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CONTENTS

AN OVERVIEW OF THE HAZARA ARC STRATIGRAPHY NORTHERN PAKISTAN

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Abstract : *The Hazara Arc, a NE-SW trending crescent-shaped trough and situated on the western limb of the Hazara-Kashmir Syntaxis, is the northernmost extremity of the sedimentary succession of the northwestarn margin of the Indian Plate. It is bounded on its north by the Panial Thrust and on its sonthern side, by the Main Boundary Thrust, The sedimentary geology of Azad Kashmir from Balakot to Muzaffarabad forms the northern tip of the Hazara Arc.*

The geological history of the Hazara Arc begins with a geosynclinal setting as is evidenced by the turbidite deposits. Afterwards, it remained as a shallow subsiding trough except it deepened during the Upper Cretaceous.

In Hazara stratigraphy, the Precambrian-Cambrian unconformable contact is marked by the basal Tanakki Conglomerate. There is invariable stratigraphic break in the succession below the Upper Jurassic. The Cretaceous-Tertiary boundary is marked by the residual deposits as laterite or ferruginous pisolite. The Eocene-Miocene time gap is marked by the basal pebble bed (Fatehjang Member).

Although the stratigraphic framework indicates vicissitude in the paleogeographic pattern of the Hazara Arc, the Miocene time determines the Hazara Arc as a hinterland to the adjacent actively subsiding Potwar Bastn.

INTRODUCTION

The Hazara Arc, a NE-SW trending crescent-shaped trough, forms the western border of the Hazara-Kashmir Syntaxis. It is the northernmost extremity of the sedimentary succession along the northwestern margin of the Indian Plate (Fig. 1). Its northern margin is bounded by the Panjal Thrust which separates its sedimentary geology from the low-grade metamorphics (Tanol Formation). It is separated from the neighbouring Potwar Basin on its southern side, by the Murree Fault (Main Boundary Thrust—MBT). The town Balakot, a gateway to the Higher Himalayas (Kaghan Valley), forms the northern tip of the Hazara Arc. The main highway from Rawalpindi to Peshawar is the dividing line betwen the western limit of the Hazara Arc (hitherto known as the Margala Hills) and the E-W trending Kala Chitta Range at a location where the mountainous belt is abruptly rising above the Potwar Basin. The purpose of the present contribution is to highlight some of the geological aspects of the Hazara Arc with reference to its basinal evolution and stratigraphic framework. Following is the stratigraphic column of the Hazara Arc where the formational names have been formalized by the

Stratigraphic Committee of Pakistan (1973, 1977) as such :

Murree Formation	Miocene

——————Fatehjang Member——————

(stratigraphical break from the Middle Eocene to Oligocene marked by the basal pebbly bed).

Kuldana Formation	Middle Eocene
Chorgali Formation	Lower Eocene
Margala Hill Limestone	
Patala Formation	Upper Paleocene
Lockhart Limestone	

——————Laterite——————

"Langrial Iron Ore Horizon" of Khan and Ahmed (1967) ; "Changlagali Member" of Butt (1974). (time gap from Upper Cretaceous to Lower Paleocene i.e., Maastrichtian to Danian interval marked by the residual deposits) :

Kawagarh Formation	Upper Cretaceous (Coniacian-Campanian)
Lumshiwal Sandstone	Lower Cretaceous
Chichali Formation	Upper Jurassic
Samana Suk Limestone	
Datta/Shinawari Formation	Lower Jurassic

————Invariable stratigraphic break————

(i.e. Precambrian Lower Jurassic or Cambrian-Upper Jurassic contacts)

Shekhan Bandi Formation	Cambrian
Hazira Formation	
Abbottabad Formation	

————————Tanakki Conglomerate————————

(basal conglomeratic deposits marking the break in the geological record)

Hazara Formation	Precambrian

GEOLOGICAL FRAMEWORK

A sedimentary depression, whether a basin or a trough, naturally has a well-defined outline. For example, the Potwar Basin is bounded on the north, by the Kala Chitta Range and the Hazara Arc. On its south is the Salt Range. The Jhelum River defines the eastern boundary, while the Indus River marks the western limit.

In this context, the configuration of the Hazara Arc presents an interesting geological setting which draws attention towards a perusal of the sedimentary geology of the Azad Kashmir from the towns Balakot to Muzaffarabad with reference to its stratigraphic and structural relationship with the Hazara Arc.

The structural configuration of the Hazara Arc shows that it forms the western limb of the Hazara-Kashmir Syntaxis and the town Balakot forms the northern tip of the Hazara Arc. However, the sedimentary geology of the Azad Kashmir between the towns Balakot and Muzaffarabad appears to be a dislocated lobe-shaped segment which is situated in the immediate vicinity of the Hazara Arc giving an individual identity. The sedimentary geology of the lobe-shaped segment, however, exposes the topmost Sirban Dolomite Member of the Cambrian Abbottabad Formation and the Paleocene-Eocene rocks of the Hazara Arc stratigraphy (Bossart *et al.*, 1984).

The stratigraphic framework, the structural setting and the geological locations of the towns Balakot and Muzaffarabad, all are in favour of interpretation that the geology of Azad Kashmir between Balakot and Muzaffarabad forms an integral part of the Hazara Arc.

The present-day geological setting of the dislocated lobe-shaped segment of the Azad Kashmir in the neighbourhood of the Hazara Arc, owes its origin due to structural complexity, whereby the Nathiagali Thrust appears to have contributed in moving the strata of the Hazara Arc to give rise to such geological framework.

STARTIGRAPHIC NOTES

Precambrian

The oldest exposed stratigraphic unit in the Hazara Arc is the Precambrian Hazara Formation. It derives its name after the Hazara District (now renamed as the Hazara Division). Exposure around Baragali along the Abbottabad-Nathiagali Road can be regarded as its type section. Here, it is unconformably overlain by the Lower Jurassic rocks (Datta-Shinawari stratigraphic level) and its base is faulted against the Lower Eocene carbonate rocks by the Nathiagali Thrust.

The stratigraphic name Hazara Formation was first used by Butt (1972) and later by Calkins *et al.* (1975) for the "Slate Series" of Middlemiss (1896) and the "Hazara Group" of Latif (1970). This formation is a thick succession of alternating beds of argillaceous and arenaceous deposits with occasional occurrence of stromatolitic limeston bands, which can be seen at Langrial Village (Langrial Algal Limestone), Lora-Maqsood Road and near Nathiagali (Miranjani Algal Limestone) along the Kalabagh-Nathiagali Forest Road.

The Hazara Formation is widely distributed and occupies the major central portion of the Hazara Arc. It is separated from the low-grade metamorphics (Tanol Formation) on its northern extent beyond Abbottabad, by the Panjal Thurst. The southerly extension, as already mentioned earlier, is marked by the Nathiagali Thrust, separating it from the Lower Eocene rocks.

The Hazara Formation is a turbidite sequence. The main turbidites characters observed in the Hazara Formation are the presence of :

(1) a widespread thick monotonous succession of alternating beds of shale, siltstone and sandstone.

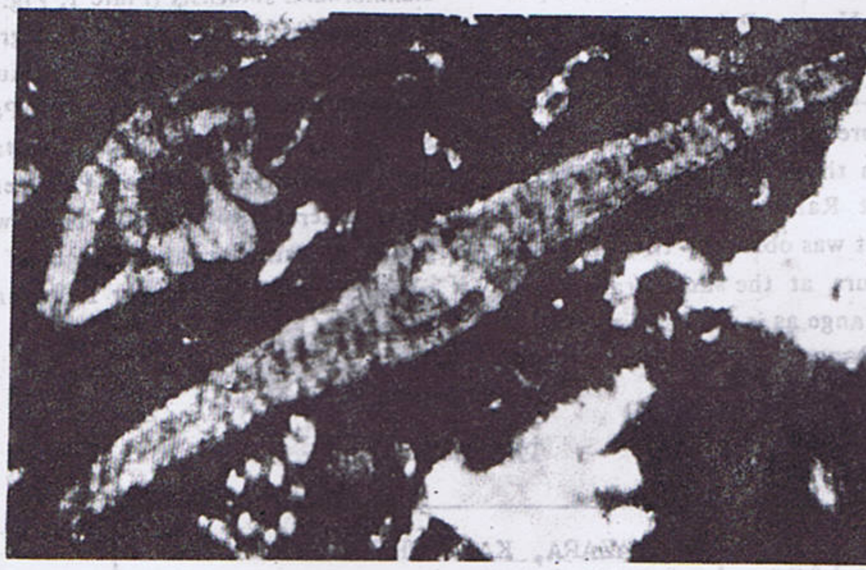
(2) Sedimentary features sueh as graded bedding (upward fining of sediments), cross-bedding and ripple marks as well as slump structures i.e., flow casts and "ball and pillow" structures.

The turbidites are characteristic of a geosynclinal setting because these happen to overlie the hemipelagic shales. Although the available thickness of the Hazara Formation reaches several hundred feet, the base of the Hazara Formation is reported to be unknown and, therefore, the presence of the hemipelagic shales becomes questionable. Despite the exposed enormous thickness and the steeply dipping beds of the Hazara Formation, the base of the Hazara Formation could not remain unexposed but, in fact, became obscured because of the faulted contact with other strata, either by the Panjal Thurst or by the Nathiagali Thrust.

It seems very unlikely that the hemipelagic shales were deposited in the Hazara Arc prior to the deposition of the Hazara Formation. This is because that the Hazara Arc was created during the Precambrian to accomodate the huge thickness of the Precambrian turbidites (Hazara Formation). The non-deposition of the hemipelagic shales is, therefore, attributed to the geological history of the Hazara Arc and the stratigraphic setting i.e., initiation of the geological setting during the Precambrian for depositing the Precambrian turbidites (Hazara Formation). However, the hemipelagic shales, if these were deposited, would have been exposed due to the influence of the tectonic style

PLATE I

a Eoannularia eocenica in association with Ranikothalia sindensis.



b Eoannularia eocenica in association with Miscellanea miscella.

c Lockhartia haimei

of the Hazara Arc, exposing almost vertical strata.

Cambrian

After the deposition of the Hazara Formation, a major geological event happened in the Hazara Arc. First of all, the widespread geosynclinal setting of the Hazara Arc disappeared due to the uplift of the major portion of the Hazara Formation and a narrow trough confined to the northwestern extremity of the Hazara Arc, developed during the Cambrian time. The shallow-water Abbottabad Formation, the Shekan Bandi Formation ("Galdanian Formation" of Latif, 1970) and the Hazira Formation were deposited in this narrow elongated trough.

The first significant break in the geological rcord of the Hazara Arc is marked by the basal conglomeratic deposits (the Tanakki Conglomerate) at the base of the Cambrian succession. Among the Cambrian succession, the Abbottabad Formation is deposited in a rythmic style. The sequence overlying the Tanakki Conglomerate begins with red-coloured. cross-bedded Sangargali Sandstone and Shale followed by pink Mahmdagali Dolomite. There is again return to red bed facies (Mirpur Sandstone and Shale) followed by off-white Sirban Dolomite.

The Sirban Dolomite is characterised by chert bands and contains economic deposits of phosphate at Kakul near Abbottabad. The presence of phosphate deposits in such stratigraphic frame work indicates shelf environments. The continued shallow shelf deposition is further substantiated by the overlying glauconitic Hazira Formation and the haematitic beds of the Shekhan Bandi Formation.

Butt (1968, p. 79), established Kihal Formation to include his newly proposed Shekhan Bandi Member (Galdanian Formation of Latif, 1970) and the Hazira Member of Gardezi and Ghazanfar (1965). In later years these facies have been accorded formational ranks. The name Shekhan Bandi Formation has priority over the name Galdanian Formation according to the normal practice of nomenclature.

In northern Pakistan, the Cambrian succession overlying the Precambrian is exposed in the Salt Range and the Hazara Arc. The stratigraphic framework at both locations exhibits paleogeographic variation as can be seen from the comparative stratigraphic table (Fig. 3). The correlation is based on the age-diagnostic trilobite genus *Redlichia* in the glauconitic Kussak Formation of the Salt Range (Fatmi, 1973) and the occurrence of pteroped genus *Hyolithes* in the glauconitic Hazira Formation (Latif, 1974).

Jurassic

A major geological event happened when the Hazara Arc became exposed for a greater time (Ordovician, Silurian, Devonian, Carboniferous, Permian, Triassic). This means that both the Precambrian Hazara Formation and the Cambrian strata became exposed for such a long time. Even at the advent of the Jurassic time, the greater part of the Hazara Arc still remained continental mass. Only a very narrow mid portion of the Hazara Arc (environs of Baragali) subsided and marine transgressive Lower Jurassic sediments containing ammonite genus *Bouleiceras* (Davies and Gardezi, 1965) were deposited (Datta/Shinawari stratigraphic level) over the Hazara Formation. This marked a major stratigraphic break between the Precambrian and the Lower Jurassic.

It is actually the Upper Jurassic time when a major transgression happened to deposit a vast blanket of shallow shelf carbonates (Samana Suk Limestone) in a large subsiding trough. Therefore, the Samana Suk Limestone happens to overlie the Cambrian succession in the environs of Abbottabad along the Hazara

A NOTE ON THE STRATIGRAPHIC DISTRIBUTION OF *EOANNULARIA EOCENICA* COLE & BERMIDEZ

BY

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The foraminiferal species *Eoannularia eocenica* has been originally reported from the Middle Eocene rocks of Cuba by Cole & Bermudez (1944). Latif (1976), however, reported it from the Upper Paleocene Lockhart Limestone of Hazara, while Butt (1987), recorded it from the Kala Chitta Range, northern Pakistan. The present author collected the rock samples from the Paleocene and Eocene rocks of the Salt Range from the Nammal Gorge (Fig. 1). It was observed that *Eoannularia eocenica* occurs at the same stratigraphic level in the Salt Range as is the case in Hazara and Kala Chitta Range. The Paleocene age of *Eoannulario eocenica* is further substantiated by the association of typical Paleocene species i.e., *Lockhartia haimei*, *Miscellanea miscella* and *Ranikothalia sindensis* (Plate 1, Fig. a-c). These observations point out the stratigraphic significance of *Eoannularia eocenica* in the Upper Paleocene deposits of northern Pakistan (i.e., Salt Range, Hazara, Kala Chitta Range) in association with the typical Paleocene benthonic foraminiferal species (Table 1) as well as establishes the stratigraphic range of *Eoannularia eocenica* from the Upper Paleocene to Middle Eocene.

TABLE-I

<table>
<tr><td>Age</td><td colspan="5">HAZARA, KALA CHITTA AND SALT RANGE</td></tr>
<tr><td rowspan="2">UPPER PALEOCENE</td><td>PATALA FORMATION</td><td rowspan="3">Lockhartia haimei</td><td rowspan="3">Miscellanea miscella</td><td rowspan="2">Ranikothalia sindensis</td><td rowspan="2">Eoannularia eocenica</td></tr>
<tr><td>LOCKHART LIMESTONE</td></tr>
<tr><td>LOWER PALEOCENE</td><td>HANGU FORMATION</td><td colspan="2"></td></tr>
</table>

Distribution of Eoannularia eocenica in the Paleocene succession of Northern Pakistan

Trunk Road, A schematic diagram is presented here to demonstrate the variable pre-Upper Jurassic unconformity (Fig. 2).

The presence of the yellow dolomite patches (secondary dolomite resulting from the diagenetic process in shallow shelf-environments), the oolitic texture and the presence of shelly layers of oysters, gastropods, bivalves, all indicate shallow water environments of deposition of the Samana Suk Limestone. The presence of the gastroped genera *Nerinea* and *Cossmanea* confirm the Upper Jurassic age of the Samana Suk Limestone. (Butt, 1962).

The Jurassic trough is further modified into a restricted marine trough to produce anoxic (oxygen-deficient) environments, thereby creating black shale facies (Chichali Formation). The presence of pyrite concretions and fragile belemnite shell *Belemnopsis* and ammonite shell *Perisphinctes* indicate marine reducing environments. Such environments promote source bed deposition, but a source rock must have a proper burial history for transformation of organic matter into hydrocarbons. The Chichali Formation lacks proper burial history and, therefore, cannot be ranked as a source rock.

Cretaceous

The anoxic trough disappeared and open marine shallow shelf environments were introduced at the advent of the Lower Cretaceous when the glauconitic Lumshiwal Sandstone containing robust ammonite fauna was deposited.

The Hazara trough deepened during the Upper Cretaceous when the Kawagarh Formation (mictritic facies) was laid down over large area. The presence of planktonic foraminifera *Globotruncana*, *Rugoglobigerina*, *Heterohelix* indicate outer neritic environments. This is the only record of deeper water facies (100-200 m depth) in the entire geological history of the Hazara Arc.

CRETACEOUS—TERTIARY CONTACT

A major geological event happened during the Upper Cretaceous (Maastrichtian) when the Hazara Arc became exposed. It remained an area of non-deposition till basal Paleocene (Danian). During this time gap, residual deposits were formed as an alteration product of the exposed carbonate rocks by the action of chemical weathering under humid climatic conditions. This produced laterite or ferruginous pisolite between the Upper Cretaceous Kawagarh Formation (Coniacian-Campanian) and the Upper Paleocene Lockhart Limestone (Thanetian) at the Cretaceous-Tertiary boundary. The residual deposits were named by Khan and Ahmad (1967) as "Langrial Iron Ore Horizon" of economic value at Dubran Ridge near Langrial (Lora-Maqsood Road) and the "Changlagali Member" by Butt (1974) after its exposure at Changlagali (Nathiagli-Murree Road). In the Kala Chitta Range, Gardezi (1974) named "Surg Laterite" to the ferruginous pisolite of Cotter (1933) exposed at Surg Village. Its excellent exposure can also be seen in the northern Kala Chitta Range at Kawa Village in the Kawagarh Range which is the type locality of the Kawagarn Formation.

While the residual deposits were formed in the Kala Chitta and Hazare from the Upper Cretaceous through basal Paleocene, a normal process of deposition took place in the Samana Range at the beginning of the Paleocene (Danian). This produced shallow shelf clastic facies (Hangu Sandstone). It is, therefore, evident that the paleogeographic variation draws attention towards presence of the Hangu Formation at its type locality near the town Hangu in the Samana Range and its non-deposition in the Kala Chitta and Hazara Ranges (Fig. 4).

Paleocene—Eocene

The Upper Paleocene and Lower Eocene rocks are widely distributed in the Hazara Arc. This indicates the existence of a widespread shallow subsiding trough where the shallow carbonate deposition predominated. The thick succession indentified into nodular Lockhart Limestone, the argillaceous Patala Formation, the nodular Margala Hill Limestone and the Chorgali Formation composed of thin-bedded limestone, was deposited in the shallow subsiding trough. This demonstrates an equilibrium between deposition and subsidence, These formations contain typical open marine shallow-water benthonic larger foraminifera of stratigraphic value. Their presence in these sediments is a testimony of open marine inner neritic (<50 m depth) environments.

A major geological event happened during the Middle Eocene when southward shift of the Hazara trough towards the adjacent Potwar Basin is envisaged. This is evident from the geographical distribution of the Kuldana Formation (typical red bed facies of shallow water origin) in the trough. Exellent section, other than the type locality of Kuldana near Murree, is exposed few kilometers further north from Kuldana along the roadside at Daryagali.

Miocene

A major geological event happened after the deposition of the Middle Eocene Kuldana Formation. This is marked by the entire uplifting of the Hazara Arc which remained exposed till Oligocene, thus creating a major time gap in the Hazara stratigraphy and maximum structural modification of the trough.

The Miocene determines the Hazara Arc as a hinterland to the adjacent actively subsiding Potwar Basin. The southernmost part of the Hazara Arc acts as a shallow shelf to the adjoining actively subsiding Potwar Basin when the Murree Sandstone is deposited as a marginal belt to the Hazara Arc but a conspicuous component of the stratigraphic framework of the adjoining Potwar Basin.

CONCLUSION

The sedimentary geology of the Hazara Arc is an excellent example of varied geological aspects. It is believed that the application of geological concepts is of fundamental importance to unravel its basinal, stratigraphic and structural framework.

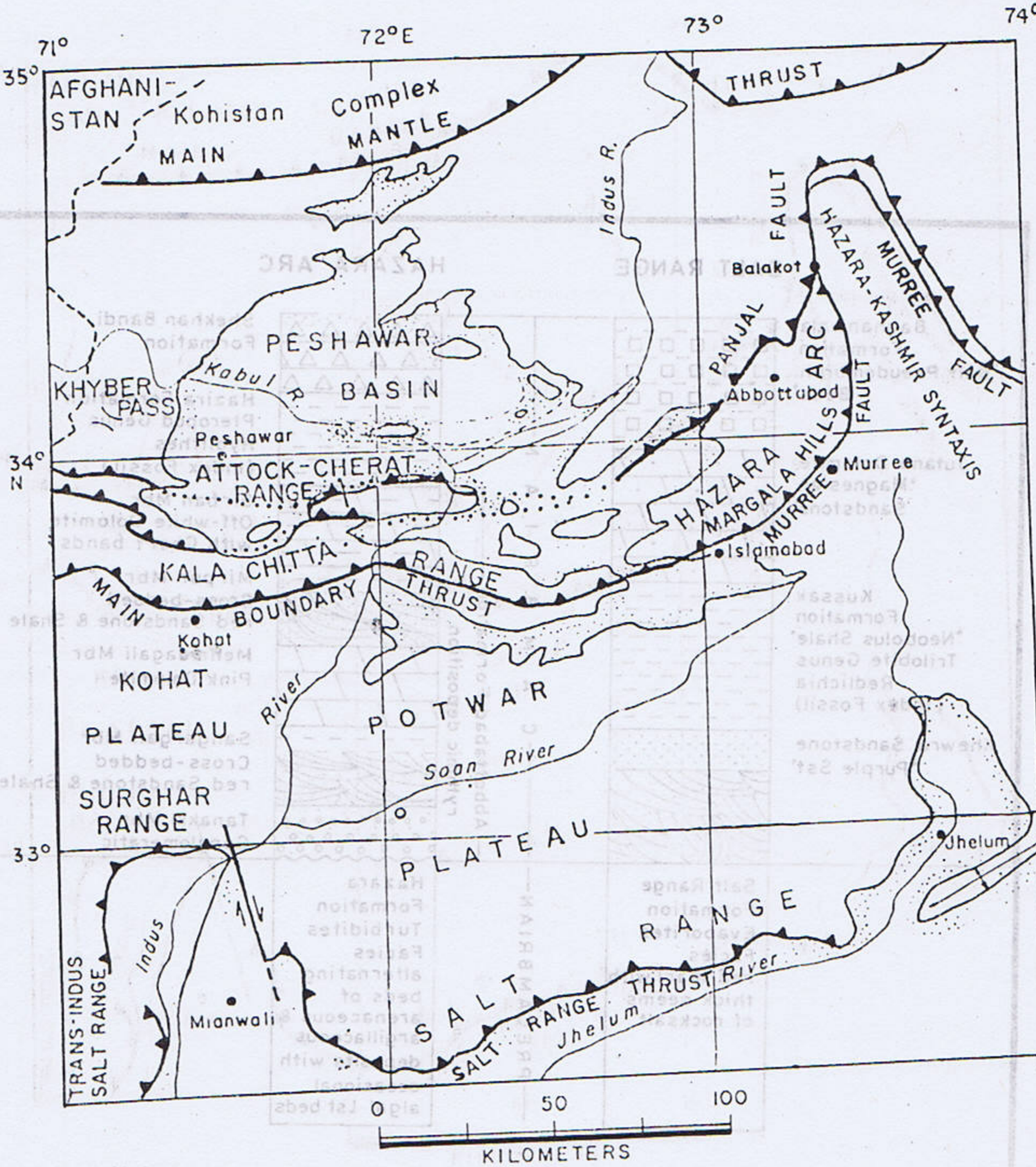

Fig. 1. Location map of the Hazara Arc northern Pakistan.

