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SHORT COMMUNICATIONS, ABSTRACTS AND REVIEWS

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PRECAMBRIAN TO EARLY PALEOZOIC OROGENESIS IN THE HIMALAYA

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ABSTRACT:- Precambrian to Paleozoic Himalayan rocks are metamorphosed from lower greenschist facies in the south to amphibolite, and granulite facies in the north. Two or possibly three, metamorphic episodes are preserved in the Precambrian shelf and platform sediments of the northern margin of Gondwana in the Indo-Pakistan plate. At least one metamorphic episode appears to be Precambrian to early Cambrian in age and significantly predates Himalayan metamorphism.

The late Precambrian to early Cambrian tectonism is evidenced by the presence of an angular unconformity, between the late Precambrian and early Cambrian rocks in Hazara, Kotli Azad Kashmir, and the Nepal Himalaya. The unconformity is marked by a basal conglomerate, which is composed of clasts of metamorphic rocks that are derived from the underlying Precambrian basement rocks of the Indo-Pakistan plate. This late Precambrian to early Cambrian tectonism is here designated the Hazaran orogeny, because it is well evidenced in the Hazara Himalaya of Pakistan. In the Hazara area, the early Cambrian Tanakki basal conglomerate of the Abbottabad Group above the angular unconformity is unmetamorphosed, whereas the underlying Precambrian Hazara Formation is metamorphosed to lower greenschist facies. The Tanakki conglomerate has cleaved metamorphic clasts derived from the underlying Hazara Formation but the matrix of the unit is uncleaved. The Hazara Formation is deformed and has growth of new mica along the axial plane cleavage, which is truncated by the Tanakki conglomerate. This confirms that the Precambrian metamorphism and tectonism occurred before the deposition of early Cambrian Tanakki conglomerate.

During the Hazaran orogeny, 600-900 Ma plutonic and volcanic rocks intruded into and extruded onto the Precambrian basement rocks of the Indo-Pakistan plate and predate the late Precambrian to early Cambrian unconformity. Somewhat after the Hazaran orogeny, 500-600 Ma peraluminous granites, with initial 87Sr/86Sr ratios of 0.7102-0.7190, intruded the Precambrian as well as earliest Paleozoic rocks. The high initial 87Sr/86Sr ratios suggest that these plutons were derived by anatexis from the basement rocks of the Indo-Pakistan plate. The 500-600 Ma plutons of the Indo-Pakistan plate may be a late Hazaran or post-Hazaran orogenic phase of the Hazaran orogeny.

The Hazaran orogeny in the Himalaya occurred before the Permo-Triassic breakup of Gondwana, and may corrlate with the Pan-African, Baikalian, Cadomian, Katangan, and Assyntic orogenies of Africa, Asia, and Europe.

INTRODUCTION

The Himalayan mountain belt is a result of collision between various continental and microcontinental fragments of Gondwana and Eurasia (Stocklin, 1977; Tahirkheli et al., 1979; Farah et al., 1984). Early separated fragments of Gondwana (Cimmeria) separated during the Permo-Triassic and collided with Eurasia in the mid-Mesozoic in association with the closing of the Paleotethys sea (Sengor, 1984). The evidence for closing of the Paleotethys sea (Cimmerian event) in the Hazara-Swat foreland fold-and-thrust belt is marked by an angular unconformity between the early Jurassic Datta Formation and the Cambrian (?) Hazira Formation (figs. 3, and 6). Along the unconformity rocks from Cambrian to Triassic have been eroded near Thandiani (fig. 6), Baragali, and Hassan Abdal due to pre-Jurassic uplift, and the Precambrian Hazara Formation is in contact with the Jurassic rocks. This evidence suggests that in the Hazara-Swat foreland fold-and-thrust belt the Cimmerian event occurred at the end of Triassic and predated the deposition of early Jurassic Datta Formation (figs. 3, 6, and

7). Between late Cretaceous and mid-Eocene, the Indo-Pakistan plate collided with Cimmeride blocks and the Neotethys sea closed, initiated formation of the current system of Himalayan folded belts. Specific evidence from Pakistan, such as rocks containing Paleocene to Eocene fossils involved in the Main Karakorum thrust near Dir (north of the Cretaceous-Cenozoic Kohistan island arc) and obducted as blocks along the Indus suture zone (south of the arc) Chaudhry et al., (1984), suggests that complete closing of the Neotethys sea occurred after the Eocene. In contrast, in the Attock-Cherat Range (south of Indus suture zone), a major tectonic event occurred at the end of Cretaceous, and predated Paleocene sedimentation (Yeats and Hussain, 1985, 1987). This evidence suggests that the collision of the Indo-Pakistan plate with Eurasia started at the end of the Cretaceous; complete closure of the Neotethys sea occurred in the post-Eocene, followed by initiation of the main phase of thrusting and folding in the Northwest Himalaya.

The timing of metamorphic events in the Himalaya remains uncertain. A central question has been whether pre-Himalayan metamorphism and deformation could be recognized at any locality. Polyphase metamorphism and deformation are commonly observed in rocks involved in the Himalayan orogeny (Gansser, 1964, 1981; Shams, 1969, 1983; Naha and Ray, 1971; Kumar and Pande, 1972; Kumar et al., 1978; Virdi, 1981; Coward et al., 1982, 1986; Divakara, 1983; Bortolami et al., 1983; Maruo and Kizaki, 1983; Ghazanfar et al., 1983; and Greco, 1986). Possibly the first of these metamorphic episodes may be of late Precambrian age, and is thus unrelated to Himalayan orogency.

According to Windley (1983) the earliest Himalayan metamorphic episode took place in the Cretaceous and a later episode associated with nappe emplacement occurred in the Eocene. Le Fort (1975), however, assigned a Miocene age to the metamorphic event associated with the main Himalayan orogeny.

Metamorphic rocks occur in three main locations in the main Himalaya:

1) The lesser Himalayan klippes; 2) the higher Himalayan crystalline belt; and 3) The Tso Morari crystalline belt of Kashmir. All of these rocks were subjected to Himalayan metamorphism. However, Rb/Sr whole rock isochron dates of 500-600 Ma on peraluminous granites from Himalaya (table 1) suggest an important pre-Himalayan intrusive event.

In this paper we have, for the first time, collected together the stratigraphic evidence from different parts of Hazara, Kohistan, and Kashmir Himalaya (fig. 1), to show that at least one metamorphic episode of Precambrian age is preserved in the Himalaya.

TECTONIC SETTING OF THE HAZARA-SWAT FORELAND FOLD-AND-THRUST BELT.

The Hazara-Swat Himalaya tectonically lies between the Margala thrust, along the southern edge of the Margala and Kalachitta Hills, and the Main Mantle thrust to the north in Allai and Swat-Kohistan (fig. 1). The MMT separates the Cretaceous-Cenozoic Kohistan island arc from the Indo-Pakistan plate. The Hazara-Swat Himalaya represents a foreland fold-and-thrust belt, which extends west from the Hazara-Kashmir syntaxis to Afghanistan, where the belt is truncated by the Sarubi tear fault (Kazmi and Rana, 1982; Yeats and Lawrence, 1984). In the Hazara-Swat foreland fold-and-thrust belt, the thrusts prograded to the southeast on the western limb of the Hazara-Kashmir syntaxis and southwest in the Kashmir foreland fold-and-thrust belt on the eastern limb of the syntaxis. Between the Panjal and Margala thrusts, the Hazara-Swat foreland fold-and-thrust belt may be considered to be the Main Boundary thrust zone in Pakistan. This zone is wider on the western limb of the Hazara-Kashmir syntaxis and narrows on the eastern limb in the Azad Jammu and Kashmir State (fig. 1).

The Hazara-Kashmir syntaxis is cut by the Jhalum left-lateral strike-slip fault. It terminates the Hazara-Swat foreland fold-and-thrust belt on the western limb of the Hazara-Kashmir syntaxis and the Kashmir foreland fold-and-thust belt on the eastern limb in the Azad Jammu and Kashmir State. The Himalayan Frontal thrust is truncated by the Jhelum fault in the Kaghan Valley (fig. 1). Along the Jhelum fault Murree Formation, Abbottabad Formation, and Hazara Formation are highly deformed near Muzaffarabad and Dubgali and around Balakot in the Kaghan Valley. Blocks of Panjal volcanics Triassic limestone were dragged several Kms further south from the Hazara-Kashmir syntaxis, along the Jhelum left-lateral strike-slip fault. The rocks are brittlely deformed and look like sedimentary melange, but rock units are still mappable. This brittle shear zone varies in width from about ½ to 2 Km. From the Kashmir side, the Main Boundary thrust, the Panjal thrust, and the Himalayan Frontal thrust are truncated by the Jhelum fault. Thrusts and folds of the Hazara-Swat foreland fold-and-thrust belt on the western limb of the syntaxis are also truncated. This suggests that the development of the Hazara-Kashmir syntaxis post-dates initial development of the Himalayan Frontal thrust and that the Jhelum fault is younger than Himalayan Frontal thrust. The Jhelum fault shows a left-lateral offset of about 31 Km along the western limb of the syntaxis. Quaternary terraces along the Jhelum fault along Jhelum, Soan, and Kunhar rivers (near Muzaffarabad, in the Soan Valley, and Balakot) are uplifted and tilted, at places these rivers having localized active landslides, all of which suggest the presence of recent activity along the Jhelum fault. This fault extends from Soan valley to the Kaghan Valley where it joins the

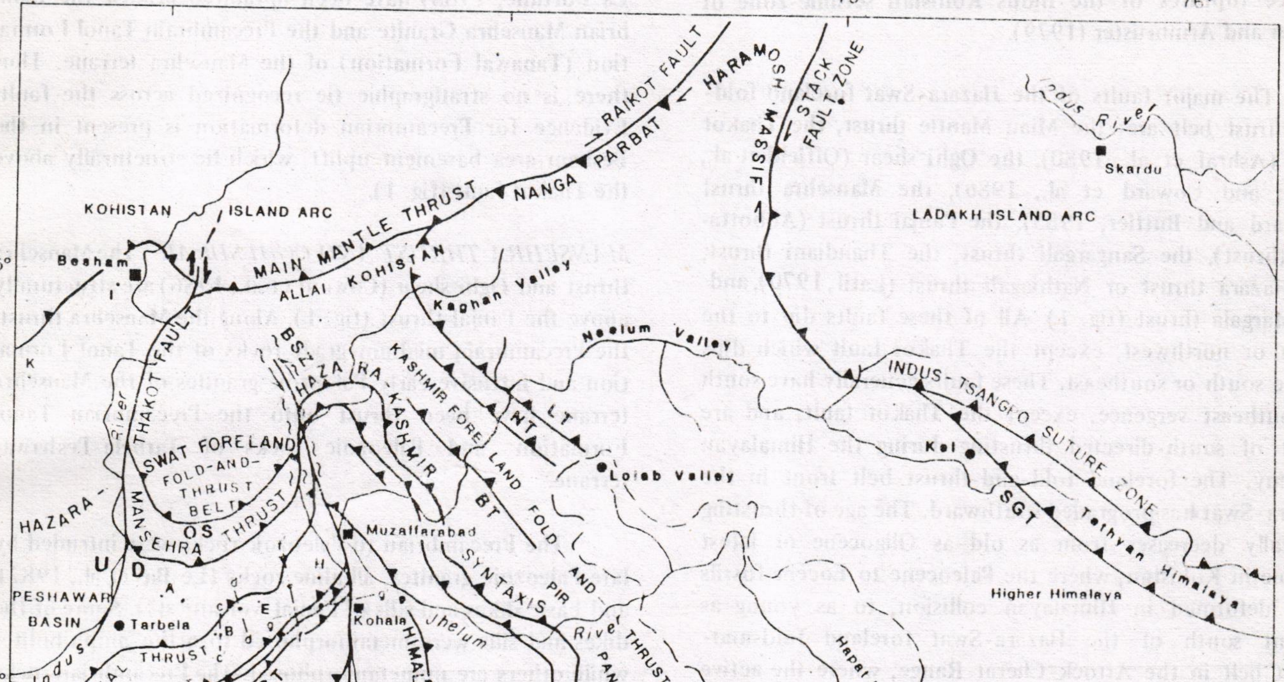

Figure 1. Tectonic map of the NW Himalaya, showing locations of the Precambrian and Cambrian unconformity in the Hazara-Swat and Kashmir foreland fold-and-thrust belts. A = Sherwan, B = Khoti-Di-Qabar, C = Tanakki, D = Sobrah, E = Public School Mirpur, F = Sangargali, G = Thandiani, H = East of Daultmar, I = Besham, J = Kotli Azad Kashmir, K = Swat, and L = Kishtwar. MBTZ = Main Boundary thrust zone, OS = Oghi shear, BSZ = Balakot shear zone, BT = Barian thrust, NT = Neelum thrust, LT = Laut thrust (Ghaznafar, Baig, and Chaudhry 1983; Ghazanfar and Chaudhry, 1986), SGT = Shontargali thrust (Tahirkheli, 1987), VT (MCT) = Vaikrita thrust (Main Central thrust), U = upthrown block, and D = downthrown block.

shear zone of Bossart et al., (1984) and extends toward the Allai-Kohistan (fig. 1). There is a strong possibility that the Jhelum fault cuts the MMT in the Allai-Kohistan toward Choar plains. The Jhelum fault may be the one of the surface ruptures of the Indus Kohistan seismic-zone of Seeber and Armbruster (1979).

The major faults of the Hazara-Swat foreland fold-and-thrust belt are; the Mian Mantle thrust, the Thakot fault (Ashraf et al., 1980), the Oghi shear (Offield et al., 1966; and Coward et al., 1986), the Mansehra thrust (Coward and Buttler, 1985), the Panjal thrust (Abbottabad thrust), the Sangargali thrust, the Thandiani thrust, the Hazara thrust or Nathiagali thrust (Latif, 1970), and the Margala thrust (fig. 1). All of these faults dip to the north or northwest, except the Thakot fault which dips to the south or southeast. These faults generally have south to southeast vergence, except the Thakot fault, and are result of south-directed thrusting during the Himalayan orogeny. The foreland fold-and-thrust belt front in the Hazara-Swat has prograded southward. The age of thrusting generally decreases from as old as Oligocene or latest Eocene in Kohistan, where the Paleocene to Eocene fossils were deformed in Himalayan collision, to as young as Recent south of the Hazara-Swat foreland fold-and-thrust belt in the Attock-Cherat Range, where the active Manki fault cuts the Pleistocene to Recent deposits (Yeats and Hussain 1985, 1987).

MAIN MANTLE THRUST: The Main Mantle thrust demarcates the collision between the Indo-Pakistan and Cimmerian blocks. It extends west from Ladakh to northern Pakistan and eastern Afghanistan (Tahirkheli et al., 1979; Gansser, 1981; Chaudhry et al., 1983). The Indus suture zone is marked by local blocks of late Cretaceous blueschist (Shams, 1972). The collision of the Indo-Pakistan and Kohistan island arc is at least as young as Paleocene. However, fission track dates of the rocks along the Main Mantle thrust have shown that its last movemet is as recent as 15 Ma ago (Zeitler et al., 1982).

THAKOT FAULT: The Thakot fault (Ashraf et al., 1980) lies northwest of the Manserhra thrust (fig. 1). It is a north-south-trending, high-angle fault which cuts the Indus suture zone in the Allai-Kohistan. The serpentinite, talc, peridotite, and amphibolite from the Allai melanges have been dragged as slivers and lenses along this fault for several Km further south. It shows the right-lateral sense of motion. The ductile to brittle deformation is pronounced along this fault. The Thakot fault may be the extension of the Darband fault in the Allai-Kohistan and is the surface reputure of the Tarbela seismic zone of Seeber et al., (1981). This fault may be an older basement fault of the Tethyan margin which has been reactivated during the Himalayan orogeny. In the northwest, the medium to high-grade metamorphic isograds (Shams, 1969; Calkins et al., 1975) of the Mansehra terrane are truncated by the Thakot fault. The Precambrain metasediments and granites of the Besham terrane (Ashraf et al., 1980; Fletcher et al., 1986; La Fortune, 1988) have been upfaulted against the Cambrian Mansehra Granite and the Precambrain Tanol Formation (Tanawal Formation) of the Mansehra terrane. Thus there is no stratigraphic tie recognized across the fault. Evidence for Precambrian deformation is present in the Besham area basement uplift, which lie structurally above the Thakot fault (fig. 1).

MANSEHRA THRUST AND OGHI SHEAR: The Mansehra thrust and Oghi shear (Coward et al., 1986) are structurally above the Panjal thrust (fig. 1). Along the Mansehra thrust, the Precambrain medium-grade rocks of the Tanol Formation and intrusive early Paleozoic granites of the Mansehra terrane have been thrust onto the Precambrian Tanol Formation and Paleozoic rocks of Tarbela-Peshawar terrane.

The Precambrian to Paleozoic rocks were intruded by late Paleozoic granites, alkaline rocks (Le Bas et al., 1987). and basic dikes and sills of Panjal volcanics(?). Some of the dikes and sills were metamorphosed to ortho-amphibolites while others are unmetamorphosed. The Precambrian rocks were affected by the polyphase metamorphism (Shams, 1969, 1983). Along the Mansehra thrust the Precambrian Tanol and the Mansehra granite are sheared. Field evidence indicates that the southern margin of the Mansehra granite near Kund, southwest and west of Bala-Najaf in Kaghan Valley has no contact metamorphic aureole, but the country rocks are sheared and show mylonitic texture. However, contact metamorphic affects are present in the central domain of the Mansehra granite where it intruded the Precambrian metamorphic rocks. The Oghi shear is between the medium-grade and high-grade rocks of the Mansehra terrane. The Susalgali granite gneiss along the Oghi shear is sheared and shows mylonitic texture. Both the Mansehra thrust and the Oghi shear are post-Himalayan metamorphism in age, because they cut the Himalayan metamorphic fabric. We suspect that the Balakot shear zone is the extension of the Mansehra thrust and Oghi shear in the Kaghan Valley.

PANJAL THRUST (ABBOTTABAD THRUST): The Panjal thrust (Calkins et al., 1975) lies over the Sangargali thrust (fig. 1). Low-grade Precambrian Tanol (Tanawal) Formation and Paleozoic rocks of the Tarbela-Peshawar terrane, are thrust south onto unmetamorphosed rocks of Cambrain to Jurassic age in the Hazara area (fig. 4 and 6). This thrust is not structurally equivalent to the Panjal thrust on the eastern limb of the Hazara-Kashmir syntaxis. It differs in both tectonic and stratigraphic setting because the late Paleozoic Panjal volcanics are not present below it in

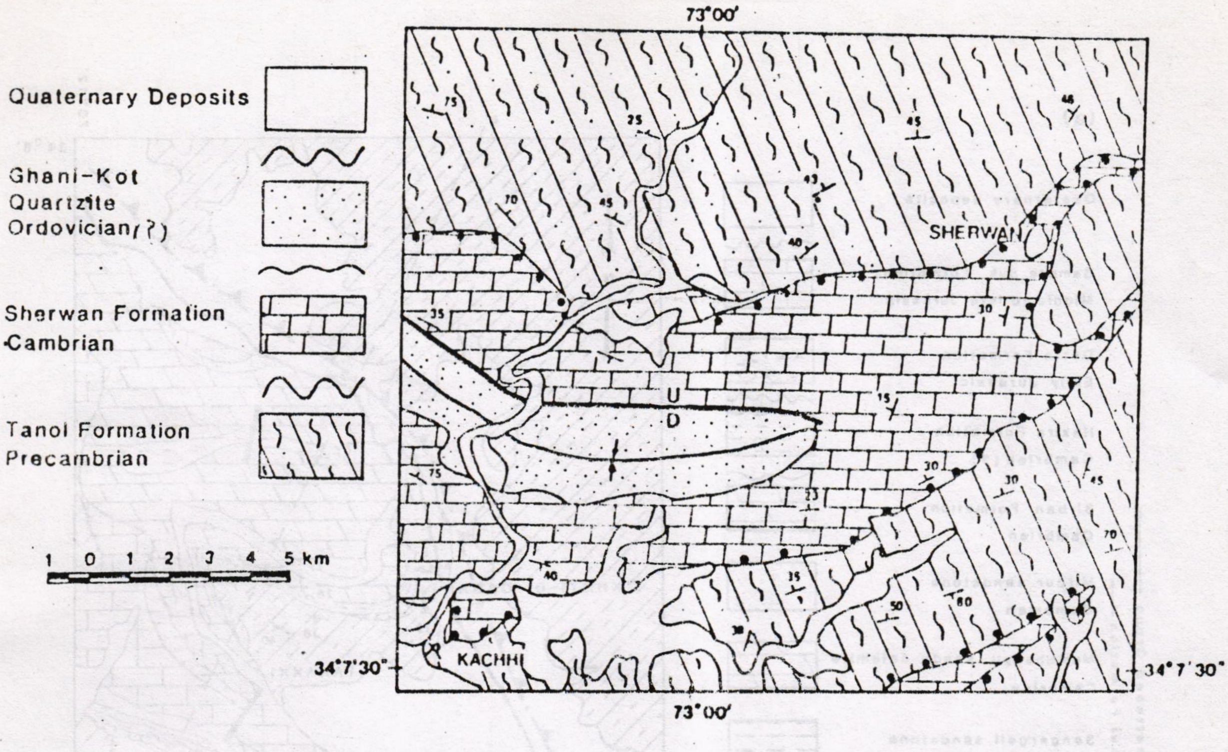

Figure 2. Geological map of the Kachhi-Sherwan area, Tarbela region (fig. 1, location A), showing the unconformity between the Cambrian Sherwan Formation and the Precambrian Tanol Formation (Modified after Ali, 1962; and Calkins et al., 1975). Dotes show the unconformity.

