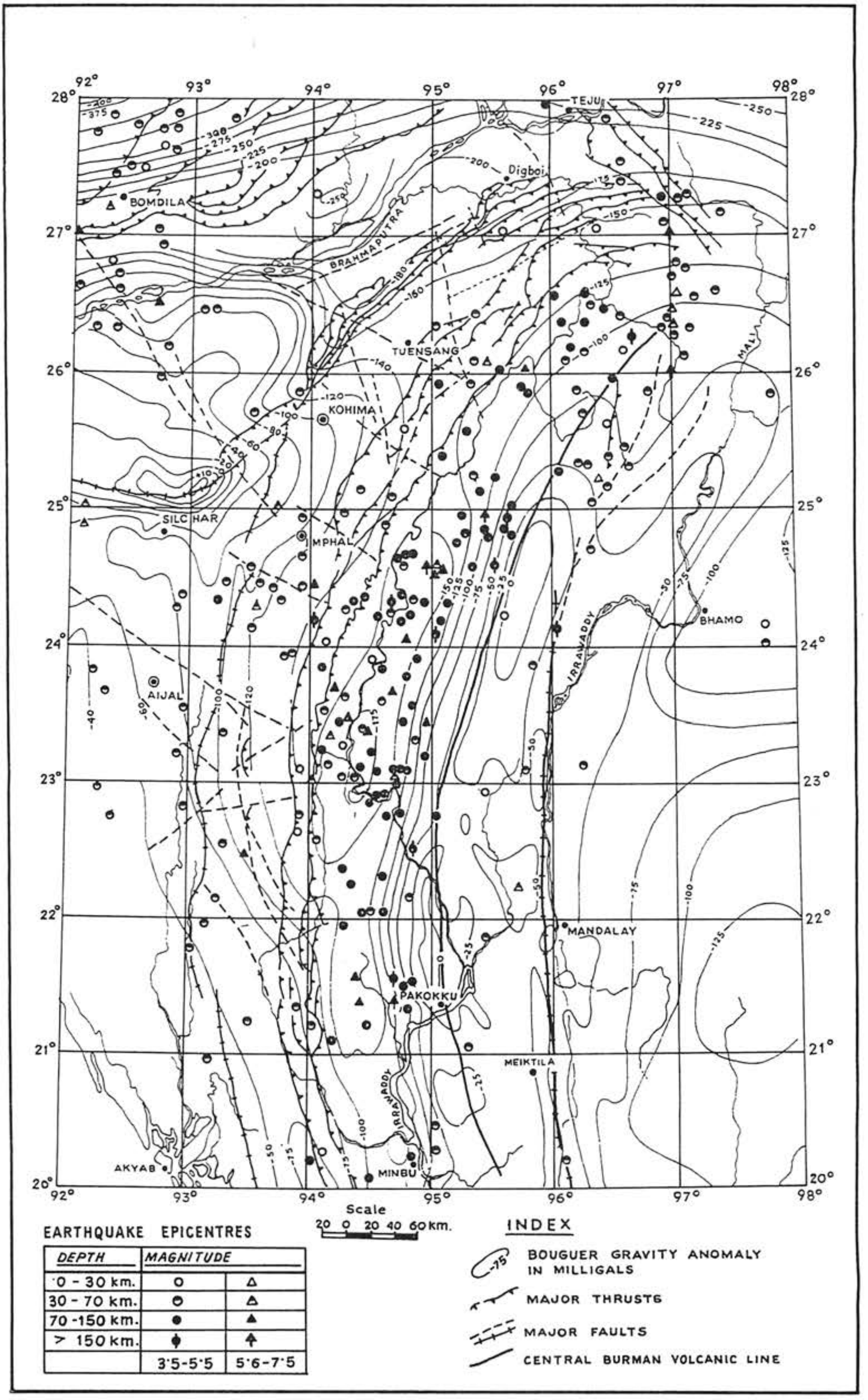

Fig. 2. Seismicity and gravity anomaly map of Naga Hills-Arakan Yoma-Chin Hills and adjoining regions – showing the Bouguer gravity anomaly contours and location of epicentres of earthquake recorded from 1845 to 1980 with major tectonic elements of the area.