(After Yeats and Hussain - 1987)

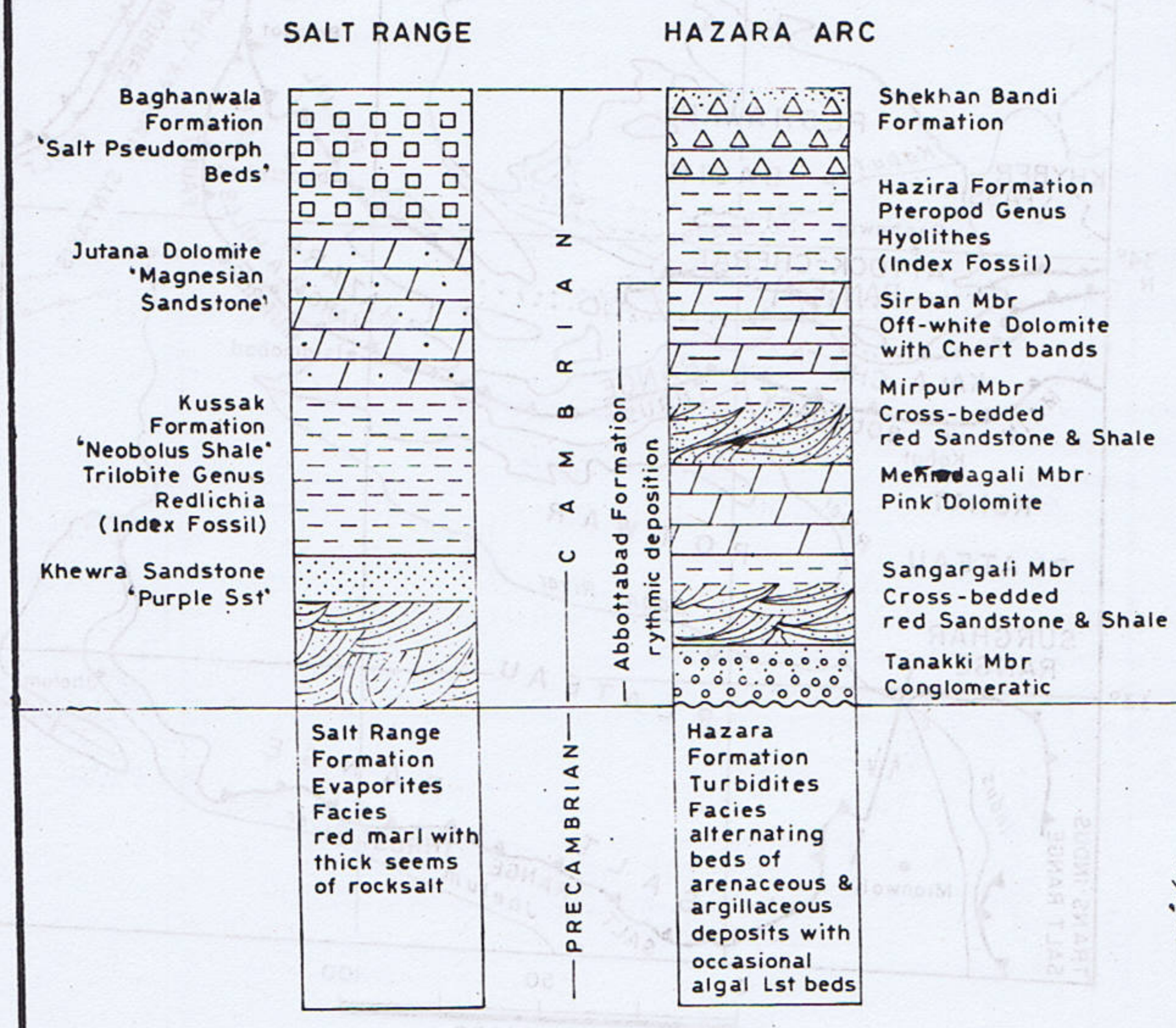

Fig: 2 . Comparison of Cambrian Stratigraphy of the Salt Range & Hazara

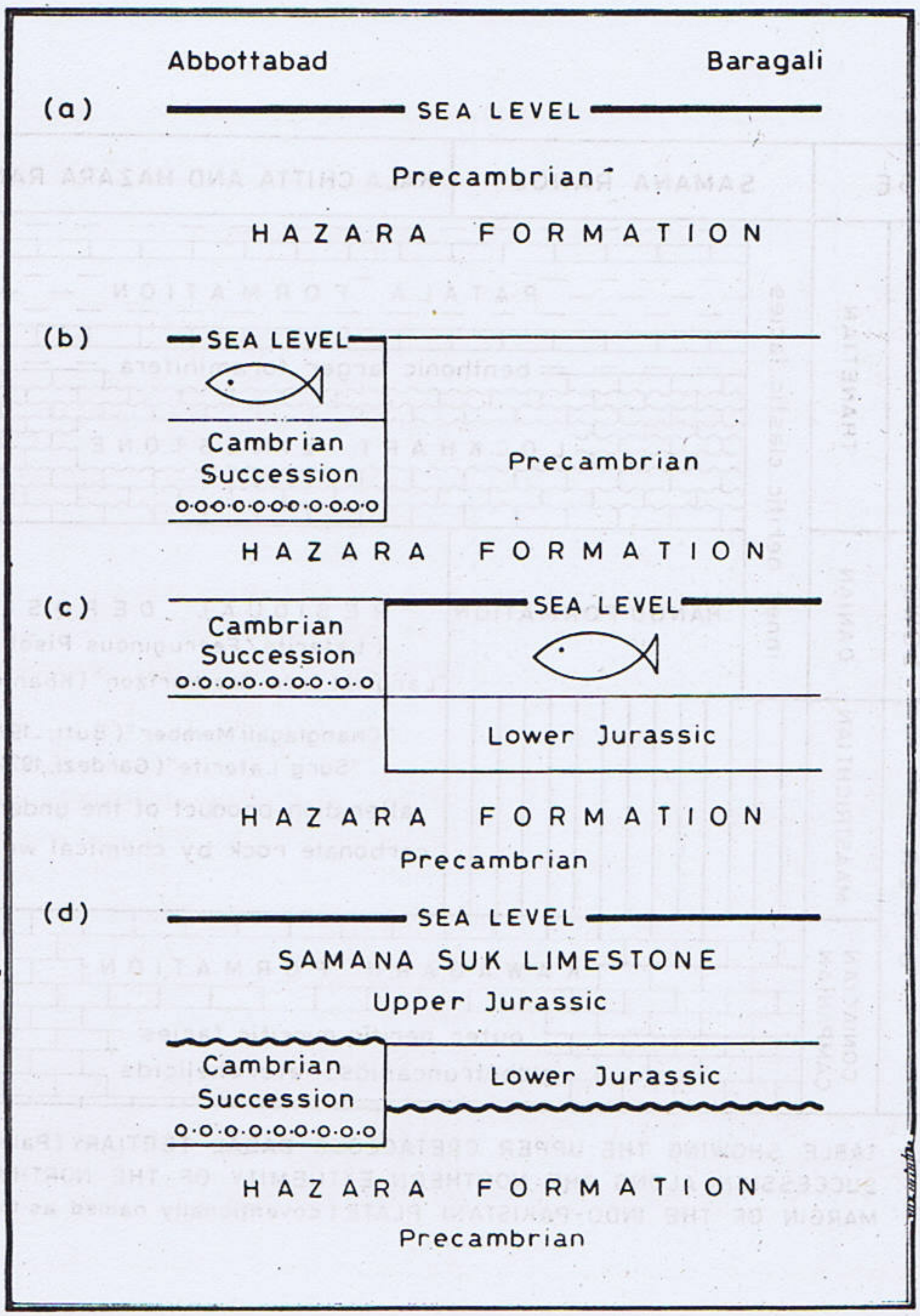

Fig.3. Schematic illustration of the Upper Jurassic transgression over the pre-existing paleogeography in the Hazara Arc

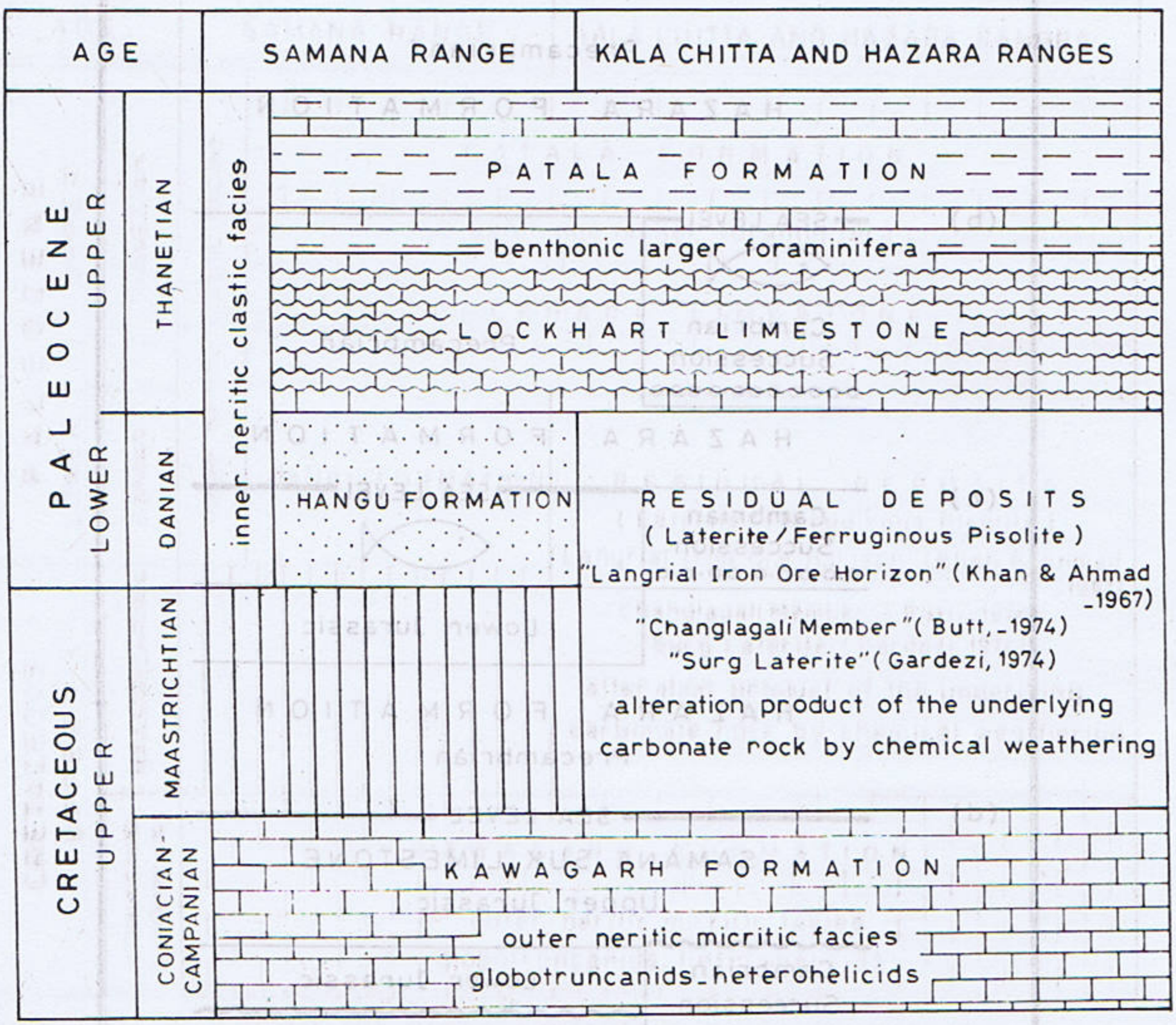

FIG.4_ TABLE SHOWING THE UPPER CRETACEOUS-BASAL TERTIARY (Paleocene) SUCCESSION ALONG THE NORTHERN EXTREMITY OF THE NORTHWESTERN MARGIN OF THE INDO-PAKISTANI PLATE (coventionally named as the Indian Plate)

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GEODYNAMICS AND COAL DEPOSITS OF PAKISTAN

BY

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Abstract : *The three coal provinces of Pakistan spread over a potential area of 2,500 sq. km. contain an estimated reserves of about 1.5 billion tons of coal. An overall pieture of these deposits have been examined by drawing suitable trend diagrams based upon more than 200 proximate chemical analysis which point out some of the basic differences between the Paleocene and Eocene coals of Pakistan, apart from their distinct structural placement in regional geology. Five significant stratigraphic coal horizons have been discussed producing original maps for probable coal basin extension in the Salt Range and Makerwal areas of the Upper Indus Basin which may open a new ehapter for future eoal exploration in Pakistan. Data on calorific values for different coals is considered to be a new tool in understanding coal basins on a regional level.*

INTRODUCTION

Eversince the introduction of plate tectonic concept in Pakistan in late seventees, geologist/geophysicists have contributed much on understanding regional geodynamicism (Tahirkheli *et al.* 1979, Farah *et al.* 1979) with topics like the movements of Indo-Pak Plate with its corresponding deformation, remnants of oceanic crust, major thrusts like the Chaman Fault, MKT and MMT leading to the discovery of Kohistan Island arc (Tahirkheli 1979) in the NW Himalaya. Later on, Shams (1983) exclusively dealt with granites of the Himalayas, Karakoram and Hindu Kush with reference to the tectonic events of this region. Quite recently, the overall challenging nature of the Himalayan geology has attracted yet others like Coward *et al.* (1986) and Pudsey *et al.* (1986) to jot it down on the same interesting topics but certainly with more facts and figures. Meanwhile a little change has been brought by Haq *et al* (1984) by introducing marine geology and oceanography of the Arabian Sea, vis-a-vis geodynamicism of Indo-Pak Plate and by Nakazawa *et al* (1985) laying emphasis on paleogeography and paleobiofacies from Paleozoic concerning basically the Tethys realm of this region. The novelty and beauty of all such contribution, in fact, has demanded to explore areas of economic interest. It is with this background that the author has made this attempt to view coal deposits of Pakistan. In the following lines a broad regional outlook has been presented elaborating more with the help of chemistry.

Regional Occurrence of Coal

Well-known coal deposits of Pakistan have been shown in Map-1, while in Fig. 1 & Table-1 important coal data like geological horizon, age, reserve position and range of chemical composition alongwith respective calorific values have been presented.

Geologically, there are five important and two less significant stratigraphical horizons making the sequential coal history in the Indus Basin of Pakistan (Map-1 & Fig. 1). The eventual deposition started around north and north-west of the Sargodha High at the beginning of Permian (top of Tobra Formation). Its small exposure has been found at Buri Khel and has been struck in drilling at Sarai Sindhu (Hassan 1986) near Multan. In Jurassic, highly insignificant coal occurrences have been reported in Surghar Range and Pezu areas. Coal of some economic interest started developing after Cretaceous when epeirogenic movements tilted the Indo-Pak Plate from SE to NW. (Gee 1983). At the beginning of Paleocene (Hangu Fm) the northwestern part around Sargodha High (Surghar Range) underwent transgression with suitable environmeots for coal development. During mid Paleocene, Sonda-Thatta area of the Indus Basin (Bara Formation) underwent with such suitable environments. It was followed by a still wider suitable paleo-environments, when during Late Paleocene, Lakhra coal field developed towards south of Hyderabad High, while central and eastern Salt Range coal (Patala Formation) has developed in the north of Sargodha High. The fifth onslaught is possibly a highly limited one as only it developed during early Eocene (Laki Formation) at the Meting Jhimpir area of the Lower Indus Basin. Later on the traditional depositional places around Sargodha and Hyderabad High entirely shifted towards west along the southern part of the newly emerging Axial Belt where coal deposited during early Eocene (Ghazij Formation) at the Quetta Syntaxis spreading towards south and south-east (Map-3) Like Jurassic, other less significant coal also occurs in Oligocene at the Dera Ghazi Khan area.

Permian Coal

The earliest coal in Pakistan has been found at Buri Khel (Map 4) at the top of Tobra Formation of Asselian age (Early Permian). Though earlier worker (Raza *et al* 1977) placed it in the Warcha Sandstone (early Permian) and also maintained that sub-vitreous Permian coal had been hit in the sub-surface in an oil wild cat in Indus Plains near Multan (Sarai Sindhu) at a depth of about 2,700 metres. Tobra Formation consists of boulder beds with claystone and siltstone (Shah 1980) deposited io glacio-fluviatile to fluviatile environments. According to Bhatti (1967) it is a detrital coal which has been deposited in sandstone beds. Maximum thickness of coal seam at Buri Khel is 162 cm while at Sarai Sindhu, it is about 3 metres. According to Hasan (1986), presence of the same has indicated the existence of "coastal forests" along the western part of the Indo-Pak plate during the Carboniferous period.

PALEOCENE COAL (MAKERWAL AREA)

Before the development of Paleocene lithofacies, let us conceive the area a bit earlier in late Cretaceous when marine, continental type, glauconitic facies developed (Lumshiwal Formation) in the Cis and Trans-Indus Salt Range which extended towards Kala Chitta, Samana Range and most of the southern part of Hazara. Subsequently deposition shifted towards north as indicated by argillaceous limestone and calcareous shale (Kawagarh Formation) while the eastern Salt Range become slowly an up-land. By the close of Cretaceous, therefore, this area faced dry and arid conditions like other parts of the world (Bain 1967). Under such environments, ferruginous laterite developed all along Cis and Trans Indus Salt Range which followed by a marine transgression as epeirogenic forces gently tilted the Indo-Pak Plate from south-east to north-west (Gee 1983). It was during this period that suitable environments prevailed at the Surghar Range extending towards north and west as shown in Map-5. Coal formed under lagoonal conditions on the ferruginous laterite and alum shales (Krup 1954).

2. Coal outcrops in the Surghar Range are about 50 Km in its strike length roughly forming a north-south linear structure with folds mostly plunging towards south, have both linear and transverse faults. Generally the rocks dip at an angle of 25° towards west. There are coal seams, but only one is consistent with thickness ranging from 2 to 3 metres which thins out towards north and north-west. Coal expoures have also been noted at Urakzai and 56 km. west of Bannu with thichness less than a metre (Map-5).

3. Petrologically coal consists of clarite and fusinite. However, the percentage of inert material, i.e. fusinite, semi-fusinite and micrinite, is extraordinary high for this Tertiary coal (Krup 1954). Another unusual factor is the absence of highly reflecting spores, acleroses and cell structures. The irregularity of coal seams have been caused by erosion subsequent to coal formation Indicating a restless paleogeographic nature of the seams and of the subsequent geologic period (Krup 1954).

4. In Table-1, range of proximate chemical composition alongwith calorific values and reserves have been given based upon reports by Krup (1954), Ahmed (1969), Chemcon (1983) aad unpublished data from PMDC files. Such chemical data has been used in drawing Fig. 2-A between fixed carbon (FC), volatile matter (VM) and sulphur(s) after making their calculations upto 100%. In order to give a realistic projection to the results between the three variants, i.e. FC, VM and S, the figure and subsequent figures of similar type, has been enlarged from its mid point between VM and FC. This impact has also been given to sulphur variant. In the said Fig. 2-A, Makerwal field is restricted at a place showing nearly an equal proportion of VM and FC with increasing trend toward sulphur.

Sonda Coal Field

By the time coal was forming in the Upper Indus Basin at Surghar Range, the Lower Indus Basin was experiencing besaltic lava flows (Khadro Formation) thereby bringing this region hotter as compared to the Potwar Basin (Raza 1981). Soon after the formation of Makerwal coal in the Upper Indus Basin, paleo-geologic conditions for coal tax formation shifted towards Lower Indus Basin on a much wider scale almost south of the present Hyderabad High where deposition started comformably over a sequence of sandstone, shale with limestone and having at least two phases of lava flows (Shah 1977). The coal bearing rock formation (Bara formation) consists of dominantly sandstone with lesser shale and minor volcanic debris. So far eleven coal seems have been noted out of which three are workable having cummulative thickness of 4 to 6 metres (Hussain 1986).

As it is a newly discovered coal field, its available data is limited. However, its range of proximate chemical composion alongwith calorific values have been produced in Table-1 drawn mainly from Hussain (1986) and the geologic map prepared by GSP (1986). On the basis of this data, Fig. 3 has been drawn for Sonhari and other coal seams. The field is rich in fixed carbon as well as in sulphur.

Late Paleoceane Coal

After the formation of Sonda coal, there is some shift in the area of coal formation in the subsequent geological era. Almost in the same geological time scale, coal started developing both at Lakhra (Lakhra Formation) in Sind and the Salt Range area of the Punjab (Patala Formation). At both these places, these formations are conformable to the underlying rocks indicating sluggishness of the Indo-Pak plate as compared early to mid Paleocene and most of the subsequent ages.

Lakhra Coal Field

Lakhra coal field has been developed in the Lower Indus Basin (Map-2). Earlier part of this formation (Lakhra Fm) consists of sandstone interbedded with limestone and shale in later stages. Sandstone is ferruginous, calcareous, with arenaceous limestone. While limestone part is thin to thick bedded, nodular and has brecciated texture (Shah 1977). As a whole it is thicker as compared to Patala Formation of the Salt Range. The Lakhra Formation is gently folded into an anticline which is 64 km. in length from to south and 16 km. from west to east (Ahmed (1969). There are several faults which trend north to south and are of high angle with dips varying 52° to nearly vertical (Memon and *et al* 1976). The faults are parallel to semi-parallel some of which can be traced up to 17 km in length but their throws do not exceed to more than 43 metres (Memon and *et al* 1976). The same authors have marked 46 faults in a limited area which are closely spaced near the fold axis.

Lakhra coal field shows a large range of chemical composition which is aptly shown in Table-1 alongwith its BTU. Like the previous coal fields, the rationship between fixed carbno, volatile matter and sulphur have been worked out. Fig. 4 has been exclusively drawn on the basis of analysis available in JICA's report of 1976. JICA has reported five coal seams which they have named as seam No. 1 to 5. As separate analysis were available alongwith ground control, trend of each seam has been shown separately in Fig. 4 from where it appears that the first seam is tending towards slightly high in volatile matter as well as in sulphur. After an interval, the second seam was deposited as a transitional one which have been named as seam No. 1 & 2 where sulphur is less but volatile matter is high as compared to seam No. 1. Then seam No. 2 was deposited which is thickest in the field and indicates a nearly equal ratio between volatile matter and fixed carbon. After this event, seam No. 3 shows slightly more inclination towards volatile matter. A places seam No. 4 has been struck hut hardly any analysis are available due to its thinness. Possible conditions of coal formations start diminishing as is also indicated by a restricted field of seam No. 5.

Other organisations like Pakistan Mineral Development Corporation (PMDC) and Geological Survey of Pakistan (GSP) have also carried out investigations on this coal field by drilling and producing several chemical analysis. Fig. 5 has been drawn on the basis of analysis available in the report of Memon and *et al* (1976) and map prepared by GSP in 1984. These earlier authors have named these coal seams as Lailian, Dhanwar and Kath instead of numbering them like JICA. Comparing Fig. 5, it appears that JICA's seam No. 2 may be regarded as Lailian and seam No. 3 as Dhanwar. Due to lack of chemical analysis of Kath seam, it is not possible to equate it with any seam as reported by JICA. Fig. 5 is also indicative that Lailian as well as Dhanwar coal seam is slightly rich in volatile matter, an aspect which compares with Fig. 4.

Presence of sulphur is an important constituent of coal seam which also determines the level of toxicity of the environments. Fig. 6 has been drawn to illustrate relationship between the sulphur derived from pyrite organic contents and sulphates. Chemical analysis are indicative that Lakhra coal field dominated with pyrite sulphur with tendency towards organic and sulphur from sulphates. Seam No. 1 is a representative of this tendency while seam No. 2 which here also incorp rates analysis of seam No. & 1, is tending more towards organic sulphur as compared to seam No. 1. In the subsequent ages the contents of organic sulphur are decreasing but yet it is more towards pyritic sulphur rather than sulphur from sulphates.

BTU chart as drawn in Fig. 10 is probably giving an impression that this is more or less equal to Punjab coal field but it tends to more towards to lower BTU values when compared on average basis.

Salt Range

As mentioned earlier, coal in the Salt Range occurs in the Patala Formation of Late Paleocene age where it spreads over an areal distance of about 80 km in its east-west regional axis. Towards north, coal in Patala Formation has been marked at Cherat, near Peshawar and Attock area of Kala Chitta Hills as shown in Map-5. Apart from these localities, this coal has also been identified at the Kotli Town of Azad Kashmir where Engineers Combine Ltd. (1978) have described 11 such localities within an east-west aerial distance of 30 km (Map-5).

2. In the Salt Range, Patala Formation has been developed as a conformable sequence over the Lockhart Formation of mainly limestone. In its early part, it is sandy, followed by shale and limestone conformable grading into the overlying Nammal Formation (Shah 1977) Towards Kotli, Patala Formation is composed of black shale with amount of interbedded limestone and sandstone. At places there is yellowish brown ferruginous mudstone (Ahmad 1981). At few places this formation is characterised by a thin layer of cherty nodules and pyritic concretions above the coal seam (Hasan 1985). Coal has been developed in the middle shaly part of the Formation.

3. There are one to two workable coal seams in the Salt Range with thickness reaching upto 1.2 metres and 1.5 metres but with an average thickness of 60 cm and 50 cm respectively.

4. There are areas where coal seam completely disappears which is attributed due to tectonic as well as non-depositional in character. Generally coal is thick towards south but thins out towards north of the coalfield. Similarly it is thick in anticlinal flexures and thin towards synclinal troughs (Shah 1980, p. 84). At Cherat thickness of coal seam ranges from 30 cm to 50 cm (Ahmad Hussain 1986, personal communication). At Kotli, coal seams are generally very thin, 3 metres (ECL 1978).

5. Range of proximate chemical composition of various coal localities of Salt Range such as Dandot, Ara, Diljaba, Dalwal, Padrar and Katha-Pail has been shown in Table-1 alongwith their calorofic values. Based upon the available data (Chemcon 1985, Ahmed 1969, Shah 1980), Fig. 2-A has been drawn for fixed carbon, volatile matter and sulphur for eastern and central Salt Range, a division adopted by Shah (1980). Similarly a separate diagram has been drawn (Fig. 2-B) for two localities of Kotli area since this coal is regarded bituminous to anthracite (Ashraf *et al* 1986). It is rich in ash and fixed carbon but low in volatile matter and sulphur.

EOCENE COAL

Baluchistan Coal Basin. It has been mentioned earlier that paleo-environments for coal formations changed entirely from the traditional cites in Punjab and Sind to Baluchistan after Paleocene (Map-1) except a small pocket at Meting-Jhimpir. Eocene represents a period of sedimentation throughout Indus and Baluchistan. According to Shah, (1977), the central Lasbela positives were submerged to the extent where identical marine sedimentation took place on both the flanks in parts, of the Axial Belt (Suture line) During this period, rapid sedimentation of shale and sandstone (Khojak Formation) started in major part of Baluchistan with some exception towards Eruptive zone where generally limestone facies developed. Coal has been developed all along the southern side of the Ghazaband Fault as shown in Map-3. Ghazij shales of Early Eocene (Shah 1977) are constituted with subordinate claystone with its middle part showing dominantly coal-bearing sandstone facies. In its later stage there is a well developed conglomeratic horizon which is regarded a marker bed for coal. The Ghazij Formation conformably overlies Dungan, Laki and Ranikot Formation at several places, yet its major part is unconformable. At Good Hope area, lying in between Sor Range and Degari, at least 14 conglomeratic beds of various thicknesses have been encountered as a post coal depositional phenomena at PMDC bore hole-2. In Fig. 11, thicknesses of these conglomeratic beds have been drawn as encountered from bottom to top within Ghazij Shale.

Range of proximate chemical composition of important Baluchistan coal field have heea presented in Table-1 alongwith their calorific values which have been separately projected in Fig. 10. In Fig. 8, a triangle diagram has been drawn between fixed carbon, volatile matter and sulphur of the several coal fields of Baluchistan. Similarly Fig. 9 has been separately drawn only for Duki coal field as 17 coal seams have been reported there (Khan *et al* 1986). Out of 17 coal seams, chemical analysis of six coal seams were sufficient to draw n diagram as shown in Fig. 9 Coal seams have been marked from bottom to top as B,C, and P etc.

Meting Jhimpir Coal Basin. Meting-Jhimpir coal field has been developed as a small coal basin in between Sonda and Lakhra coal field (Fig. 1). The field spreads over an area of 50 sq. km. with a workable coal seam of about one metre in thickness. The coal-bearing horizon is in Laki Formation of Early Eocene in age (Shah 1977). Unlike Gnazıj Formation of Baluchistan, its basal part is lateritic where a sequence of lateritic clay and shale with beds of arenaceous limestone, lignite and ferruginous and calcareous sandstone which has been named as Sonhari Member. Whereas the later sequence of Laki Formation is mainly composed of nodular limestone witn shales and sandstone at still later stages. Fig. 7 has been drawn between the three variants, *i.e* , fixed carbon, volatile matter and sulphur which is based on proximate analysis of 17 coal samples from this field. Present trend is distinctly in favour of volatile matter. In Fig. 7, field covered by dotted line is a rather better representation. Range of chemical composition has been presented in Table-1 while calorofic values are projected in Fig. 10.

DISCUSSION ANC CONCLUSION

Lean occurrence of Permian coal in Pakistan at present is much of theoratical interest rather than of economy. During late Carboniferous to early Permian, this part of the globe was equally glaciated like rest of the world. According to Nakazowa (1985), at the beginning of Permian (Asselian-Sakmarian) the strata in central Afghanistan, south-east Pamir, Salt Range and Kashmir are represented by terrigenous clastic rock facies yield Goodwana fauna (cool-water fauna) suggesting that such areas were situated in the marginal part of Gondwana-land or peri-Gondwana which became warmer during later stage.

Presence of coastal forest (Hasan 1986) along the western part of the Indo-Pak plate (map-4) during Permo-Carboniferous period is a lucid hypothesis. On map-4, the author has drawn a possible extent of Permian coal field alongwith other Gondwanic coal fields of India. The huge coal deposits at Gadwari, Mahanadi and other basins of India are indicative that this coal was formed in 'closed shelfs' along rift valleys rather than the open ones, a situation which is present in Pakistan regarding the occurrence of this coal.

Presence of Permian coal at Burikhel may lead to someone to think that Sargodha-Shahkot positive highs might have provided a barrier thereby creating suitable places for the development of such coal. But these ridges are of much post Permian phenomena. The only possibility left is to locate micro-undulations and ditches alongwhich such forests might have found suiiable place for their ultimate change into coal. In fact, in an article Nazirullah *et al* 1986) on the burried shield around Jhang, the authors pointed out an east-west trending high north of Ashoba Rest House and have postulated to hit such areas at about less than 1000 metres depth. Such studies appears to be of limited nature. As it is a challenging task to delineate the then shelf area, its possible surfacial configuration and detailed paleo-environs are needed in detail before taking any costly drilling programme. Highly generalised regional gravity maps (Farah *et al* 1977) possibly may not serve this purpose.