Hazara, whereas in the Kashmir foreland fold-and-thrust belt a thick sequence of Panjal volcanics is exposed along the Pir-Panjal Range below the Panjal thrust. In Kashmir, to the south of the Panjal thrust is the Main Boundry thrust, which is a well defined fault between the molasse of Murree Formation and metamorphic rocks. But in the Hazara area below the Panjal thrust, the Main Boundary thrust is not a well defined tectonic feature. It constitutes an imbricated thrust zone of Precambrian to Cenozoic rocks, which may be called the Main Boundary thrust zone (MBTZ, fig. 1). The terrane north of the Panjal thrust (fig. 1 and 2) contains no definite evidence for the Precambrian metamorphism.

SANGARGALI THRUST: The Sangargali thrust overlies the Thandiani thrust, and emplaces the rocks of Precambrian, Cambrian, and Cenozoic over the rocks of Mesozoic to Cenozoic age. There is evidence for Precambrian metamorphism and tectonism in the tectonic block between these two thrusts (figs. 6 and 7).

THANDIANI THRUST: Above the Hazara thrust is the Thandiani thrust, which emplaces rocks of Precambrian, Jurassic, and Cretaceous age onto rocks of Jurassic age (fig. 6).

HAZARA THRUST: The Hazara thrust (Nathiagali thrust) is structurally above the Margala thrust (fig. 1), and emplaces rocks of Precambrian to Cenozoic age over rocks of Mesozoic to Cenozoic age. On the southwest of the Hazara-Kashmir syntaxis in Hazara area, this is the first fault that places low-grade metamorphic rocks onto unmetamorphosed Mesozoic to Cenozoic rocks further south.

MARGALA THRUST: The Margala thrust (Murree thrust) is structurally below the Hazara thrust (fig. 1), and separates the Oligocene to Pliocene age Murree and Siwalik molasse on the south from Eocene and older rocks on the north in the Margala and Kalachitta Hills. It is the northern most boundary of the Murree and Siwalik molasse in the northern Potwar Basin of Pakistan.

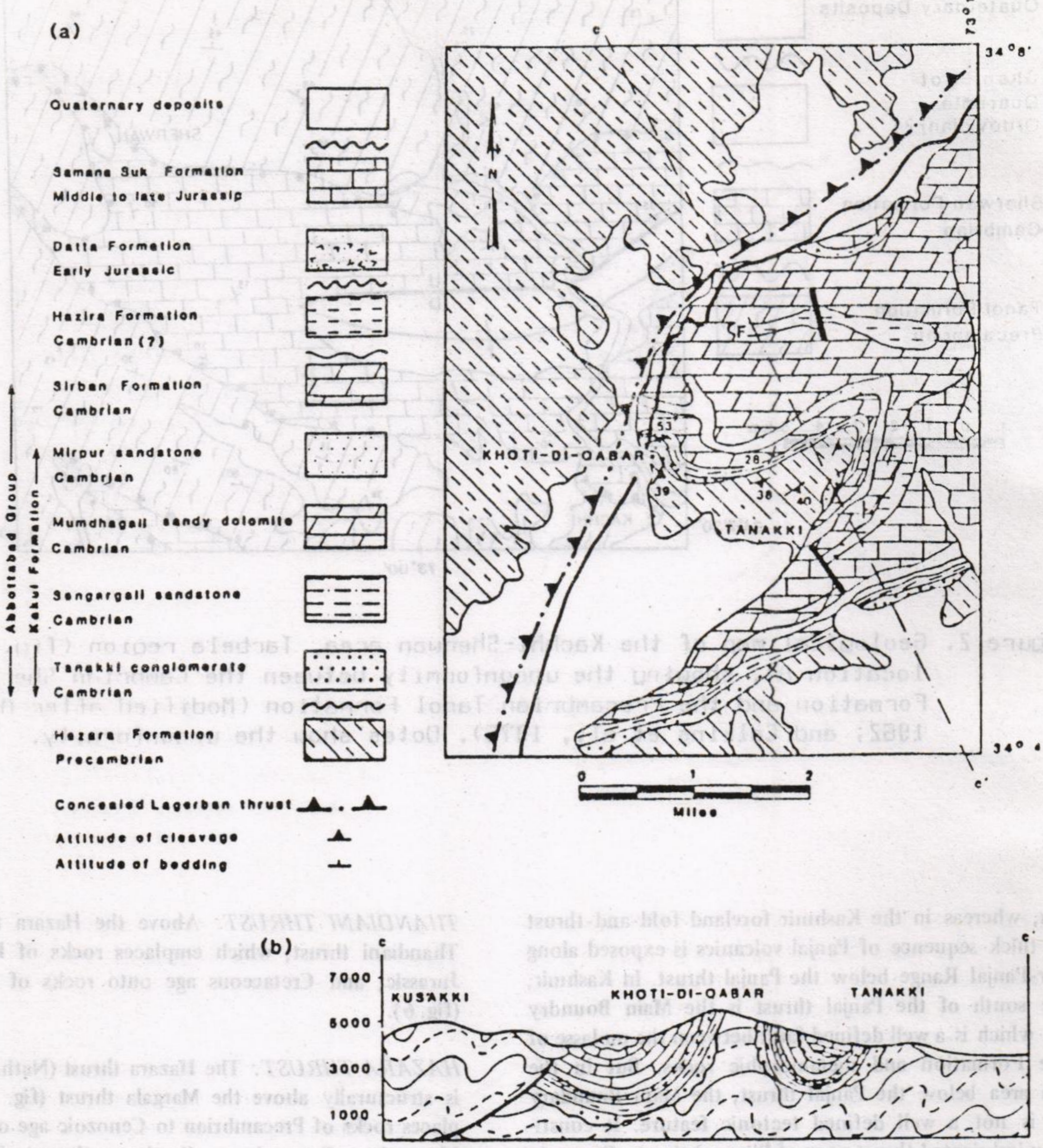

Figure 3. (a) Geological map of the Khoti-Di-Qabar and Tanakki areas (fig. 1, location B and C), showing the angular unconformity between the Tanakki conglomerate at the base of the Cambrian Abbottabad Group (Modified after Latif, 1970)." F" marks the Cambrian fossil locality. The Tanol Formation is missing between the Abbottabad Group and the Hazara Formation. The Ordovician (?) to Triassic rocks between the Hazira Formation of Cambrian (?) and Datta Formation of early Jurassic are eroded. (b) Geological cross-section along the line c-c′ on figures 1 and 3a showing the unconformity at the base of the Tanakki conglomerate.

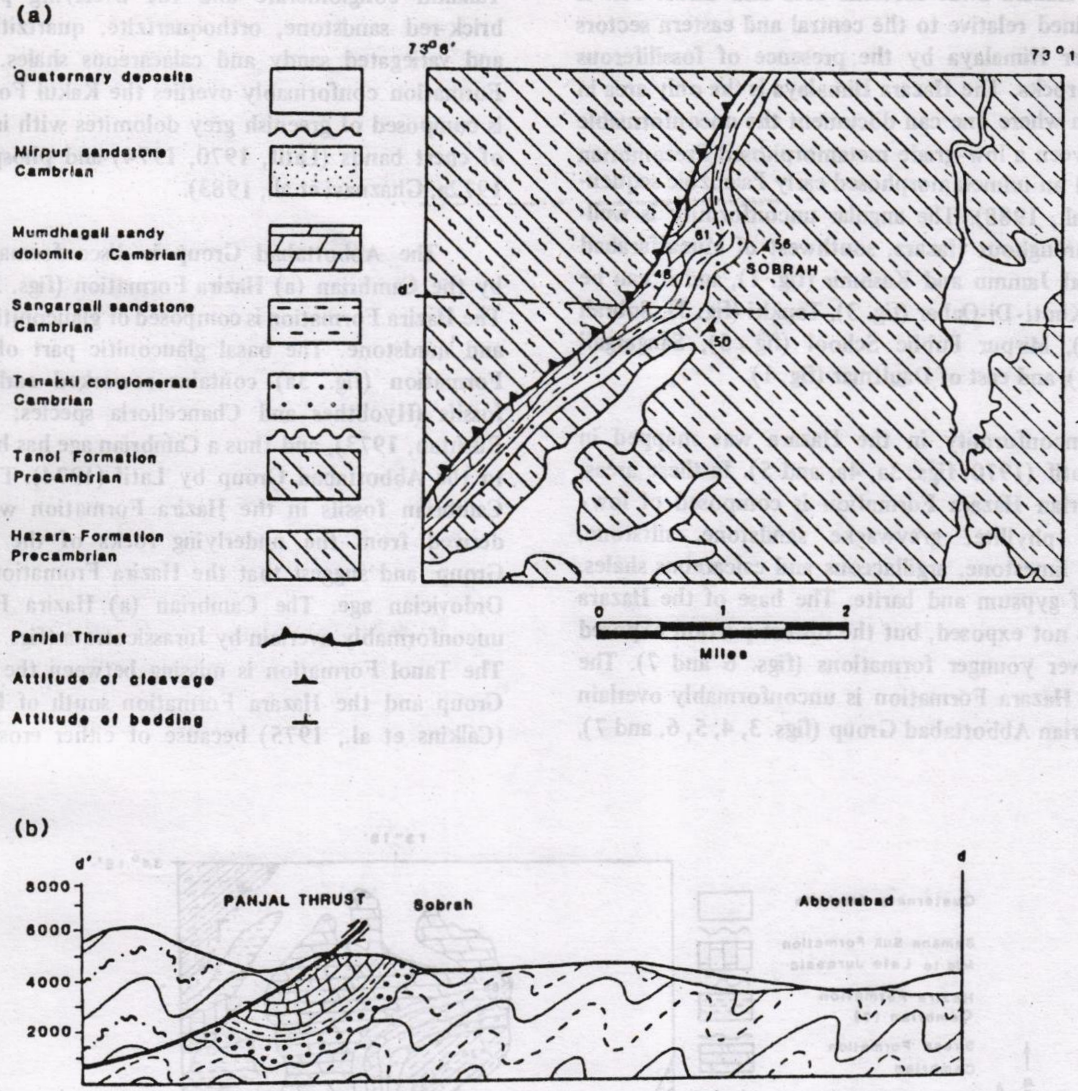

Figure 4. (a) Geological map of the Sobrah area (fig. 1, location D), showing the angular unconformity at the base of the Tanakki conglomerate (Modified after Latif, 1970). The Tanol Formation between the Hazara Formation and Abbottabad Group is eroded or was not been deposited to the east of the Panjal thrust. (b) Geological cross-section along the line d′-d on the figures 1 and 4a, showing the unconformity between the Abbottabad Group and the Hazara Formation. The low-grade metamorphics of the Tanol Formation have been thrusted onto the Cambrián of the Abbottabad Group along the Panjal thrust.

FIELD EVIDENCE FOR PRECAMBRIAN TECTONISM AND METAMORPHISM IN THE HIMALAYA

Hazara-Swat Himalaya: The stratigraphy of the Hazara area in the Hazara-Swat foreland fold-and-thrust belt is well constrained relative to the central and eastern sectors of the Lesser Himalaya by the presence of fossiliferous Phanerozoic rocks. The Hazara Himalaya is the only area in the Himalaya where one can document the unconformable contact between a low-grade metamorphosed Precambrian sequence and an unmetamorphosed early Paleozoic sequence (Baig et al., 1988). The angular unconformity is well-developed throughout Hazara, southwest of Muzaffarabad State of Azad Jammu and Kashmir (fig. 1), and it can be observed at Khoti-Di-Qabar (fig. 3), Tankki (fig. 3), Sobrah Gali (fig. 4), Mirpur Public School (fig. 5), Sangargali (figs. 6 and 7), and east of Daultmar (fig. 1).

This unconformity in the Hazara was mapped in details by Latif (1970; figs. 3a, 4a, and 5). In these areas, the Precambrian Hazara Formation is composed of low-grade slate, phyllite, greywacke sandstone, siltstone, stromatolitic limestone, argillaceous and calcareous shales, and layers of gypsum and barite. The base of the Hazara Formation is not exposed, but the lowest portion exposed are thrust over younger formations (figs. 6 and 7). The Precambrian Hazara Formation is unconformably overlain by the Cambrian Abbottabad Group (figs. 3, 4, 5, 6, and 7), which consists of psammitic to calcareous rocks. The psammitic rocks are called the Kakul Formation and calcareous rocks are called the Sirban Formation (Latif, 1970 and 1974). The Kakul Formation is composed of the basal Tanakki conglomerate and the overlying purple shale, brick-red sandstone, orthoquartzite, quartzitic dolomite, and variegated sandy and calacareous shales. The Sirban Formation conformably overlies the Kakul Formation and is composed of greenish grey dolomites with intercalations of chert bands (Latif, 1970, 1974) and phosphate (Latif, 1972a; Ghaznavi et al., 1983).

The Abbottabad Group is disconformably overlain by the Cambrian (a) Hazira Formation (figs. 3, 5, and 6). The Hazira Formation is composed of glauconitic sandstone, and mudstone. The basal glauconitic part of the Hazira Formation (fig. 3a) contains reworked early Cambrian fossils (Hyolithes and Chancelloria species; Latif, 1972; Rushtan, 1973), and thus a Cambrian age has been assigned to the Abbottabad Group by Latif (1974). The reworked Cambrian fossils in the Hazira Formation were possibly derived from the underlying rocks of the Abbottabad Group, and suggest that the Hazira Fromation may be of Ordovician age. The Cambrian (a) Hazira Formation is unconformably overlain by Jurassic strata (figs. 3, 5, and 6). The Tanol Formation is missing between the Abbottabad Group and the Hazara Formation south of Panjal thrust (Calkins et al., 1975) because of either erosion or non-

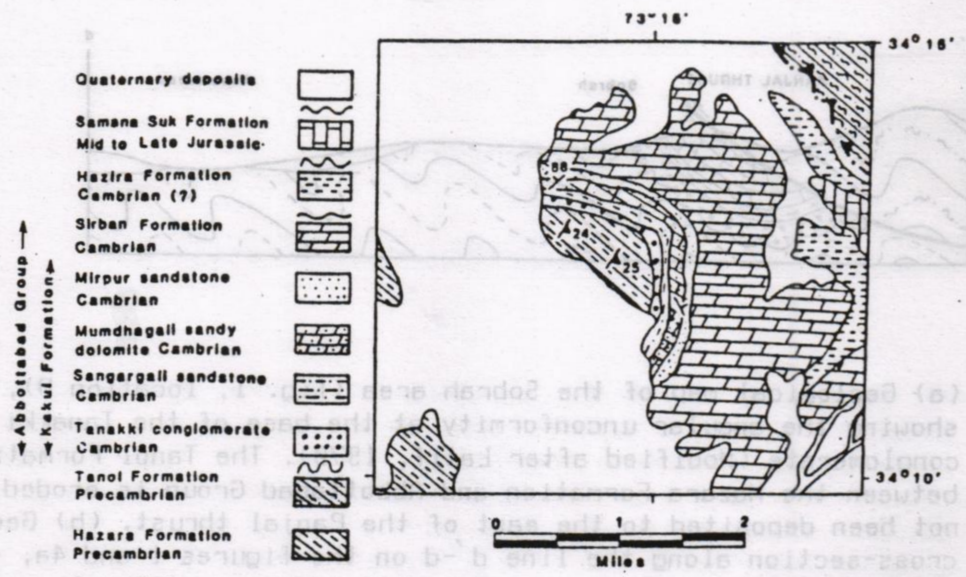

Figure 5. Geological map of the Public School Mirpur area (fig. 1, location E), showing the angular unconformity at the base of the Tanakki conglomerate (Modified after Latif, 1970). Tanol Formation is missing above the Hazara Formation.

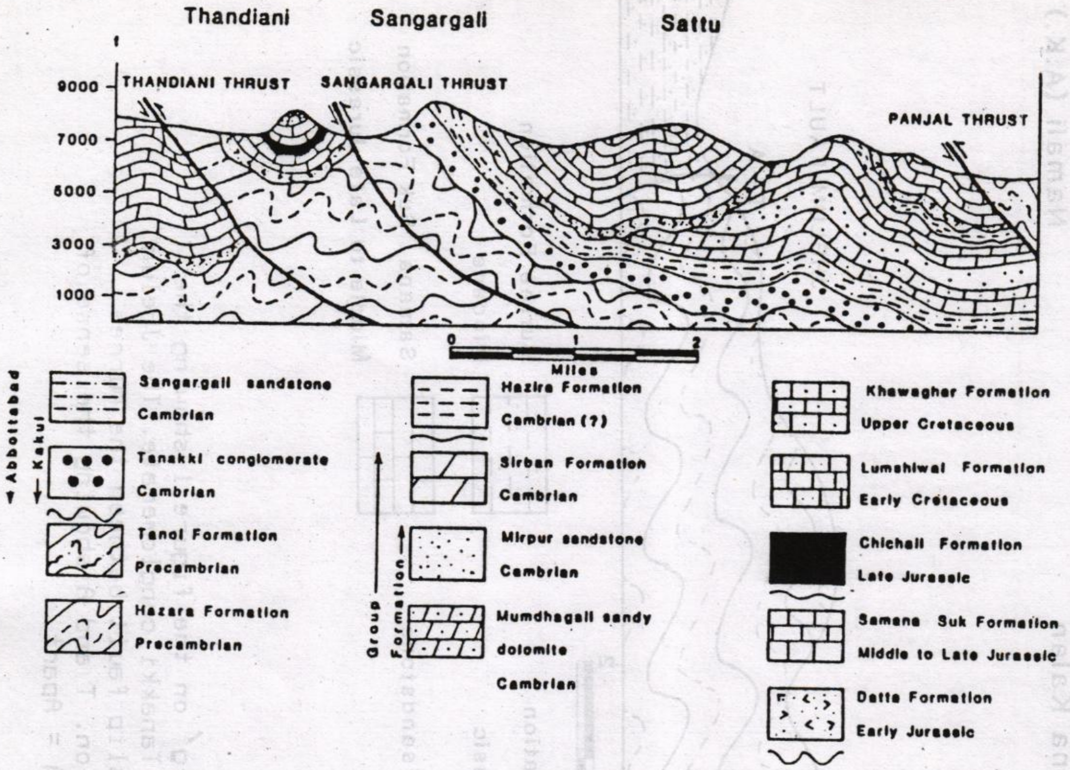

Figure 6. Geological cross-section line f-f' on the figure 1 showing the The unconformity at the base of the Tanakki conglomerate. The contact of the Datta Formation of early Jurassic and Cambrian (?) Hazira Formation marks an unconformity. Near Sattu and Sangargali the Hazira Formation and most of the Abbottabad Group havebeen eroded below the Datta Formation. Whereas, near Thandiani tht Abbottabad Group and the Hazira Formation are eroded along the pre-Jurassic angular unconformity and the Datta Formation of early Jurassic is in contact with the Precambrian Hazara Formation. The Panjal thrust brings the Precambrian Tanol Formation over the Cambrian to Mesozoic rocks of the Hazara area. The Tanol Formation is absent from this area.

deposition.

In the Hazara area, Cambrain to Cenozoic sedimentary rocks above the unconformity are unmetamorphosed, whereas the underlying Precambrian sediments are metamorphosed, to lower greenschist facies. The Precambrian Hazara Formation below the angular unconformity is deformed and has growth of metamorphic mica along the axial plane cleavage. The overlying Tanakki conglomerate of the Abbottabad Group is undeformed, contains no cleavage, and truncates cleavage in the Hazara Formation. The basal conglomerate has metamorphic, quartz veins, and rare basic clasts, derived from the underlying basement rocks in an unmetamorphosed matrix. These data confirm that the unconformity postdates the metamorphism and tectonism of the underlying Precambrain rocks in the Hazara Himalaya, and therefore requires that the metamorphism must be early Cambrian age or older.