Plateau and Mikir hills. The shallow focus (< 70 Km) earthquakes are spread all over the region except the Shan block which is relatively aseismic.

The Bouguer gravity anomaly map has been prepared from the similar maps published by Verma and Mukhopadhyay (1977) and Evans and Crompton (1946) for the area lying south of 27° latitude and from the gravity anomaly map of Asia on 1:9 m scale published by the U.S. Airforce in 1971 for the area lying north of the 27° latitude (Fig. 2). The anomaly varies from +20 milligals in the southeast corner of Shillong Plateau to – 400 milligals in the eastern Himalayas at the north-western corner of the area under reference.

The gravity anomaly map reveals interesting features. In the Surma basins, Chin Hills - Arakan Yoma - Naga Hills area and in the Central Burman basin gravity contours run in a N-S arcuate pattern almost parallel to the regional structural trend. In the north they are deflected towards east in the Hukuang valley and Mismi block area. The zone between the eastern margin of the Indo-Burman volcanic line is characterised by a zone of gravity minima with lowest value of -175 milligals. Further to the east and adjoining the volcanic line gravity value increases to 0 (positive by contrast).

The gravity values gradually diminish towards north of the Shillong Plateau and reach up to -300 milligals in the eastern Himalaya. The contours run in a general E-W trend with a certain sharp kink along the belt of outer fishscale thrusts of the upper Assam basin (Belt of Schuppen).

DISCUSSION AND CONCLUSION

From the geological records described in the foregoing it is evident that there was N-S arcuate linear landmass along the eastern margin of the present day Chin Hills - Arakan Yoma - Naga Hills (Indo-Burman Orogen) which formed the Threshold belt (Brunnschweiller, 1966) during Palaeozoic-early Mesozoic time. To the east of this was a peneplained landmass with Pre-Cambrian metamorphic basement covered by Palaeozoic-Mesozoic rocks which subsided gradually to form the Central Burman Tertiary back arc basin. To the west of the Threshold belt was a sea. During Upper Mesozoic times foraminiferal limestone, grit and conglomerate were deposited on the shelf on either side of it.

The eastern margin of the sea started subducting below the threshold belt during Palaeocene-Eocene times due to eastward movement of the Indian plate giving rise to the development of the Disang and Yoma flysch trough with the deposition of radiolarian cherts and euxinic flysch. The Central Burman basin gradually subsided due to the pull of subduction below it.

During upper Eocene time when the lithospheric plate subducted to about 100 km depth there was a cessation of steady state subduction resulting in decoulping of the subducting slab, shallowing of the flysch trough, prevalence of widespread continental conditions over the Central Burman basin and initiation of the SBZ volcanic fronts along the Central Burman volcanic line (inner arc) at a distance of about 160 km from the subduction zone (Fig. 3). This period was also marked by the gradual emergence of the Indo-Burman Orogen.