Presence of lateritic beds at the top of Cretaceous and subsequent development of overling alum shales in the Surghar Range are suggestive of an early severe dry spel followed by a marine transgression at the dawn of Paleocene (Hangu Formation). During the entire span of Paleocene, the 'warm point' for development of forests first developed at the north-western part of the Upper Indus Basin (Makerwal coal basin, vide map-5), later shifted to Lower Indus Basin at Sonda followed by their still larger development both at the Lower Indus (Lakhra) and Upper Indus Basin (Salt Range, map-5). The peculiar development and shifting of the 'warm point' from Upper to Lower Indus Basin and vice-versa is a thoughtful point the true significance of which is yet to be worked out even from hydrocarbon potential point of view, especially keeping in view the fact thar during this period Indo-Pak plate simply came in contact with the Eurasian plate in the north and probably the process of collision was in its fance. The quiescent nature of the Indo-Pak plate might have a relation on the development of coal. Based upon chemical data, in Fig. 2 it is pertinent that there is an equilibrium between the contents of volatile matter and fixed carbon showing tendency towards volatile matter. As expressed earlier quality of coal improves towards south at Makerwal. Small exposure of coal at Urakzai and west of Bannu as marked in map-5 produces a natural extent of this coal basin. Trend diagram in Fig. 2 is also indicative of good quality coal may be found further towards south and south-west from the present coal workings at Makerwal.

Mid Paleocene Sonda coal field in the Lower Indus Basin is currently under investigati ns due to its recent discovery. However trend diagram (Fig. 3) on the basis of available data is suggestive that it will be a highly broad coal field which will show extension more towards north and north-east from its presently investigated site near Kalri Lake. Hussain *et al* (1986) has held it as a 'back barrier' deposit due to Hyderabad High in its north. It is difficult to accept this notion unless it is confirmed that the Hyderabad High is a pre-Mid Paleocene event.

Lakhra coal field in the Lower Indus Basin has been developed at the 'Hinge Line' of the Indo-Pak Plate as is indicative from its nearly horizontal dips and other structural features. The Lakhra coal field has not experienced severe impact of tectonic forces as compared to Baluchistan coal which has been mainly developed in the Quetta Syntaxis and also the Salt Range coal showing influence of Hazara Syntaxis.

Trend diagram for Lakhra coal seams has been drawn in Fig. 4 & 5 which appears to be quite interesting. The first seam has been developed in a balanced environment of marine and continental conditions. The transitional seam No. 1 & 2 is showiug some tendency towards marine environments, a trend which continued upto the deposition of seam No. 3. After this event, both the continental and marine environments for coal development were nearly collapsed as evident from the insignificant development of seam No. 4. However, again better environmental conditions prevailed but of a short duration as well as space under which seam No. 6 was deposited.

Rise and fall of the sulphur contents in various seams alongwith their geographical distribution itself appears to be one of the characteristics in determining the depositional environments of coal. In general, it is held that close to the continental areas, there will be less organic sulphur which will increase towards marine conditions alongwith increase of the volatile matter. In a report on a part of Lakhra (JICA 1976) sulphur has been analysed further into organic, pyritic and as derived sulphates. In Fig 6, another trend diagram has been drawn for various coal seams of Lakhra and 8 analysis belonging to the Shahrig area of Baluchistan. From this diagram, it is deduced that seam No. 1 started depositing in a broad environment of continent as well as marine, the later trend of which prevailed during the deposition of seam No. 2 and seam No. 3 with decreasing condition for seam No. 5 a trend quit compatible with our earlier derivation. In the same diagram, data for the Top and Bottom coal seams of Sharigh area is indicative that these coal seams deposited in a much more marine conditions as compared to Lakhra coal field.

In Salt Range, coal is exposed about 30 km in length along its east-west axis which, in fact, has been reduced three times less from its original length by tectonic pulses as a result of which several flexures have been developed with tight anticlines but broad synclines. The influence of this east-west deformation is restricted within a zone of 4 to 8 km all along its axis. Beyond this zone, towards north surface features are less disturbed as is also indicated by maps prepared by Gee (1981) and even it stands true by oil wells as shown by Khan et al (1985).

During late Paleocene, coal has developed all along the Salt Range besides its exposures at Cherat, Attock and the Kotli area of Azad Kashmir, producing a natural spread of coal basin as shown in map-6. Trend diagram as shown in Fig. 2-A separately for Central and Eastern Salt Range is indicative that contents of volatile matter are increasing towards east. Contrary to it in Fig. 2-B, chemical results from Dandili and Bengang areas of Azad Kashmir are showing an exceptional richness fixed carbon contents, reaching upon anthracite (Nawaz et al 1986) a point only explainable as due to severe influence of tectonic forces at Hazara-Kashmir Syntaxis. But it needs further studies to confirm whether or not only the tectonic forces are responsible for higher contents of fixed carbon or there is some separate role of different forest species, as compared to the then forest at the Salt Range. Leaving aside this aspect, still trend in Fig. 2-B is indicative that contents of volatile matter show a tendancy towards south contrary to the Salt Range where this tendancy is towards east and north-east. From these trend diagrams the author is of the the view that contents of volatile matter increases away from shore line, towards deeper waters alongwith an increasing contents of sulphur, especially organic sulphur. Opposite to this postulation, it is also held that amount of fixed carbon increases more towards shore lines. In the light of this idea, it is opined that comparatively better and thick coal may be found further towards south of the present Main Frontal Thrust (MFT) line of the Salt Range under the veneer of alluvium as being a downthrown block. But bore hole data at Lila and Kundian do not show any Paleocene strata which has been mostly eroded away or has not been deposited at all, Against this disappointment, yet there is a hope to find coal beneath the Salt Range itself as shown in Fig. 2. Salt Range itself has overrided upon its own sequence upto a distance of 16 km (Lillie & *et al* 1986). The possibility of aboriginal coal beneath the entire exposed sequence of Salt Range is highly likely.

While dealing with Eocene coal, two distinctions are expressed here while comparing it with Paleocene coal. These are :

1. Paleocene coals show tendancy towards fixed carbon while Eocene coals favour towards volatile matter.

2. Eocene coal basin of Baluchistan is divided into several smaller coal fields due to the impact of severe Eocene tectonic forces while Paleocene coal basins are relatively much undisturbed.

As mentioned earlier, Eocene coal is confined mostly in Baluchistan and in a small pocket of Sind at Meting-Jhimpir area (Map-2 & 3). The existing several coal fields have been named from administrative point of view which has got nothing to do with the geological boundaries. Trend diagram as drawn in Fig. 8 shows that northern part of the Degari-Sor-Range syncline possibly represent the central tendancy of the coal deposition whereas Sharigh and Mach areas appear as an off-shoot of this tendancy, meaning more towards volatile matter. As coal in Baluchistan is confined towards southern side of the Axial Belt, authors of the Colombo Plan Report (1961) maintain that coal material entered into Baluchistan somewhere at a point near to Quetta from where it spread to south and south-east. Our early deduction that volatile matter increases away from shore lines is being confirmed from Fig. 8 pertaining to Baluchistan coal.

Due to the availability of considerable chemical data for separate 6 coal seams out of 17 of the Duki area (*Khan & et al* 1986), Fig. 9 has been drawn to further explore the foregoing idea. During the dedosition of B/C and D coal seams of Duki area, much of the environments are similar to those of the Sor Range area while the subsequent coal seams at Duki have become very rich in volatile matter contents as well as in sulphur while the subsequent coal seam i.e., P seam, the paleo-environments again retreated more towards the so-called here as central tendancy. It may also mean that shore line once at Quetta later on shifted towards south-east. Age-wise it would mean that Sor Range coal seams may have deposited more or less simultaneously with the coal seams at Duki while the later coal seams of the Duki area may become equivalent with areas like Mach etc.

It has been held here that Eocene coal basin of Baluchistan has been divided into several coal fields by tectonic forces during Eocene. If presence of conglomeratic beds are regarded a result of such forces, then the impact of forces can be quantified PMDC has recently carried out a drilling programme at the Good Hope area, a place in between Degari and the Sor-Range coal mining area. Here, bore hole-2 was spudded within Ghazij Shales. Corresponding logs are indicative presence of 14 conglomeratic beds upto the depth of coal seam with a cummulative thickness of 56.68m, after taking corrections of dip factor. Fig. 11 has been drawn on the basis of this data. As a post-coal depositional phenomena, there is a remarkable accumulation of stresses, reaching a climax, then a release, again accretion and its release followed by a trail of fall. The bipolar skewness is a prominent feature at least in this part of the area. At Degari, it has also been held (Malik 1982) that tectonic forces acted on this area from NE to SW direction.

In Fig. 8, Meting-Jhimpir coal field of Eocene age is showing the same remarkable tendancy towards volatile matter just like other Eocene coal fields of Baluchistan. The dotted line is rather a more appropriate line for the field. Although data is restrictive, but it is suggestive to explore its extension possibly towards south-east.

In Fig. 10, a bar chart diagram has been drawn showing the range of calorific values of all the coal fields of Pakistan. The several coal fields of Baluchistan show an increase in calorific values from Mach and Duki coal field to Sor-Range coal field with some abnormal behaviour at Sharigh. Similarly there is also gradual increase from Dalwal to Dandot and Katha Pail in the eastern Salt Range. Although such pattern on this chart apparantly do not signify any relationship with the regional behaviour of coal and the coal basins. For example, the trend from Sor Range to Mach and Duki side signifies that calorific values increase towards marginal areas rather than away from the shore lines. This trend also appears from Dalwal to Katha Pail area of the Salt Range. For the reconstruction of coal basins, the author feels that calorific values may also become an important tool besides other geological factors.

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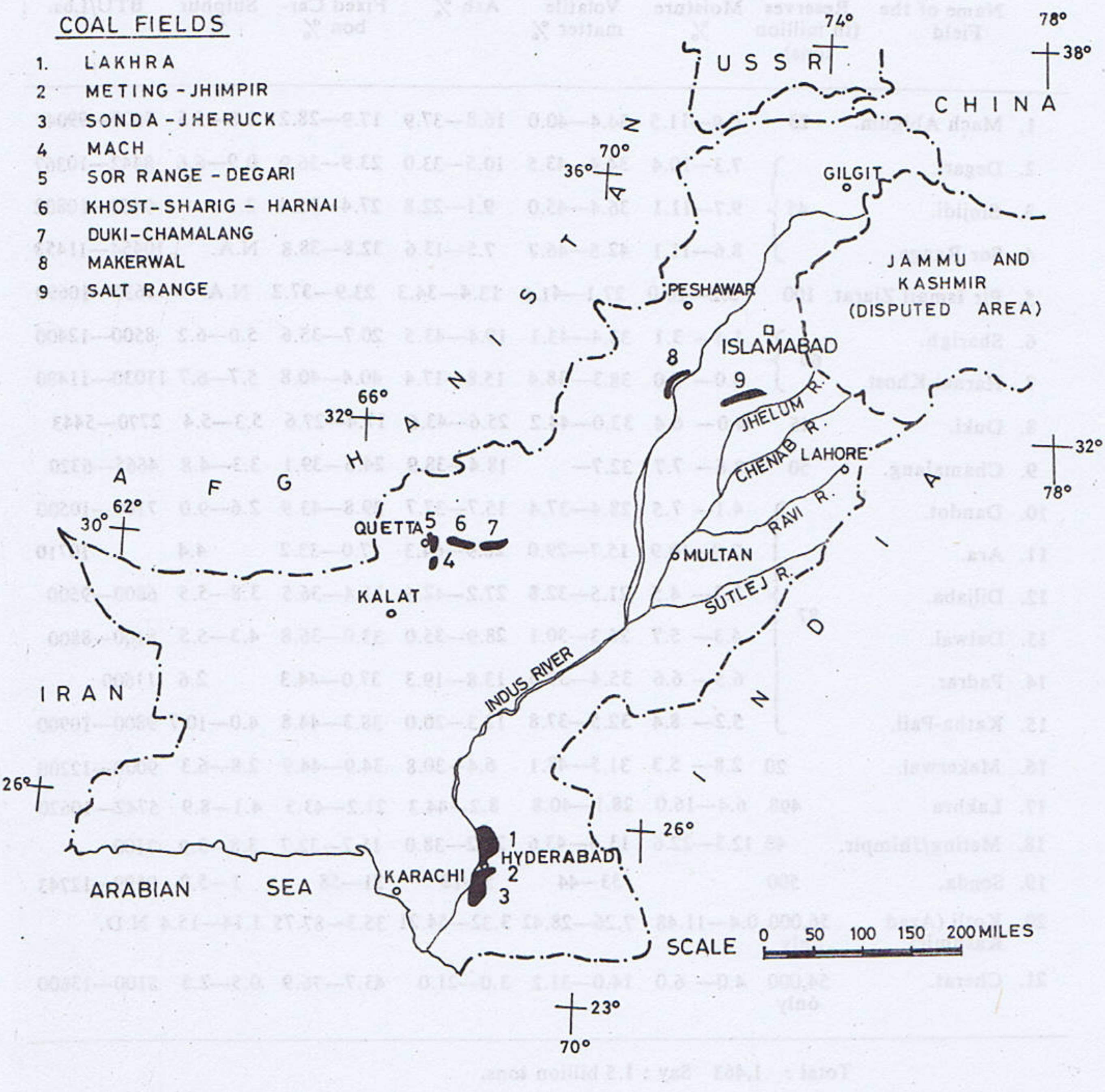
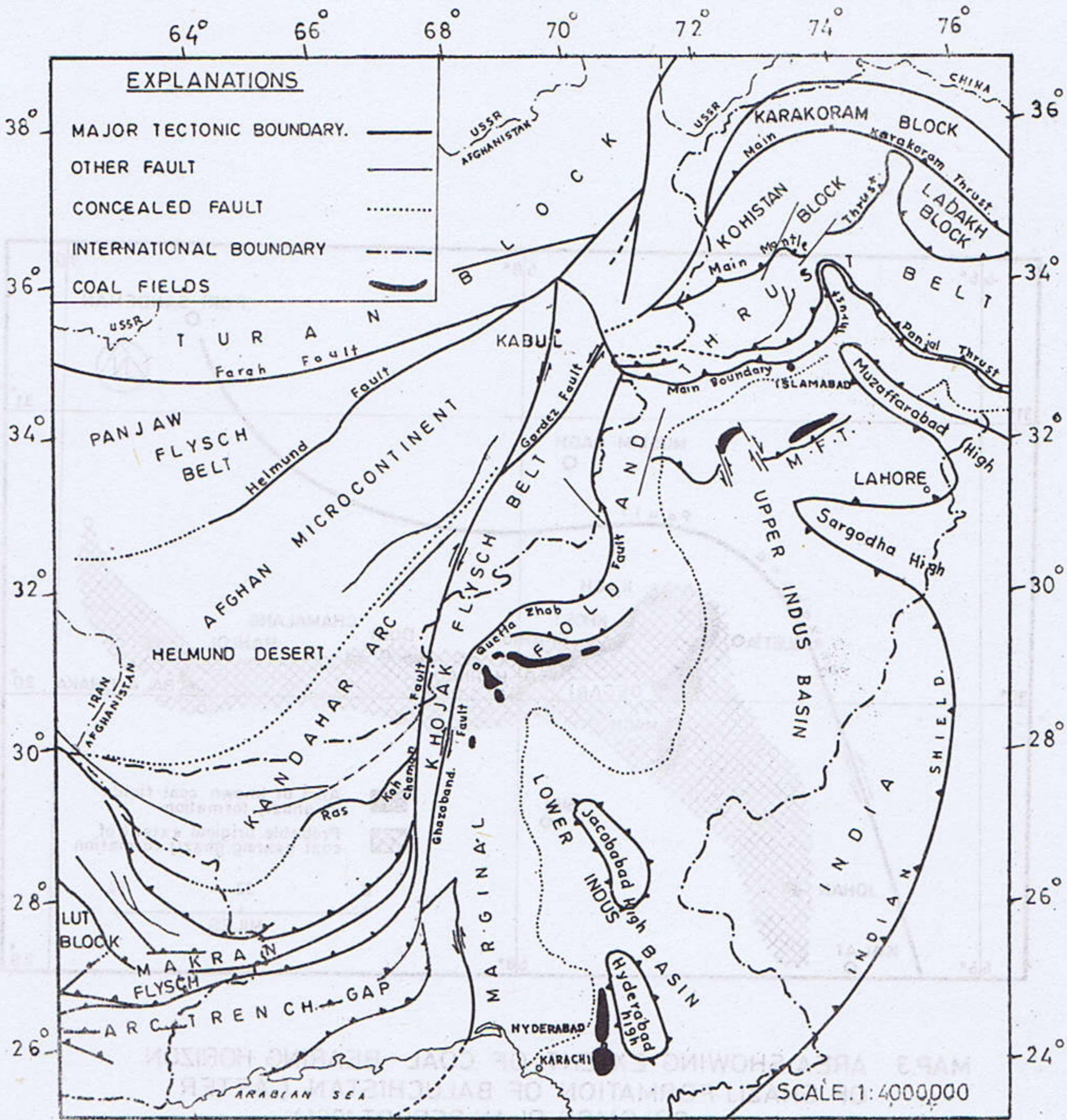
Name of the Field	Reserves (in million tons)	Moisture %	Volatile matter %	Ash %	Fixed Carbon %	Sulphur %	BTU/Lbs.
1. Mach Abigum.	23	6.9—11.5	34.4—40.0	16.8—37.9	17.9—28.2	2.8—5.5	7600—9904
2. Degari.		7.3—10.4	34.4—43.5	10.5—33.0	23.9—36.9	0.9—6.6	8442—10367
3. Sinjidi.	45	9.7—11.1	36.4—45.0	9.1—22.8	27.4—35.4	2.1	9463—10802
4. Sor Range.		8.6—11.1	42.5—46.7	7.5—13.6	32.8—38.8	N.A.	10454—11453
5. Pir Ismail Ziarat.	100	5.2—10.0	27.1—41.6	13.4—34.3	23.9—37.2	N.A.	9635—10690
6. Sharigh.	60	1.4— 3.1	33.4—43.1	19.4—43.5	20.7—35.6	5.0—6.2	8500—12400
7. Harnai-Khost.		4.0— 5.0	38.3—38.4	15.8—17.4	40.4—40.8	5.7—6.7	11030—11480
8. Duki.	45	4.0— 6.4	33.0—44.2	25.6—43.6	17.4—27.6	5.3—5.4	2770—5443
9. Chamalang.	50	3.6— 7.7	32.7—	18.4—38.9	24.6—39.1	3.3—4.8	4665—6320
10. Dandot.		4.1— 7.5	28.4—37.4	15.7—37.7	29.8—43.9	2.6—9.0	7100—10500
11. Ara.		2.9—10.9	15.7—29.0	26.9—64.3	17.0—33.2	4.4	10710
12. Diljaba.	87	3.2— 4.5	21.5—32.8	27.2—42.6	31.4—36.5	3.8—5.5	6800—9500
13. Dalwal.		4.3— 5.7	26.3—30.1	28.9—35.0	33.0—36.8	4.3—5.5	8100—8800
14. Padrar.		6.5— 6.6	35.4—37.3	13.8—19.3	37.0—44.3	2.6	11600
15. Katha-Pail.		5.2— 8.4	32.5—37.8	12.3—20.0	38.3—44.8	4.0—10.7	9800—10900
16. Makerwal.	20	2.8— 5.3	31.5—48.1	6.4—30.8	34.9—44.9	2.8—6.3	9000—12206
17. Lakhra	498	6.4—16.0	28.1—40.8	8.2—44.3	21.2—43.3	4.1—8.9	5742—10620
18. Meting/Jhimpir.	40	12.3—22.6	13.4—43.6	28.2—38.0	11.7—32.7	3.8—3.9	7100
19. Sonda.	500		33—44	5—18	31—58	1—5.2	9599—12743
20. Kotli (Azad Kashmir)	56,000 only	0.4—11.48	7.26—28.42	3.32—54.21	35.3—87.75	1.14—15.4	N.D.
21. Cherat.	54,000 only	4.0— 6.0	14.0—31.2	3.0—21.0	43.7—76.9	0.5—2.5	5100—13600

Total : 1,463 Say : 1.5 billion tons.

Table : Reserve position, range of chemical composition and calorific values of known coal fields of Pakistan.

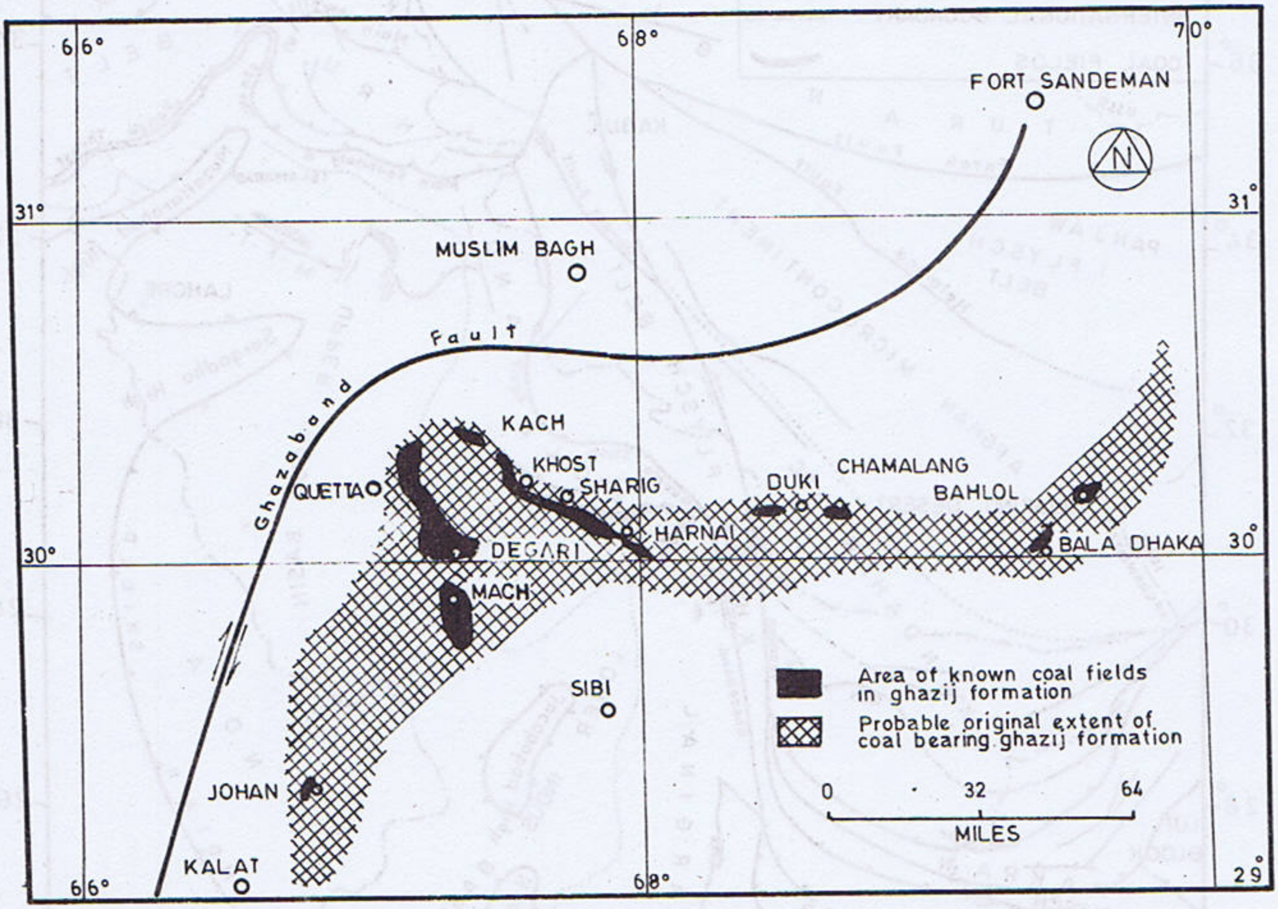


MAP. 1. LOCATIONS OF MAJOR COAL FIELDS OF PAKISTAN

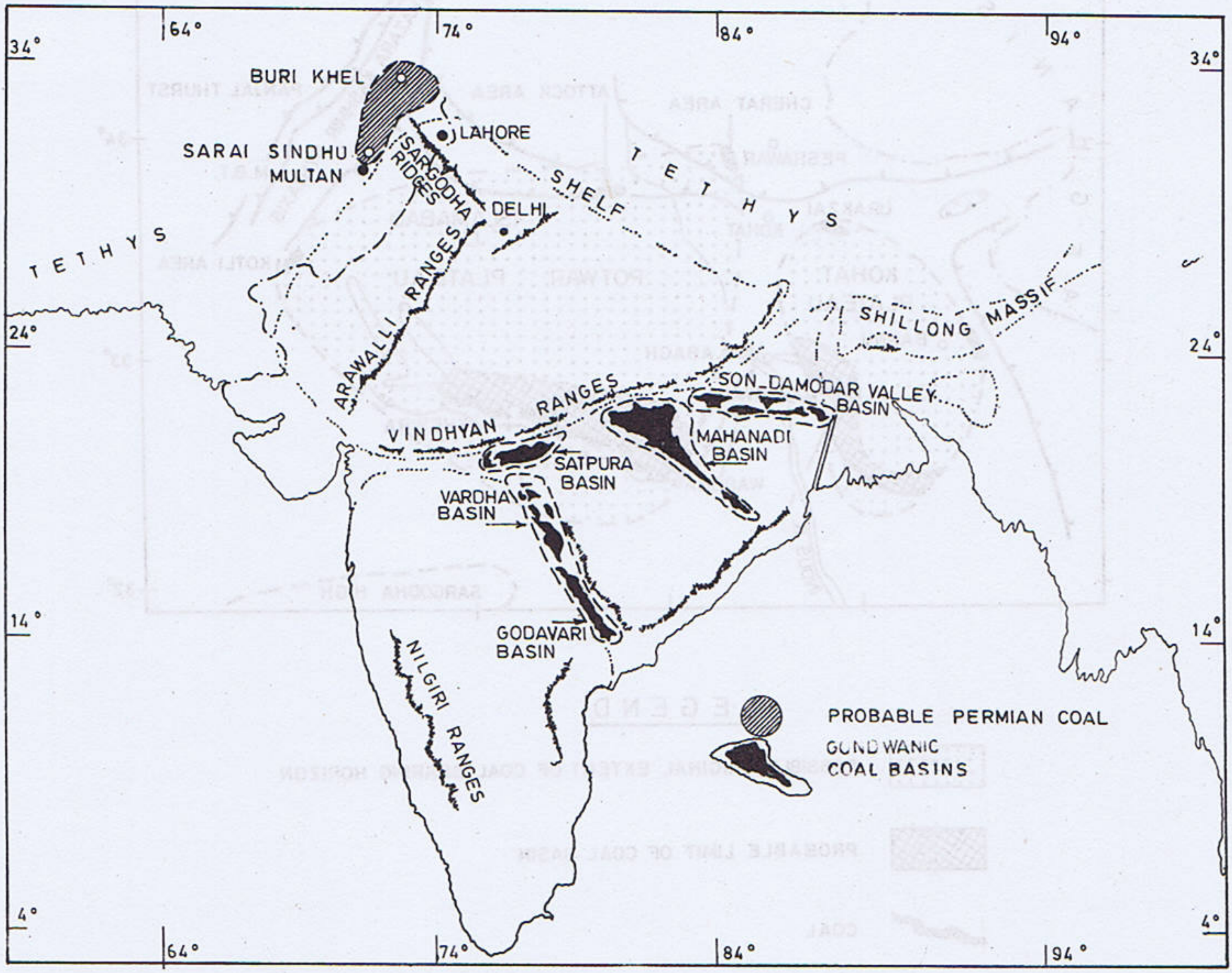


MAP 2. MAJOR TECTONIC BOUNDARIES AND COAL FIELDS OF PAKISTAN.