A stratigraphic sequence of the Precambrian to Paleozoic rocks that overlies the Panjal thrust (fig. 1) is exposed in the Tarbela-Peshawar terrane (Ali, 1962; Martin et al., 1962; Stauffer, 1968; Latif, 1970a; Calkins et al., 1975; Pogue and Hussain, 1986). At Tarbela, the Precambrian Hazara Formation unconformably overlies the Salkhala Formation (Sharda Group of Ghazanfar et al., 1983) and is unconformably overlain by the Tanol Forma-

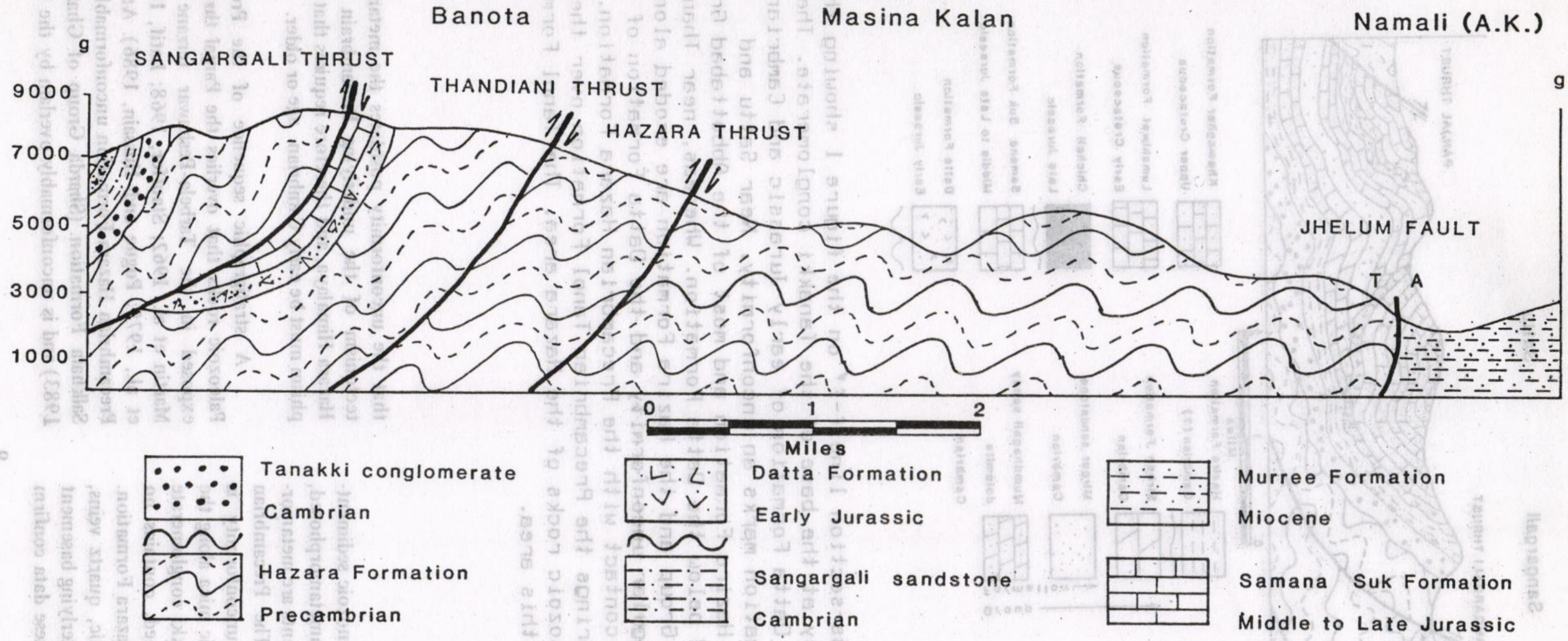

Figure 7. Geological cross-section line g-g′ on the figure 1 showing the unconformity at the base of the Tanakki conglomerate. The Jhelum fault is a left-lateral strike-slip fault between the Murree Formation and the Hazara Formation. T and A showing the sense of motion on the fault. T = Tear, A = Apart.

tion (Calkins et al., 1975). The Tanol Formation is Precambrian and is composed of dominantly psammitic rocks with minor argillaceous and calcareous rocks. The Tanol Formation is metamorphosed to low-grade and is intruded by the basic sills and dikes of the Panjal volcanics(?). The Sherwan Formation unconformably overlies the Tanol Formation (fig. 2). It is composed of a basal conglomerate that is overlain by quartz-mica schist, quartzite, and dolomite. The dolomite of the Sherwan Formation contains Cambrian Hyolithes fossils near Sherwan (Ghaznavi and Ahmed Hussain personal communication, 1986) similar to the Cambrian Hyolithes found by Latif (1972) from the Hazira Formation in the Abbottabad area. This confirms the Sherwan Formation to be Cambrian in age. The name Sherwan Formation is here used for rocks previously designated the Triassic Kingriali Formation by Calkins et al., (1975). There are no Triassic rocks exposed in the Hazara, Tarbela, and Manserhra area. The Sherwan Formation is disconformably overlian by Ordovician(?) Ghani-Kot quartzite, which resembles in lithology with the Ordovician Misri Banda quartzite of Pogue and Hussain (1986). The basal conglomerate at the base of the Sherwan Formation overlying Tanol Formation is composed of metamorphic clasts, derived from the underlying Tanol Formation, The metamorphic clasts in the basal conglomerate are stretched and deformed in phyllitic to weakly schistose matrix (Ali, 1962; and Calkins et al., 1975). The Hazara and Tanol Formations are deformed and have two sets of folding with associated cleavages (Calkins et al., 1975). The one phase of deformation below the unconformity may be of Precambrian age. In this area, the overlying Cambrian sequence is metamorphosed to low-grade, during the younger Himalayan metamorphism and deformation, that generated east-west-trending, south-verging folds. There is no definite evidence for Precambrian metamorphism in the Tarbela-Peshawar terrane, because the Precambrian to Paleozoic rocks are affected by the younger Himalayan metamorphism and deformation. The dating of the Precambrian rocks of Tarbela-Peshawar terrane may show the weak Precambrian metamorphic affects, if the Himalayan metamorphism has not completely reset the earlier Precambrian metamorphism.

In Swat, south of the Main Mantle thrust (fig. 1, location K), the northern Margin of Indo-Pakistan plate constitutes shelf and platform sediments of Precambrian to Phanerozoic age. These were metamorphosed to kyanite grade during the Himalayan orogeny (Lawrence et al., 1985; J. DiPietro, work in progress, 1988). An unconformity appears to be present between the Precambrian Manglaur schist and Phanerozoic Alpurai schists (Kazmi et al., 1984, 1986). The Precambrian Manglaur schist is intruded by the Cambrian (?) Swat granite gneiss, which does not intrude the overlying Phanerozoic rocks. A biotite from Swat granite gneiss gave an Ar40/Ar39 date of 515 Ma (H. Maluski in Jan et al., 1981). Although, there are no Rb/Sr and U/Pb dates available for the Swat granite gneiss, Le Fort et al., (1980, 1983) correlated it with the Mansehra granite, which has a Cambrian age. No basal conglomerate has been reported at the unconformity. Two metamorphic foliation have been reported from the Manglaur schist; the earlier metamorphic foliation is thought to be Precambrian (?) age and the later metamorphic foliation related to the Himalayan orogeny (Kazmi et al., 1984, 1986). The Ar40/Ar39 dates of 29.5±0.3 to 39.9±0.2 Ma have been obtained from the metamorphic rocks of Swat (Rosenberg, 1985; Lawrence et al., 1985). These dates indicate that in this sector of the Hamalaya, the pre-Himalayan metamorphism have been reset by the younger Himalayan metamorphism.

In the Besham area (fig. 1, location I) the contact between the Korara Group and the Precambrian Besham Group is an angular unconformity (fig. 8). A metaconglomerate is present at the base of Karora Group (Jan and Tahirkheli 1969; Ashraf et al., 1980; Fletcher et al., 1986; LaFortune, 1988; Baig work in progress, 1988) which has clasts of pebbles, cobbles, and boulders of granite gneiss, biotite gneiss and schist, amphibolite, graphitic schist, marble, quartzite, and pegmatite, derived from the underlying Besham Group. The Besham Group of rocks were intruded by the basic and acidic igneous rocks which were deformed and metamorphosed before the deposition of the Karora Group. Later, both the Karora and the Besham Groups of rocks were metamorphosed and deformed. The post-Karora Group metamorphism and deformation at places has not completely obliterated the earlier metamorphic foliation in the Besham Group. The earlier metamorphic foliation in the Besham Group is truncated by the Amlo basal conglomerate of the Karora Group (fig. 8), and suggests that at least the earlier foliation in the Besham Group is older than the foliation in the Krora Group. The age of the Karora Group is either Paleozoic or Precambrian, and gives an upper age limit for pre-Himalayan deformation, metamorphism, and magmatism in the Besham Group.

Southern Jammu & Kashmir State: The Muzaffarabad, Kotli, Poonch, Riasi, and Jammu areas tectonically lie between Himalayan Frontal thrust or Main Frontal thrust on the south and the Main boundary and Panjal thrusts in the north (fig. 1).

In Kotli District, State of Azad Jammu and Kashmir (fig. 1, location J), the Precambrian Dogra Formation (Dogra slate) is unconformably overlain by the Cambrian Sirban Formation of the Abbottabad Group (Ashraf et al., 1983). The Dogra Formation is composed of grey, dark grey to black slate, phyllite, chlorite schist, and sericite schist with graphitic to carbonaceous impurities. It is interbedded with Precambrian basaltic flows (Dogra trap), which are locally amygdaloidal (Chaudhry and Ashraf, 1984). A conglomerate at the base of the Cambrian Sirban

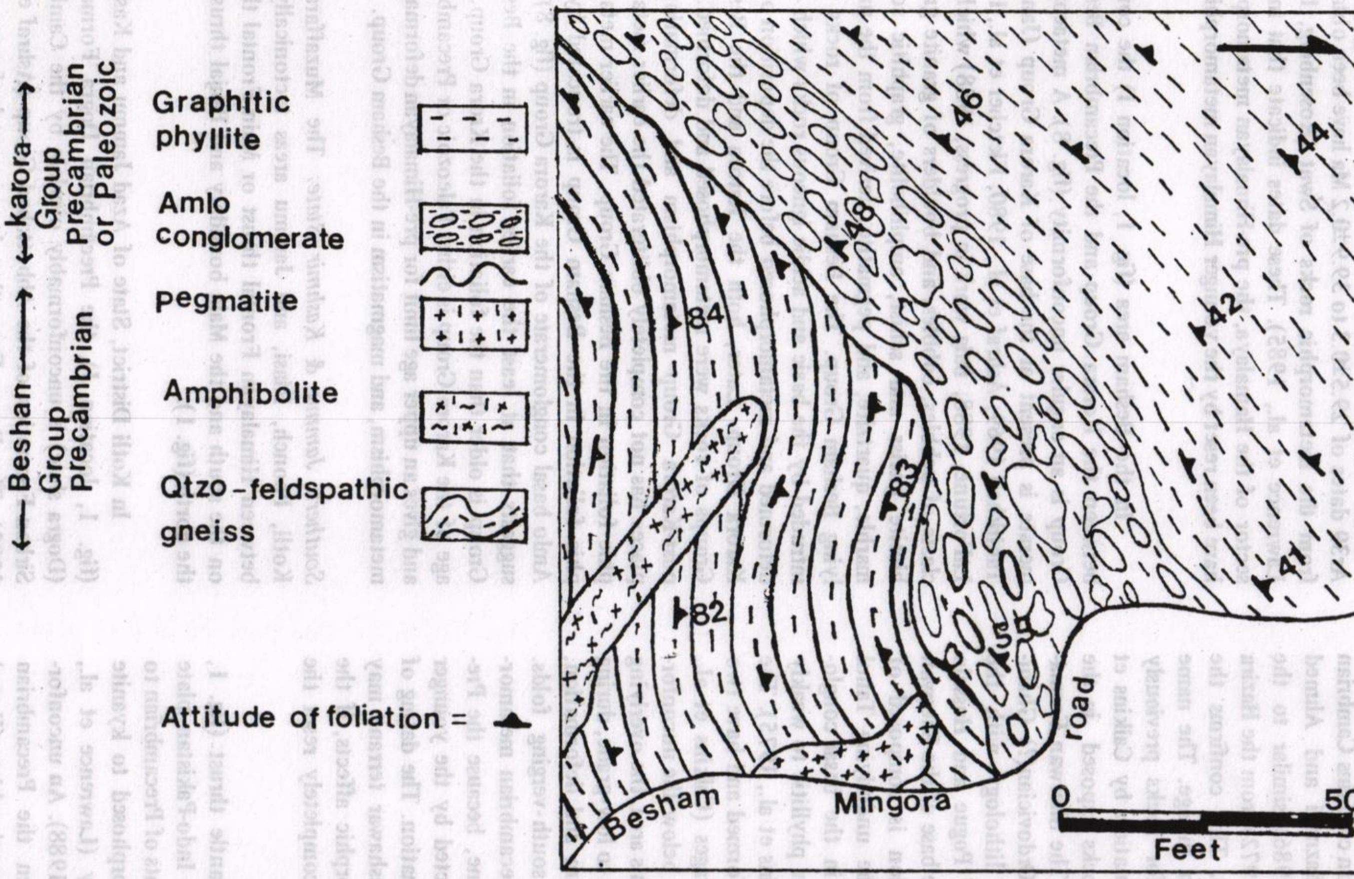

Figure 8. Geological field sketch map showing the field relations of the Karora and Besham Groups, near Dipiar village about 4 Km west of Besham (fig. 1, location I) along the Besham Mingora road. The contact between the Karora Group and the Besham Group is marked by an angular unconformity. The amphibolite and pegmatite do not intrude the overlying Karora Group. The dashed lines in the Karora and Besham Groups show the general trend of foliation. The foliation in the Besham Group is truncated by overlying Amlo basal conglomerate of the Karora Group.

Formation overlies the Precambrian Dogra Formation. It contains metamorphic clasts of the underlying Precambrian Dogra Formation. The Tanol and Kakul Formations are absent and therefore were eroded from or were not deposited between Precambrian Dogra Formation and the Cambrian Sirban Formation of the Abbottabad Group. The Cambrian rocks above the unconformity are unmetamorphosed, whereas the underlying Precambrian Dogra Formation is deformed and shows lower greenschist facies metamorphism. Thus, the Cambrian unconformity postdates the Precambrian metamorphism and deformation of the underlying Dogra Formation.

Near Chrtru-Singpor northwest of Kisthwar, Doda District, Jammu and Kashmir State (fig. 1, location L), the Precambrian Salkhala Formation (Sharda Group of Ghazanfar et al., 1983) is overlain by the Cambro-Silurian Chingam Formation, which underlies the Muth Formation of Devonian age (Gupra and Datta, 1979). A basal conglomerate (Chrtru pebbly phyllite) between Chingam Formation and the Precambrian Salkhala Formation is present. The basal conglomerate is poorly sorted and is composed mainly of grit, pebble, cobble, and minor boulders. The thickness varies from 10-300 meters, and locally it pinches out. Clasts are rounded, sub-rounded, and are composed of sub-angular vein quartz, quartzite, limestone, slate,and basic rocks derived from the underlying Precambrian rocks. The pebbles are stretched in the schistose calcareous matrix. The Salkhala Formation is composed of phyllite and schist with intercalations of carbonaceous schists, micaceous quartzite, and marble that are metamorphosed from chlorite to staurolite and kyanite grade. However, kyanite and staurolite schists are rare. The schist of Salkhala Formation grades upward into the overlying phyllite unit of grey to greyish brown, which has minor carbonaceous and quartzose intercalations.

The Salkhala Formation below the basal conglomerate is folded along axes trending NNW-SSE, and Paleozoic rocks above the unconformity have more open folds trending northwest. The foliation in the Salkhala Formation trends NNE to NNW.

We suggest that below the Chrtru pebbly phyllite at least one phase of deformation and metamorphism may be of Precambrian age, because the underlying Precambrian rocks have at least two sets of cleavages with respect to the overlying Paleozoic rocks (Gupta and Datta, 1979).

THE POSSIBLE EXTENT OF UNCONFORMITY IN THE HIMALAYA

Himalaya: In the Simla and Kumaon (fig. 9) areas of the Himalaya, the Precambrian-Cambrian boundary is not well defined because of the lack of faunal control. The Precambrian to Paleozoic rocks are metamorphosed and deformed. The grade of metamorphism increases from low-grade in the south to high-grade in the north. In these areas, geologists should look for an angular unconformity between Paleozoic and Precambrian rocks to delineate the ages of metamorphic episodes.

To the Main Boundary thrust in Nepal, the Kathmandu nappe was thrust south along the Kathmandu fault. The Kathmandu nappe includes rocks of Precambrian, Cambrian, Ordovician, Silurian, Devonian, Permo-Carboniferous and Paleogene age. The Precambrian to early Paleozoic metasediments were intruded by early Paleozoic granites (Le Fort et al., 1983). The grade of metamorphism decreases from garnet to chlorite upward in the nappe unit. Kumar et al., 1978) observed an angular contact between the early Cambrian Tistung Formation and Precambrian Bhimphedi Group. It is exposed in the Tistung Kulikhani road, near Tistung village, Kathmandu (fig. 9), Central Nepal. It is marked by a sharp contact without a basal conglomerate. The rocks above and below the angular contact are metamorphosed. The Paleozoic rocks above the angular contact have one metamorphic foliation, whereas rocks of the Precambrian Kulikhani Formation of the Bhimphedi Group below it exhibit at least two distinct metamorphic foliations. The angular unconformity between the early Cambrian and Precambrian metasedimentary rocks postdates the earlier metamorphic foliation associated with Precambrian tectonism and predates the later metamorphic foliation related with the Himalayan orogeny (Kumar et al., 1978).

THE POSSIBLE EQUIVALENTS TO THE HAZARA FORMATION IN THE NW HIMALAYA

In adjoining areas, the Hazara Formation is equivalent to Landikotal (Khyber) slate, Dakhnar Formation, Dogra Formation, and Simla slate. To the northeast and southeast of Hazara-Kashmir syntaxis, the Kashmir foreland fold-and-thrust belt constitutes Precambrian to Paleozoic rocks of psammitic, pelitic, and calcareous facies. These rocks show transition from Lesser Himalayan shallow water platform and shelf facies to Higer Himalayan deep water facies.

Kumar et al., (1984) described the Precambrian and Paleozoic rocks of the Lolab Valley and Haptnar Valley sections in the Kashmir Valley (fig. 1). The Machhal Formation underlies the Paleozoic sequence and is mainly composed of slate, argillite, and subordinate quartzite. The Machhal Formation correlates with the Dogra slate (Dogra Formation) of Wadia (1934), Batal Formation of Srikantia (1981), and Marinag Formation of Shah (1968, 1982). The contact is gradational with the overlying Lower Cambrian Lolab Formation. The Lolab Formation is composed of

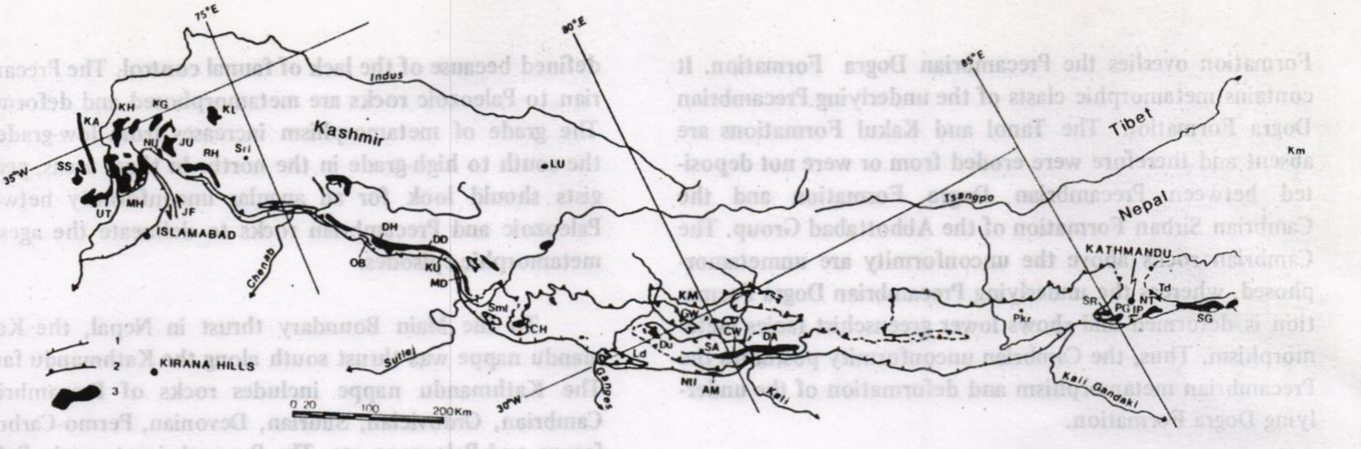

Figure 9. Location map for the Lesser Himalayan granite belt (Modified after, Le Fort et al.,1983). 1 = Main Boundary thrust zone, 2 = Thrust 3 = Late Precambrian to early Paleozoic granitic belt, and JF = Jhelum fault. Saidu Sharif (SS = Swat granite), Kogha (KA), Utla (UT), Mansehra (MH), Kohistan (KH), Kaghan (KG), Nauseri (NU), Jura (JU), Kel (KL), Rashian (RH), Outer band of Dalhousie (OB), Dalhousie (DH), Dhaola Dar (DD), Kulu (KU), Mandi (MD), Lahul (LU), Amritpur (AM), Chor (CH), Champawat (CW), Dandeldhura (DA), Dudhatoli (DU), Gwaldam (GW), Ipa (IP), Lansdowne (LD), Narayan Than (NT), Palung (PG), South Almora (SA), Sindhuli Garhi (SG), Simchar (SR), Timaldanda (TD), and Kangmar southern Tibet (Km). Town locations: Srinagar (Sri), Dharamsala (Dhs), Simla (Sml), Naini Tal (Ntl), Pokhra (Pkr), and Kumaon (KM) area of Himalaya.

siltstone, sandstone, and quartzite. It contains the trilobites *(Redlichia noetling, R. cf. kanjazeri. Tunquesella obesa)* and brachiopods *(Neobolus, Botsfordia granulata)* of early Cambrian age (Kumar et al., 1984). A basal conglomerate has not been recognized in the Kashmir valley, but in the Kotli Azad Kashmir and Chrtru-Singpor Kishtwar, a basal conglomerate is present between Precambrian and Cambrian rocks. There is a need to look for the basal conglomerate in other parts of Kashmir. If this unconformity is not present in other parts of Kashmir, then the Dogra Formation of Kotli, Poonch, and the Hazara Formation of Hazara are different tectono-stratigraphic units with respect to the Machhal and Marinag Formations of the Kashmir Valley and Batal Formation of Spiti. These were deposited farther offshore of the Precambrian to Paleozoic passive margin of Indo-Pakistan plate in the Kashmir and Spiti Basin, and later on thrusted southward during the Himalayan orogeny.