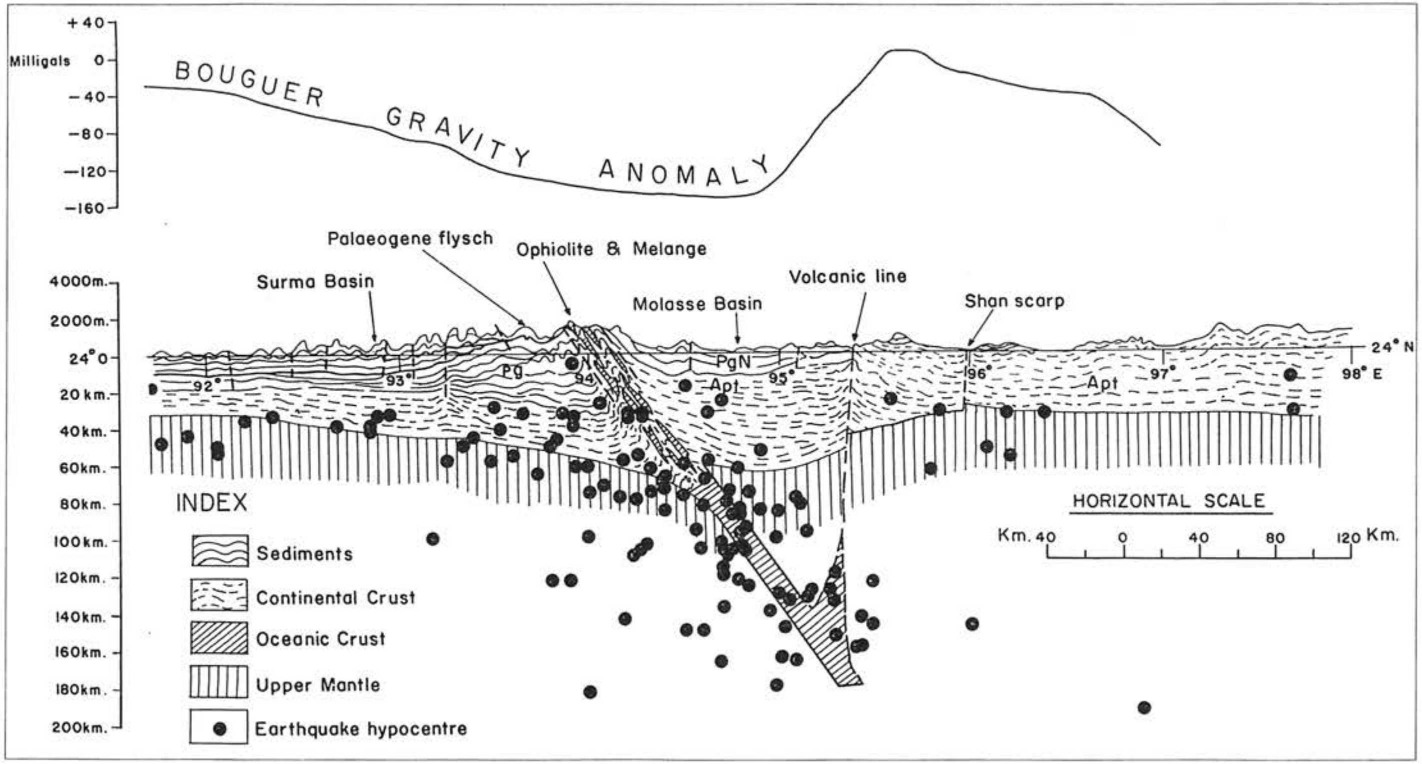

Fig. 3 Geological section along 24° latitude. Data of surface geology were plotted originally on 1:1 m scale with hypothetical subsurface geology. All the earthquake hypocentres falling between 23° and 25° latitude have been projected on to the vertical plane of the section. All letter symbols are as indicated in Figure 1.

During Oligocene time the process of subduction continued slowly while Central Burman basin extended further east upto the Shan Boundary fault and the flysch trough shallowed up as the Indian plate came close by the Threshold belt.

At the close of Oligocene the Assam-Burma flysch trough was completely closed leading to the detachment of the subducting slab and obduction of the decoupled slab along with the overlying flysch and marginal upper Mesozoic shelf sediments to form the zone of ophiolite and melange (Figs. 1 and 3). The metamorphic basements of the threshold was thrust over the zone of ophiolites and melange due to eastward push of the Indian plate. This resulted in the creation of the Indo-Burman Orogen in which are welded the metamorphic basements, Triassic-Jurassic sediments, Cretaceous-Eocene ophiolites, flysch and shelf sediments (Fig. 1).

Concentration of intermediate focus earthquake in a linear belt east of the ophiolite and melange indicates that the Indian plate is still subducting below the Shan block (Fig. 3) at an angle of 50° to 60° towards east (Das and Filson, 1975).

The Bouguer gravity anomaly pattern shows that the crustal composition and disposition pattern has got uniformity along the N-S arcuate zone parallel to the Indo-Burman orogen. The gravity minima between the flysch/ophiolite belt and the volcanic line suggest the sagging of the crust and huge thickness of sediments in this zone due to east ward subduction of the volcanic line represents the upwelling of the melted oceanic crust and shallow basement east of the line.

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