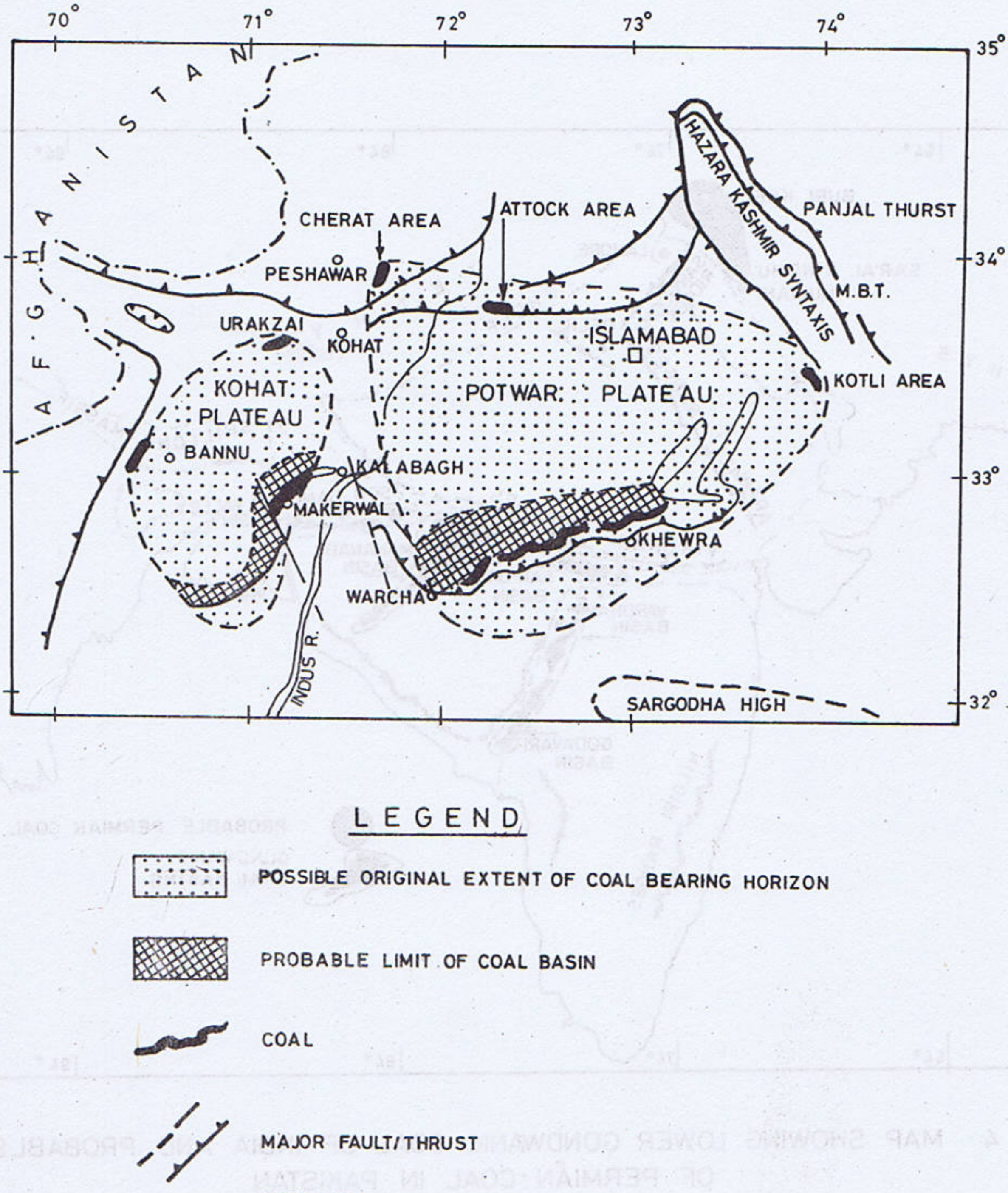
(Modified after Farah et al 1984)



MAP.3 AREA SHOWING EXTENT OF COAL BEARING HORIZON OF GHAZIJ FORMATION OF BALUCHISTAN (AFTER COLOMBO PLAN REPORT 1961)



MAP. 4 MAP SHOWING LOWER GONDWANIC COAL OF INDIA AND PROBABLE EXTENT OF PERMIAN COAL IN PAKISTAN



MAP 5. EXTENT OF COAL BEARING HORIZON OF HANGU FORMATION (MAKERWAL AREA) AND PATALA FORMATION OF SALT RANGE, PUNJAB & NWFP

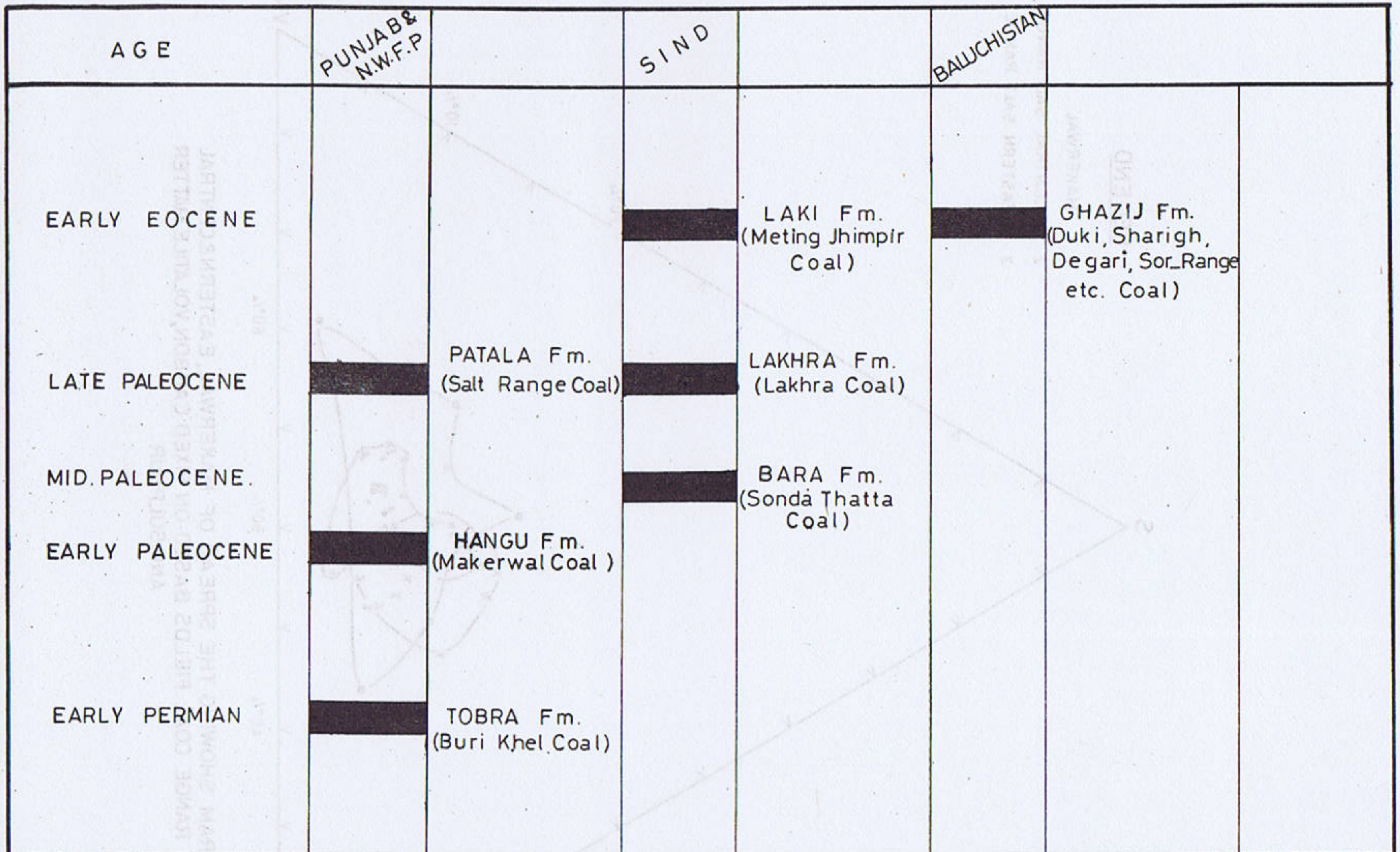


FIG. NO. 1 COAL BEARING GEOLOGICAL HORIZONS IN PAKISTAN

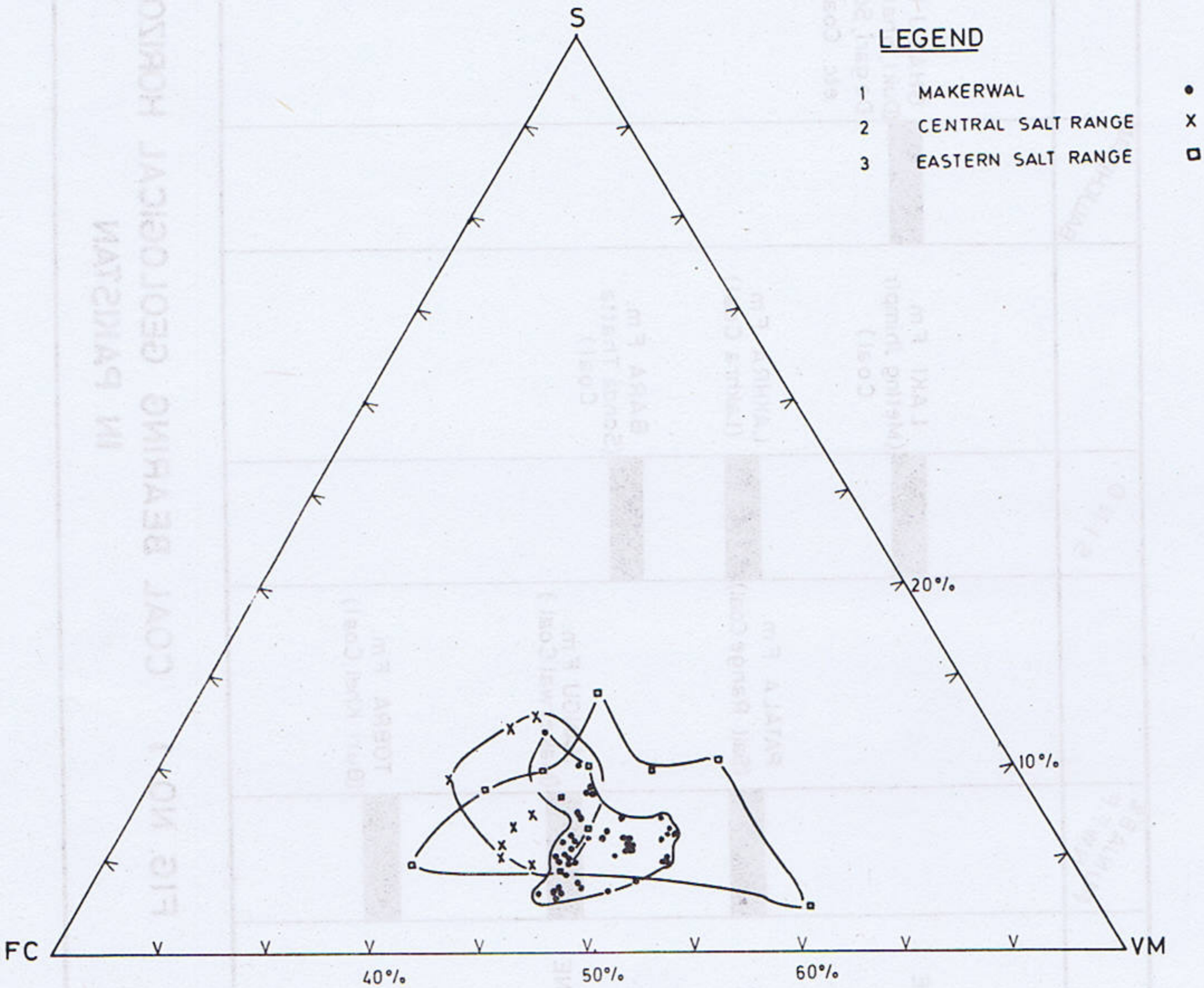


FIG. 2_A. DIAGRAM SHOWING THE SPREAD OF MAKERWAL, EASTERN & CENTRAL SALT RANGE COAL FIELDS BASED ON FIXED CARBON, VOLATILE MATTER AND SULPHUR.

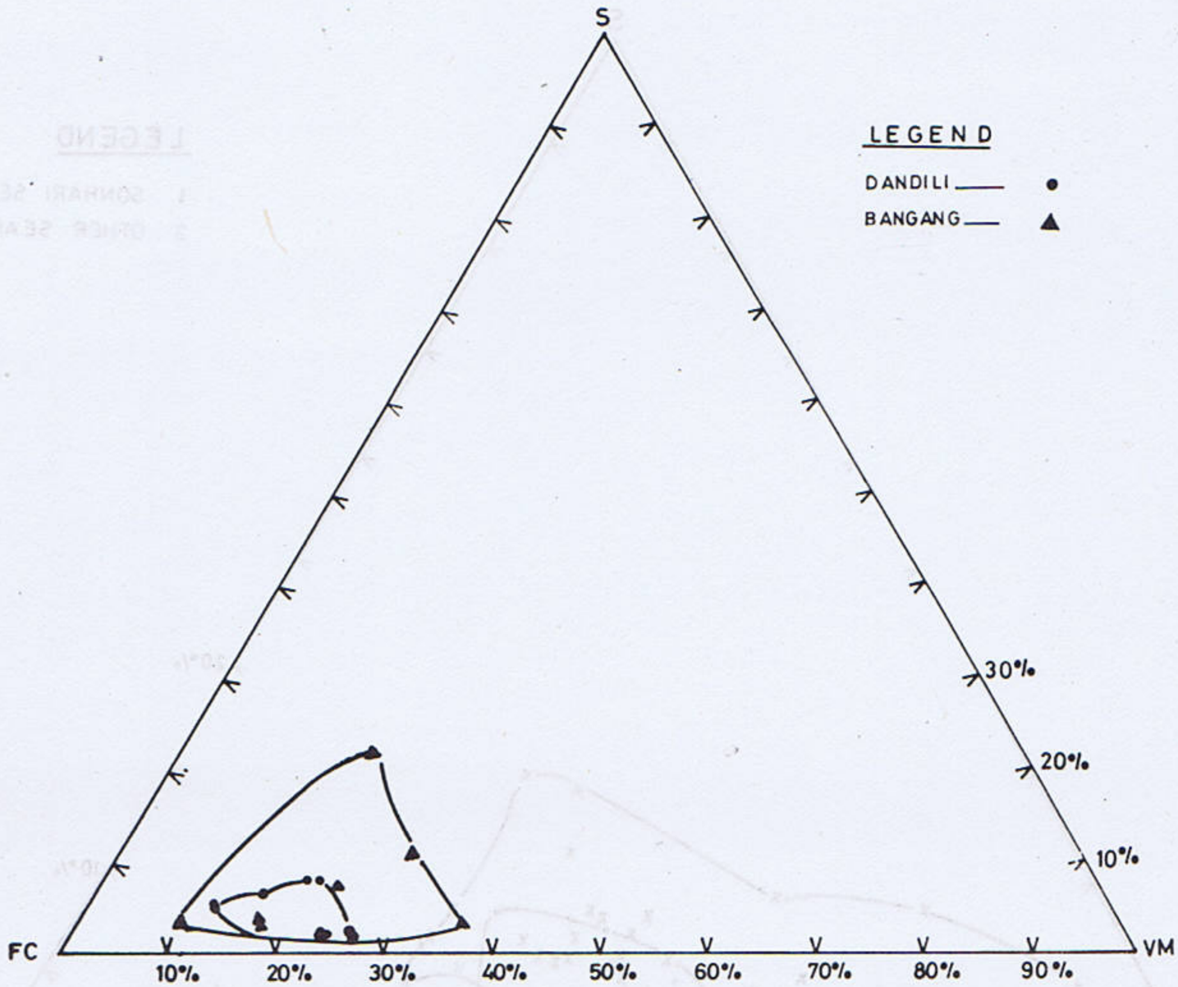


FIG. 2 B. DIAGRAM SHOWING THE SPREAD OF COAL FIELD AT DANDILI AND BANGANG, AZAD KASHMIR BASED ON FIXED CARBON, VOLATILE MATTER AND SULPHUR.

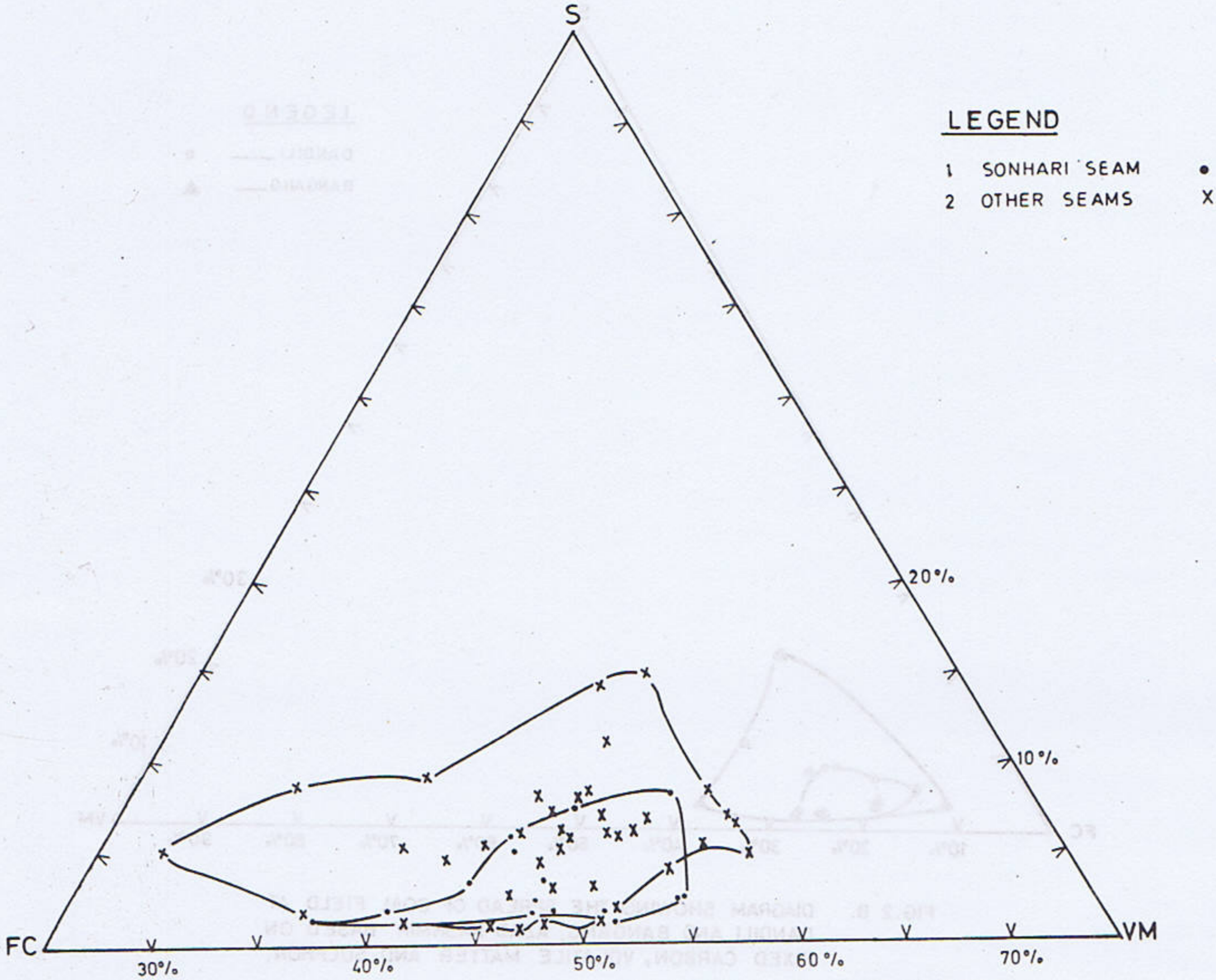


FIG.3 RELATIONSHIP BETWEEN THE FIXED CARBON, VOLATILE MATTER AND SULPHUR OF THE SONHARI AND OTHER COAL SEAMS AT SONDA COAL FIELD, SIND.

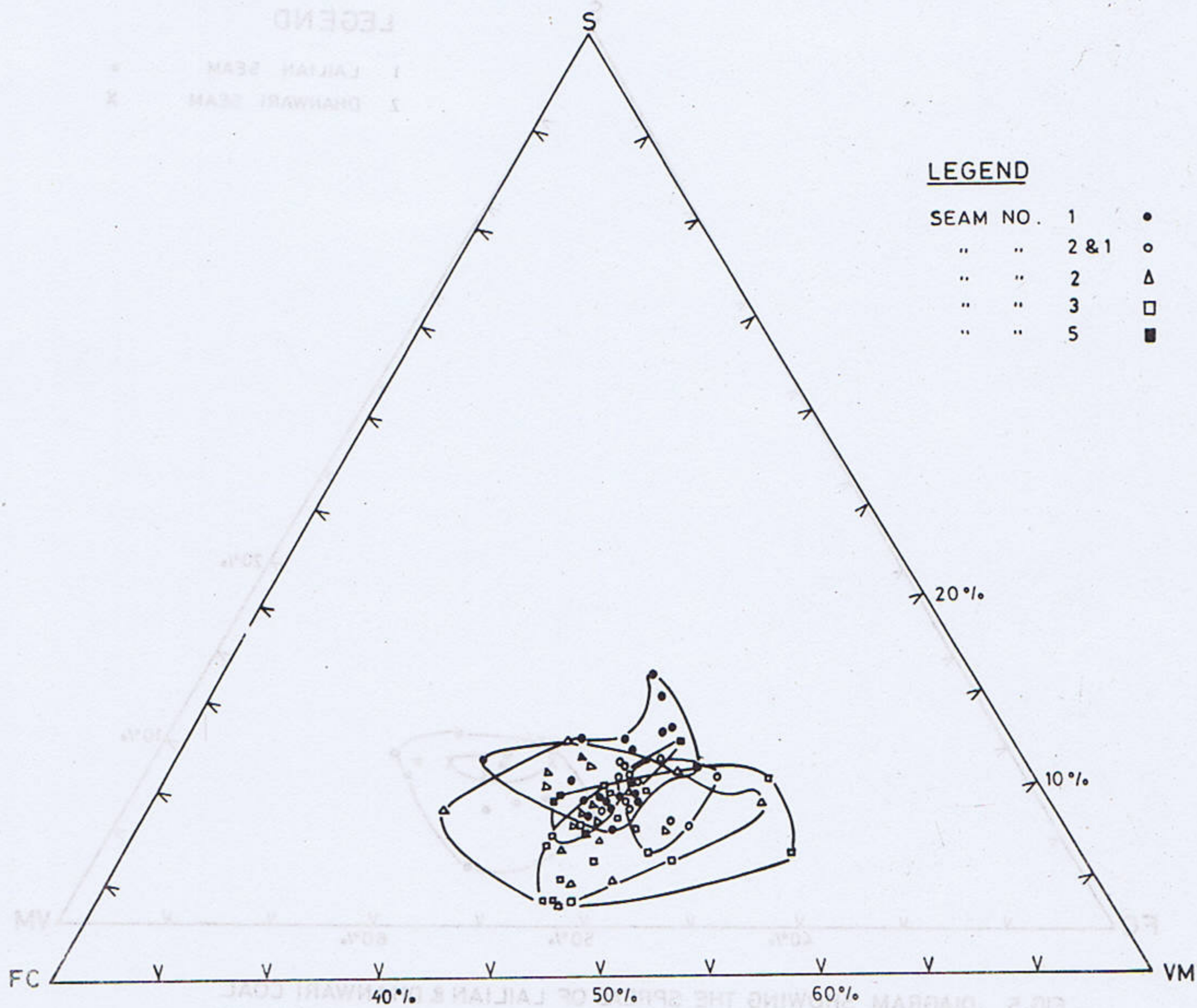


FIG. 4 LAKHRA COAL FIELD BASED ON JICA'S ANALYSIS SHOWING RELATIONSHIP BETWEEN FIXED CARBON (FC), VOLATILE MATTER (VM) AND SULPHUR (S)

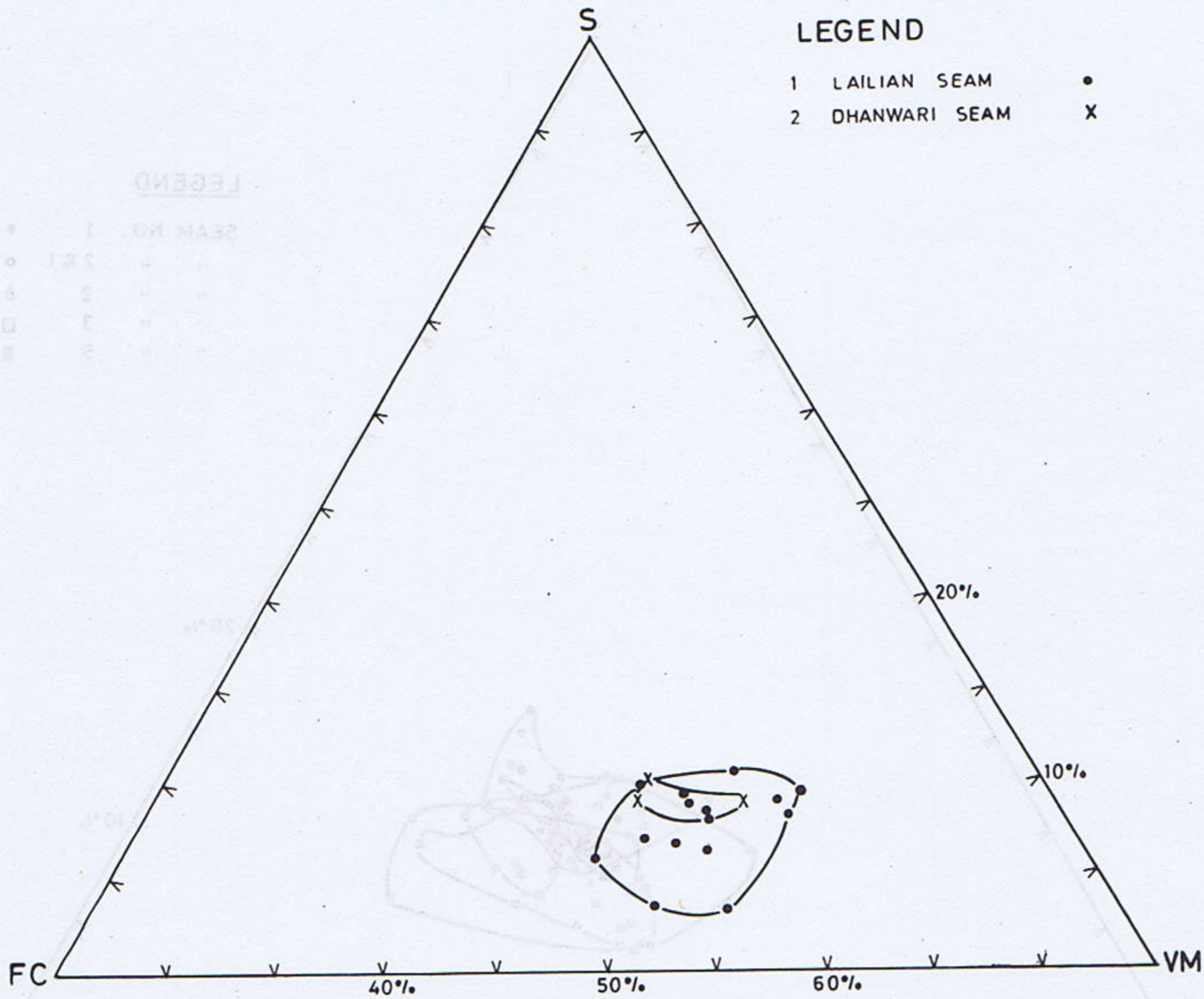


FIG. 5 DIAGRAM SHOWING THE SPREAD OF LAILIAN & DHANWARI COAL SEAMS AT LAKHRA COAL FIELD BETWEEN THE THREE VARIANTS OF FC, VM & S.