DISCUSSION

The above descriptions of field relations support the existence of a late Precambrian to early Cambrian tectonic episode in the Himalaya. Earlier workers have suggested the possibility based on: A) isotopic data of metamorphic rocks; B) stratigraphic data; C) and the presences of late Precambrian to early Paleozoic granites (fig. 9).

A). Krummenacher (1961, 1966) dated metamorphic rocks from the Nepal Himalaya and suggested the possibility of Precambrian metamorphism. Detrital muscovite from the quartzite unit of the Nawakot nappe of Higher Himalaya has a K/Ar date of 728±12 Ma, whereas biotite from schists, granites, gneisses, diorite, and arkosic sandstone gave dates of less than 20 Ma from Kumbu and Kathmandu nappes. From the middle part of Nepal, a detrital sericite from the carbonaceous schists gave 1280 Ma; detrital muscovite from Kunchla series gave 872 Ma; uralite from an extrusive rock has given date of 819±80 Ma; a microcline in a granite pebble gave a date of 354 Ma; and phlogopite from a marble gave a date of 381 Ma (Krummenacher, 1961, 1966). He interpreted the older dates to an ill-defined Precambrian metamorphism and the 354 Ma date to argon loss. Dates less than 20 Ma are probably reset by the Himalayan orogeny.

In the Hazara-Swat foreland fold-and-thrust belt, Crawford and Davies (1975) analyzed Sr-isotope ratios of whole-rock samples of slate from the Hazara Formation. We recalculated these model dates to be 752±20 Ma. 728±20

Ma, and 951±20 Ma by using a decay constant of $1.42x 10^{-11}/yr$ (Steiger and Jager, 1977) and using the initial 87Sr/86Sr ratio of 0.7000 assumed by Crawford and Davies (table. 1). These dates probably show the age of provenance of the Hazara Formation to be Precambrian, if so, the deposition of the Hazara Formation must post-date this age and be late Precambrian in age. The metamorphism of the Hazara Formation must be late Precambrian or earliest Cambrian, as the Hazara Formation is overlain unconformably by the unmetamorphosed rocks bearing Cambrian fossils.

Crawford (1981) analyzed 14 samples of Dogra slate (Dogra Formation) from Kashmir, which yielded an apparent Rb/Sr date of 930-980 Ma with initial 87Sr/86Sr ratios of less than 0.85. The Chail series gave a date of 650 Ma, with an initial 87Sr/86Sr ratio of 1.0729. Because accurate 87Sr/86Sr initial could not be calculated for these isochrons, the dates are not reliable.

The above cited data suggest that the Precambrian shelf and platform sediments of the northern margin of the Indo-Pakistan plate were deposited in the late Precambrian and were possibly weakly affected by the late Precambrian to early Cambrian metamorphism. In the areas of the Himalaya, where the Precambrian basement rocks are strongly affected by the younger Himalayan metamorphic overprint, it is difficult to obtain Precambrian metamorphic dates because of thermal resetting during the Himalayan orogeny.

B). The unfossiliferous nature of the Lesser Himalayan rocks made it difficult for earlier workers to confirm the existence of pre-Himalayan deformation. Some workers have suggested the possibility of a late Precambrian to early Cambrian deformation on the basis of tracing of the Indian shield structures into the Himalaya, where they have provided control to the younger Himalayan structures (Gupta, 1964; Valdiya, 1984) and by correlation of the unfossiliferous Lesser Himalayan stratigraphy to the Precambrian Vindhyan basin of the northern India (Jain et al., 1980; Valdiya, 1984). Due to the Precambrian to early Cambrian deformation (?), deposition in this basin terminated in the Paleozoic. The related unconformities have a time gap of most of the Paleozoic, leaving the time and nature of deformation uncertain (Jain et al., 1980). Faced with these uncertainties, some workers concluded that there was no good evidence for pre-Himalayan deformation, and that only the epeirogenic granites were recorded (Powell and Conaghan, 1973; Powell et al., 1979; Ganseer, 1981; Windley, 1983).

The presence of the regional angular unconformity in the Hazara, Kotli Azad Kashmir, and Nepal Himalaya between late Precambrian and early Cambrian rocks, provides the best stratigraphic evidence for the Precambrian deformation and metamorphism.

The Precambrian psammitic, pelitic, and minor calcareous to carbonaceous facies of the Hazara Formation, Dakhnar Formation, Landikotal (Khyber) and Simla slates, and related units elsewhere in the Himalaya, represent the Precambrian flysch that was deposited along the northern margin of the Indo-Pakistan (Gondwana) plate. These sediments may have been deposited during the early phase of Precambrian orogeny, and were later deformed, metamorphosed, and intruded by the Precambrian to Paleozoic basic and silicic plutonic rocks.

C) Granitic and metamorphic rocks are present in the Lesser, as well as in the Higher Himalayan crystalline slab. There are two main groups of granitic rocks that have Rb/Sr and U/Pb isochron dates of approximately 500-600 Ma (fig. 9 and table 1) and 600-1800 Ma respectively, have high initial 87Sr/86Sr ratios, and were intruded into metasediments of the Himalaya (Le Fort et al., 1980. 1983; Valdiya, 1983; Sharma, 1983; Zeitler et al., 1986; Zartman and Zeitler in Baig et al., 1988). These Precambrian to Paleozoic granitic and metasedimentary rocks were intruded by the very young tourmaline granites in the Higer Himalaya, which have given dates of approximately 25-30 Ma (Rb/Sr isochrons and K/Ar mineral dates; Mehta, 1980; Zeitler et al., 1982, Zeitler, 1985; and Sharma, 1983). The Ar40/Ar39 dates (25-30 Ma) and fission-track cooling ages of 15-30 Ma indicate that some degree of metamorphism affected most of the Himalayan rocks in NW Pakistan and India (Mehta, 1980; Rosenberg, 1985; Zeitler et al., 1982, Zeitler, 1985; and Sharma, 1983).

Earlier workers (Powell and Conaghan, 1973; Powell et al., 1979; Gansser, 1981; and Windley, 1983) considered the late Precambrian to early Paleozoic granites in the Himalaya to be related to epeirogenesis because they found no good evidence for pre-Himalayan deformation. According to Le Fort et al., (1980), the early Paleozoic granites could not be correlated to a definite orogeny like the Pan-African or to a simple thinning of the Precambrian crust of the Indian plate, because no evidence for pre-Himalayan metamorphism could be found. But the development of the axial plane cleavage with the growth of new mica fabric in the Precambrian rocks of the Hazara Himalaya, below the Cambrian basal conglomerate of the Abbottabad Group definitely provides evidence for metamorphism and deformation at this time.

The late Precambrian to early Cambrian plutonism and volcanism occurred, before the deposition of the Cambrian rocks of the Indo-Pakistan plate. In Kashmir, the basic Dogra trap is intruded into the Precambrian Dogra Formation (Wadia, 1928; Chaudhry and Ashraf, 1980,

Table 1. Isotopic data from the Himalaya and the southern Indo-Pakistan plate.

Rock type	Locality	Method	Calculated $^{87}Sr/^{86}Sr$ initial	Age in Ma years	Reference
Granite	Crystalline nappe in South-Lahul Himachal Pradesh	Rb/Sr whole rock isochron	0.7200±0.002	495±16	Frank (1977)
Migmatitic gneisses	Kulu Himachal Pradesh	,, ,,	0.7190±0.0007	500±8	Mehta (1976)
Granite	Kangmar South-Tibet	,, ,,	0.7186 ±0.0018	485±6	Wang et al., (1981)
Granite	Kangmar South-Tibet	,, ,,	0.7140±0.001	484±7	Debon et al., (1981)
Augen gneisses	Tibetan slab Central Nepal	Rb/Sr Pseudo Isochron	0.7097±0.0120	517±62	Le Fort et al., (1982)
Granites	Simachar and Plung Central Nepal	Rb/Sr combined isochron	0.7106±0.0027	493±11	Le Fort et al., (1983)
Granite	Palung Central Nepal	Rb/Sr whole rock isochron	0.720	486±10	Beckinsale (in Mitchell, 1981)
Granites & migmatites	Behsud Afghanistan	,, ,,	0.7106	496 ±11	Montenate et al., (1981)
Granite	Simachar Central Nepal	,, ,,	0.7205 ±0.0046	466±40	Le Fort et al., (1983)
Micro-granular inclusions	,, ,,	,, ,,	0.7085±0.0048	511±55	,, ,,
Granite	Mansehra Hazara Himalaya	,, ,,	0.7189±0.0006	516±16	Le Fort et al., (1980)
Almora granodiorite Champawat granite	Almora nappe	Rb/Sr combined isochron	0.7109±0.0013	560±20	Trivedi et al., 1984)
Granite	Mandi Himachal Pradesh	Rb/Sr whole rock isochron	0.7180	510±100	Jager et al., (1971)
Biotite granites	Sarangri & Rungathach, Manikaran	,, ,,	0.7190	467±45	Bhanot et al., (1979)
Central gneisses	Rohtang pass Mandi area	,, ,,	0.07113±0.0007	600±9	Mehta (1977)

Table 1 (Contd).

Migmatitic gneisses	Kulu area	" "	0.7190±0.0007	519±8	" " "
Granite	Mandi area	" "	0.7019±0.0015	564±12	" " "
Metabasic xenoliths in granite	" "	" "	0.7001±0.0005	682±20	" " "
leucocratic granite	" " "	" "	0.8110±0.0007	321±6	" " "
Mandi granite	" " "	Rb/Sr(Mu,Bi) mineral date	0.7019±0.0015	426±12	" " "
Leucocratic Mandi granite	" " "	" "	0.8110±0.0007	333±6	" " "
Grey-green fine-grained rhyolite	Kirana & Bulland Hills Pakistan	Rb/Sr whole rock isochron	0.712±0.009	831±20	Davies and Crawford (1971)
Brown aphenitic volcanic	" " "	" "	" " "	838±20	" " "
Grey, fine-grained rhyolite	" " "	" "	" " "	809±20	" " "
Fine-grained acid volcanic	" " "	" "	" " "	865±20	" " "
Very fine-grained volcanic	" " "	" "	" " "	841±20	" " "
Glassy fine-grained porphyry	Tobra Form. Salt Range	" "	" " "	786±20	" " "
Felsite	Barmer India	" "	0.7094±0.0009	729±10	Crawford and Compston (1970)
Rhyolite	" "	" "	" " "	733±10	" " "
Fine-grained rhyolite	" "	" "	" " "	500±10	Crawford and Compston (1970)
Agglomerate	Miniari India	" "	" " "	734±10	" " "
Tuff bomb in agglomerate	" "	" "	" " "	719±10	" " "
Rhyolite	Barmer India	" "	" " "	724±10	" " "
Tuff	Bisala India	" "	" " "	740±10	" " "

Table 1 (contd.)

Granite	Jalor India	" "	" " "	411±10	" " "
Siwana-type Granite	Jasai India	" "	" " "	701±10	" " "
Granite	" " "	" "	" " "	691±10	" " "
Granite	Jalor India	" "	" " "	743±10	" " "
Hazara slate	7 miles south of Mansehra	" "	assumed initial 0.7000	752±20	Crawford and Davies (1975)
Hazara slate	near preveous locality	" "	" " "	728±20	" "
Hazara slate	near Tanakki	" "	" " "	951≃20	" " "

Note. Dates upto 1977 have been recalculated by using Steiger and Jager (1977) decay constant of $1.42x10^{-11}$/yr for Rb Mu = Muscovite, and Bt = Biotite.

1984). Near Bulland and Kirana Hills, Sargodha, Pakistan, the acidic and pyroclastic rocks and high level intrusions have Rb/Sr whole rock isochron dates of 809±20 to 865±20 Ma and initial 87Sr/86Sr ratio of 0.712±0.009 (recalculated from Davies and Crawford, 1971; table 1).

In India the Malani volcanic rocks, comprising tuff, rhyolite, and agglomerate, were followed by intrusion of comagmatic granites (Jalor and Siwana granites) and dikes of felsic, mafic, and intermediate composition (Pareek, 1981). The Malani volcanics overlie the Precambrian metamorphic rocks of the pre-Delhi and Delhi Super Groups and are overlain by the Cambrian sedimentary rocks of the Marwar Super Group (Pareek, 1981). Crawford and Compston (1970) dated Malani volcanic suite. We recalculated these dates using Rb decay constant of $1.42x10^{-11}$/yr (Steiger and Jager, 1977), with a 87Sr/86Sr initial of 0.7094±0.0009, and obtained Rb/Sr whole rock isochron dates of 411±10 to 743±10 Ma (Table 1). Apatite from the Jalor granite, which intrudes the Malani volcanic rocks, gave a fission track cooling date of 600±70 Ma (Sharma, 1975). However, the same felsic volcanic rocks near Tosham yielded a Rb/Sr whole rock isochron date of 940±20 Ma (Kochhar, 1974).

In the Khewra Gorge, eastern Salt Range, Pakistan, the Trachytic Khewra trap intrudes the Salt Range Formation of late Precambrian age (Mosebach, 1956; Martin, 1962), but does not intrude the overlying Khewra sandstone of early Cambrian age.

The dating of metamorphic, plutonic, and volcanic rocks of the Indo-Pakistan plate, combined with evidence of the Precambrian deformation and metamorphism in the Hazara Himalaya, confirm that late Precambrian to early Cambrian orogenesis occurred in the Indo-Pakistan plate.

Sometime after the late Precambrian to early Cambrian metamorphism and deformation, the early Paleozoic 500-600 Ma peraluminous granites like Behsud (Afghanistan), Mansehra, Swat, Kogha, Kaghan, Nauseri, Jura, Rashian, Mandi, Kangmar, Simacher, Palung, and related granites elsewhere in the Himalaya, intruded into the Precambrian to earliest Paleozoic rocks of the Indo-Pakistan plate (fig. 9). Their generally high initial 87Sr/86Sr ratios (most 0.710 to 0.720, table 1) suggest that these plutons principally were derived by anatexis from the Precambrian basement rocks of the Indo-Pakistan plate. The presence of meta-basic inclusions and xenoliths with dates of 682±20 Ma, and 87Sr/86Sr initial of 0.7001±0.0005 (recalculated from Mehta, 1977; table 1), and some granites with low 87Sr/86Sr ratios (table 1) may indicate that these plutons have some mantle contribution. The early Paleozoic granites may be a late-or-post-orogenic phase of the Hazaran orogeny. These orogenic phases occurred on the Indo-Pakistan plate before the Permo-Triassic breakup of Gondwana and may relate to its amalgamation as a supercontinent in the late Precambrian to early Paleozoic.

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PALEOENVIRONMENTAL INTERPRETATION OF PALEOGENE STRATA NEAR KOTLI, AZAD KASHMIR, NORTHEASTERN PAKISTAN

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ABSTRACT:– In the Kotli area of east-central Pakistan, the Subathu Formation was deposited by a single cycle of transgression and regression during the early Eocene. The marine Subathu section, which is developed on a pre-Eocene bauxite, records the successive passage of a coastal coal swamp; a very muddy shoreline; shallow and highly turbid but quiet offshore waters depositing unfossiliferous green mud and organic debris; clearer and probably deeper but still occasionally turbid water over fetid muds and marls beyond the coastal turbid zone; progressively shallower water depositing shales and higher energy limestones; an oyster bank; a delta-related submergent sand-bar complex; and a back-bar bay or lagoon that trapped river muds. Finally, progradation of a brackish coastal marsh across the bay is inferred from the succeeding slowly accumulated and completely pedogenized onshore clays. The topmost marine shale is inferred to correlate with a regional regression at the end of the early Eocene.

INTRODUCTION

Outcrops near the town of Kotli are important because they intervene between the very different Paleogene facies exposed in the Hazara region (around Murree in the Margalla Hills and near Muzaffarabad) and those near Kalakot and Riasi villages in India (figure 1). They have been examined previously by Lydekker (1883) and Wadia (1928), and they have recently been remapped by Mr. Raffi Ullah of the Geological Survey of Pakistan and restudied by Ashraf and others (1983).

As shown on Figure 2, the Kotli outcrop is essentially an elliptical dome, elongated parallel to the regional NW-SE strike. The south side of the dome is breached by a major thrust fault and its crest is highly undulatory. The core of the dome incorporates the pre-Cenozoic Jammu Limestone, the Paleogene Subathu Formation, and the Oligocene or Miocene Murree Formation. The Kamroti area, which was examined in greatest detail, is at the southwestern corner of one of the undulations. In that area, the section is repeated by a high-angle reverse fault that breaks the northeastern side of the dome between Kamroti and Nikial 6 km to the east. The base of the upthrown block is a slice of Jammu Limestone, but the lowest stratum exposed on the footwall becomes progressively younger to the south: two miles north of Kamroti, Jammu Limestone is faulted against itself but south of the Kamroti-Nikial road it is juxtaposed against Murree beds. Intense drag folding of the Subathu beds near the fault can be seen along Batala Nala, a stream valley NE of Kamroti.

RESULTS: DESCRIPTIONS OF STRATA

Figure 3 summarizes the Kamroti section and shows both the nomenclature favoured by Ashraf and others (1983) and correlations with Singh's (1973) divisions of the Subathu in the Kalakot and Riasi areas. The lettering of the Kamroti sub-units in this paper is for ease of refrence only and is not proposed as a formal subdivision. The name Subathu is used here because the Kotli section has more in common with Subathu strata immediately

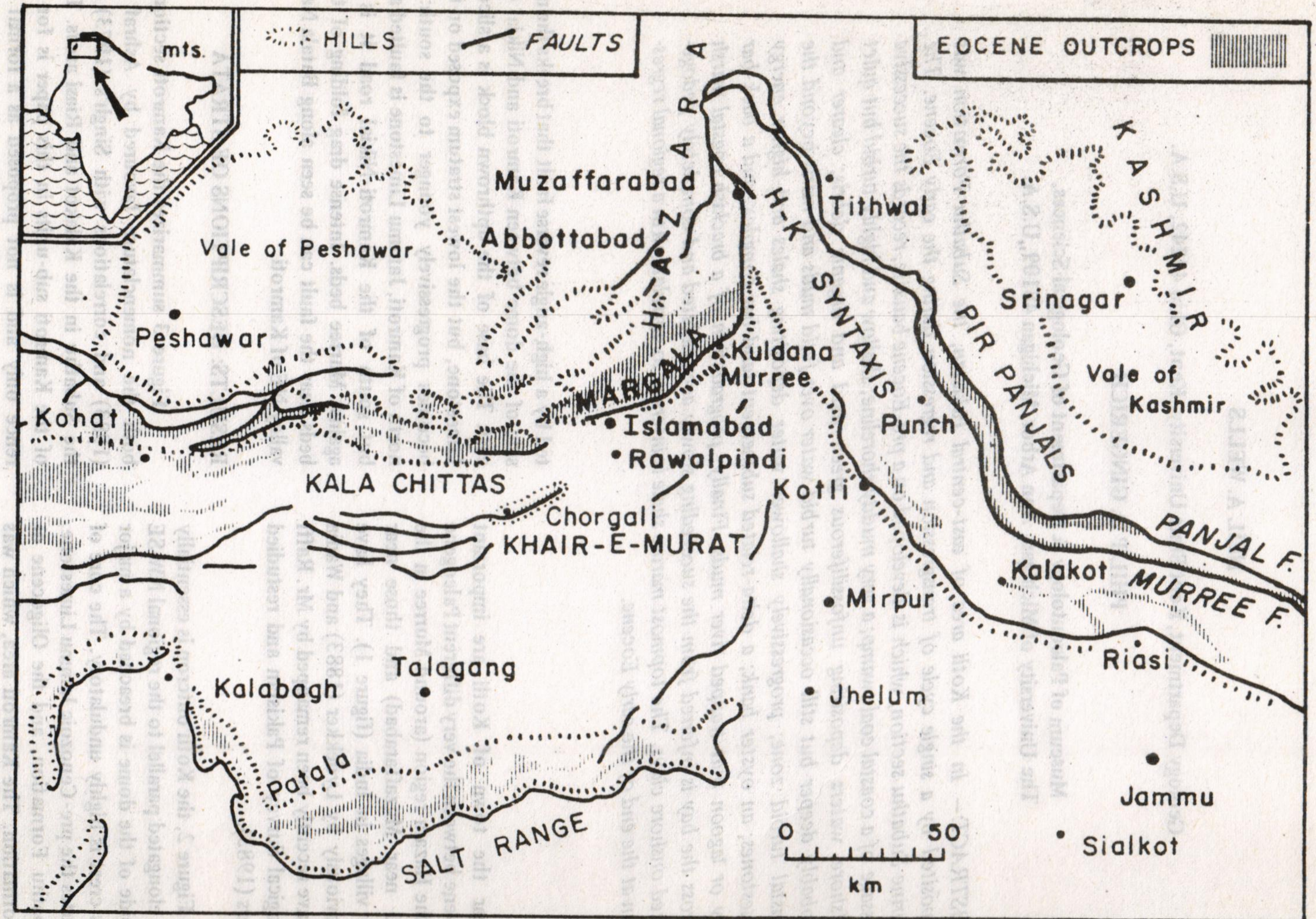

Figure 1: Faults, hill ranges, and Eocene outcrops around the Hazara-Kashmir syntaxis (arrow in inset map of Indo-Pakistan subcontinent shows location of figure).