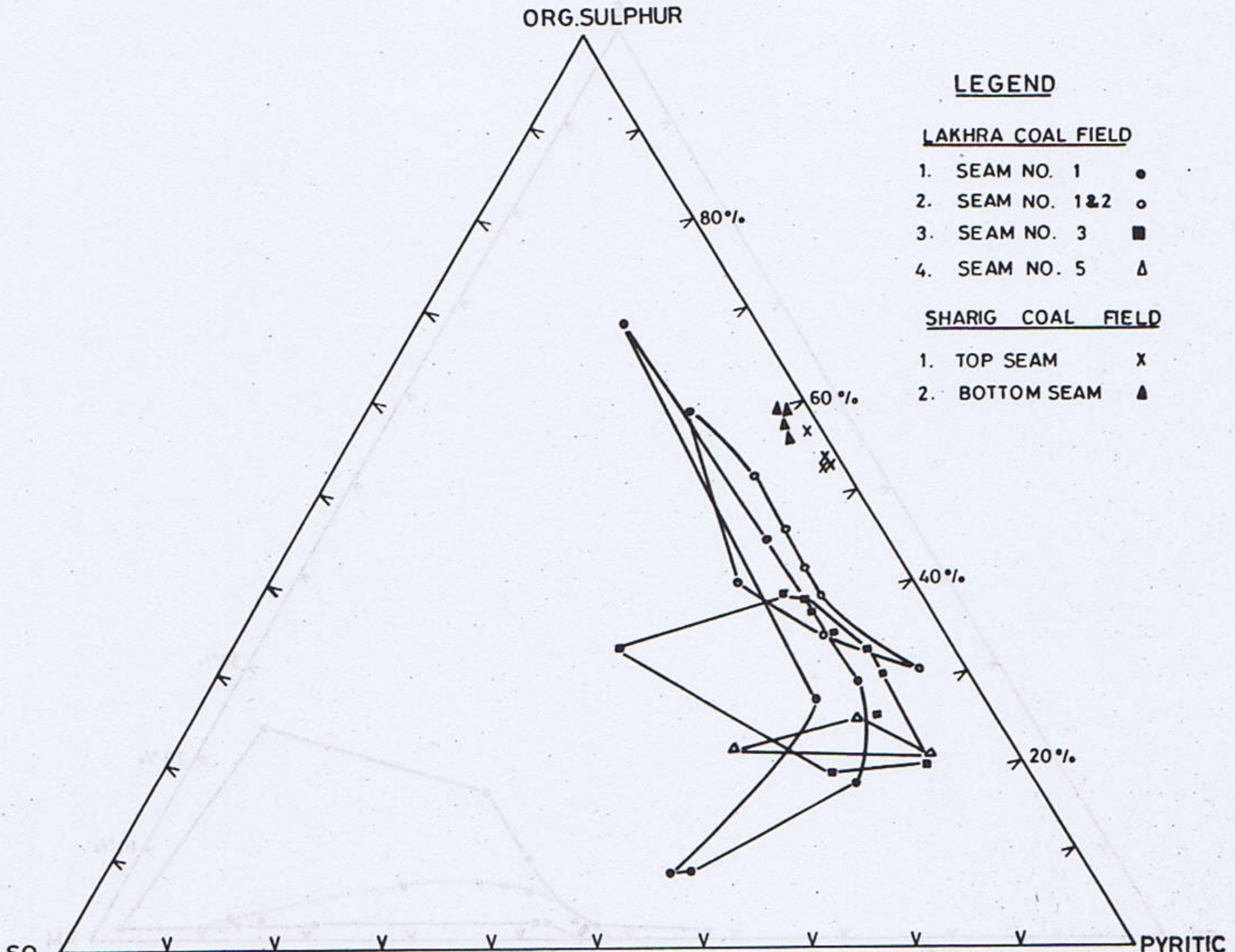


FIG. 6 RELATIONSHIP BETWEEN ORGANIC SULPHUR AND INORGANIC SULPHUR OCCURRING IN SULPHATES AND PYRITE IN SEVERAL COAL SEAMS OF LAKHRA AND SHARIG

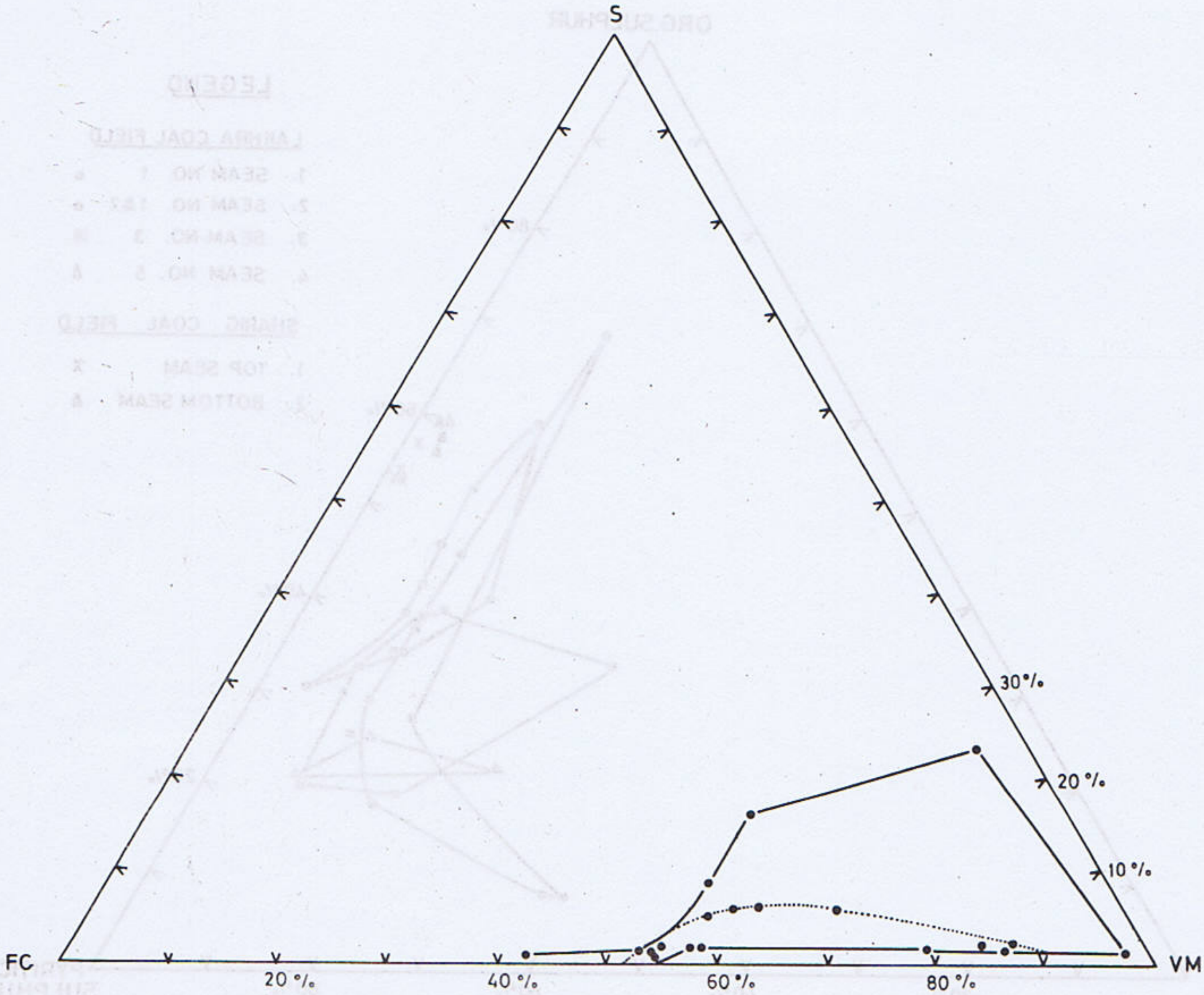


FIG. 7 METING_JHIMPIR COAL FIELD SHOWING RELATIONSHIP BETWEEN FIXED CARBON, VOLATILE MATTER & SULPHUR.

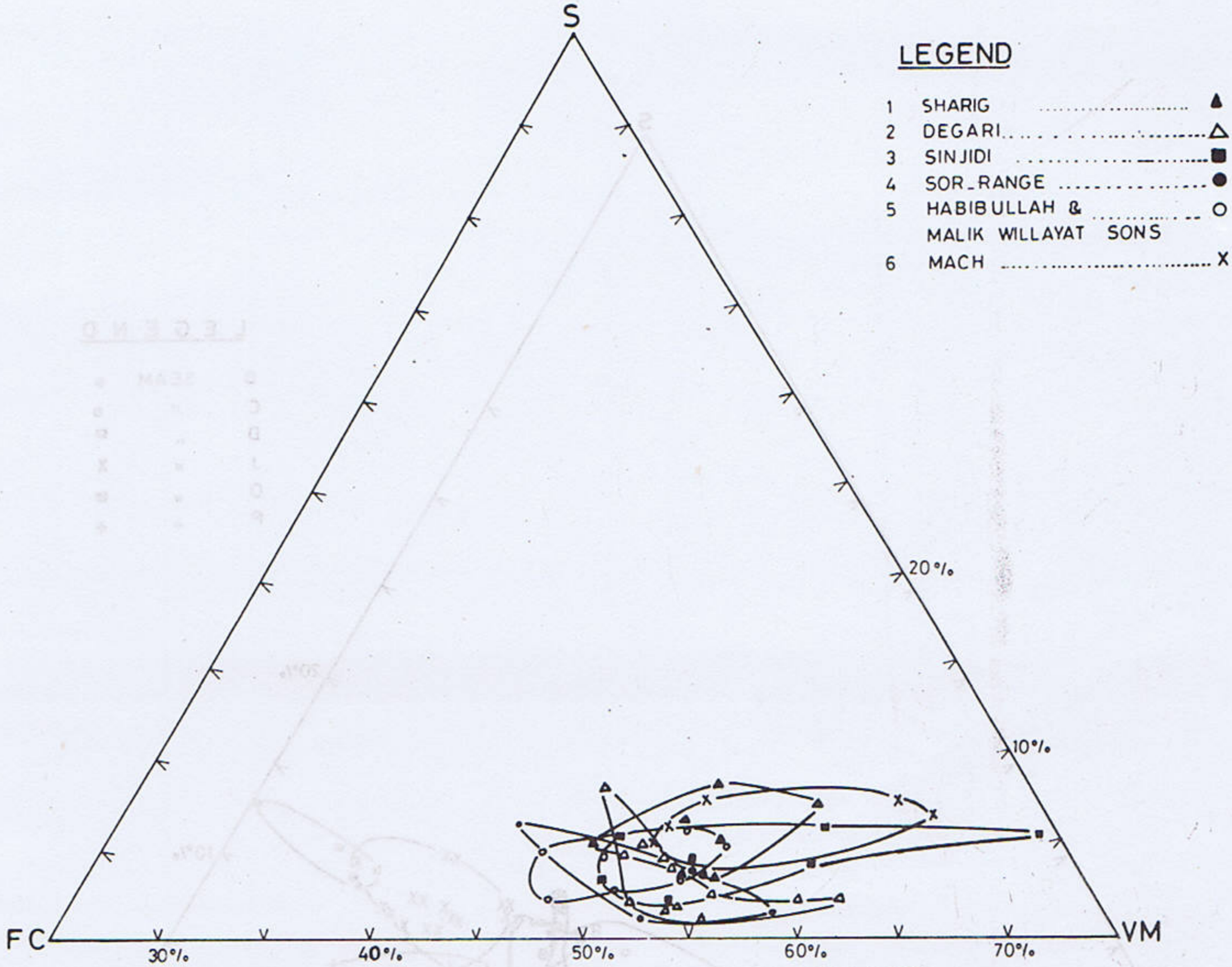


FIG.8 RELATIONSHIP BETWEEN THE FIXED CARBON (FC), VOLATILE MATTER (VM) AND SULPHUR (S) OF THE SEVERAL COAL FIELDS OF BALUCHISTAN.

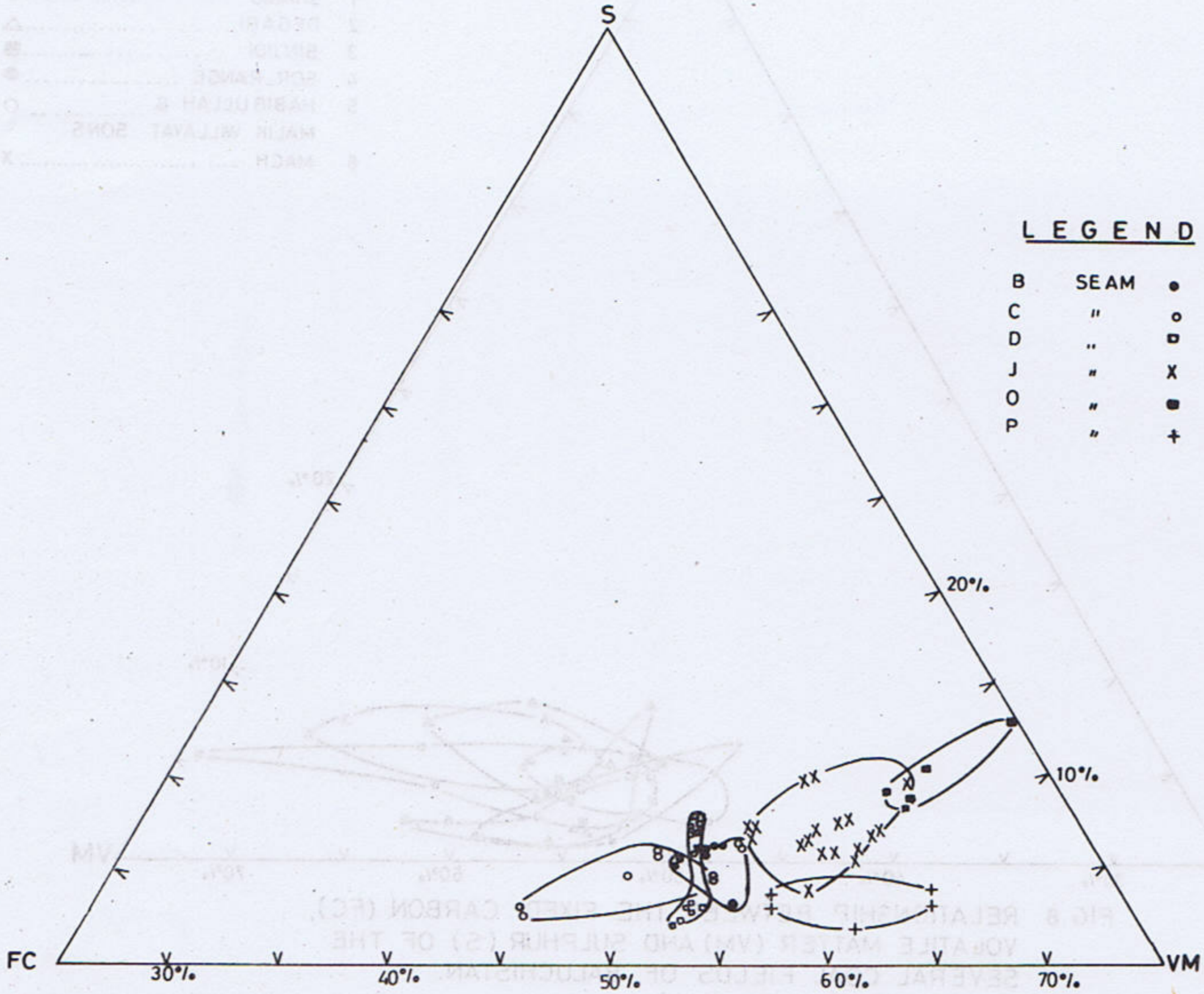


FIG-9 DUKI COAL FIELD BASED ON GSP's ANALYSIS (1985) SHOWING RELATIONSHIP BETWEEN FIXED CARBON (FC), VOLATILE MATTER (VM) AND SULPHUR (S) OF VARIOUS COAL SEAMS

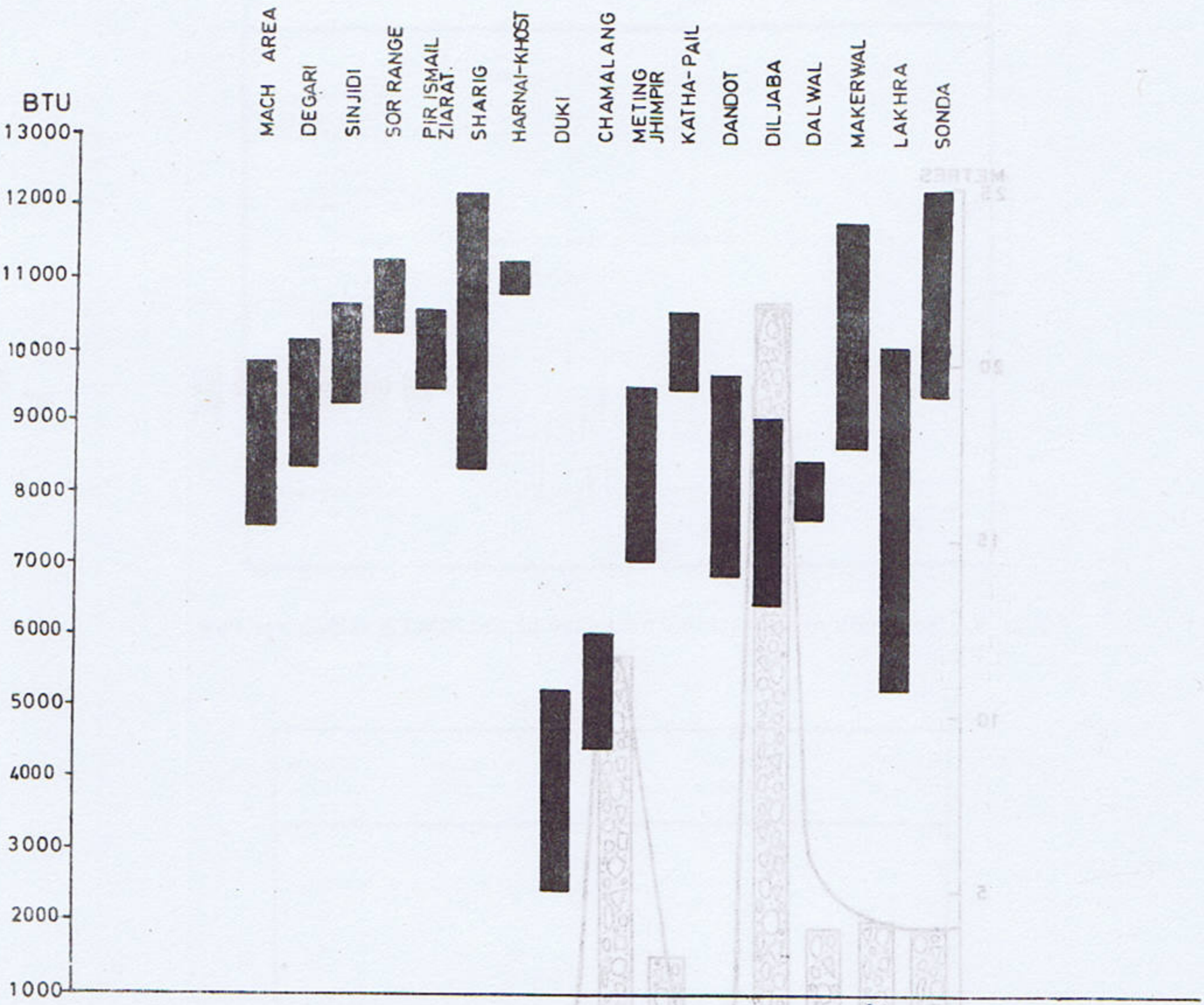


FIG.10 BAR CHART SHOWING THE RANGE OF CALORIFIC VALUES (BTU) OF VARIOUS COAL FIELDS OF PAKISTAN

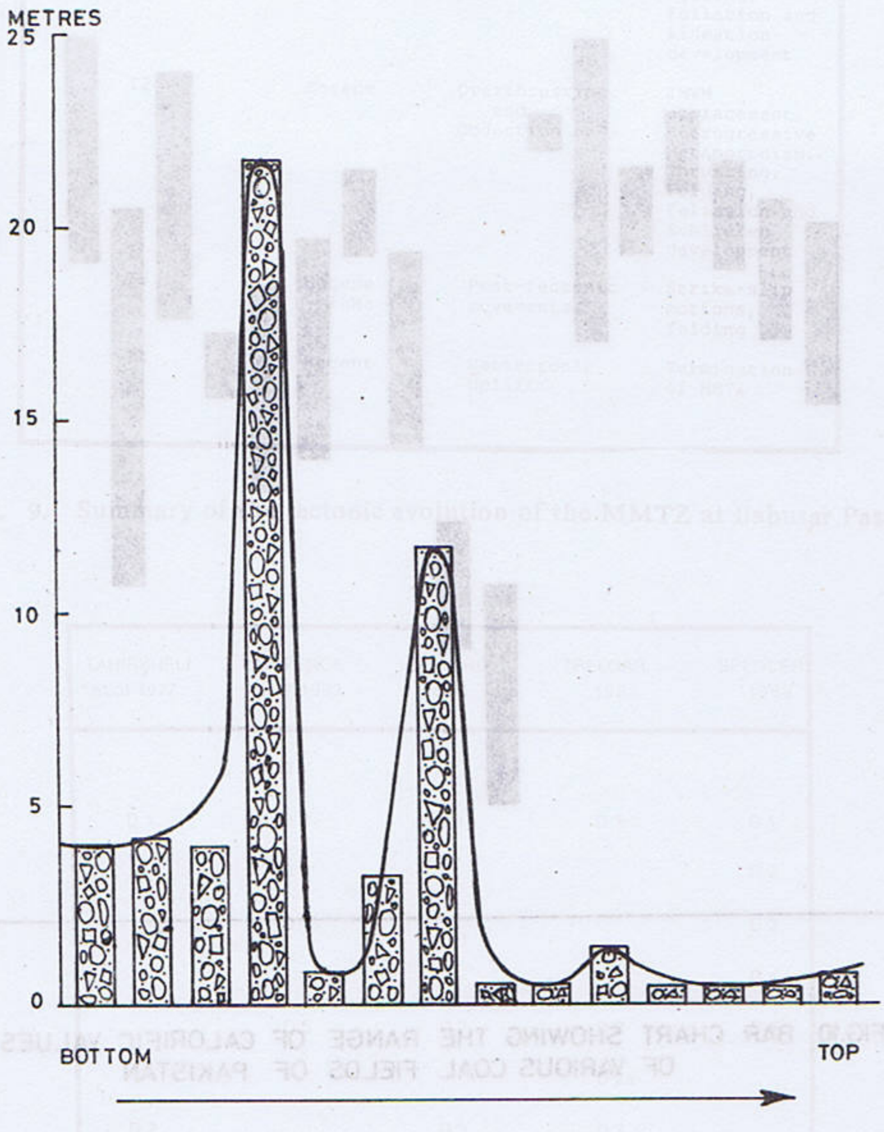


FIG. 11. THICKNESSES OF CONGLOMERATIC BEDS ENCOUNTERED AT PMDC BORE HOLE-2, GOOD HOPE AREA, BALUCHISTAN

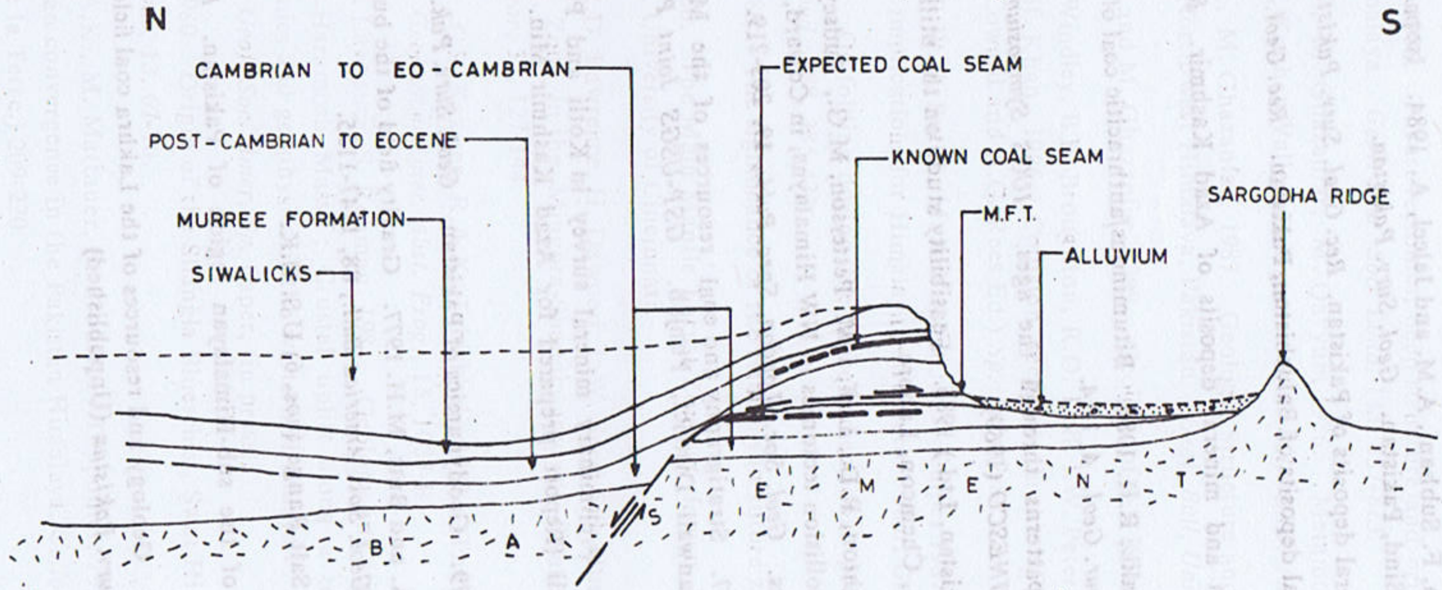


Fig. 12. SKETCH DIAGRAM SHOWING EXISTING KNOWN COAL SEAMS AND EXPECTED PALEOCENE COAL IN THE CENTRAL SALT-RANGE.

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DEFORMATION ON THE MAIN MANTLE THRUST ZONE AT BABUSAR PASS, NW HIMALAYA, PAKISTAN

BY

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Abstract : *The Main Mantle Thrust Zone passes through the Babusar Pass area as a complex zone of, not just one, but three thrust faults that enclose a complex assemblage of two tectonic melanges. This Indus Suture Melange Group includes an earlier subduction-related Ultramafic melange and a later metavolcanic melange. Deformation on the suture zone results in the formation of various structures that give a six phase deformational history dividing the area into four structural domains. This leads to a four stage tectonic evolution, comprising of a subduction stage, obduction stage, lateral movement stage and a neotectonic stage.*

INTRODUCTION

The Indus-Tsangpo Suture of the Himalaya (Gansser, 1980) is recognised as the major tectonic break between the Indian Sub-continent and the collage of terrains that constitute Eurasia (Figure 1). This suture divides in Ladakh. India : the earlier, northern extension known as the Northern Suture (NS) and the later southern extension, the westward continuation of the Indus-Tsangpo Suture, as the Main Mantle Trust (MMT). This southern extension thus separates the Kohistan Arc to the north from the Indian Plate to the south and is regarded as the site of a former subduction zone between the colliding Indian and Asian Plates (Tahirkheli *et al.*, 1977). Although the lithologies, structure and deformation along this southern suture are still poorly defined, it is now not thought to be a single thrust fault as previously defined (Tahirkheli *et al.* 1977, 1979) but a complex zone of many thrust faults enclosing a complex array of tectonic melanges (Lawrence *et al.*, 1983) Kazmer, 1986.

REGIONAL SETTING

Geographical setting and previous workers

Babusar Pass (4,172 m) forms the main col and watershed between the Kaghan Valley and the Thak Valley, 80 km northeast of Naran and 43 km south of Chilas in northeast Pakistan (Figure 2). Regional interpretations of the Kohistan area have been put forward by many workers (Tahirkheli *et al.* 1977, 1979 ; Coward *et al.* 1986, 1987) who have a general agreement that the MMT is a suture zone separating the Kohistan Island Arc and the Indian Plate. Yeats and Lawrence(1984) and Kazmer(1986) discussed

(* Present address : Institute of Geology, ETH-Zentrum. CH-8092, Zurich, Switzerland) the structural geology along the MMTZ and the underlying metasedimentary rocks and noted five stages of deformation associated with the suture zone. Coward *et al.*, (1986) suggest that the bulk of the deformation occurred between the late Cretaceous and the mid Eocene, envisaging a four stage deformational history.

Regional geometry of the MMT

The MMTZ extends westwards from Ladakh, in India, to eastern Afghanistan, a distance of some 1,500 km. The suture zone is irregular in plan, possibly reflecting the shape of the edge of the Indian Shield. It generally dips northwards at medium to low angles (20-45°), but in sections the deformations of later periods have tilted the original angle of inclination to steep and even vertical A drastic variation in width can be seen along the length of the MMT as the suture zone varies in outcrop width from 10-15 km at Swat to only 1 km at Babusar Pass. The lithologies present within the suture zone are varied, but can generally be recognised as ophiolites and melanges (Kazmi *et al.*, 1984 ; Shams. 1980) and they give rise to a general term of the Indus Suture Melange Group.

Both footwall and hanging wall lithologies vary along strike. Two groups are juxtaposed in the hanging wall, the Jijal- Patan complex and the Kamila Amphibolites, whilst, in the footwall. the MMT overrides a variety of pre-Cambrian rocks of the Indian Plate. These changes along strike represent, not only lithological changes, but also changes in the depth of origin and type of metamorphism. How and why this is so is unclear. Butler *et al.* (1988) suggest that the MMT is a relatively high level feature which developed as a break back thrust within the Kohistan Arc removing, in places, the earlier ductile deformed rocks both along the footwall and the hanging wall. Alternatively, the MMT could be experiencing different rates of uplift along strike, so exposing rocks of different crustal levels (Zeitler 1982, 1985). Fission track 40 Ar/39 Ar cooling ages suggest that there is a progressive increase in the uplift rates from west to east. Coward (1986) suggests that tectonic compression gave rise to uneven crustal buckling resulting in different uplift along the MMT.

The MMT and the Nanga Parbat-Haramosh Massif

Certainly one of the most interesting areas of geological study in the NW Himalaya, is that of the Nanga Parbat-Haramosh Massif (NPHM). Zeitler (1985) records details of the rapid uplifting of the Massif which results in the folding of the MMT around the syntaxis. Butler *et al* (1988) have mapped parts of this junction between the NPHM and the Kohistan Island Arc, renaming the reworked displacement as the Raikot Fault. Displacement along the fault is reverse slip with some right lateral strike slip. The MMT also appears again on the eastern side of the NPHM where a similar displacement of the suture zone by the Stak Fault occurs (Madin *et al.* 1988).

THE INDUS SUTURE MELANGE GROUP

One of the most characteristic features of the MMT is the occurrence of subduction and obduction related lithologies at the contact of the Indian Plate and the Kohistan Island Arc. These units usually have different structural and lithological characteristics, indicating a distinct geological origin and correlation with a specific tectonic event in the evolution of the Kohistan Himalaya. Detailed descriptions of these lithologies have been given in the Mingora-Shangla area of Swat (Kazmi *et al.* 1984) and Chaudhry and Ghazanfar (1989), the latter have also made an attempt to correlate the suture lithologies along a certain length of the suture zone. The Indus Suture Melange

Group (ISMG) is considered to be the remnants of the lithosphere of the Tethys ocean. The definition of the ISMG is used in conformity with the Gansser (1974) description of an ophiolitic melange associated with suture zones connected to plate boundaries.

Suture zone lithologies at Babusar Pass

Two melanges are found at Babusar Pass (Figure 3) - an Ultramafic Melange and a Metavolcanic Melange. The Babusar Ultramafic Melange is a band of lenticular lenses containing clasts of altered ultramafic and mafic rocks set in a foliated matrix of talc carbonates, zeolites, chlorite and quartz. They show a distinctive greenschist facies metamorphism and history of ductile deformation (undulatory extinction, sub-grain enhancement and shear bands). Their mineralogy suggests that it represents oceanic lithospheric rocks deformed during initial subduction. The Tatabai Metavolcanic Melange consists of greenstones and greenschists of volcanic and volcanoclastic origin preserved in fault blocks and wedges. They are generally separated by bands of mylonites and cataclasites indicating the possibility of numerous small scale thrusts. The lithologies generally consist of quartz, chlorite, plagioclase, epidote, clinozoisite and mica with the greenschist foliation well defined by the micas. Some brittle fabrics are preserved in the clasts with angular fragments set in a finer grained matrix. They represent a parallochthonous, high level magmatic suite associated with the obduction of the Kohistan Arc.

The ISMG is bounded to the south by the Sharda Group (Chaudhry *et al.*, 1986, 1987). These metasediments of the Indian Plate consist of amphibolite facies rocks, a regionally metamorphosed series of marbles, amphibolites, quartz-feldspar gneissess, garnet-mica schists, graphitic schists and chloritic schists that represent an allochthonous platform. The ISMG is bounded to the north by amphibolites, sea floor volcanics and sediments of the Kohistan Island Arc. They consist of a variety of lithologies that are weak to moderately foliated, generally consisting of amphibole, quartz, biotite and muscovite mica, representing the crust of a magmatic arc.

INTERNAL STRUCTURE OF THE MAIN MANTLE THRUST ZONE

The local deformational history of the Main Mantle Thrust Zone (MMTZ) can be divided into four stages of tectonic evolution that is subdivided into six phases of deformation (Figure 4), the first three phases of deformation being intrinsically related to deformation only in the Indian Plate (Figure 5). Faults, folds, foliations, slickensides, lineations and xenoliths were found and their complex interactions, as well as their limited occurrence, seem to suggest that they are tectonically (secondary), rather than lithologically (primary) controlled.

Subduction stage

Three phases of Indian plate deformation are associated with the subduction of the Indian plate beneath the Kohistan Arc. D1 consists of the emplacement along the east-west striking, 36 degree northward dipping Babusar Thrust above the Sharda Group (Indian Plate rocks) forming the Babusar Ultramafic Melange. The contact is represented by an intensely sheared blastomylonite and shows in places occasional northward plunging, moderate to steeply dipping slickensides (Figure 6e) that are commonly mineralised by chlorite. A strong foliation (Figure 6f), with preferential development of mica-rich differentiated layers, is deformed by extensive isoclinal folding. The folds, of centimeter size amplitudes, probably relate to an early period of nappe formation. A second, D2 phase of deformation is a strong, northward plunging mineral stretching lineation development (Figure 6h) that is again confined to the Sharda Group and the Babusar Ultramafic Melange. These north-northeast plunging, 1-50 cm amplitude, open to tight folds occur on a variety of scales and warp the earlier isoclinal folds (Figure 6a). A final D3 phase of deformation comprises of thurst related east-west plunging incipient sheath fold development, implying the simple shear nature of the MMTZ (Figure 6a). All the above structures are only found in the Indian Plate metasediments and its associated melange. A kyanite-sillimanite, high grade. upper amphibolite facies metamorphism is associated with deformation, but is not due to the obduction of the Kohistan Arc along the MMT.

Obduction stage

The terminal collision of the Indian Plate resulted in the obduction of the Kohistan Island Arc along the Kohistan Thrust, an east-west striking, 30 degree northward dipping discontinuity. This, therefore, brings a separate structural domain into contact with the underlying, highly deformed Sharda Group, which subsequently becomes retrogressed. This D4 thrusting resulted in the formation of the Tatabai Metavolcanic Melange, the 35-40 degree, later formed (relative to the Kohistan Thrust) northward dipping, Tatabai thrust. It forms the leading edge of an anastomosing fault zone with several small scale thrusts, represented by mylonites and thin discontinuous bands of sheared serpentinite. Associated with this are minor F4 small, upright 5-30 cm amplitude angular folds which have sharp hinges that plunge steeply to the north (Figure 6c). Noticably, they do not deform any other folds or lineations, only a supposedly later formed east-west foliation (Figure 6g). Xenolith shapes give a calculated average (n=X:Z) ratio as 11.7:1 compared with an estimated original of 2:1 (Flinn, 1962). Therefore, the Y : Z ratio is calculated as 5.85 : 1 which when plotted on a Flinn diagram lies in the constricted ellipsoid field. The stereoplot direction of the xenoliths, with the maximum strain extension plunging to the east confirms the simple shear nature of the MMTZ development (Figure 6i). A Barrovian-type of overprinted retrogressive metamorphism is associated with the rejuvenation of movement along the MMTZ during the obduction.

Lateral movement stage

A D5 phase of deformation involves late stage dextral motions along the MMTZ with the hanging wall moving to the east (Figure 6d). This is examplified by small scale, northerly plunging 'Z' shaped parasitic folds with dextral vergence. That they plunge down the dip of the MMTZ, and are only found in the ISMG, suggests that they are formed at a late stage in the history of the suture zone.

Neotectonic stage

Uplift of the MMT occurred after the lateral movements had ceased at about 15Ma (Zeitler, 1985). However, more recent deformation, associated with the Nanga Parbat-Haramosh Massif possibly resulted in the reworking of the MMTZ (D6) along a neotectonically active fault tentatively called the Raikot Fault after (Butler *et al*, 1988), although no evidence has yet been found that the two faults correlate). The fault is vertical, shows no suture melange group lithologies that were seen in the MMTZ, strikes north-south and is obviously younger than the MMTZ.

SYNTHESIS

That the thrusts of the MMTZ formed at different times is only noticeable by looking at the distribution of the structures and the complex folding and refolding associated with them. This is more visually apparent if a summary of the structures formed in the four stage development of the MMTZ is shown

Figure 7). It emphasises that the suture zone can be readily divided into four structural domains (Figure 8) which clarify the history of the deformation. The SD1 structural domain consists of the subducting Indian plate and its associated melange (combining D1, D2 and D3). The SD2 structural domain consists of the amphibolites of the Kohistan Arc and its associated metavolcanic melange (D4 deformation). The SD3 structural domain is contained within the ISMG (D5 deformation) and the whole area can be regarded as the SD4 structural domain as it was all affected by the neotectonic uplift of the NPHM. A summary of the deformation is shown (Figure 9). The MMTZ marks a significant break in metamorphic conditions from upper amphibolite facies in the Indian Plate to lower greenschist facies in the Kohistan Arc, including the melanges.

DISCUSSION

Any attempt to compare the deformational events at Babusar Pass with those along strike of the MMT will probably show marked differences. This is due to the progressive eastward suturing along the collision zone with India colliding with Asia first near Afghanistan at 62 Ma and progressively colliding eastwards to India where terminal collision occured in 55 Ma (Coward *et al.* 1987). Therefore, different times of subduction, led to different rates of collision and subsequently different rates of uplift, exposing different lithologies along the length of the suture zone. Correlations of any lithology along the suture zone, means therefore, correlation of completely different facies and levels of subduction that makes comparisons difficult. Comparisons with Tahirkheli *et al.* (1977), Coward (1983), Lawrence *et al.* (1933) and Treloar (1988) show some similarities (Figure 10). The tectonic evolution of the MMTZ is shown diagramatically (Figure 11).

CONCLUSIONS

The Main Mantle Thrust is complex suture that separates the Indian Plate and the Kohistan Arc. The Main Mantle Thrust Zone at Babusar Pass (Spencer, 1988) consists of three main thrusts that formed at different times, as examplified by the structures associated with the suture zone, and juxtaposes lithologies of ophiolitic and Island arc affinities in two different tectonic melanges. The suture zone is the site of a subduction zone formed by continent-island arc collision. The MMTZ consists of six phases of deformation that resulted in the formation of various structures in four structurally homogenous domains invoking a four stage tectonic evolution. Deformation ranges from the pre-Cambrian to Recent and is associated with both progressive and retrogressive metamorphism. Recent neotectonic activity, due to the formation of the NPHM has resulted in the formation of the Raikot Fault.

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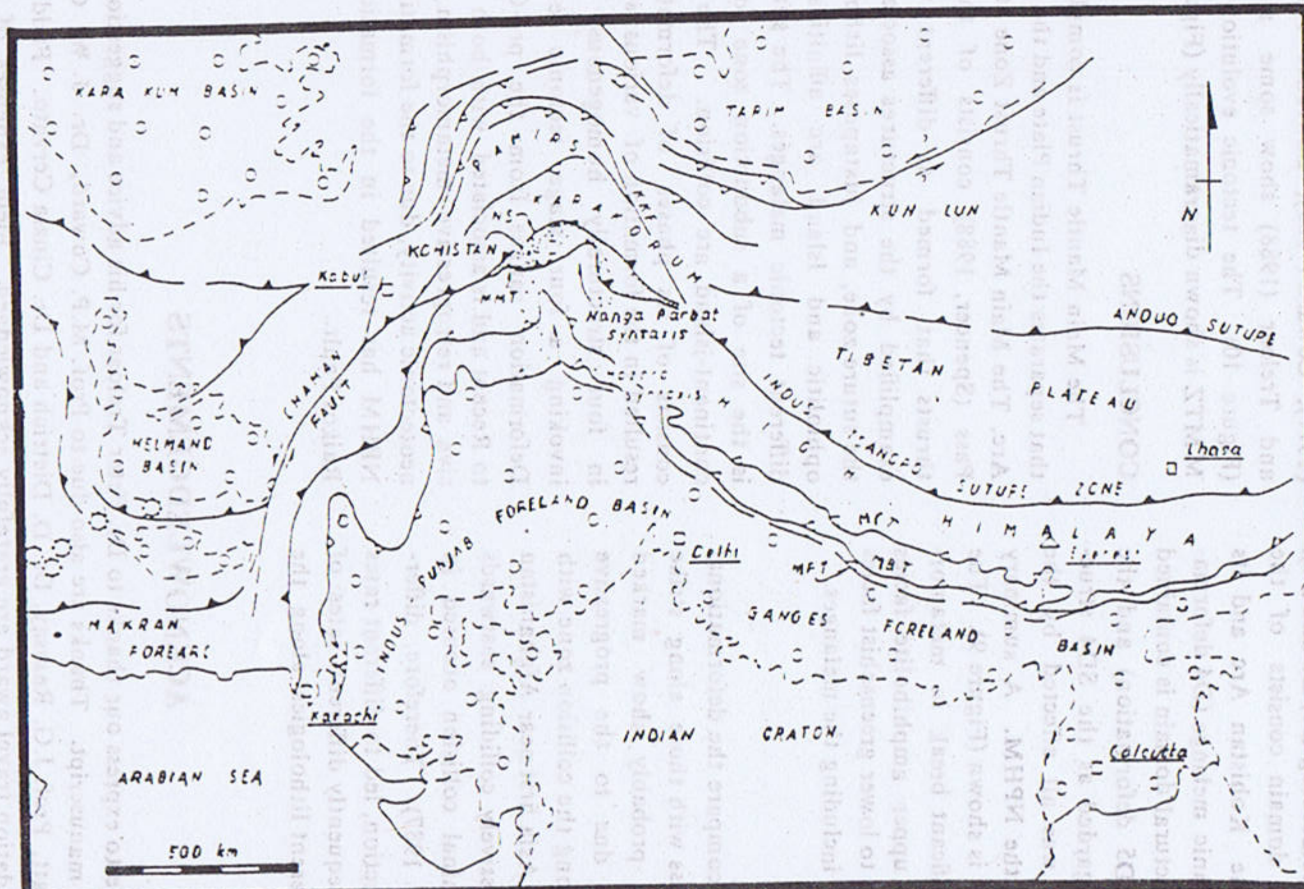

Fig. 1. The Indus Tsangpo Suture Zone of the Himalayas. It divides in Ladakh to form the earlier Northern Suture to the north and the later formed MMT to the south, enclosing the Kohistan Island Arc.

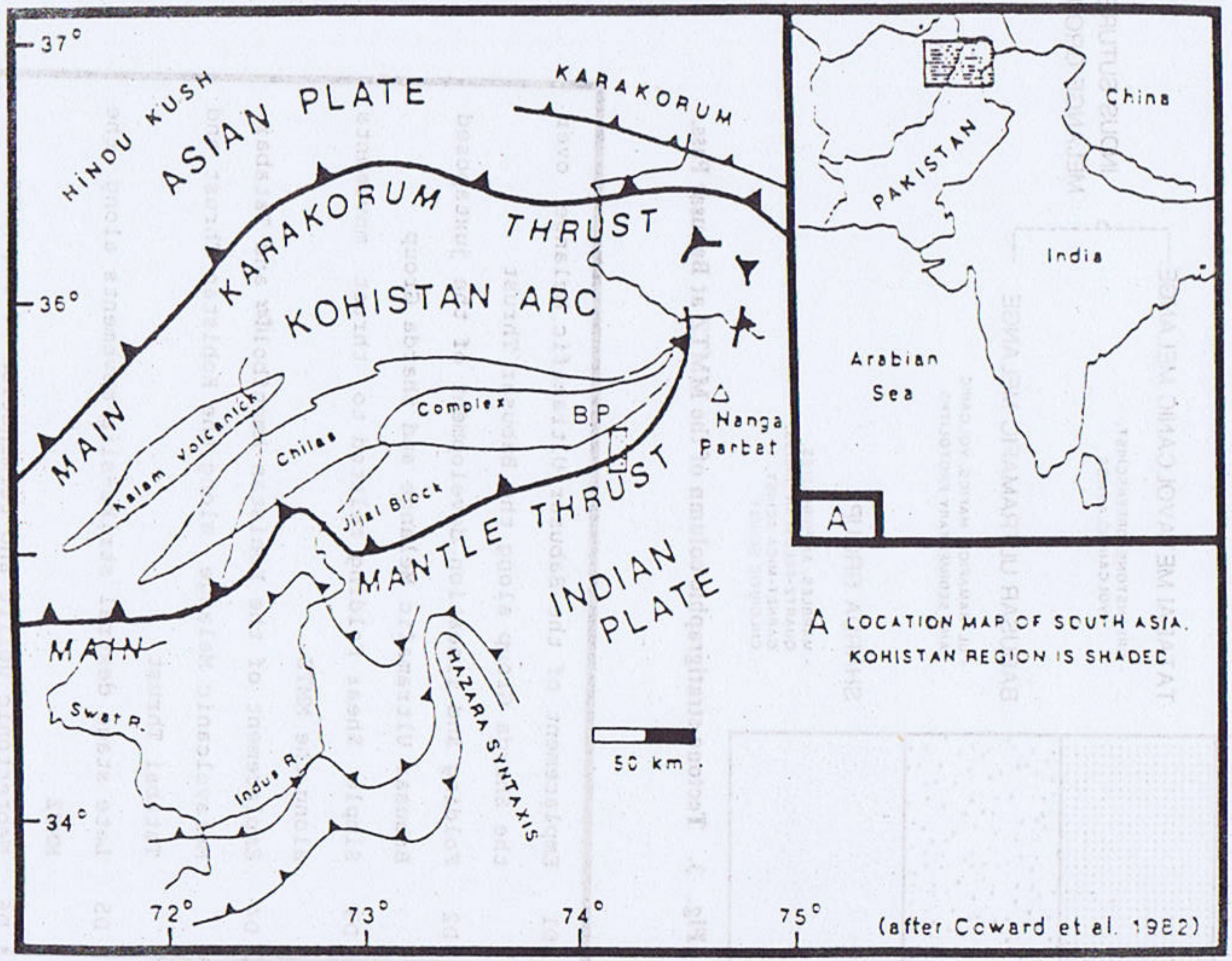

Fig. 2. Map to show the position of Babusar Pass (B. P.) on the MMT, NW Himalaya.

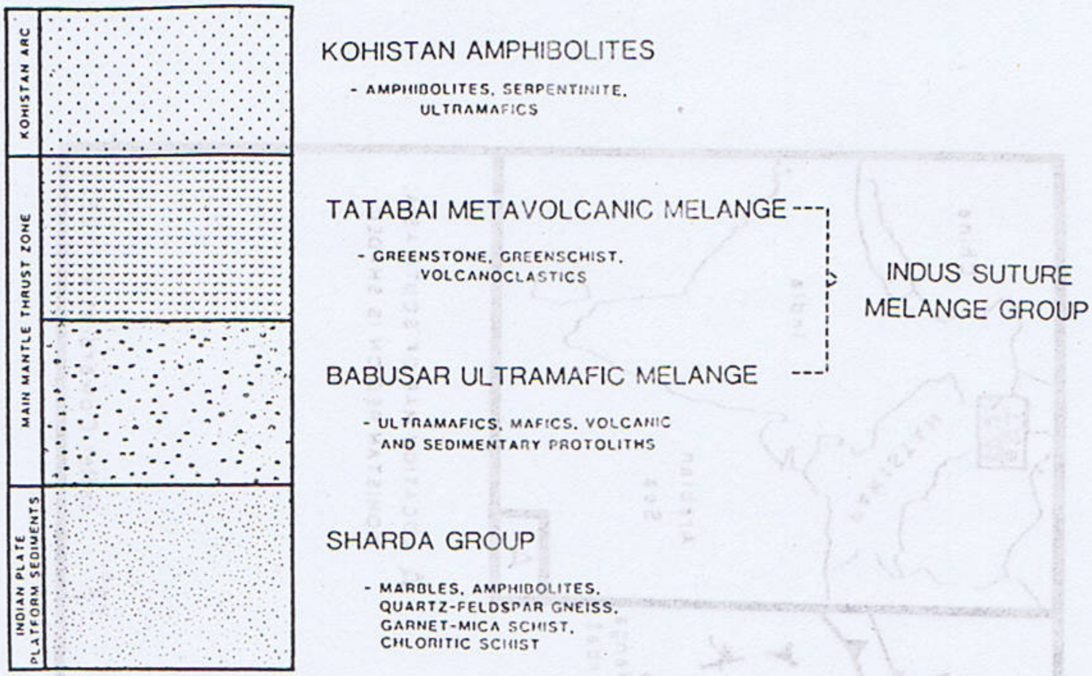

Fig. 3. Tectono-stratigraphic column of the MMTZ at Babusar Pass.

D1	Emplacement of the Babusar Ultramafic Melange over the Sharda Group along the Babusar Thrust
D2	Folding and lineation development of the juxtaposed Babusar Ultramafic Melange and Sharda Group
D3	Simple Shear Folding related to thrust movements along the MMTZ
D4	Emplacement of the Kohistan Amphibolites and Tatabai Metavolcanic Melange along the Kohistan Thrust and Tatabai Thrust
D5	Late stage dextral strike-slip movements along the MMTZ
D6	Neotectonic uplift and termination of the MMTZ.

Fig. 4. Summary of the phases of deformation on the MMTZ at Babusar Pass. Note that the first three phases of deformation are found only in the Indian Plate Metasediments.

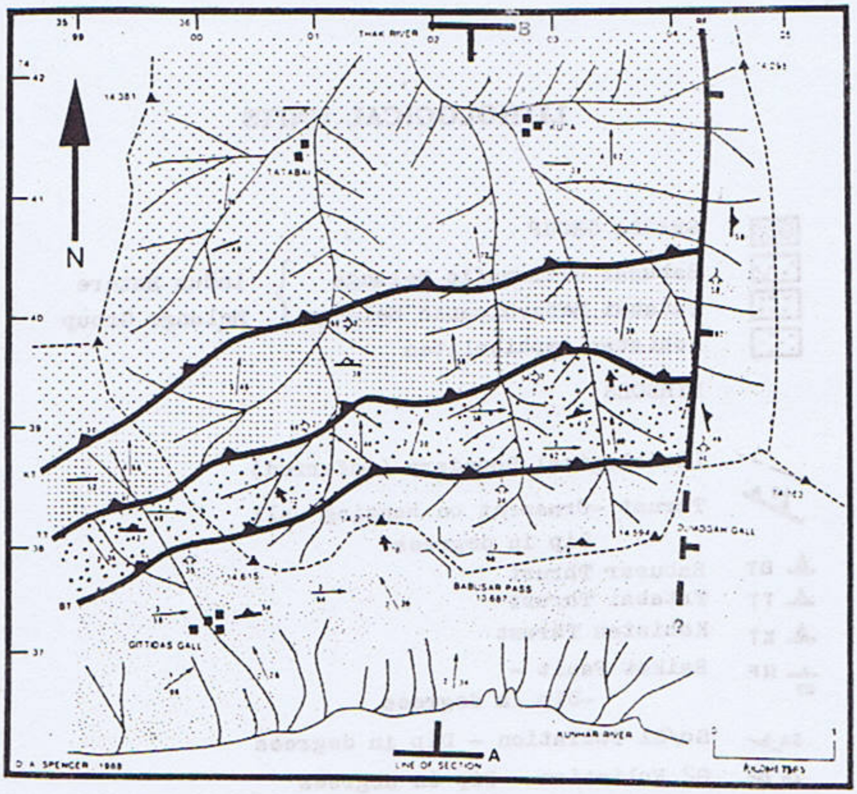

Fig. 5. (a) Geological Map of Babusar Pass.