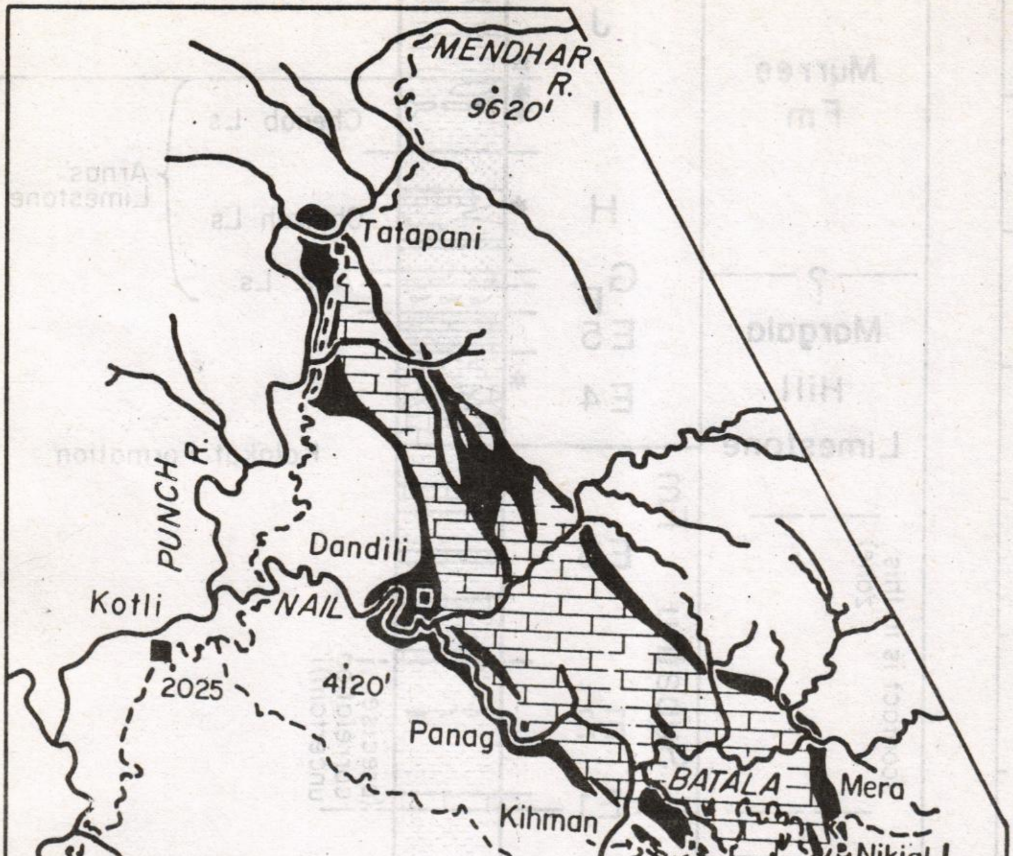

Figure 2 : Map of Kotli area. Solid black shows outcrops of Eocene, limestone pattern shows Jammu "Limestone" (redrawn from Ashraf and others, 1983).

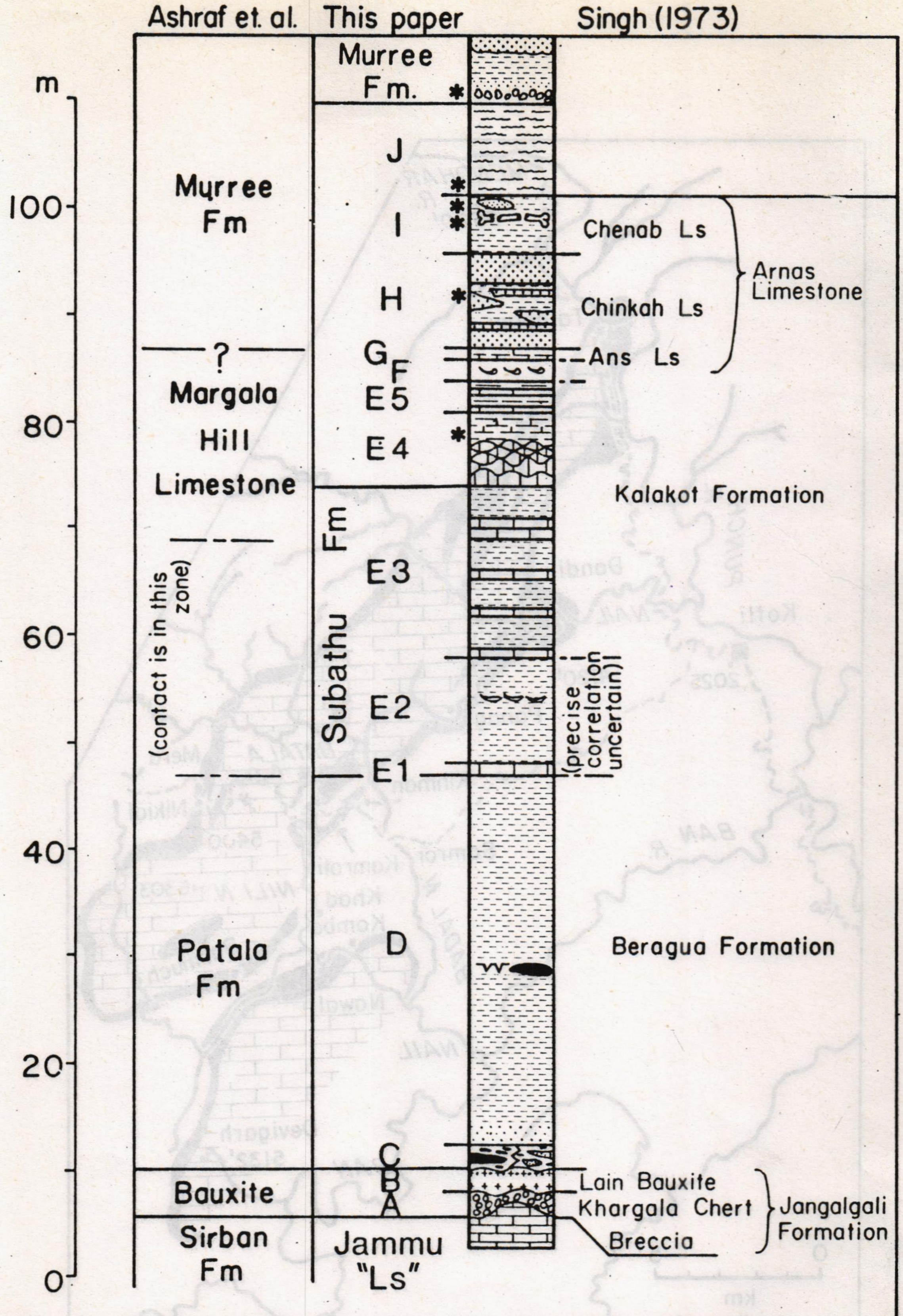

Figure 3 : The Subathu section at Kamroti, near Kotli, with correlation to the stratigraphy of Singh (1973) and Ashraf and others (1983). From Unit C up into unit E, the section is basically transgressive, whereas starting with Unit E-4 (if not lower), the section is regressive. Key: asterisks mark vertebrate fossil horizons; the broken bone in unit I marks the Batala Nala bone bed; concave upward marks in F and E-2 represent oysters, black in D & C is coal; and dots and crosses in B are boehmite pisolites and kaolinite clay respectively.

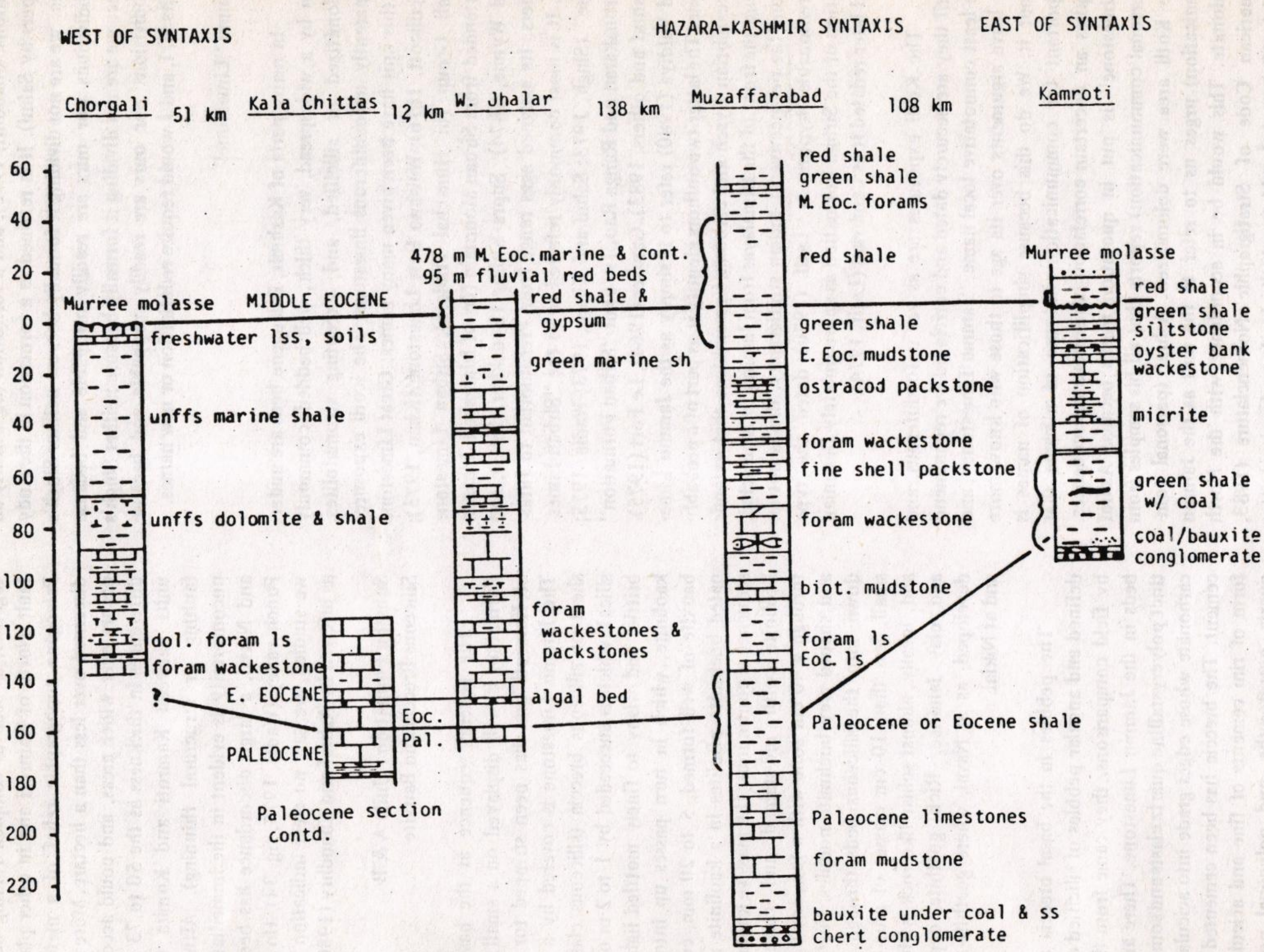

Figure 4: Correlation of early Eocene sediments around the Hazara-Kashmir syntaxis. Parentheses indicate uncertainty of correlations due to unfossiliferous sequences, but lines show best-guess correlations based on the paleogeographical hypotheses of Wells (1984). The structure around Muzaffarabad is very complex, and the section may well have been thickened by cryptic faulting or folding, so Wells has arbitrarily shrunken his measured section by 33%.

across the Indian border and with Subathu facies (predominantly olive shales) at the type section than with any Pakistan facies known to the authors. The name is not free of problems, as it has been used as a group (La Touche, 1888; Singh, 1973), a series (Wadia, 1975 and previous editions; Chaudhri, 1972), and a formation (e.g., nearly all papers by Sahni). It is retained as a formation in the study area: we are not dividing it formally because neither Singh's subdivisions nor ours are readily mappable and because area: we are not dividing it formally because neither Singh's subdivisions nor ours are readily mappable and because units H, I, and J would require redefinition or new names.

Jammu "Limestone"

In many parts of Kashmir, Paleogene beds are underlain by a widespread, very thick, well bedded, commonly dolomitized or silicified, and, excepting stromatolites, apparently unfossiliferous limestone. The Kotli exposures of this unit have been given many names: Great Limestone (Medlicott, 1876); Waishno Devi Limestone (Khan, 1973); Shali Group (in Himachal Pradesh); Sirban Limestone (extended from Sirban Mountain NW of Islamabad: Waagen and Wynne, 1874); Supra-Kuling (Lydekker, 1883); and others. Its assigned ages range from Precambrian to Jurassic. It is most commonly referred to as the "Sirban Limes tone" (Singh, 1973; Sahni and Khare, 1973; Wadia, 1975; Karunakaran and Ranga Rao, 1976) or "Sirban Formation" (Ashraf and others, 1983). Gansser (1964), Le Fort (1975) and Valdiya (1980) refer to it simply as the Jammu Limestone. The latter two authors identify it as part of a probably Precambrian flysch and carbonate assemblage that extends along the front of the Himalayas from Jammu to Arunachal. From the perspective of Indian stratigraphy, this is not an unreasonable hypothesis. Latif (1970) dated the type section of the Sirban Formation as approximately Devonian and later redated it as Cambrian (Latif, 1974).

The Kotli exposures are as yet unfossiliferous, and until they are securely dated and correlated we recommend the least connotative local name, "Jammu Limestone", and we leave arguments over its age to those who know more about it. We do this because simplification of names is important for communication, but use of a name that implies an uncertain correlation has serious consequences. "Limestone" is put in quotation marks because Ashraf (personal communication) reports that all his samples from the Kotli area were dolomitized. Ashraf (personal communication) urges us to refer to the unit as the Jammu Dolomite. This would be in accordance with the North American Code of Stratigraphic Nomenclature (1983, article 18a), and should eventually be done, barring better correlation with the Sirban Formation. However, we did not study the unit, so we do not wish here to make changes to prior usage.

Surface topography on the top of the Jammu Limestone is not easily assessed. Its surface is irregular, as reported by Ashraf and Chaudhry (1980), but it is intensely folded, and around Kamroti and Nikial the Jammu "Limestone" and the Paleogene strata seem everywhere folded together, as seen in complex folding near the Batala Nala fault. North of Kamroti and in other places mild local pre-Paleogene topographic relief of a meter or two can be discerned over less than a hectare. More relief undoubtedly occurs over wider areas, and could account for such local differences in thickness as the 50 to 73 m change in lower units between Kamroti and Komba (as could cryptic faulting or structural thinning). Although no angular unconformity is evident in the immediate area of Kamroti and Nikial, a large discordance has been reported in the Punch valley (Wadia, 1975, fig. 34). However, in the areas we studied, we saw no clear indication of a karst surface, as inferred by Ashraf and Chaudhry (1980).

Subathu Formation: Units A & B
Siliceous Breccia and Bauxite

The general sequence at the base of the Subathu Formation is well displayed on a small hillside northwest of Kamroti that has been stripped for coal and bauxite. The Jammu Limestone is covered by a thin but irregular sheet of siliceous breccia (siliceous clasts cemented with silica), which is succeeded by 1 to 2 m of smooth, massive, brittle, and wispy to finely mottled light to medium grey kaolinite, which in turn passes up into hematite-stained bauxite of well-formed, 5 to 20 mm, concentrically laminated boehmite pisolites in a kaolinite matrix. The whole sequence is continuous: the massive kaolinite grades up into kaolinite with red-stained and close-packed pisolites through a 40 cm zone with a few, small, irregularly spaced and shaped grey boehmite nodules. Furthermore, it grades down into the siliceous beds through a thin zone with small, less than 10 cm masses of grus-like rotten quartz and, locally, almost schist-like rock with contorted quartz and clay laminae. Rich goethite deposits are locally developed, as at Naval, where goethite coats the breccia, and at Nikial.

The pebbles in the basal breccia are mostly clearly defined and angular pebbles of silicified carbonate. Judging by field comparisons, they came from the abundant chert beds in the Jammu Limestone. There are also some indistinct polycrystalline quartz clasts and some clasts of silicified carbonate whose edges grade into acicular or equant quartz cement. The breccia has been cemented with silica, in the form of rim cements of fine and acicular quartz crystals, quartz overgrowths, and polygonal pore-filling cement. (The clasts with the poorly defined edges may have been limestone pebbles that were silicified after redeposition, during cementation). Lastly, the breccia seems to have suffered dissolution of silica, particularly toward the top of the breccia where the fabric has been obscured by corrosion and stylolitization of the quartz along crystal boundaries and between clasts or cements. The masses of rotten quartz and the schist-like rock seem to have undergone the same history of extensive silicification and subsequent desilicification, but with removal of much more silica. This is indicated because the quartz laminae interlayered with kaolinite are actually strips of cement-like acicular quartz, polygonal quartz, and silicified carbonate like the chert pebbles that have become isolated between stylolites.

According to X-ray diffraction studies, units A and B are made up of silica, kaolinite $[Al_4(Si_4O_{10})(OH)_8]$, boehmite pisolites [$AlO(OH)$] in kaolinite, and goethite [$FeO(OH)$]. Wells (1984) identified dickite from X-ray diffraction, but Ashraf and Chaudhry (1980) identify kaolinite instead of dickite by differential thermal analysis. Further analysis by Wells suggests that kaolinite is indeed more likely. Ashraf and Chaudhry additionally identify some diaspore and gibbsite. Chemically, this is typical of a bauxite, which is to say that the components are relatively simple chemical segregates.

The question of the origins of bauxite is controversial (e.g., see discussions of the Jamaica bauxite by Comer, 1975, 1976; Comer and others, 1980; Sinclair, 1976, 1980), and, at the present stage of study, the standard arguments apply equally well to the Kamroti deposit. The possibilities are that the parent material was a) clays and other insolubles weathered from the Jammu Limestone, b) sediment washed into karstic depressions from elsewhere, or c) volcanic ash. Although far from proven, the first seems the most reasonable, given that the breccia seems to have been derived from the Jammu Limestone (Wells, 1984; Wadia, 1928, p. 262-264), that progressive dissolution in the upper quartz shows evidence of descent of the leaching zone, and that the area was in tropical and subtropical latitudes in the Mesozoic and early Cenozoic (Klootwijk, 1979); Klootwijk & Bingham, 1980). Wadia believed that the bauxite was formed recently in primary clay on modern moderately sloping limestone outcrops, because at one outcrop bauxite changed to clay as it disappeared into a hillside. However, he may have observed a fortuitously located lateral change of the sort seen by Rao (1931) to the southeast in India, where the same bauxites commonly change laterally into clay seams.

Unit C: Coaly Shale

This unit comprises a relatively constant 2 or 3 m of dark organic-rich shale and either coal or carbonaceous sandstone. At Tattapani, Nikial, Komba, and Kamroti, coal is absent where sandstone is present and vice versa. The coal is thin, low grade, friable, and pyritic (as are the shales) (see Simpson, 1904, for coal analyses). The shales contain many poorly preserved and fragmentary plant fossils. The sandstones are thin and probably broadly lenticular, and are interbedded with shales. No crossbedding was evident. One fine, pyritic, argillaceous calcarenite low in a dark shale sequence directly above the pisolitic bauxite contains ostracodes, relatively long fragments of molluscs, some echinoid debris, *Cibicides*-like foramanifera, a few miliolids, and some small coral intraclasts, all cemented with long and perpendicularly oriented calcite needles. A slightly higher and coarser, 20-cm-thick, argillaceous and organic-rich sandstone, located 2.4 m above the bauxite in a sequence of black, brown, and dark green shales, contains small, rare, and poorly preserved clams, echinoid plates, and many small Jammu Limestone lithoclasts.