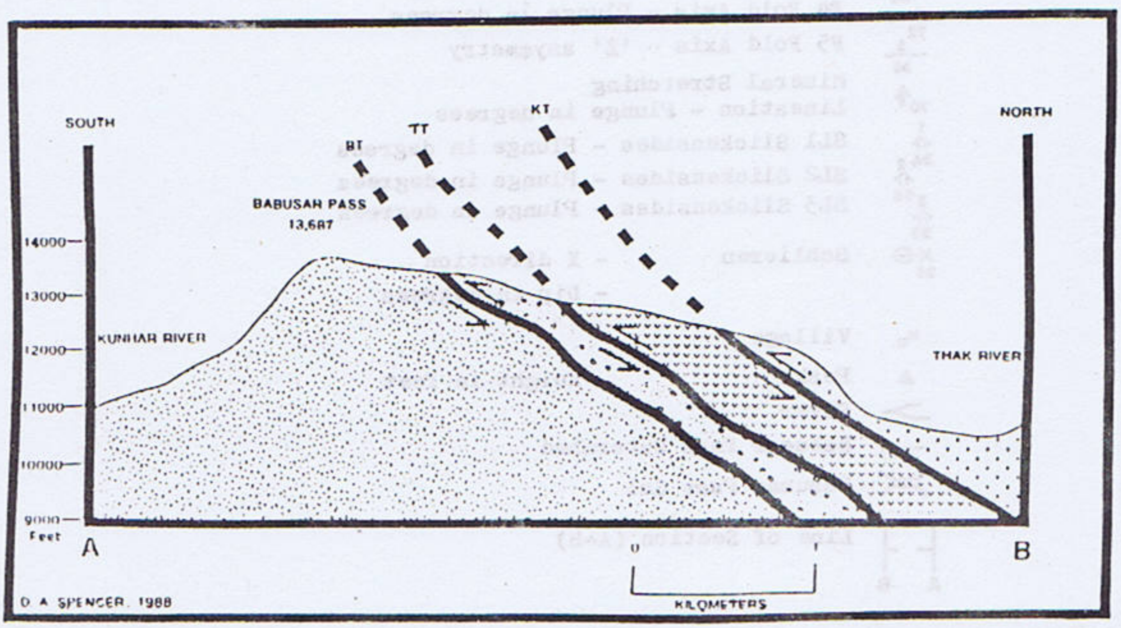

Fig. 5. (b) Simplified south-north cross section shows the position of the MMTZ.

LITHOLOGICAL UNITS

SHARDA GROUP

Babusar Ultramafic Melange } Indus Suture
Tatabai Metavolcanic Melange } Melange Group
Kohistan Amphibolites

SYMBOLS

Lithological Boundary (inferred)

40 Thrust -Ornament on hanging wall
Dip in degrees

BT Babusar Thrust
TT Tatabai Thrust
KT Kohistan Thrust
RF 87 Raikot Fault -
-Dip in degrees

54 So/S1 Foliation - Dip in degrees
40 S2 Foliation - Dip in degrees
1 08 F1 Fold Axis - Plunge in degrees
2 30 F2 Fold Axis - Plunge in degrees
3 58 F3 Fold Axis - Plunge in degrees
4 72 F4 Fold Axis - Plunge in degrees
5 38 F5 Fold Axis .. 'Z' asymmetry
70 Mineral Stretching
Lineation - Plunge in degrees
1 34 SL1 Slickensides - Plunge in degrees
2 66 SL2 Slickensides - Plunge in degrees
3 58 SL3 Slickensides - Plunge in degrees
X 36 Schlieren - X direction
- Dip in degrees

Village
Peak - Height in feet
River
Babusar Pass Watershed
Babusar Pass Col

A B Line of Section (A-B)

Fig. 5. (c) Key to 5a and 5b.

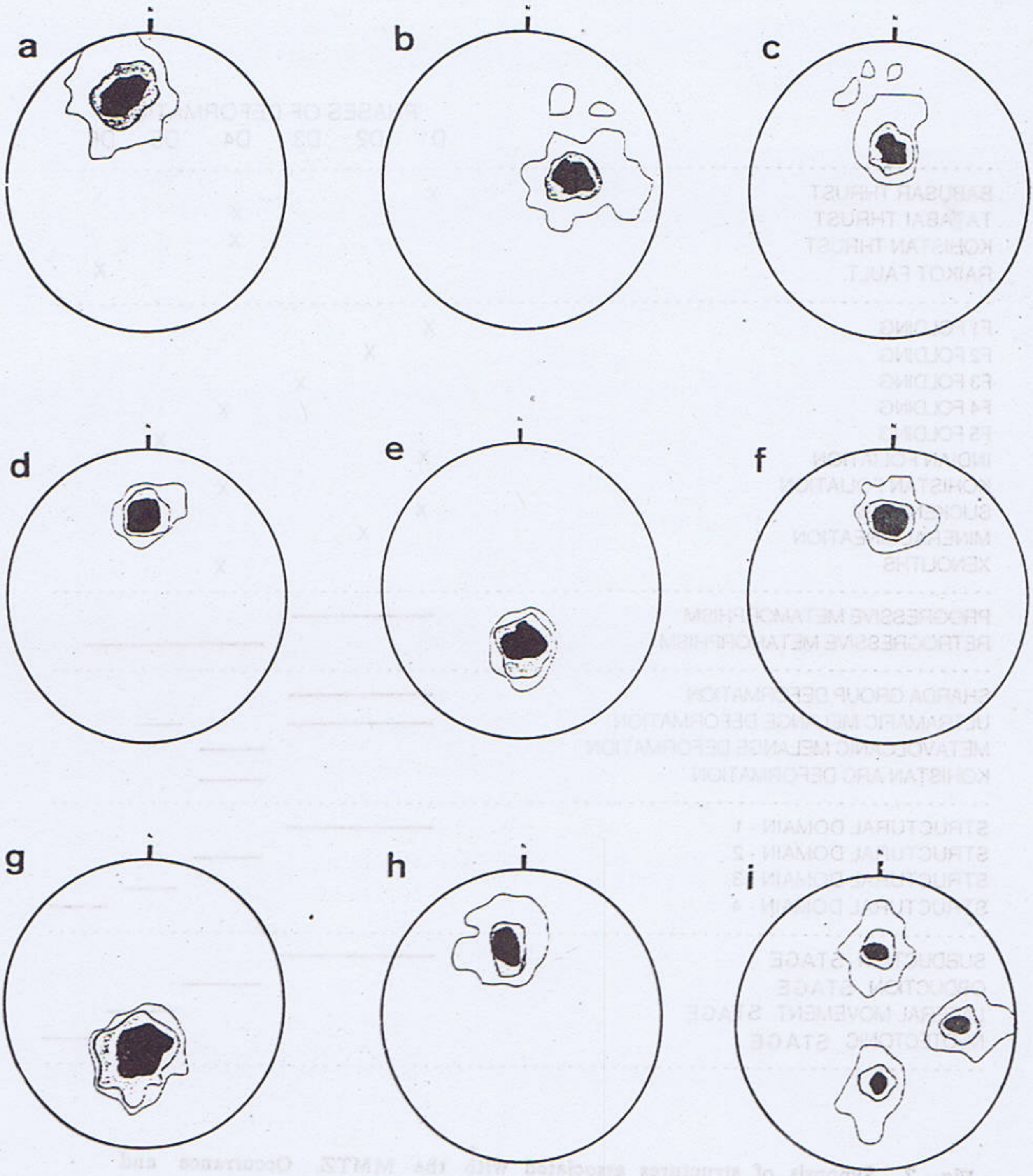

Fig. 6. **Stereoplot contour diagrams. (a) F2 fold plunges. (b) F3 fold plunges (c) F4 fold plunges, (d) F5 fold plunges. (e) SL1 slickensides. (f) Indian Plate foliation. (g) Kohistan Arc foliation. (h) Mineral stretching lineation (i). X,Y,Z principal strain axes of xenoliths. Contour intervals are 1%, 10%, 20%. Lower Hemisphere projections. Schmidt equal area net. N-North.**

	PHASES OF DEFORMATION					
	D1	D2	D3	D4	D5	D6
BABUSAR THRUST	X					
TATABAI THRUST				X		
KOHISTAN THRUST				X		
RAIKOT FAULT						X
F1 FOLDING	X					
F2 FOLDING		X				
F3 FOLDING			X			
F4 FOLDING				X		
F5 FOLDING					X	
INDIAN FOLIATION	X					
KOHISTAN FOLIATION				X		
SLICKENSIDES	X					
MINERAL LINEATION		X				
XENOLITHS				X		
PROGRESSIVE METAMORPHISM	—	—	—			
RETROGRESSIVE METAMORPHISM				—	—	—
SHARDA GROUP DEFORMATION	—	—	—			
ULTRAMAFIC MELANGE DEFORMATION	—	—	—		—	
METAVOLCANIC MELANGE DEFORMATION				—		
KOHISTAN ARC DEFORMATION				—		
STRUCTURAL DOMAIN - 1	—	—	—			
STRUCTURAL DOMAIN - 2				—		
STRUCTURAL DOMAIN - 3					—	
STRUCTURAL DOMAIN - 4						—
SUBDUCTION STAGE	—	—	—			
OBDUCTION STAGE				—		
LATERAL MOVEMENT STAGE					—	
NEOTECTONIC STAGE						—

Fig. 7. Synopsis of structures associated with the MMTZ. Occurrance and relative time relationships of structures (a) divides the region into areas of deformation (b) giving four structural domains (c) and therefore a four stage tectonic evolution (d).

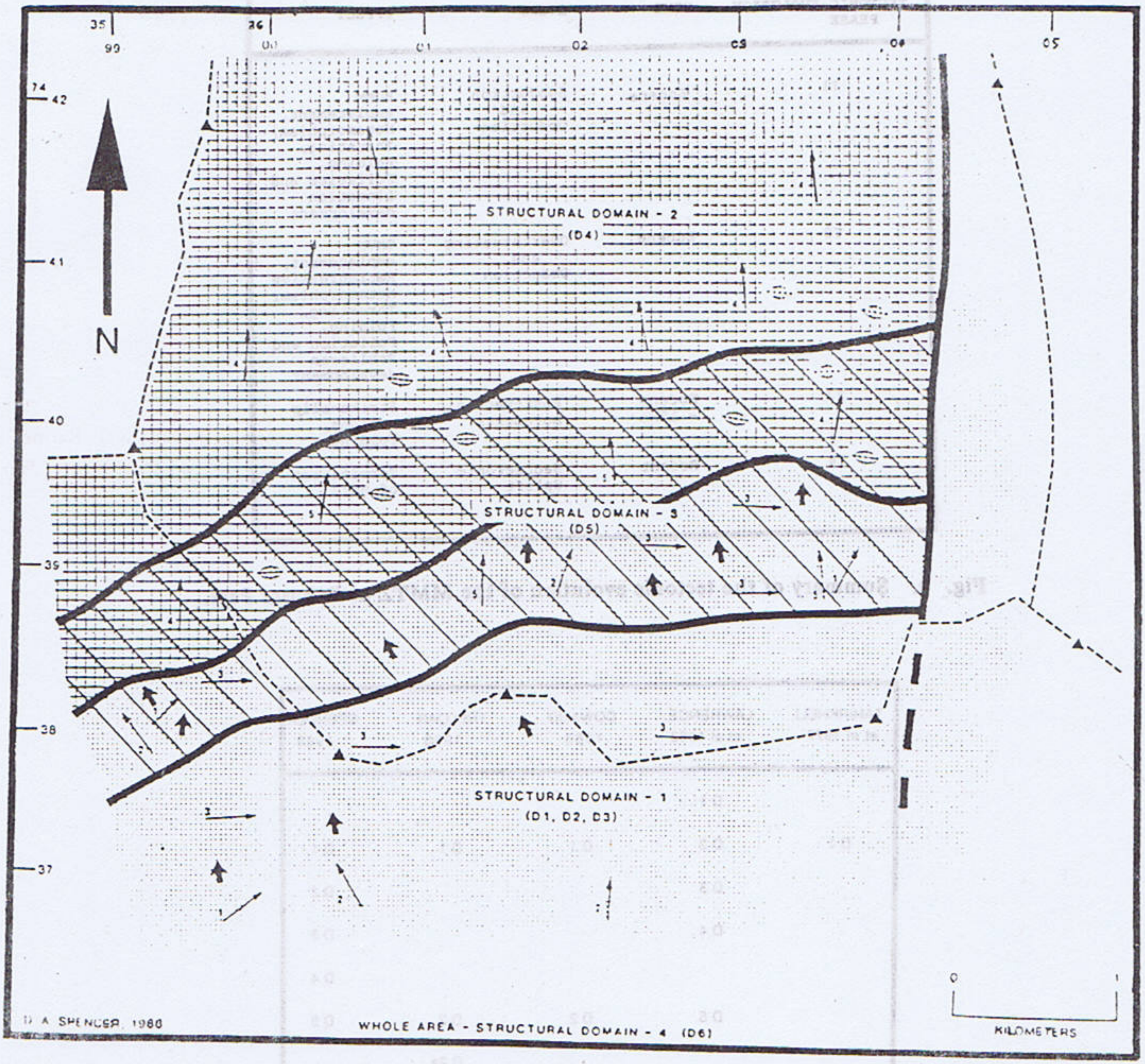

Fig. 8. Map to show the structural domains at Babusar Pass. Key same as in figure 5 (c).

TECTONIC EVOLUTION PHASE	TIME	EVENT	EFFECT
T1	Eocene	Subduction and Obduction	BUMM emplacement, Metamorphism, Thrusting, Folding, Foliation and Lineation development
T2	Eocene	Overthrusting and Obduction	TMVM emplacement, Retrogressive Metamorphism, Thrusting, Folding, Foliation and Schlieren development
T3	Eocene - 15Ma	Post-tectonic movements	Strike-slip motions, folding
T4	Recent	Neotectonic Uplift	Termination of MMTZ

Fig. 9. Summary of the tectonic evolution of the MMTZ at Babusar Pass.

TAHIRKHELI et al 1977	LAWRENCE et al 1983	COWARD 1983	TRELOAR 1988	SPENCER 1989
	D 1			
D 1	D 2	D 1	D 1	D 1
	D 3			D 2
	D 4			D 3
				D 4
	D 5	D 2	D 2	D 5
			D 2a	
D 2		D 3	D 3	
		D 4		
				D 6

Fig. 10. Comparison of phases of deformation by various workers along strike of the MMT.

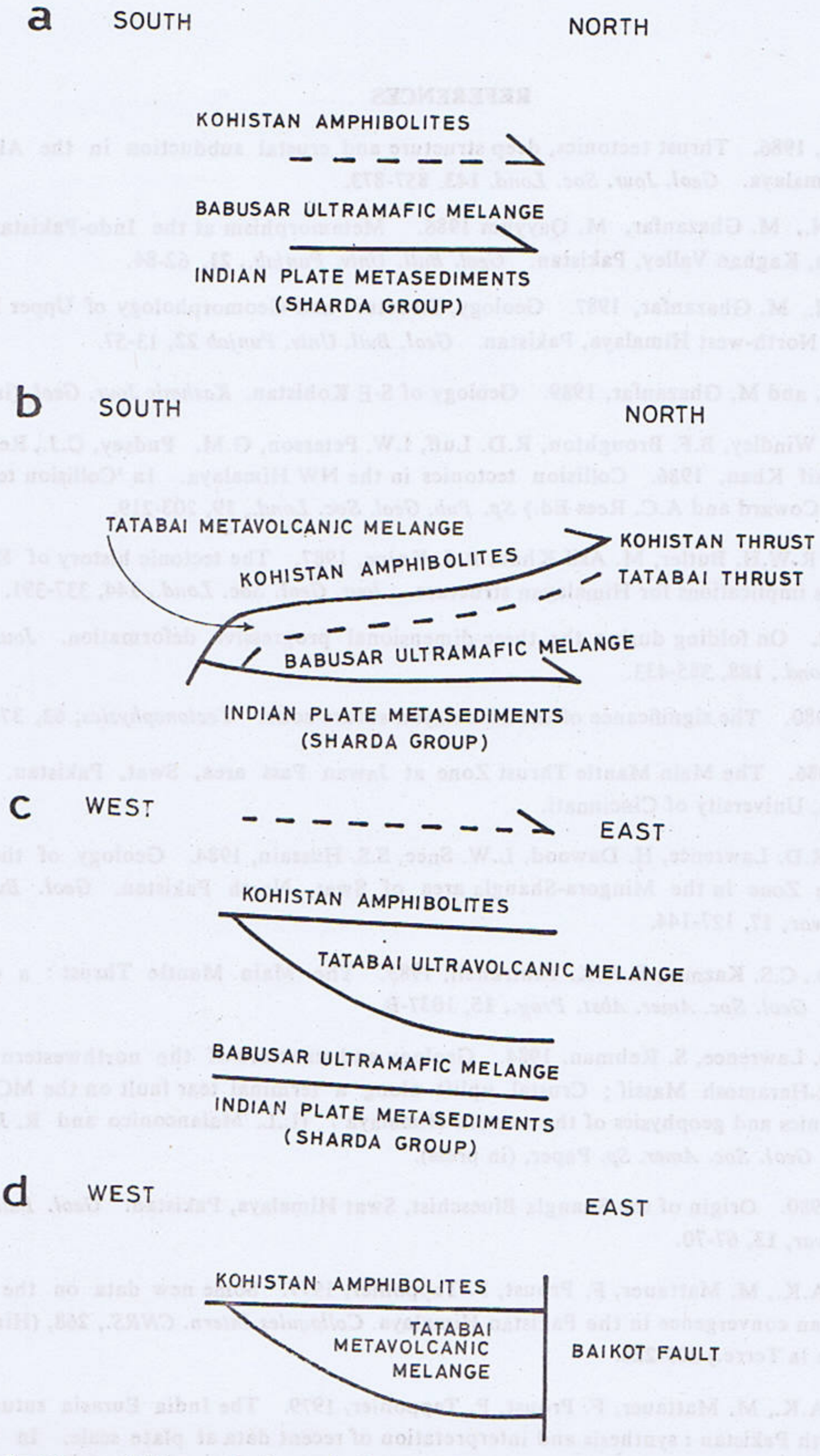

Fig. 11. Summary of the evolution of the MMTZ at Babusar Pass. Stage 1-Subduction stage. Stage 2-Obduction stage. Stage 3-Lateral movements. Stage 4-Neotectonic uplift.

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PETROGRAPHY, METAMORPHISM, NATURE AND ORIGIN OF AGGLOMERATIC SLATE IN KAGHAN VALLEY, DISTRICT MANSEHRA PAKISTAN

BY

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Abstract : *The Agglomeratic Slate in Kaghan Valley is a lithologically heterogeneous unit. It is composed of graphitic schist, micaceous quartzite, feldspathic quartzite, pelitic schist, feldspathic chlorite calcite schist, marble and metaconglomerate. The graphitic schist and feldspathic quartzites contain volcanogenic material. In Kashmir it contains well defined volcanic horizons. The unit was deposited under varying environmental conditions, continental, lagoonal and marine in a deepening cratonic rift, and represents continuation and, at places ; a replacement of Tanawals of Kashmir.*

INTRODUCTION

The name Agglomeratic Slate was given by Middlemiss (1910, 1911). The unit was studied subsequently among others by Bion (1928), Wadia (1931, 1975), Calkins *et al.* (1975), Bossart *et al.* (1984) and Ghazanfar *et al.* (1984). Bossart *et al.* (1984) called this unit "Chushal formation" in Kaghan Valley.

The heterogeneous nature of this unit, some unique textures and the associated volcanic, volcanogenic material as well as the nature of underlying Tanawals and overlying Panjal Formation make the origin of Agglomeratic Slate controversial. The present paper describes the lithology and petrography of this unit in Kaghan Valley and summarises the views on origin at the end.

Lithologies in Kaghan Section. Between Shino Marbles and Jared Quartzites (Fig. 1) between Shino and Tutan on the Kaghan Valley roadside there is a relatively thin but very prominent sequence of graphitic schist and metaconglomerates with occasional thin bedded marble bands, pelitic schists, feldspathic chlorite calcite schist, micaceous quartzite and feldspathic quartzite. This represents the Agglomeratic Slate unit of Kashmir. In Kashmir the sequence contains well defind acid to intermediate volcanic rocks but in the Kaghan Valley well defined volcanic horizons are difficult to find though sedimentary material derived from volcanics is present.

Graphitic Schist. The graphite schist is silver grey to steel grey on fresh surface and dark grey to dark brownish grey with rusty patches on the weathered surface. It is fine grained, well cleaved and contains small pyrite cubes which leave square cavities when removed by weathering. There are also thin quartz veins which are folded and make prominent white boudins.

Marble and Feldspathic Chlorite Calcite Schist. The marble is medium grey, thinly laminated with fine white partings and is intercalated with feldspathic chlorite calcite schist.

The Marble and feldspathic chlorite calcite schist occur towards the contact of Agglomeratic Slate with the older Jared unit.

Metaconglomerate. The metaconglomerate is best exposed on the path from Chushal village to Kamil di Gali. It consists of rock pebbles of graphitic schist, quartzite, marble, calc-schist and of granite. The rock is poorly sorted but shows a degree of foliation. The matrix is phyllitic. The conglomerate shows two varieties, one is coarse grained and the other is relatively fine grained. The coarse variety contains boulders one foot or more across. The conglomerate is dark brownish grey on weathered surface and grey on fresh surface.

Feldspathic quartzite and Micaceous Quartzite. The metaconglomerate sequence also contains impure quartzite, medium grey on fresh surface and brownish grey on the weathered surface. It is highly sheared and contains abundant feldspar. At places quartzite is micaceous and contains black tourmaline grains.

Pelitic Schist. It occurs as thin beds which are silver gray to off-white. It weathers to earthy gray and rusty earthy grey colours.

PETROGRAPHY

A petrographic study of the Agglomeratic Slates shows that in addition to metaconglomerate there are six main rock types present in this unit. These are as follows :—

1. Feldspathic quartzite.
2. Pelitic schist.
3. Graphitic schist.
4. Feldspathic chlorite-calcite schist.
5. Micaceous quartzite.
6. Marble.

These units have been described below and their composition is presented in Table 1.

1. *Feldspathic quartzite.* This unit is characterised by a hypidioblastic to xenoblastic texture Mylonisation is a fairly consistent feature. Groundmass is often fine grained and even cryptocrystalline in many cases. Gneissic to subgneissic structure is developed at many places.

Albite generally ranges in size from 0.15 to 2.0 mm. It occurs as porphyroblasts as well as tiny crystals in the groundmass. At some places it shows chess-board twinning. K-feldspar is mainly a poorly perthitic microcline. It has the same mode of occurrence and size range as albite.

Quartz generally occurs as deformed fragments and ranges upto 3.5 mm in size. It shows very strong strain effects. Fracturing and crushing of grains is evident. The grains show a strong strain extinction.

Both muscovite and biotite may occur. They occur as tiny flakes and shreds. They generally range in size from 0.05 to 0.40 mm.

The rock contains areas, patches and fragments of cryptocrystalline matter. The distribution of this matter is irregular and erratic. Iron oxides, tourmaline, zircon and graphitic matter occur as accessories.

2. *Pelitic schist.* These rocks are very fine grained and schistose. The grains and flakes are generally less than 0.08 mm. However a few bigger porphyroblasts of chlorite are also present which sometimes are set across the main foliation.

Chlorite and muscovite are persistent mica minerals and occur as discrete tiny flakes as well as aggregates. It is interesting to note that while muscovite and chlorite are ubiquitous, biotite is not. Biotite is greenish brown rather than brownish green in colour. Graphite, pyrite, iron oxides, sphene, epidote and zircon are the accessory minerals. These rock are characterised by the lack of feldspar and carbonate.

3. *Graphitic schist*. This unit has been studied but not modally analysed. It is extremely fine grained and sublepidoblastic. It contains nodules and cubes of pyrite. It is composed mainly of muscovite, quartz and graphite. Graphite is in fact mostly amorphous. Crystalline to cryptocrystalline graphitic matter is very small in amount. Iron oxides (mainly goethite) occur as alteration products of pyrite. Sphene, biotite, chlorite and tourmaline occur as accessories. Some samples also contain patches of chlorite.

4. *Feldspathic Chlorite-Calcite Schist*. This rock unit shows porphyroblastic to xenoblastic textures. The rock shows, at places, the presence of reconstituted cryptocrystalline matter of volcanic derivation.

Quartz occurs as porphyroblasts as well as very tiny grains. Quartz grains are often strained and even fractured. It shows strong sectorial extinction. It generally ranges in size from 0,2 to 1.8 mm.

Well twinned grains, plates and patches of calcite form as essential part of this rock and generally range in size from 0.1 to 5.0 mm. Feldspar is an essential constituent. Both albite and microcline are present. They occur as tiny groundmass constituents as well as bigger crystals (upto 1.0 mm). Patches and fragments of cryptocrystalline matter are also present.

Iron oxides, tourmaline, zircon and graphite occur as accessories. Biotite is lacking while muscovite may be present.

5. *Micaceous Quartzite*. Only one sample of this rock was studied. It is fine grained and granoblastic. Foliation is generally lacking. Tourmaline and zircon are present as accessories. The grain size ranges from 0.05 to 0.38 mm.

6. *Marble*, It is fine grained and often microcrystalline to cryptocrystalline. The coarser parts are from 0.15 to 0.40 mm in size. The rock is very rich in carbonate. Iron oxides and quartz are the accessories. The rocks studied are unfossiliferous. It is a spary micrite.

MINERAL ASSEMBLAGES

Following is a petrographic summary of various lithologies of this unit. The mineral composition of this unit is given in Table 2.

Greenschist Facies
Biotite Grade
Low Grade Metamorphism

1. *Pelite Schist*.

CGQ 83. Muscovite-Quartz-Chlorite-Graphite-Pyrite-Magnetite-Tourmaline.

CGQ 84. Quartz-Muscovite - Chlorite-Biotite - Magnetite-Tourmaline.

CGQ 85. Quartz-Chlorite-Muscovite - Biotite-Magnetite-Tourmaline.

CGQ 86. Muscovite-Quartz-Chlorite-Tourmaline-Epidote-Sphene-Zircon.

Texture. Phyllitic to sub-schistose. Lepidoblastic to sub-porphyroblastic.

2. *Micaceous Quartzite*.

CGQ 87. Quartz-Muscovite-Tourmaline-Zircon

Texture. Xenoblastic, orthomylonitic.

3. *Feldspathic-Chlorite-Calcite Schist*.

CGQ 88. Quartz-Calcite-Chlorite-Albite-K-feldspar-Magnetite-Tourmaline-Graphite.

CGQ 89. Quartz-Calcite-Chlorite-Albite-Magnetite-K-feldspar.

CGQ 90. Quartz-Calcite-Chlorite-Muscovite-Cryptocrystalline matter-Albite-Zircon.

Texture. Lepidoblastic and sub-prophyroblastic.

4. *Marbles.*

CGQ 91. Calcite-Quartz.
CGQ 92. Calcite-Quartz.

Texture. Granoblastic to granular.

5. *Graphitic Schist.*

CGQ 93. Quartz-Graphite-Muscovite-Chlorite-Biotite-Pyrite-Sphene-Tourmaline.

Texture. Sub-lepidoblastic.

6. *Feldspathic Quartzite.*

CGQ 94. Quartz-Albite/Oligoclase-Microcline/K-feldspar-Cryptocrystalline matter-Tourmaline-Graphitic matter.

CGQ 95. Quartz-Albite/Oligoclase-Cryptocrystalline matter-Microcline/K-feldspar-Muscovite-Tourmaline-Biotite-Zircon-Pyrite.

CGQ 96. Quartz-Albite/Oligoclase-Muscovite-Tourmaline-K-feldspar.

CGQ 97. Quartz-Microcline/K-feldspar-Albite/Oligoclase-Muscovite-Cryptocrystalline matter.

CGQ 98. Quartz-Albite/Oligoclase-Muscovite-Microcline/K-feldspar-Biotite - Tourmaline.

Texture. Porphyroblastic, sub-gneissic and orthomylonitic.

The Agglomeratic Slate in Kaghan is clearly metamorphosed in greenschist facies and falls in the biotite grade.