Unit D: Green Shales

Above the basal coaly shales are about 35 m of dark to olive unfossiliferous shale. The unit is as thin as 21 m at Komba. North of Kamroti very shaly coal is quarried in the middle of the shale. Some associated limonitic siltstone shows two horizons of small mudcracks, and a little higher, in a coaly fine shale, is the lowest identified fossil, the pelecypod *Ostrea (Liostrea)* cf. *flemingi*. Ashraf and others (1986) have noted the shaly coal at several other localities near Kotli.

Unit E: Limestones and Shales

This part of the section shows an upward increase in fossiliferous limestone. The subdivisions described below are based on exposures around Kamroti: their facies are typical for this part of the section, but the units are not regionally correlable.

The basal limestone, unit E-1, is a 40 cm thick, hard, fetid, clayey, and echinoidal micrite with fragmentary echinoids (mostly spines), pelecypods, and gastropods. It also contains a considerable amount of silt-sized euhedral untwinned and unordered albite (95-100% Na, as determined by X-ray diffraction analysis according to the methods of Wright and Stewart, 1968a & b). Untwinned and unordered albite would seem to be volcanic in origin, and while no glass or other volcanic debris is evident, this unit apparently represents the only evidence, albeit indirect and reworked, of volcanism seen in this part of the Subathu (note that Wadia, 1928, reports peridotite dikes in the bauxite and Pascoe, 1964 p. 1561 ff., discusses volcanics interbedded with probable Laki-age Subathu-like beds in the Indus Valley volcanic belt far to the northeast).

Unit E-2, 10 m of shale, is a short-lived repeat of unit D shale, with the exception of a thin layer of quartz-silt-rich and moderately organic micrite with mollusc fragments and some poorly preserved foraminifera identified as *Nummulites* cf. *N. atacicus/mamilla*[1] and *Assilina granulosa* var. *spinosa/subspinosa*.

Because *Nummulites mamilla* is though to have been the alternate (haploid) generation of *N. atacicus*, the term *N. atacicus* could refer to both forms. However, the occurrence of one and not the other may be ecologically or environmentally significant. Therefore, in this paper, references to both the diploid and haploid forms of a foraminifer will follow the format "Genus microspheric form/presumed megalospheric form". Otherwise, only the form mentioned is intended.

Unit E-3, 16 m of shale with argillaceous limestone and calcareous siltstone, represents a slight increase in both limestone and fossils. Most of the limesones are dark and pyritic. The beds vary from laminated to bioturbated. Fossils, mostly foraminifera and small pelecypods, are a lesser component of the rock. Foraminifera include small megalospheric *Assilina leymeriei* and *A. subdaviesi* and a disproportionately small number of the corresponding, large, microspheric forms *A. granulosa* and *A. daviesi*. *Nummulites atacicus/mamilla* is present. Fishbones and a fish tooth were also found. Fossils are both fragmentary and whole, but none have been bored and the fragments seem to represent the same population as the whole ones.

Unit E-4 includes a very distinctive lenticular to wavy-bedded limestone that was identifiable in all outcrops in the Kamroti and Nikkial area. Small-scale crossbedding is evident in the lenses and beds. The limestones are silty and organic micrites with mollusc fragments, complete, single-valve, and fragmentary ostracodes, echinoid spines, and a small *Cushmanella* – or *Lamarckina*-like rotalid foraminifer.

Unit E-5 is a 3.25 m limestone and shale sequence that grades from unit E-4 into the overlying oyster beds. The topmost meter has thin oyster-shell-rich layers, one of which contains an abundance of thick and 5 cm long echinoid spines. Some beds seem traceable for at least 1.5 km. The formainifera are primarily *Assilina: Assilina granulosa* var. *spinosa/A. leymeriei* var. *subspinosa*, *A. laminosa/sublaminosa*, and possible *A. dandotica*. Also observed were rare *Operculina sp., Lockhartia hunti* var. *pustulosa*, and *Nummulites mamilla*. All the *Assilina* species are heavily granulated as illustrated by Singh (1970): Gill (1953, p. 84) suggests that the more spiny or granulated varieties of *A. granulosa* (varieties spinosa and *subspinosa*) are found in limestones, whereas smoothness typifies shales.

Unit F: Oyster Bank

Unit F is a 2 m bed of oyster limestone that is recognizable in all Kotli outcrops. The oyster shells are very small fragments at base and increase in size to the top, where the oysters are whole and unbroken. The shell fragments are heavily bored (as much as 70% of a shell may have been removed). Most boring seems to have been done by sponges to produce tiny bulbous living chambers, and both sides of the shells are bored equally. The limestone is essentially a coquina with a matrix of clayey micrite.

Unit G: Nummulitic Limestone

Unit G is a 0.4 m shaly nummulitic limestone. This facies is not prominently exposed, but it is present stratigraphically above (i.e. shoreward of) the oyster limestone in most sections. It is packed with small megalospheric *Nummulites mamilla*. The corresponding microspheric from, *N.* of. *atacicus* is almost entirely absent, and those few that are present are very young. The rest of the unit is light to medium grey shale.

Unit H: Sandstones and Claystones

Unit H is a 10 m layer of clastics, comprising 30 to 50 cm thick and laterally variable shales, siltstones, and clean fine sandstones, all between two regionally extensive, prominent, ledge-forming 1 m thick, massive, and very well sorted fine sandstones. The massive beds are light brown in color and contain a very little calcite and clay and rare pelecypod fragments. They are completely bioturbated. More shaly beds are less bioturbated and individual burrows can be seen. Two impersistent 35 cm beds of greenish sandstone with small coal clasts contain bone concentrations, mostly of fish, and some large marcasite nodules. The top of the upper ledge-forming sandstone passes up into green shale through some 70 cm of light tan soft sandy shale.

Unit I: Green Shale

The marine section is capped by 0.5 to 6.8 m of plain olive-green shales. Near Kamroti the unit is 5.75 m thick and contains several fossil beds. On the east wall of the ravine heading south of Kamroti a narrow 10-cm-thick lens of silt, clay, small intraclasts, and small bones and teeth of fish and mammals occurs less than 1 m below the top of the green shales. Mammals include rodents, small artiodactyls, and a perissodacty. Turtles, crocodiles, and one or two species of small and high-spired snails are also represented. An almost idential deposit has been found on the mountain spur descending northeast of Nikial, and similar but smaller lenses without mammalian fossils are found near the top of the green shales in other areas.

Fragmentary turtle remains, small-to medium-sized mammalian bones such as phalanges, metapodials, and vertebrae, and a few teeth of *Pilgrimella* and at least one other large mammal were found scattered over two otherwise unremarkable horizons in the green shales 1.2 and 1.4 m below the transitional purple shales in Batala Nala, 1 km north of Kamroti. (See Wells and Gingerich, 1983, West, 1983, and Sahni and Khare, 1973 for more information about *Pilgrimella.*) The bones seem to have been oriented, for the ten bones that are more than 2.5 times longer than wide showed an average N75°W-S75°E orientation (standard deviation = 27°). The fossils do not touch each other and are in no way part of a lens of coarse material.

Unit J: Transitional Purple Clay

Unit J comprises a transitional, mostly purple, variegated clay zone between the top of the green clays and the base of the Murree Formation, which is in many places marked by a fluvial pebbly sandstone with clay intraclasts, soil nodules, bone fragments, and some reworked foraminifera. The transition is of variable thickness: 2.4, 3.0, 3.05, and 9 m in four localities. The base of the transition is in most areas a clay-clay boundary marked by an abrupt but irregular colour change from olive green to some shade of purple or blue-purple. The clay then changes gradually upward through red-purple to red-brown. Where the section is not interrupted by a sandstone, the clay shows a gradual colour shift into colours typical of the Murree Formation.

The basal purple clays seem mineralogically and texturally like those below, but in addition to their color differences they also differ in being thoroughly bioturbated in showing green root traces and reduction spheres, and in having soil nodules, highly irregular colouring, other pedogenic features, and some furrows and fissures that are filled with red clay from above. Locally, burrowing has introduced purple clay into the underlying olive-green shale.

The fauna of unit J includes some rare and isolated rodent and perissodactyl teeth, turtle fragments, and the freshwater snail *Planorbis.* On Kihman Hill, west of Kamroti on the Kotli road, 27 medium-sized (5-10 cm long) bones were found in a layer just above the base of the purple shales. According to field identifications by Dr. D. Russell, the bones included vertebrae, bits of a femur, a large astragalus, various other foot and hand bones, and a rib. Smaller wrist and ankle bones, a probable *Pilgrimella* premolar, and a lower right P4 of Kalakotia simplicidentata were found at approximately the same level about a hundred meters away. Isolated bones and teeth have also been found in unit J at Kamroti and Batala Nala. Wadia (1928) reports a seemingly nearly identical "ossiferous pseudoconglomerate" with chelonian and mammalian bones from the basal purple shales at Nikial. (Paleontologists of the University of Michigan and the Museum National d'Histoire Naturelle of France received permission to visit Wadia's sections in 1981, but they were unable to rediscover his fossil bed.)

Murree Formation

The Murree Formation comprises about 1500 to 2500 m of thickly interbedded reddened fluvial sandstones and floodplain muds. Wherever evident, crossbedding indicates flow essentially from the north, which is to say from the Himalayas, not from the Indian craton as incomprehensibly reported in many early geological accounts. The Murree beds in Azad Kashmir appear to be completely conformable with the underlying Subathu beds. The base of the Murree Formation must actually occur somewhere in Unit J, but because there is no clear break between red Murree shales and reddened Subathu shales, the base of the Murree can for convenience be drawn at the first sandstone above the highest non-red marine Subathu shale. The basal Murree sandstones contain reworked Eocene foraminifera and abundant pebbles of low-grade muscovite-chlorite-quartz-feldspar schists, which are not found in underlying Subathu sandstones.

INTERPRETATIONS OF DEPOSITIONAL ENVIRONMENTS

Shorelines must clearly once have been present at the top and bottom of the Subathu, because the bauxite and the Murree Formation and terrestrial, so it appears that the marine Subathu section is a single complete transgressive-regressive cycle.

Insofar as the bauxites are terrestrial and even the lowest arenites are marine, unit C should contain a shoreline, but none is apparent. The sandstones, being thin and interbedded with shales, are not particularly beach-like. Presumably, the shoreline deposits were either cannibalized during the transgression or they were very muddy, mucky and indistinct. The coal could either represent high spots, such as coastal, on-shore, swamp deposits between sandy inlets, or low spots between sand bars that collect drifting and waterlogged vegetation, depending on whether the coal turns out to be marine drift coal or *in situ* freshwater coal. The combination at Tattapani of relatively rich coal and what is either a topographically caused absence of bauxite or the local downcutting of a narrow coarse sandstone through the bauxite and kaolinite suggests local fluvial and coal swamp conditions. Unit C shales are therefore probably mostly sub-beach shoreline accumulations of organic rich muds along a low-energy, muddy, flat and well-vegetated coast, possibly with broad low hillocks of Jammu

Limestone inland.

In Unit D, the very muddy coast becomes a very muddy offshore zone. The abundance of shale and organic debris and the general absence of fossils and limestone suggest rapid sedimentation in relatively near-shore, turbid, and low-energy, but not necessarily deep, water. The mud appears to have limited the fauna despite local abundance of organic debris. The coal and mudcracked shale probably indicate the local formation of an emergent and vegetated muddy shoal or island. The occurrence of the mudcracked shale in the middle of unit C without other signs of shoaling, enclosing concentrations of beach sand, or the like further indicates low-energy conditions. The coal was seen in other sections by Ashraf and others (1986): if the coal outcrops form a continuous layer they would indicate either progradation of the coastline during a temporary stillstand or a temporary reversal of the general transgression.

The overall increase in limestone and fossils seen beginning with unit E is probably due to an overall (but fluctuating) decrease in turbidity of the water and consequently lower rates of clastic sedimentation. The similarity of the faunas of whole and fragmented fossils in Unit E-3 argues for an *in situ* population, but the lack of borings in those fossils, which argues for rapid silting, and the general sparsity and low diversity of the fossils all together suggest a rather inhospitable sea floor. The increased benthic fauna in E-4 and E-5 indicates increasing habitability. E-4's distinctive lenticular bedding results when ripple-forming currents can not scavenge enough sand-size material in a muddy environment to form a rippled sand sheet (Reineck & Singh, 1980, p. 113 ff.).

For unit F, one can deduce that sedimentation was slow, to allow time for the very extensive boring of the oyster shells. One can also conclude that wave energy was low, because very fragile bored shells and shell fragments have been preserved, and the little allochthonous sediment present is clay-sized. However, some shells are broken, shell fragments must have been turned occasionally to allow boring on both sides, and the upward coarsening implies at least a minimal energy gradient, so wave energy was not non-existent. The bed presumably represents the slow progradation of an oyster bank over its debris that had been winnowed seaward.

The abrupt change into the foraminiferal fauna in the unit G limestone above may indicate a less stable and/or less hospitable environment, for all *Assilina*, all *Operculina* and nearly all microspheric *Nummulites*, except for a few young ones, are excluded. The nummulitic beds can not be explained by selective concentration or winnowing of units E or F. Of the material in E and F, oyster shells and fragments span the size range of *N. mamilla*, the microspheric *Assillina* are larger and the megalospheric ones are the same size, and one or another of these would have been left behind or moved in with the *Nummulites*, depending on the manner of concentration. Therefore, G is interpreted as an unusual *in situ* community. The oyster bank could have been a positive feature and in quiet water it may have been a partial barrier to water movement, but unrelated salinity gradients (increasing or decreasing toward shore), increased environmental instability, or vegetational change could also adequately explain faunal restriction. The youthfulness of the few microspheric *Nummulites* present suggests that it was difficult to become a large old nummulite in this environment. On its own, the rarity of large tests might indicate that conditions were very good and favored early reproduction and/or asexual reproduction (see Wells, 1986; Hallock, 1985, Leutenegger, 1977), but the absence of other rotalines belies this.

The clean fine quartz sandstones and siltstones of unit H do, however, seem to indicate some sort of effective physical barrier or bar. They have been largely winnowed of clay and they separate organic-rich foraminiferal grey beds from unfossiliferous and organic-free but still reduced olive-green shales. The complete bioturbation of at least two beds thicker than a meter suggests slow net sedimentation, even on the bar. The absence of pedogenic features or red staining suggests that the bar may never have been significantly emergent. It might be possible to equate this with a distributary mouth bar off a delta or deltaic sands reworked into a post-abandonment delta-margin island sand, considering its moderate to high sorting, extensive bioturbation, and enclosure in clays.

The green clays of unit I are quiet-water deposits, logically lagoonal or bay muds that accumulated behind the sand bars of unit H. The fossil beds in the green clay apparently indicate upward shoaling of the green clay floor into the surf zone, which was evidently quite gentle. The mud pellet and fish bone lenses could have accumulated, been spread out in a lens, and been winnowed by the continual passage of waves over a depositional high spot. Appropriate sites of preferred deposition may have occurred at the confluence of two opposing currents or wave patterns or where a rip current died. The fossil bed at Batala Nala, in contrast, is more probably a lag, scavenged by the removal of a thickness of clay. The way the bones are scattered along specific horizons does not point to a bringing together of material so much as an exhumation and reorientation of unassociated rare coarse debris without otherwise moving or collecting it, in the manner of the formation of a desert pavement or hamada by deflation by wind.

Bioturbation of the shales and abundant rootlet mottling at the base of unit J probably represent a marshy shore at the back of a lagoon. The mammalian fossils, all terrestrial, in unit I demonstrate nearness to the shore. They might represent bodies flushed from the marsh into the sea. The actual shoreline must have been an almost insignficant emergence of wet mud under, for example, a salt marsh or mangrove swamp, for there is no obvious change in grain size to indicate a shoreline. Neither is there any indication of change in the manner of supply of sediment to correlate with the major change from green to red shale that undoubtedly reflects Eh change related to emergence from the sea and the onset of drainage. (Wells, 1984, found such color changes to be typical of many marine to continental transitions in Eocene strata throughout north-central Pakistan: see also Wells and Gingerich, 1983). The energy of incoming waves, such as they were, must have been almost entirely expended on the offshore sand bars and then finally dissipated in crossing the back-bar lagoon or bay and entering the vegetation. The similarity of later oxidation and pedogenization of mud that was at first deposited in salt water) implies a continual filtering of mud across the shoreline (through the marsh or swamp) and into the back of the bay without changes in its texture. The net movement of sediment from the land to the sea is shown by the presence of terrestrial mammals in the green shales, and the presence of turtles and freshwater snails in the transitional zone below fluvial sandstones supports the idea that at least some of the transitional section was originally deposited in fresh water.

Apparently similar fossil beds in an equivalent stratigraphic position have been reported 15 km along strike in India, in the Kalakot area (Ranga Rao, 1971, 1973; Sahni and Khare, 1971, 1973; Karunakaran and Ranga Rao, 1976; Sahni and Srivastava, 1976; Russell and Zhai, 1987). Note that Sahni and his colleagues place the J facies in the Subathu Formation, but that Ranga Rao refers the unit to the "Kalakot Zone" of the Murree Formation. Some comments on their taphonomy have been made by Ranga Rao (1972), Khan (1973), and Sahni and others (1981, 1983), but relatively little is known as yet. Ranga Rao (1972) notes that the fossils are very well preserved; were buried at different rates but with little transportation; include many more jaws than postcranial bones; represent a disproportionate number of juveniles; and indicate that tapiroids and artiodactyls lived in different areas. The action of soil acids can account for the selective preservation of relatively dense and massive jaw bones and enamelled teeth. The lack of transportation of fossils, their variable burial rates, the apparent extensiveness of the bone layers, and extensive soil formation together suggest that these bone layers may represent concentration in soil horizons by virtue of episodic but overall extremely slow sedimentation.

Overall, the deepest water, the switch-point from transgression to regression, may have occurred between the top of unit D or E-2 and the base of E-4, for D (or E-2) represents the limits of influence of shoreline muds, whereas the lenticular limestones at the base of unit E-4 represent occasionally or lightly felt wave action and precede more coastal deposits. Note, however, that cessation of mud deposition might be a factor of geography or supply processes rather than distance. The sporadic occurrence of foraminifera and limestones through unit E suggests that occasional excessive turbidity may have been a greater problem for colonization by benthic foraminifera than excessive depths, for depth should be a more stable and therefore inappropriately constant and consistent control. Compared to the transgressive sequence, the regressive sequence appears to have been a little less muddy and of slightly higher energy, given the crossbedding is E-4 and the sorted, though fine, sands in H.

DISCUSSION

Correlation from Kotli to Kalakot

The Kotli Subathu exposures, not surprisingly, correlate very closely with exposures at nearby Kalakot and Riasi to the southeast, in India, (Figure 3). Many of the units of Singh (1973) are readily identifiable: A is theKhargala Chert-Breccia Member and B is the Lain Bauxite Member of the Jangalgali Formation; C and D are the Beragua Formation; and E and perhaps the oyster bed F compose the Kalakot Formation. The rest is presumably equivalent to the Arnas Limestone, for its basal 5-20 m thick Ans Limestone Member is identifiable in the 0.4 m nummulitic bed in G. However, the 4-6 m Chinkah Limestone Member and the 2-5 m Chenab Limestone Member are not comparable with H and I, although they would seem to be equivalent.

These discrepancies show that Kotli and Kalakot-Riasi environments were not always precisely similar. Although the basal bauxite is widespread around Kalakot and Riasi (Wadia, 1928; Sign, 1973), both Sahni and Khare (1973) and Karunakaran and Ranga Rao (1976) depict sections that lack it. Both the amount and grade of coal (up to 7.5 m, but averaging less than a meter) and the amount and type of iron are very variable (Simpson, 1904). Sahni and Khare (1973) state, without presenting evidence, that in their section the coal, lower sandstones, and carbonaceous shales, apparently equal to C and D, are nonmarine, but Sahni and others (1983) indicate the presence of oysters and *Assilina* (*Nummulites*) *dandotica* low in the dark shales near Subathu village. The literature suggests a moderately varied landscape of poorly drained freshwater swamps, better drained higher areas, and brackish to saline muddy lagoons and bays with varying degrees of protection from waves and currents. Such environments were probably largely a result of pre-Subathu topography developed on the Jammu Limestone.

There appear to have been no major lateral changes in the main part of the formation, the marine limestones and shales of D and E. The whole formation generally thickens northwestward (Bhandari and Agarwal, 1966), but this trend is slightly reversed between Kalakot and Kotli. Khare (1976) identified a fossil shark, *Notidanus primigenius*, from the equivalent of E.

In contrast, the upper marine beds show a considerable change from the muddy lagoon or bay deposits of Kotli (units G, H, and I) to the foraminiferal Arnas Limestone across the Indian border. According to Singh (1973), the base is a depauperate nummulitic limestone, like G, with *Cibicides*, *Quinqueloculina*, and *Triloculina*. The succeeding shelly grey Chinkah Limestone Member contains only the latter two foraminifera, and the overlying greenish-grey Chenab Limestone Member is unfossiliferous. The passage shoreward from a normal assemblage upward through a nummulite and miliolid assemblage to a miliolids-only zone, and lastly into a foraminifer-free zone strongly suggests development of abnormal and restricted conditions toward shore.

An upward faunal restriction was also noted in Pakitan, but the fauna involved, its pattern of disappearance, and the associated lithologies are different. Kotli and Kalakot presumably shared the same climates and had much the same E-to-onshore depth ranges. Therefore, temperature and temperature variability should have been similar, except as associated with water movement. The most likely environmental problems are therefore salinity, turbidity, vegetation, and perhaps predation (Hottinger, 1982, 1983; Hallock and Glenn, 1986). Miliolid-only faunas have frequently been observed near Eocene evaporitic beds in the Kohat District in north-central Pakistan, suggesting their association with moderate hypersalinity (Wells, 1984, 1986). From the excess of clays and the paucity of miliolids at Kotli, it seems likely that G, H, and I were too brackish and perhaps too turbid for miliolids and other forams, perhaps because the area was on or too close to a delta, with the water becoming fresher and muddier toward shore. The Indian area was more likely a slightly hypersaline, protected or very gradually sloping, lower-energy coast, with limited influx of freshwater and clay from onshore and of normal sea water and clay from offshore.

By all accounts, the transitional shale of J changes little from India to Pakistan, so presumably soil-forming factors such as climate, vegetation, parent material, and drainage were similar in both areas. Mammals, freshwater snails, crodiles, and turtles have been recorded at many localities and a freshwater to possibly brackish fish fauna has been indentified in India (Wadia, 1928; Sahni and Khare, 1973; Karunakaran and Ranga Rao, 1976; Khan 1976; Khare, 1976; Sahni and others, 1981, 1983).

Age of Subathu Formation in Kashmir and Azad Kashmir

The age of the Kotli-Kalakot Subathu Formation is somewhat uncertain. Despite occasional reports of middle Eocene foraminifera (Ranga Rao, 1971), the most detailed work on the foraminifera produced none that were not predominantly early Eocene (Singh, 1970, 1973). Work on the Kotli foraminifera supports this conclusion, as does analysis of the ostracodes by Tewari and Singh (1966). However, this conclusion is only binding on unit E (the Kalakot Formation) because of the distribution of fossils.

Only one foraminifer, the early and middle Eocene *Nummulites atacicus/mamilla*, is present in unit G, the Ans Member. Singh (1973) considers this proof of a middle Eocene age for the whole Arnas Formation (units G, H, and I), because none of the other foraminifera in unit E below has an age range that extends into the middle Eocene. However, no other middle Eocene foraminifera are present either, and the presence of only one kind of large benthic foraminifera is easily interpreted as a result of local environmental conditions.

Units A and B have produced no definitive fossils. Singh (1973, fig. 4) includes them in the early Eocene, whereas Sahni and Khare (1973) claim that the breccia is Precambrian. Ashraf and others (1983) wisely exclude the breccia and bauxite from the Paleogene section because their development concluded with burial by Subathu sediments, thus implying no inherent relationship with Cenozoic sediments and an earlier age, possibly much earlier. There is no stratigraphical, paleontological or lithological basis for identifying them as Datta Formation (Jurassic, Salt Range), as has been informally suggested.

We found no definitive fossils in units C and D. Singh (1973) placed the Beragua Formation (C and much of D) in the early Eocene, whereas Sahni and Khare (1973) suggested a Thanetian (late Paleocene) age. Ashraf and others (1983) report "*Assilina*, *Lockhartia*, *Discocylina*, etc." and infer a Paleocene age. However, without specific identifications such a fauna could be early Eocene (Nagappa, 1959). Sahni and others (1983) report *Assilina dandotica*, which is according to Nagappa (1959) and others the only Paleocene *Assilina*, apparently from unit C. However, Sahni and others (1983) also note an unconfirmed report of the existence of an early Eocene *dandotica.* At present, the bauxite is probably best dated as pre-Eocene and the coaly shales as coincident with any major eustatic rise or tectonic change locally identifiable near the start of the Eocene.

. The transition zone J should eventually be exactly datable by vertebrate fossils (see Russell and Zhai, 1987). Some workers place it at the top of the Subathu Formation (Sahni and Khare, 1971, 1973) whereas others have included it in the Murree Formation (Bhandari and Agarwal, 1966, p. 62; Singh, 1970, 1973; Ranga Rao, 1971a, 1972; Khan 1973), but all identify it as essentially transitional or terrestrial yet coastal (following Bhatia and Mathur, 1965). Sahni and Srivastava (1977) now consider it to be middle Eocene (Lutetian) on the basis of its rodents. Ranga Rao, on the other hand, dates the same beds as early late Eocene because he identified middle or even upper Eocene foraminifera in the marine beds below and because he considers that the mammalian fauna is 1) younger than the middle Eocene Ganda Kas (Chharat) fauna of Pakistan, 2) older than the latest Eocene Pondaung fauna of Burma, and 3) probably older than the late middle to early late Eocene Irdin Manha fauna of Mongolia. Neither set of arguments is clearly superior: our mammalian fossils from units I and J all seem identical to species known from Indian Subathu sites and suggest to us a possibly latest early Eocene and/or middle Eocene age. Unit J seems to be a perfectly transitional link between the underlying unoxidized green shales and the overlying red shales and sandstones of the Murree Formation. The lowest Murree sandstones contain evidence of recent uplift (their reworked Eocene foraminifera and pebbles of low grade schist), and they also represent a reversal of the paleoslope from a northward slope to a southward one. However in the Kotli area, these changes are not represented by an angular unconformity or even an obvious erosional break. Proposed ages for the Murree Formation, which is very poorly dated here, range from Eocene to Miocene, so J may be a considerably condensed section or it may even contain a cryptic shale-on-shale paraconformity. Retreat of the sea from this area seems likely to be part of complete and more or less synchronous withdrawal of the seas from northern Pakistan: in the Kohat district to the west, at least, maximum regression is marked by deposition of the terrestrial lower part of the Kuldana Formation, which is dated as latest early Eocene and/or earliest middle Eocene (Gingerich and others, 1983; Wells, 1983, 1984). It seems best to conclude that the marine part of the section is entirely or almost entirely early Eocene in age and that unit J is possibly not.

Correlation across the Hazara-Kashmir Syntaxis into Pakistan

The exposures in the Hazara Hills between Islamabad and Murree, those at Muzaffarabad, and the parautochthonous ones between the Murree and Panjal thrusts from north of Punch to southeast of Dalhousie have long been referred to as the "Hazara facies" of the Subathu Formation and have been broadly split into the "Hill Limestone" and the overlying "Variegated Beds" (Pinfold, 1918; Pascoe, 1964). All have been brought closer to the Kotli area by thrusting.

Hazara Hills: The Hazara section north of Murree is the most studied of the "Hazara facies" outcrops (Lydekker, 1883, p. 93 ff.; Middlemiss, 1896; Latif, 1970 a & b, 1976). However, sections near Murree are much faulted and they are difficult to study.

Latif named the Hazaran Subathu facies as the Galis Group, which he subdivided into 1) variegated sandstone, lateritic limonite, pisolitic hematite, coaly shales, and coal, under fetid and well-bedded to massive limestones with mid-Paleocene foraminifera (the Mari Limestone); 2) late Paleocene open-marine shales (Kuzagali Shale); 3) dark grey, nodular to massive limestones with early Eocene foraminifera including *Assilina laminosa, Nummulites atacicus,* and *Alveolina elliptica* (the Margala Hill Limestone); 4) thinly bedded light grey marls and limestones with early Eocene foraminifera *Assilina daviesi, Globigerina prolata* and *G. yeguanesis* (Lora Formation); and 5) the Kuldana Formation. Near Murree town, the Kuldana Formation comprises 300 m of interbedded continental red beds, fluvial granulestones, "transitional" coastal-plain and marsh variegated purple shales, off-red pedogenized freshwater and saline-lacustrine marls and limestones, formerly evaporitic beds and lenses, and olive marine shales with lenticular foraminiferal limestones (Wells, 1984). Latif identified late early Eocene foraminifera and earliest middle Eocene foraminifera from the Kuldana Formation.

Latif's basal four units are the old "Hill Limestone". In keeping with recent trends to consolidate stratigraphic names in Pakistan, Latif (1976) and Shah (1977) have subsumed the Mari Limestone into both the Hangu Sandstone and the Lockhart Limestone (from the Samana Range, SW of Peshawar), the Kuzagali Shale into the Patala Shale (from the Salt Range), and the Lora Formation into the Chorgali Formation (from the Khair-e-Murat Range), and kept the Margala Hill Limestone and the Kuldana Formation.

Muzaffarabad: The outcrops at Muzaffarabad, referred to by Calkins and others (1975) as the Kala Chitta Group, comprise a basal unit of quartzose sandstone, coal-bearing cabonaceous shale, and/or pisolitic bauxite in kaolinite shale, followed by 50 to 600 m of grey to green shales and grey and locally foraminiferal nodular limestones, and an overlying 20 to 600 m "transitional zone" of marls alternating with red and green shales (Calkins and others, 1975). The basal unit is essentially identical to units A, B, and C at Kotli, and it is developed on locally stromatolitic but otherwise unfossiliferous Jammu-Limestone-like carbonates that Calkins and others identify as probably late Paleozoic Kingriali Formation.

The lower limestone and shale section (the "Hill Limestone") was measured by Wells in 1981 in a section along the Muzaffarabad-Neelum Valley road. This section is shown in Figure 4, although its scale has been arbitrarily reduced by one-third relative to the other sections to indicate uncertainty over true thickness and possible cryptic structural duplication. Despite the complex folding and faulting in the Muzaffarabad area, this section apparently shows extensive depositional interbedding of Margala Hill Limestone facies, Lora-Formation-like facies and shales like the Kuzagali Shale. Latif (1970a) mapped all such repetitions of units in the Murree area as the result of faulting and folding, but at least some, if not most, of the repetition in the Neelum Valley section seems due to primary interbedding. By analogy, this suggests that the succession of formations seen by Latif may have been an underestimate of more complex interbedding of facies types.

The proof of the interbedding of "formations" despite the probability of some structural repetition is that some of the possible repeats contain foraminifera of different ages. According to our foraminiferal studies, the lower 150 m or so of the section is Paleocene, as it contains *Operculina salsa/subsalsa* up to that level, in addition to *Lepidocyclina punjabica, Lockhartia haimei, Discocyclina*, and *Miscellanea miscella.* There is then an unfossiliferous 50-m shale, followed by an apparently Eocene limestone, with *Lockhartia haimei* and fragments of probable *Nummulites* and *Assilina.* At 259 m above the base, there are undoubtable, complete, lower Eocene *Nummulites atacicus, Assilina granulosa*, and *Alveolina.* The upper part shows interbedding of red beds (including thick green sandstones and minor freshwater micrites) with marine limestones, shales, and oyster beds, which are of middle Eocene age. The first red bed occurs at 341.5 m, and the succeeding green shale and limestone contain middle Eocene *Nummulites* cf. *uronensis, N.* cf. *pinfoldi, Assilina granulosa, A. umbilicata*, and *A.* cf. *papillata.* In short, then, given the nature of the section and the degree of local deformation, the thicknesses have a low probability of being correct, but the samples clearly indicate Paleocene through middle Eocene marine deposition.

Parautochthonous zone: The beds in the parautochthonous zone between the Murree and Panjal Faults, locally known as the Rajpur Formation, comprise just less than 300 m of brilliantly colored, unfossiliferous, variegated red, purple, and green shales with minor sandstones and limestones above 100 to 150 m of thick, dark grey, fetid, and foraminiferal limestones and shales with *Nummulites, Assilina, Alveolina, Operculina,* and *Ostrea* (Lydekker, 1883; Wadia, 1928, p. 258 ff.; Karunakaran and Ranga Rao, 1976, p. 6 & 17). The upper beds, as Wadia noted, are clearly like the type Lower Chharat (= Kuldana) in the southwest of the Hazara Range and the Kuldana beds near Murree in the southeast.

Beds almost identical to the Rajpur Formation crop out just in front of the Murree Fault, SE of Punch, as described by Wadia (1928). This constitutes the first Subathu-equivalent exposure northwest of Kotli. Wadia (1928, p. 265-268) named the beds the Jokan Limestone, but in describing them he apparently misinterpreted their age and structure (Karunakaran and Ranga Rao, 1976). The incompletely exposed sequence consists of a lower 100 m of olive-green shales and mostly lenticular foraminiferal limestones, and an upper 150 m of unfossiliferous thick red marly shales with intercalated thin green shales with oysters. The lower unit also contains minor red clays and greenish-grey fine sandstones and one 5-m thick non-lenticular limestone. The foraminifera in the highest limestones include *Assilina granulosa* var. *spinosa, A. daviesi*, and *Orbitolites complanatus*, and thus correlate with both the Kotli and type sections of the Subathu Formation (Karunakaran and Ranga Rao, 1976). Cotter (in Wadia, 1928) identified upper Eocene fossils from the same beds, but they may have been early to middle Eocene *Nummulites atacicus/mamilla.* In many respects, the upper part seems to be a multiple repetition of the Kotli facies F through J, whereas the lower unit is closer to facies D and E.

In short, the Hazara facies are divisible into a lower, more offshore, dark shale and fetid limestone section, and an upper section of intercalated shallow-water nearshore and on-shore green shales and variegated red beds. The Jokan Limestone/Rajpur Formation exposures link the bipartite Hazara facies to the essentially unipartite and essentially lower Eocene marine Subathu at Kotli with its single, essentially non-fluctuating, and conclusive regression. In turn, the Hazara facies are nicely linked to the Kohat Basin strata by way of facies exposed in the Kala Chitta hills (Wells, 1984; Figure 4). The Kotli section can be thought of as composed primarily of Hazaran "Hill Limestone" facies. Note, however, that the sections in the Kohat basin, and, to a lesser extent, those in the Kala Chitta hills and at Muzaffarabad, show a return of marine deposition after complete regression at the end of the early Eocene (Wells, 1984), whereas the Kotli section, like those in the Salt Range, shows only the single, unrepeated, transgression and regression.

Lastly, there are significant affinities between the Subathu Formation at Kotli and the Chorgali Formation in its type section in the Khair-e-Murat Range in the centre of the Potwar Plateau. The Chorgali Formation is also recognizable at the top of the lower Eocene in the Kala Chitta hills to the north and above the Sakesar Limestone in the Salt Range. Briefly, the type section of the Chorgali Formation comprises five main facies:

Although the apparent energy level of deposition decreases from the base of the section up to the 60 m thick shales, upward shallowing and an increase in salinity toward shore are indicated by the changing lithologies and faunas. From the base, these changes are: *Nummulites* in pelspari-

. . . . Top of section at Chorgali Pass . . . .

3 m	Pedogenized, variegated yellow, purple, red and white marls with rootlet traces and "craze-plane" microcracks (Brewer, 1964), which used to be ostracodal micrites and shales;
2.2 m	Locally silicified, marine, miliolid and ostracodal pelsparites grading up into partly silicified, formerly pelletal, pedogenized (dewatered, nodularized, and microcracked), possibly saline-lacustrine, ostracodal and gastropodal micrites;
60 m	Olive shales with rare layers of small nodules of silty ostracodal biomicrites and pelmicrites with mostly dissolved mollusc and echinoid fragments, locally capped by 2 m of purple-stained shale;
58 m	Essentially unfossiliferous but in places bioturbated marly to dolomitic light brown siltstones, with possible algal beds with very tiny miliolids at base and a thin rootlet-ridden limestone of oolitically coated intraclasts in the middle, that overall grade upward from 10% to 80% light olive grey shale; and
13 m	Shallow-water and upward-shoaling nummulitic limestones, *Assilina* dolomitized limestones, and silty ostracodal and/or *Lockhartia* dolomicrites, with *N. atacicus/mamilla, A. laminosa/sublaminosa, Lockhartia conditi,* an intermediate between *L. tipperti* and *L. haimei (=L. hunti* var. *pustulosa), Orbitolites complanatus, Discocyclina* of. *douvillei,* a small *Alveolina,* and small benthic forams such as bulimulids and *Nonion.* [NB: the basal 5 m may be definable as Margala Hill Limestone.]

. . . . Base of section at Chorgali Pass . . . .

tes; *Assilina* in partly dolomitized wackestones and packstones; *Lockhartia* and ostracodes in silty dolomicrite; and milioid-only shales. Dolomitization seems to have been relatively early in the *Lockhartia* beds, for it followed most bioturbation, but it is cut by and thus apparently preceded a late phase of mostly vertical burrows.

Insofar as the Chorgali Formation both comprises nearshore deposits of early Eocene age with a Kotli-like fauna of benthic foraminifera and shows a single regression late in the early Eocene that left the the land dry during middle Eocene fluctuations of the shoreline to the north and to the west, the Khair-e-Murat Chorgali exposures have an equivalent paleogeographic history to the Kotli exposures. The Khair-e-Murat section could be thought of as primarily H and I facies, expanded 5 to 10 times, over a slightly shallower-water, less reducing, and slightly dolomitized G – or E5-like limestone, and under a complex but partly J-like pedogenized zone. This suggests a lack of major changes in the coastline around or across the Hazara-Kashmir syntaxis.

Because there is a thin string of Subathu-age outcrops all the way across northern India (see Wells, 1984, fig. 6.5) and because they are composed mostly of nearshore deposits (Wells, p. 320-328), there is a tendency to think of the string as more or less parallel to the Subathu shoreline. However, the outcrops are produced by the frontmost two or three Himalayan thrust faults. There are a few outcrops in Nepal that are not dissimilar to the Muzaffarabad exposures (e.g. Tewari and Gupta, 1976), except that the would-be belt of exposures in that sector of the Himalayas tends to be hidden by overthrusts. One can make the hypothesis that exposures can be ranked in order of nearness to the shoreline by the thickness of Paleocene strata overlying the basal weathered zone: ca. 150 m at Muzaffarabad; 2-25 m or so at Kotli, 0 or 8 m at Subathu village (Mathur, 1969; Wells, 1984, p. 324). At first glance, this agrees broadly with the overall thickness of the marine section, and future data on the exactness of the agreement across northern India may tell us whether inundation and/or tilting were uniform along the subcontinent's leading edge. Note that the basal Subathu beds mark the southern shore of the Subathu sea (as shown by the absence of Subathu facies in deep boreholes just south of the outcrop belt in northern India (Bhandari and Agarwal, 1966), but, as mentioned, the base of the Murree Formation and its equivalents marks the arrival of Himalayan molasse from the north: this is the evidence for the aforementioned reversal of the Subathu paleoslope. A gentle slope reversal could account for the total or near total lack of sedimentation occuring in unit J, between Subathu and Murree beds.

OTHER CONSIDERATIONS

Ashraf and others (1983) have named units C and D, and possibly part of E, as Patala Formation and higher units as Margala Hill Limestone. In one sense, this may seem to fit with equating the Chorgali Formation with units H, I and J. However, the authors are not in agreement with such a nomenclature. First, we do not know enough to imply so close a correlation. Second, the creeping extension of certain formational names in Pakistan has the bad side effect of obscuring exact age relationship. Third, this practice also obscures lithological diversity and complicates paleogeographic analysis and facies correlations.

The basis for the first complaint is that if there are several limestones and shales at Muzaffarabad, we need to know which and how many are represented in Hazara and in Kotli. With respect to the complaint about obscuring age relationships, there is an all too common tendency to extend a formational name by lithological correlation and simultaneously and groundlessly to assume equivalent chronostratigraphic correlations between the same strata. Early Cenozoic stage boundaries are far from precisely located in most sections in Pakistan and within-stage correlations are necessarily based on concepts of paleogeographic development (e.g., Wells, 1984). This problem can be seen in recent treatment of the Patala Formation. Shah (1977) incorporated the Tarkhobi Shales into the Patala and refers them to the Paleocene, whereas Wells (1984) showed that some upper strata contained early Eocene foraminifera. Similarly, the dating by Ashraf and others (1983) of their Kotli Patala as Paleocene may have been unduly influenced by Patala ages elsewhere.

The third problem is indirect but serious. Formation names are extended to demonstrate and simplify regional correlation, which is quite properly the first order or business in regional stratigraphy. It should also lay the ground work for the next step, which is understanding the details and nuances of the region's geological history, which is to say understanding regional paleogeographic development. If all the strata have been incorporated into giant and far-reaching formations, the first step in paleogeography is dismantling the formations into smaller formations or members and rechecking ages and correlations. By this time, the literature will probably by quite confusing. As preparation for paleogeographic analysis, it would be far better stay as much as is possible and reasonable with initially defined local formations and to aggregate them into groups rather than into each other. Making correlations with other units is very important but it can be done without unification and subsumption of names.

CONCLUSIONS

The Subathu Formation at Kotli consists of:

A) a residual conglomerate of chert clasts and other insoluble material, all almost certainly weathered from the underlying Jammu Limestone;

B) a pre-Eocene bauxitic weathering profile;

C) carbonaceous shales, with thin coal in some places and sandstone in others, covered by

D) thick green unfossiliferous shales, which with C represent mostly sub-beach to turbid and shallow-water accumulations of mud and muck moved offshore by waves and currents from a very low energy, muddy well-vegetated, and swampy coast;

E) dark shales and fetid but mostly fossiliferous limestones that accumulated in slightly higher-energy waters, either when the transgression had moved the turbid coastal zone to the south or when the local supply of clastics ceased;

F) an oyster bank, characterized by slow sedimentation under conditions of just high enough energy to winnow clay;

G) an unusual single-species nummulitic limestone that apparently represents a chemically or thermally inhospitable and/or less stable environment;

H) a submergent, fine-clastic, offshore-bar complex that was highly burrowed and was frequently reworked by waves of low to moderate energy;

I) a brackish back-bar bay or lagoon that trapped mud and animal remains carried out to sea from the marshes along the shore; and

J) on-shore clays, completely pedogenized and apparently representing very slow sedimentation until the earlist Himalayan molasse was swept into the region.