Nature and Origin of Agglomeratic Slates

The Agglomeratic Slate not only shows a highly heterogeneous lithology but also much lateral variation. These have been described as a sedimentary, sedimentary volcanic and volcanogenic sequence. In the Kaghan Vally between Shino and Tutan on the roadside and in its northward continuation at Chushal there is a thin but prominent sequence with the lithologies described above i.e. graphitic schist and metaconglomerates with occasional thin bedded marble bands. feldspathic chlorite calcite schist, pelitic schist, micaceous quartzite and feldspathic quartzite. In the Neelum valley further to the south in Azad Kashmir the sequence apparently contains some acid to intermediate volcanic rocks which become more well defined further south-east in the Pir Panjal. In Kaghan valley, however, well defined volcanic horizons were not found though sedimentary material derived from volcanics is present. Other lithologies described by various authors from different areas include conglomerates, agglomerates, grit, sandstone, quartzites, slates, tillites and acid to intermediate volcanics (Middlemiss 1910, 1911, Wadia 1931, 1975, Calkins *et al.* 1975, Pareek 1976, Gupta *et al.* 1983, Bossart *et al.* 1984, Ghazanfar and Chaudhry 1984).

The origin and nature of Agglomeratic Slate have been discussed at length by Middlemiss (1910, 1911) and Wadia (1931, 1975). These authors have presented their detailed observations over a large area. Middlemiss (1910, 1911) regarded this unit a joint product of explosive volcanic action combined with ordinary subaerial deposition. The other view which he was equally willing to accept was that the rocks had been formed under glacial or arctic conditions, the frost weathered debris being subsequently transported by floating ice masses to lakes.

According to Wadia (1931, 1975) the origin of Agglomeratic Slates is not easy to understand. This unit is thousands of meters thick ... "much of it is composed of fine greywacke like matrix with embedded angular grains of quartz.

But the rock does not appear to be an ordinary sedimentary deposit, in as much as the embedded fragments are quite angular and often become very large in size at random. They are pieces of quartzite, slate, porphyry, granite, etc. irregularly dispersed in a fine grained matrix".

Wadia (1931), however, expressed skepticism regarding the glacial origin, "the matrix of the slate often is full of devitrified and altered glass with phenocrysts of feldspar. The presence of Lower Gondwana plants in beds immediately overlying the volcanics favours the inference that the slate conglomerate is a glacial deposit corresponding to the Talchir boulder beds. No faceted or striated pebbles are, however, seen in slates ; on the contrary the pebbles are frequently quite angular".

Calkins who worked both in Lower Kaghan and Lower Neelum Valley as well as Pareek (1976) and Gupta *et al.* (1983) who worked further southeast in Kashmir considered the Agglomeratic Slates a sedimentary volcanic sequence.

On the other hand Bossart *et al.* (1984) working only in Kaghan valley described the unit as conglomerates and tillites, the former passing upwards into a glaciofluviatile subarkose.

The present study in Kaghan confirms the views expressed by Wadia (1931, 1975) and the description of this unit from Pakistan is similar to that of Gupta *et al*, (1983).

In Kaghan valley the marbles, pelites and calcareous schists are mostly marine. Horizons with marine fauna (Wadia 1975) have been reported elsewhere from outside Pakistan, too. The conglomerates may represent sub-aerial deposition and may well be glaciofluvial in part.

In the context of the origin of Agglomeratic Slate it would be useful to consider the nature of the underlying Tanawal Formation also. The Tanawal Formation in Kaghan is a sequence of psammitic and pelitic schists, quartzites and quartzitic schists, Although in Kaghan, the contact between these two units is often faulted yet sections with gradational contacts have also been described by Middlemiss (1911), Wadia (1931) and Ghazanfar and Chaudhry (1984). The Tanawals in Kashmir occur in disconnected and isolated basins. They fill the gap between Cambrian (Slate Series) and Permo-Carboniferous. In Poonch Wadia (1931) noted lateral passage into Agglomeratic Slate. The Tanawals themselves were deposited probably from Ordovician to Lower Carboniferous when the Hazara Kashmir landmass was developing disconnected basins leading ultimately to a phase of continental rifting. This rift was then ingressed by the sea.

From the above account we may conclude that the Agglomeratic Slate is a highly heterogeneous formation containing volcanic, volcanogenic, continental, glacial and marine facies. It was laid down at a time when India was thousands of kilometers to the south of its present position under subarctic conditions and was passing through a phase of rifting along its northwest margin. The unit is generally better developed to the southeast in Kashmir where among other facies the volcanic part is well developed and better defined.

Regarding the age of the Agglomeratic Slate Formation Wadia (1975) writes "at a few localities several interesting suites of fossils have been discovered which are identical with forms entombed in the underlying Fenestella Series (Upper Carboniferous). Again according to him the presence of Lower Gondwana plants in beds immediately overlying the volcanics favour the inference that the slate conglomerate is a glacial deposit corresponding to the Talchir boulder bed of Salt Range. The latter is considered Upper Carboniferous. He further

writes "the Agglomeratic Slate of Nagmarg and Bren contains Lower Gondwana plants, associated with a series of sandstones and Shales containing a marine brachiopod fauna and Eurydesma". This horizon corresponds with the Euredysma bed of Salt Range considered Upper Carboniferous (Uralian). The Agglomeratic Slates, therefore, range in age from Upper Carboniferous to Permian.

ACKNOWLEDGEMENT

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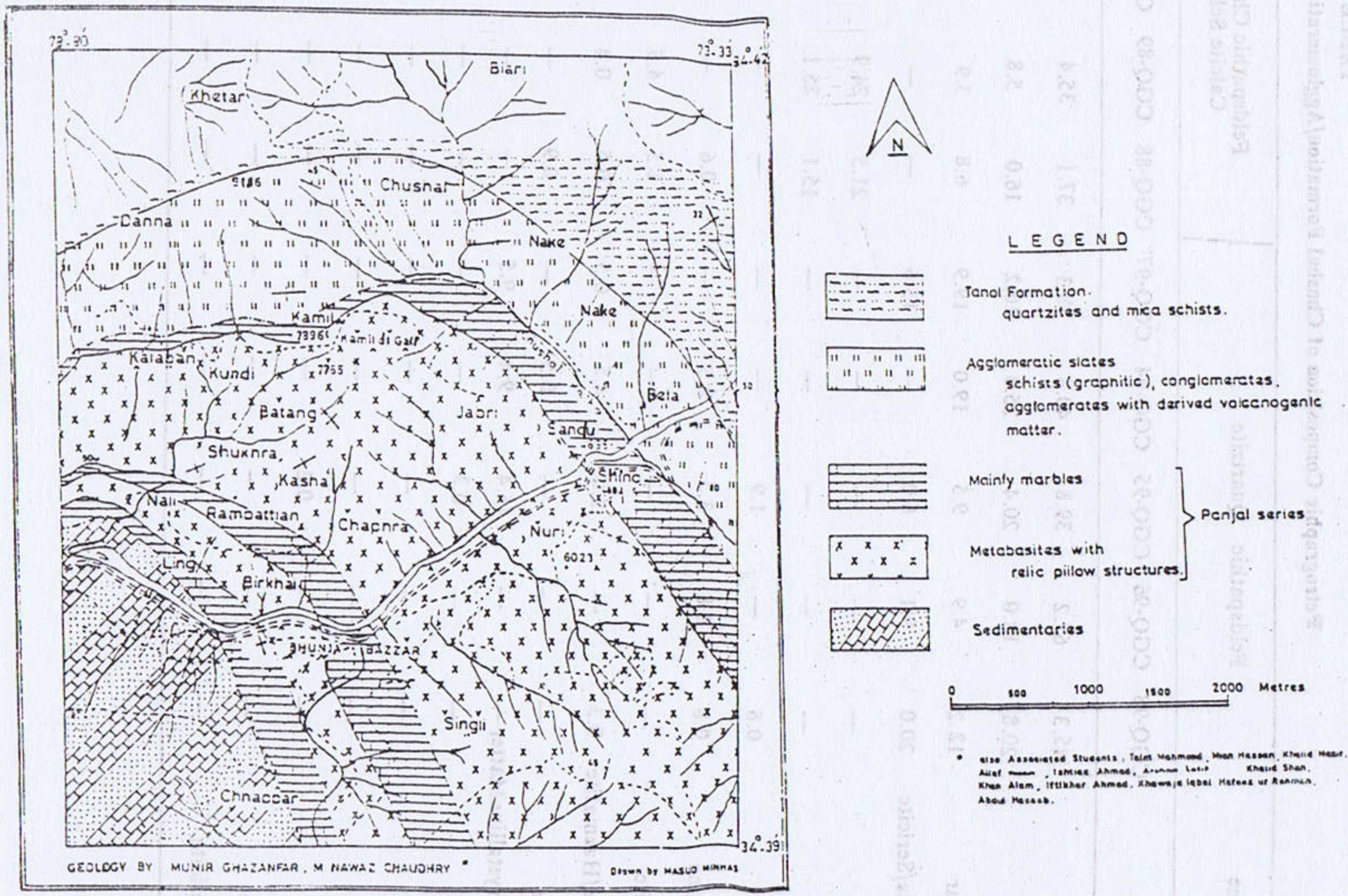

Fig. 1 GEOLOGICAL MAP of MALKANDI-SHINO AREA KAGHAN VALLEY

TABLE NO. 1

Petrographic Composition of Chushal Formation/Agglomeratic Slate

Rock Name	Feldspathic Quartzite					Feldspathic Chlorite-Calcite Schist		
Slide No.	CGQ-98	CGQ-96	CGQ-95	CGQ-94	CGQ-97	CGQ-88	CGQ-89	CGQ-90
Quartz	45.3	67.2	39.8	40.8	38.3	37.1	35.4	45.7
Albite	20.8	18.0	20.4	25.3	16.2	16.0	5.8	9.9
K-feldspar	12.2	4.9	9.5	19.0	19.9	6.8	3.9	—
Muscovite/Sericite	20.0	9.1	6.0	—	15.6	—	—	0.5
Calcite	—	—	—	—	—	21.5	24.9	19.4
Chlorite	—	—	—	—	—	15.1	25.1	7.8
Biotite	0.6	—	1.9	—	—	—	—	—
Tourmaline	0.8	0.8	3.5	0.5	—	0.6	—	—
Magnetite	—	—	—	—	—	1.5	4.5	—
Limonite/Haematite	0.3	—	2.0	4.5	0.5	0.5	0.4	0.5
Graphite	—	—	—	0.5	—	0.9	—	—
CryptocrystallineMatter	—	—	16.4	9.4	9.5	—	—	16.0
Zircon	—	—	0.3	—	—	—	—	0.2
Sphene	—	—	—	—	—	—	—	—
Apatite	—	—	—	—	—	—	—	—
Pyrite	—	—	0.2	—	—	—	—	—
Epidete	—	—	—	—	—	—	—	—
Clay/Sericite	—	—	—	—	—	—	—	—

Pelite Schist				Graphitic Schist	Micaceous Quartzite	Marble	
CGQ-85	CGQ-84	CGQ-86	CGQ-83	CGQ-93	CGQ-87	CGQ-92	CGQ-91
55.8	56.5	33.2	50.6	30.0	79.5	0.4	2.5
—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—
7.2	32.1	—	35.2	42.3	14.7	—	—
—	—	—	—	—	—	99.1	97.0
25.6	6.2	6.5	9.5	14.7	—	—	—
7.5	0.5	—	—	2.9	—	—	—
0.5	0.9	1.1	0.9	0.6	5.3	—	—
3.4	2.8	—	0.4	0.4	—	—	—
—	1.0	—	—	—	—	0.5	—
—	—	1.0	2.6	8.1	—	—	—
—	—	—	—	—	—	—	—
—	—	0.3	—	—	0.5	—	—
—	—	0.6	—	Tr	—	—	—
—	—	—	0.8	—	—	—	—
—	—	—	—	1.0	—	—	—
—	—	0.8	—	—	—	—	0.5
—	—	56.5	—	—	—	—	—

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LESSER INDIA VERSUS GREATER INDIA ON THE PLATE SCALE

BY

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Abstract : *Large tracts of the rock outcrops in the Himalayas previously considered to be of Permo-Carboniferous age are now known to be late Precambrian—Cambrian in age. Similarly tillites (Tannaki and Blaini Conglomerates) associated with these onterops are correlated with Precambrian-Cambrian glacial beds of Eurasia. Besides, the floral affinities are also best explained by a Permian localion af Himalayas in clase proximity to the Eurasian land mass. Tbis implies a concept of Greater Eurasia and Lesser India on the plate scale.*

INTRODUCTION

Identification and differentiation of India and Eurasia continental components mainly rely upon the presence or absence of Gondwana elements. Therefore, it is necessary to define the Gondwana elements,

Gondwana land is a concept which relates to southern hemispheric continents in Permo-Carboniferous time. This concept varies with regard to the life span and extent of Gondwana land. Strictly Gondwana land means lands of Gonds (who inhabit the area where first Permo—Carboniferous ice age deposits were found in India) and refers to an area. Therefore, Gondwana land as pointed out by Crawford (1979, p. 104) is tautologous.

In practice, Gondwana is used as a name for a supergroup of sediments associated with glacial tillites of Permo-Carboniferous age and to the flora of the same affinity. Hence, conventionally the Permo-Carboniferous glaeial tillites and Gondwana flora (*Glossopteris* and *Gangomopteris*) have mainly been regarded to be the distinguishing criteria for the identification of Gondwana land component.

THE AGE PROBLEM

As recently as 1972, the Tanakki Conglomerate of Hazara and Blaini Boulder beds of the Himalayas have been regarded to be of Permo-Carboniferous age. In the absence of any fossil evidence. Tanakki and Blaini Conglomerates were correlated with the Talchir bed of the Salt Range (Wadia, 1957 ; Surrange, 1966, p. 55). This correlation was based entirely on the apparent lithological resemblance and on the fact that the Talchir Boulder beds of the Salt Range were the only tililte of known Permo-Carboniferous age.

Discovery of Cambrian fossils in the rock unit overlylng Tanakki Conglomerate (Latif, 1972 ; Rushton, 1973. p. 142) now designates Tanakki in Hazara to represent Late Precambrian glaciation. The Blaini Conglomerate occupies the same position in the regional sequence of the adjoining Himalayas as Tanakki occupies in Hazara. Therefore, Blaini and post Blaini associated rocks including Krol and Jammu Limestones which were regarded to be of Permo-Carboniferous age and a Gondwana component because of their correlation with

Tanakki of Hazara and Talchir of the Salt Range, are now known to be of Late Precambrian-Cambrian age. Blaini and the associated rocks occupy very large areas of the Himalayas and stretch from the Main Boundry Fault in the south to Kummaon and Tibet in the north (Gansser, 1964, p. 242). Gansser (1964, fig. 144) outlined the northern extension of Gondwana in the Himalayas into Tibet mainly on the occurrence of Blaini and associated rocks. This provided the basis to Crawford (1974) and Powell and Conaghar (1975, p. 730) and Powell 1979, p. 7) to propose the concept of a Greater India extending its northern continental boundary into Tibet and over further up to Tien Shah.

This can be longer be regarded as valid. Instead, considering a later Precambrian-Cambrian age for Blaini and associated rocks (including Tanakki in Hazara) and their correlation with the Eurasian rocks of the same age (Bhatti, 1981, p. 21), the evidence suggests that the Himalayas is part of the Eurasian continent and its southern extension lies on the Main Boundary Fault. This implies a concept of a Lesser India and assumes that the Hazara is part of the Eurasian continent.

FLORAL EVIDENCE

The suggestion for the Himalayas be ng part of the Eurasian continent is further supported by the floral evidenee. The distinctive genera of *Glossopteris* and *Gangamopteris* have long been taken to be diagnostic of Gondwana land, But the occurrence of Permian flora from the Pacific coast of Eurasia, through Kuznetzk Basin and Mongolia to Turkey, indicates an extensive distribution of *Glossopteris* and associated plants almost all along the southern part of the Eurasian continent (Smiley, 1979, p. 311).

It is also further stipulated that the ecotonal admixture of Gondwana and Angora floral elements in the central Eurasian region north of India, the presence of *Glossopteris* flora along the Himalaya and the presence of *Glossopteris* in Cathaysia Province east of the India can all best be explained by a "Permian location of Himalaya in close proximity to the Eurasian land mass".

CONCLUSION

This implies that the so-called Gondwana type floral distribution is not a valid criterion to differentiate between Gondwana and non-Gondwana components. Therefore, he Eurasian and Indo-Pakistani continental boundaries proposed in the previous models (Powell and Conaghan, 1975, Fig. 2; Powell, 1979, Fig. 6), based on the concept of Greater Gondwana land fragment, are in the need of modifications because the basis of this concept-floral and glacial as discussed above, has largely been eroded away by the revised geologic data. A delineation of Lesser India considering large tracts of Himalayas to be part of Eurasia, is proposed versus concept of Greater ludia.

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KARACHI OFF SHORE PHOSPHOGENIC SYSTEM

BY

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Abstract : *There is sufficlent evidenee that oceanic upwelling system is operative off the Karachi coast and this system being the major mode of phosphate deposition makes this part of ocean richest in nutrient. Sompling of the sea floor sediments was carried out along* 20 *to* 30 *fathom bathymetric contour for a distance of* 20 *miles southwest of Karachi. Analysis of the samples show* P_2O_5 *values of* 0.56 *to* 1.18 *which is considered to be slightly phosphatic. An apparent reason why phosphate is not being deposited in the area is the close proximity to the mouth of the Indus River which brings an enormous influx of the sediments,*

Sampling of Recent sediments at the desired depth of 60 *to* 80 *fathoms in the area further southwest of Karachi is thought to provide meaningful results.*

INTRODUCTION

The classic theory of phosphate deposition first proposed by Kazakov (1937) and further augmented by McKelvey and others (1953) is based on the concept of an oceanic upwelling system, which is the major mechanism required for recycling the deep supply of phosphorus back to the surface. The theory emphasizes that an ample open connection of the ocean with the basin is necessary. It brings about a physico-chemical adjustment which is essential for phosphate deposition.

Phosphorus distribution in the oceans has been studied by Gulbrandson and Robertson (1973). They point out that upwellings constitute the major areas of high organic productivity in the oceans and provide a continuous supply of phosphorus to the surface. The upwellings are the result of major ocean current divergences and principally occur along the west coast of continents at subtropical latitudes. McKelvey (1967) noted the occurrences of seafloor phosphorites in the known areas of upwelling. That led him to believe that deposition of phosphate is caused by oceanic upwelling. Subsequent studies have demonstrated that the sea floor phosphorites are, in fact, Tertiary phosphorites that have been reworked into modern sediments (Riggs, 1979).

Radiometric dating by Kolodny (1969), and Kolodny and Kaplan (1970) suggest that the ocean-floor phosphorites are generally not forming today. Several investigators including Burnett aud Veeh (1977) and Veeh and others (1973 ; 1974) regard phosphorite on the sea floor off the Peru-Chile coast and off the southwest African coast as Recent sediments which are forming due to the upwelling process. Poor age control, reworked nature of the sediments, low grades of phosphates, and doubtful evidences of the potential upwelling system do not demonstrate an explicit and dynamic relationship between upwelling and the recent deposition of phosphate (Manheim and others, 1975 ; Parker and Siesser, 1972 ; Milliman and others, 1975).

UPWELLING AND PHOSPHATE DEPOSITION

Rizki (1970) recorded the following observations off the Karachi coast of Pakistan :

1. Horizontal and vertical distribution of phosphorus demonstrates sufficient evidence of upwelling and divergence.
2. The upwelling of layer after layer of cold water that is rich in phosphorus results in the enrichment of phosphorus. The concentration in the coastal water is 2 ug/1. Excessive and regular upwelling makes the Karachi coastal water one of the richest in nutrients.
3. A thermal gradient coincides with the pH Eh variation profile.

It is evident from the data recorded by Rizki (1970) that upwelling is a source of phosphorus rich water ; it is a mechanism for moving these waters into the continental shelf environment and brings about physico-chemical changes that are recessary for the deposition of phosphate. This is in confirmity with the original concepts on the deposition of phosphate as proposed by Kazakov (1973) and McKelvey (1867) and meets most of the fundamental requirements of a phosphogenic system.

MASS MORTALITY

In addition to the above, a lower layer with minimum oxygen rises and causes mass mortality of animals and creates other biological havoc.

Ryther (in Matthew, 1970) reported 20 times as much nutrient as average surface water from the coastal area west of Karachi. Here some of the coldest water anywhere in the tropics comes welling to the surface. Sometimes plankton bloom is so thick that it is deadly to fish. In 1957 (Matthew, 1970) a widespread solid layer of dead decaying fish floated on the surface which amounted to millions of tons.

Hence, it is evident that the Recent sediments off the Karachi cost are receiving an exceptional over-supply of decaying biomass which would augment the contained phosphorus constituents.

In consideration of the above factors, particularly the Recent sediments off Karachi coast could contain anomalous phosphate values.

SEA FLOOR SEDIMENT SAMPLING

A follow-up sampling of the sediments for a distance of 20 miles along the 20 to 30 fathom bathymetric contour southwest of Karachi was carried out by the author (1977, progress report, National Fertilizer Corporation, Pakistan). Analyses of the samples show P_2O_5 values of 0.56 to 1.18%. These values are not anomalous, and the sediments are considered to be slightly phosphatic. The sediments represent a depth that is not deep enough for phosphate to accumulate ; and a favourable area of 60 to 80 fathoms depth, as proposed by Kazakov (1937), could not at that time be sampled.

CONCLUSION

In spite of a potentially conducive environment, particularly because of the upwelling, it is not evident that a significant deposition of phosphate is taking place off the Karachi coast. This does not conflict with the phosphogenic theory. It rather ; represents a case which shows that upwelling alone cannot produce phosphate and the system has to be in balance with all requirement to be productive. An apparent reason why phosphate is not being deposited in the area is the close proximity to mouth of the Indus River, which brings an enormous influx of the sediment (Matthews, 1970). It is an excellent example of the phosphogenic theory which requires a starved basin condition for the effective deposition of phosphate, and it shows that a detrital influx will ruin a phosphogenic system.

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A NOTE ON THE STRATIGRAPHIC DISTRIBUTION OF *EOANNULARIA EOCENICA* COLE & BERMIDEZ

BY

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The foraminiferal species *Eoannularia eocenica* has been originally reported from the Middle Eocene rocks of Cuba by Cole & Bermudez (1944). Latif (1976), however, reported it from the Upper Paleocene Lockhart Limestone of Hazara, while Butt (1987), recorded it from the Kala Chitta Range, northern Pakistan. The present author collected the rock samples from the Paleocene and Eocene rocks of the Salt Range from the Nammal Gorge (Fig. 1). It was observed that *Eoannularia eocenica* occurs at the same stratigraphic level in the Salt Range as is the case in Hazara and Kala Chitta Range. The Paleocene age of *Eoannulario eocenica* is further substantiated by the association of typical Paleocene species i.e., *Lockhartia haimei*, *Miscellanea miscella* and *Ranikothalia sindensis* (Plate 1, Fig. a-c). These observations point out the stratigraphic significance of *Eoannularia eocenica* in the Upper Paleocene deposits of northern Pakistan (i.e., Salt Range, Hazara, Kala Chitta Range) in association with the typical Paleocene benthonic foraminiferal species (Table I) as well as establishes the stratigraphic range of *Eoannularia eocenica* from the Upper Paleocene to Middle Eocene.

TABLE-I

<table>
<tr><th>Age</th><th colspan="5">HAZARA, KALA CHITTA AND SALT RANGE</th></tr>
<tr><td rowspan="2">UPPER PALEOCENE</td><td>PATALA FORMATION</td><td rowspan="3">Lockhartia haimei</td><td rowspan="3">Miscellanea miscella</td><td rowspan="2">Ranikothalia sindensis</td><td rowspan="2">Eoannularia eocenica</td></tr>
<tr><td>LOCKHART LIMESTONE</td></tr>
<tr><td>LOWER PALEOCENE</td><td>HANGU FORMATION</td><td></td><td></td></tr>
</table>

Distribution of Eoannularia eocenica in the Paleocene succession of Northern Pakistan

PLATE I

a Eoannularia cocenica in association with Ranikothalia sindensis.

b Eoannularia cocenica in association with Miscellanea miscella.

c Lockhartia haimei

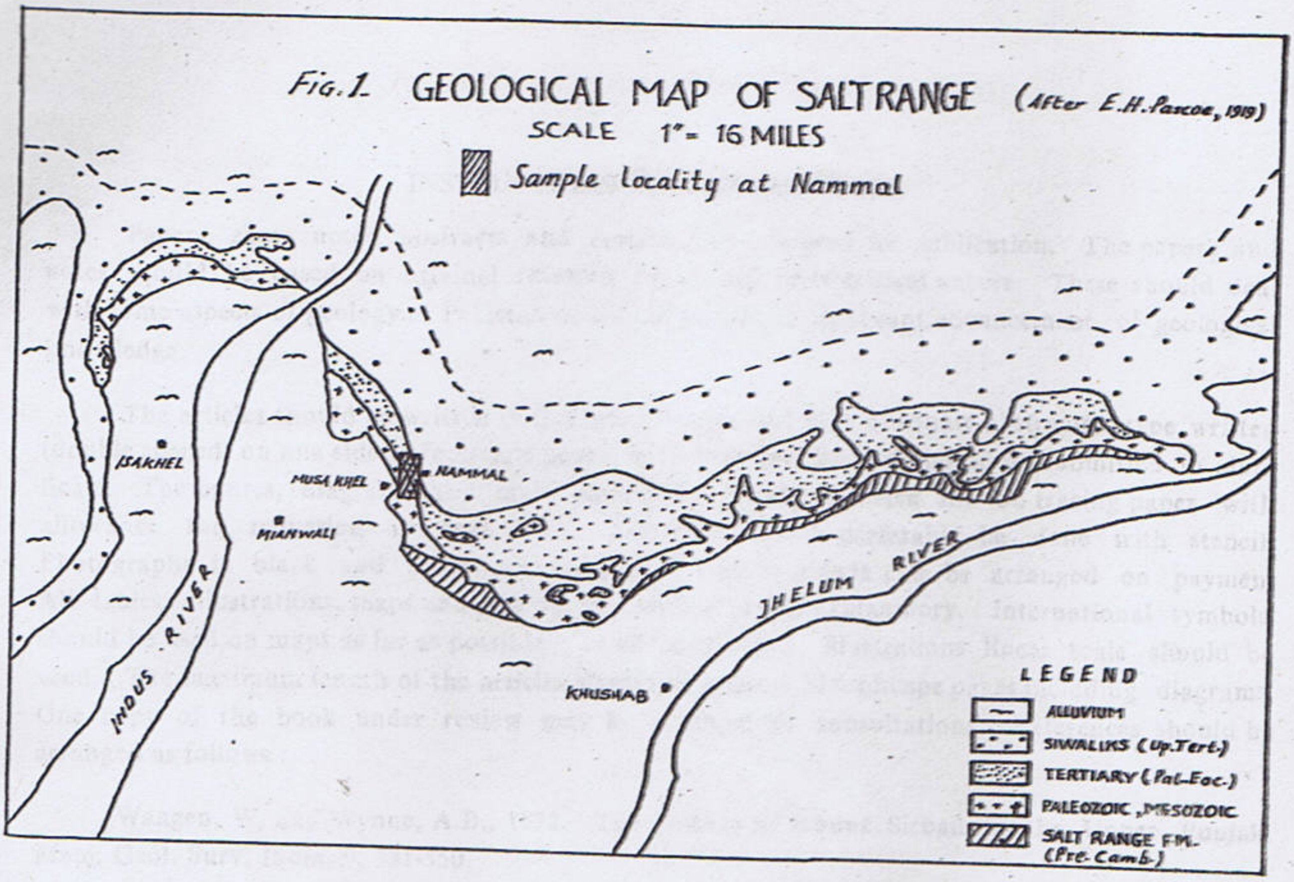

Fig. 1 GEOLOGICAL MAP OF SALTRANGE (*After E.H. Pascoe, 1919*)

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