This section correlates very closely with the Indian sections along strike that were described by Singh (1973), except that in India units H and I are replaced by well developed limestones. Units E through G are early Eocene, and C, D, H, I, and lower J may be too, although I an J may very well be middle Eocene.

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A CAMBRIAN UNCONFORMITY REPRESENTED BY GALDANIAN FORMATION IN ABBOTTABAD DISTRICT, N.W.F.P. PAKISTAN

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ABSTRACT:– In abbotabad District Galdanian Formation is formed at the top of Abbotabad Formation. The Upper Abbotabad Formation contains marine phosphorite deposit which laterally changes over to turbidite phosphorite bed associated with Galdanian vareigated beds and to Galdanian continental deposits. It is evident from such lithologies that in Upper Abbotabad times the geological environments were such that deep sea conditions were lacking. However, the continental to shelf environments were dominating. In the deeper shelf conditions normal inorganic precipitation of phosphorite was in progress whereas bauxitization and lateritization was occuring continuously on projections (small islands) above sea level. The intervening zones between continental projections and sea conditions contained reddish to brown red siltstone, brownish red cherty dolomite, reddish cherty siltstone or chertstone and overlain by fine-grained quartzose siltstone.

The present study, therefore, envisages that phosphorite is facies equivalent of Galdanian Formation whereas Hazira Formation is definately younger than both of them and is possibly not related to Galdanian Formation.

INTRODUCTION

Galdanian unconformity is thought to be Cambrian in age as it underlies Hazira Siltstone containing fossils *Hyolithes, Allonia tripodophora, Lapworthella spp.* and *Rushtonia spp* (Fuchs and Mostler, 1972; Latif, 1972). In the earlier studies by Gardezi and Ghazanfar (1965) and Latif (1974), it was thought that Galdanian Formation is part of Hazira and showed that the formation is laterally replaced by the Hazira Formation in the Abbotabad region. Latif (1970) also correlated the Galdanian Formation with the Panjal series of Kashmir. In Geological Survey of Pakistan publication (Shah, 1977) Galdanian is also shown as part of Hazira. Calkins et al. (1975) included Galdanian Formation in Datta Formation of Jurassic age.

The present investigations carried out by the senior author during November 1980 to December 1983 revealed on the basis of detailed geological mapping, aditting and drilling that the following sequence (Fig. 1) is likely for the Cambrian rocks in the Abbotabad area.

(3) Hazira Formation : Siltstone and shale. — Cambrian Formation

(2) Galdanian Formation, lateral facies of Kakul phosphorite. (Unconformable). — –do–

(1) Abbotabad Formation : Dolomite — –do–

This Cambrian unconformity is superimposed by another post-Cretaceous unconformity weathering down to the Abbotabad Formation. The latter unconformity is represented by formation of bauxite/laterite (Ashraf et al. 1980) and can be correlated with a general unconformity before the deposition of Paleocene rocks in many parts of Pakistan. However, the Galdanian formation represents unconformity within Cambrian rocks formations as mentioned above.

GEOLOGY

In order to understand the Galdanian unconformity clearly a brief description of following formations may be necessary they are Upper Abbotabad Formation, Phos-

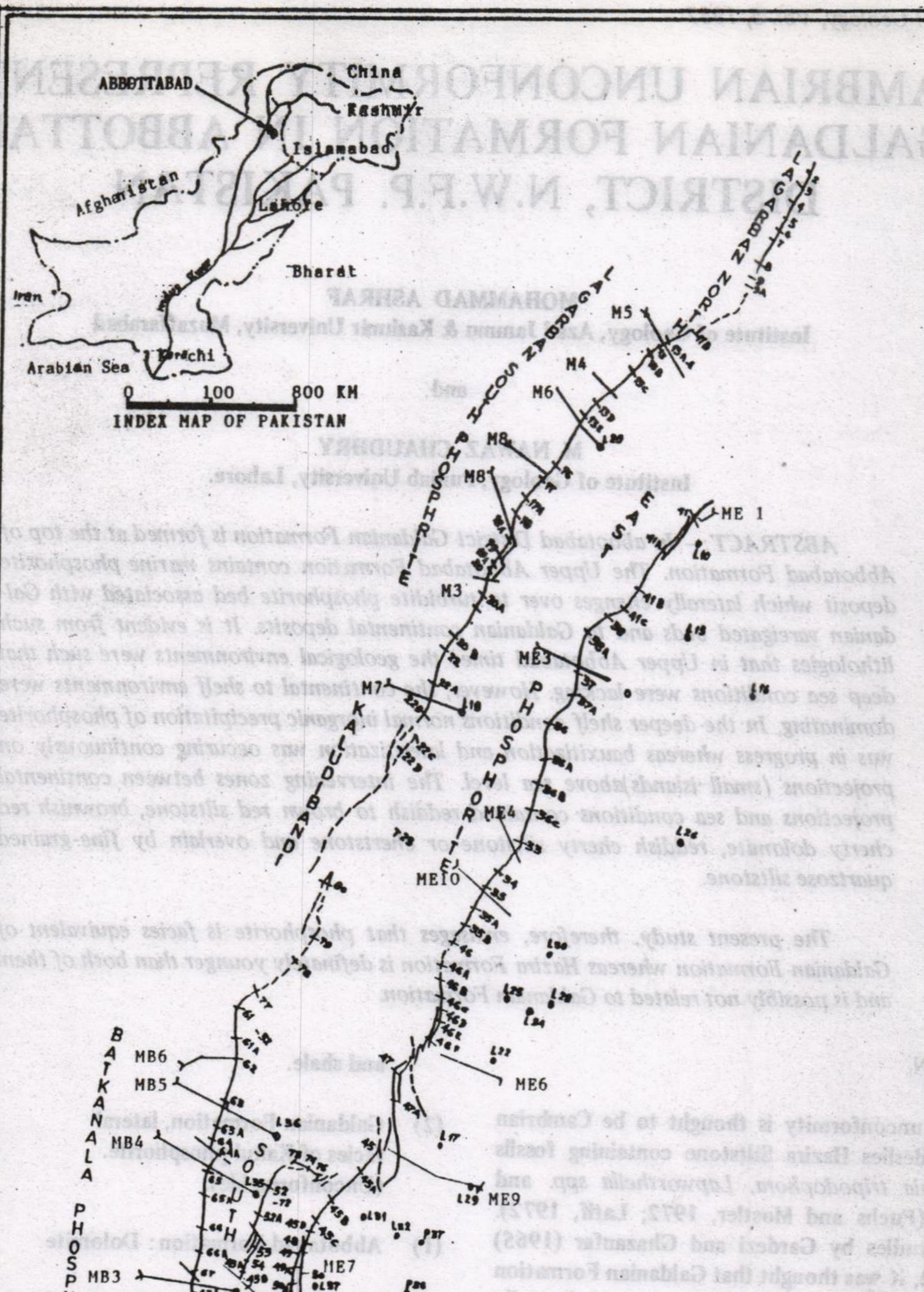

FIG:1 PHOSPHORITE OUTCROPS OF LAGARBAN AREA, ABBOTTABAD.

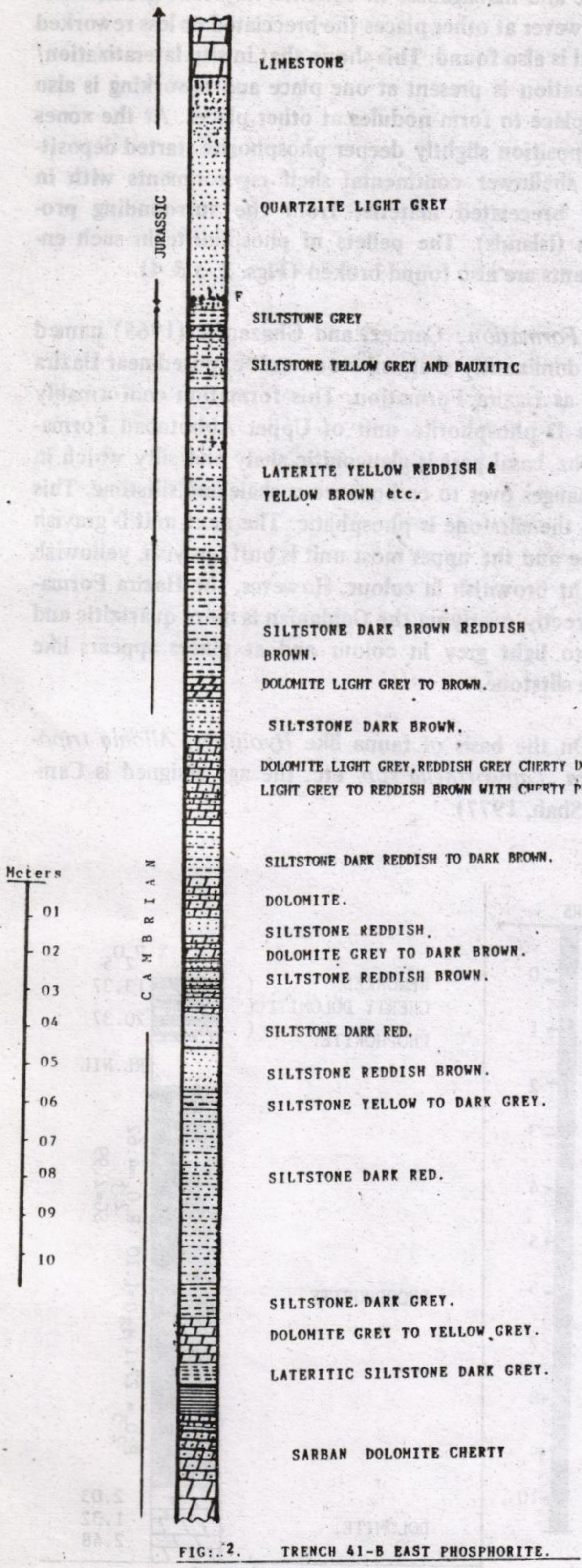

FIG: 2. TRENCH 41-B EAST PHOSPHORITE.

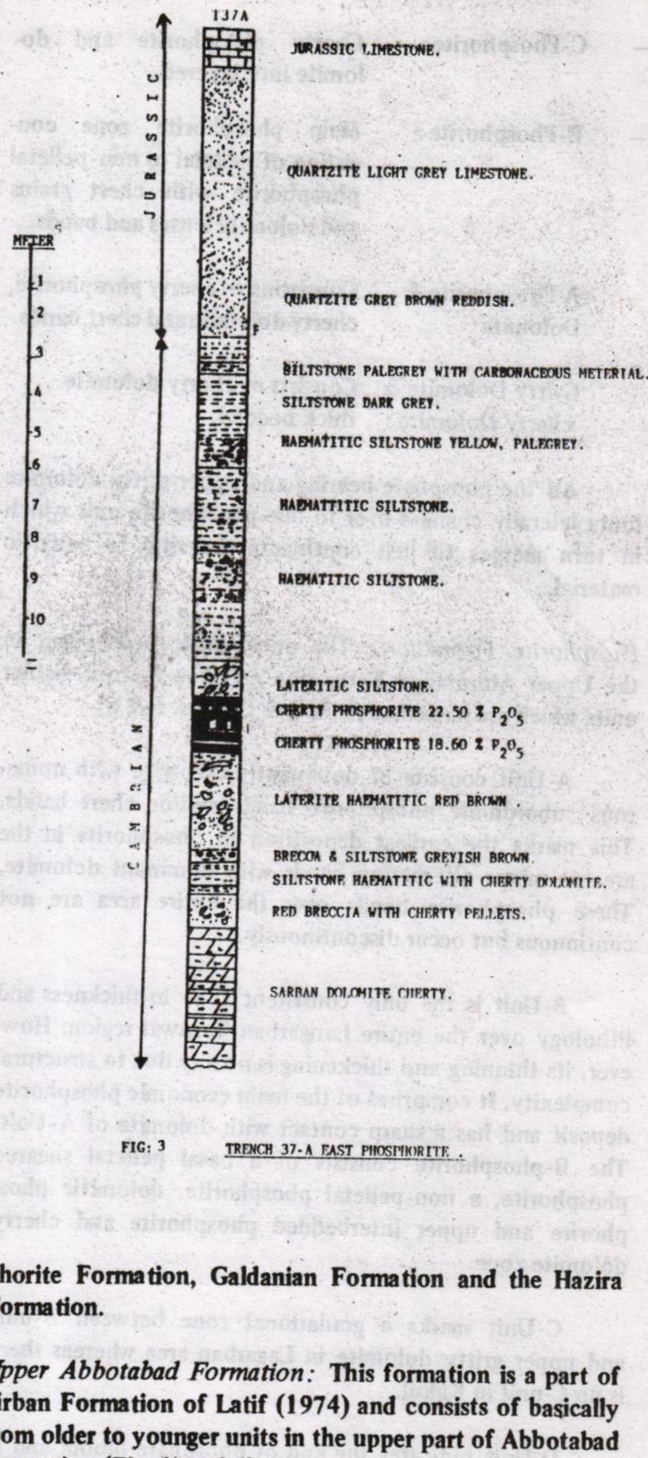

FIG: 3 TRENCH 37-A EAST PHOSPHORITE .

phorite Formation, Galdanian Formation and the Hazira Formation.

Upper Abbotabad Formation: This formation is a part of Sirban Formation of Latif (1974) and consists of basically from older to younger units in the upper part of Abbotabad Formation (Fig. 1) as follows :

– **D-Phosphorite :** Irregularly deposited pelletal phosphorite, overlain by Hazira siltstone.

– **Gritty Dolomite:** With chert grains and chert and cherty dolomite bands.

– **C-Phosphorite:** Cherty phosphorite and dolomite interlayered.

– **B-Phosphorite:** Main phosphorite zone consisting of pelletal to non-pelletal phosphorite with chert grains and dolomite lenses and bands.

– **A Phosphorite & Dolomite:** Consisting of cherty phosphorite, cherty dolomite and chert bands.

– **Gritty Dolomite & cherty Dolomite:** Consists of cherty dolomite thick bedded.

All the phosphate bearing and upper gritty dolomite units laterally changes over to one phosphorite unit which in turn merges to just continental lateritic to bauxitic material.

Phosphorite Formation: The phosphorite beds occur in the Upper Abbotabad Formation as three to four distnct units which are named as A. B, C & D (Figs. 5 & 6)

A-Unit consists of dominantly dolomite with numerous subordinate phosphorite bands and/or chert bands. This marks the earliest deposition of phosphorite in the area as minor alternating bands, with dominant dolomite. These phosphorite bands over the entire area are not continuous but occur discontinously.

B-Unit is the only consistent zone in thickness and lithology over the entire Langarban-Tarnwai region. However, its thinning and thickening is mainly due to structural complexity. It comprises of the main economic phosphorite deposit and has a sharp contact with dolomite of A-Unit. The B-phosphorite consists of a basal pelletal sheared phosphorite, a non-pelletal phosphorite, dolomitic phosphorite and upper interbedded phosphorite and cherty dolomite zone.

C-Unit marks a gradational zone between B-unit and upper gritty dolomite in Lagarban area whereas there is no C-unit in Kakul.

D-Unit indicates the end of phosphate bloom and is overlain by Hazira siltstone conformably. It is not in Kakul and East phosphorite.

Galdanian Formation: It is a distinct unit consisting of haematitic redstone (lateritic), siltstone, bauxite, claystone, chertstone, cherty and quartzitic breccia of verious colours (red, purple, white grey and dark grey colours). At some places the lateritic and bauxitic/claystone alongwith manganese ore show reworking forming nodules of haematite/goethite and managanese in bauxitic/claystone groundmass etc. However at other places the brecciated or less reworked material is also found. This shows that in situ lateratization/bauxitization is present at one place and reworking is also taking place to form nodules at other places. At the zones of redeposition slightly deeper phosphorite started depositing in shallower continental shelf environments with in coming breceiated material from the surrounding projections (islands). The pellets of phosphorite in such environments are also found broken (Figs. 2, 3 & 4).

Hazira Formation: Gardezi and Ghazanfar (1965) named the predominantly shale-siltstone unit exposed near Hazira Village as Hazira Formation. This formation conformably overlies D-phosphorite unit of Upper Abbotabad Formation. The basal part is glauconitic shaly and silty which in turn changes over to carbonaceous shale and siltstone. This part of the siltstone is phosphatic. The next unit is grayish siltstone and the upper most unit is buff, greyish, yellowish and light brownish in colour. However, the Hazira Formation directly overlying the Galdanian is more quartzitic and white to light grey in colour and at places appears like reddish siltstone.

On the basis of fauna like *Hyolithes, Allonia tripodophora, Lapworthella spp.* etc. the age assigned is Cambrian (Shah, 1977).

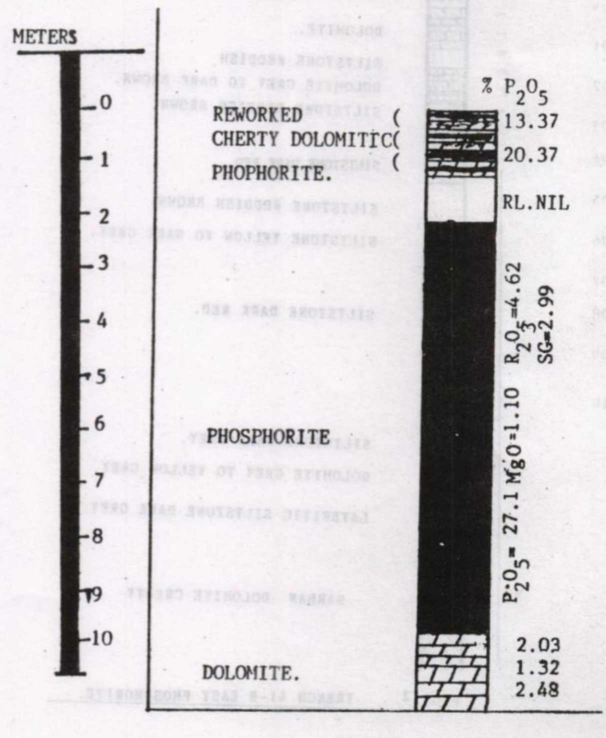

FIG. 4 DRILL HOLE L-19 PHOSPHORITE.

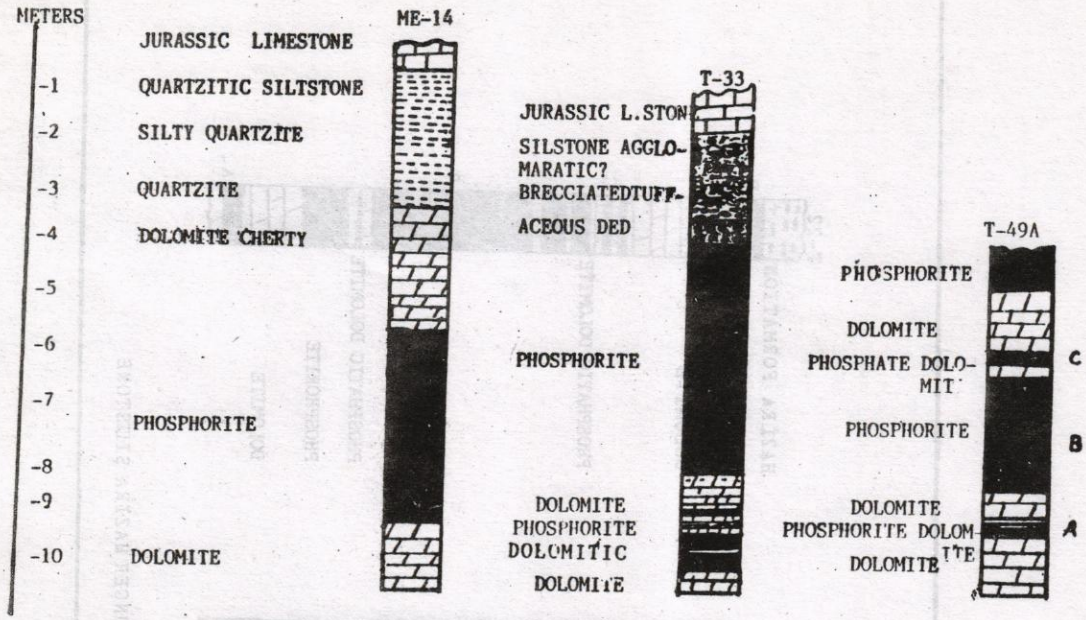

FIG. 5 PHOSPHATIC TRENCHES OF EAST PHOSPHORITE

CONCLUSIONS

On the basis of correlation of the following formations (Upper Abbotabad Formation, Phosphorite Formation, Galdanian Formation, and Hazira Formation) following conclusions are drawn:

(i) The Upper Abbotabad Formation may be redefined as Hazara Phosphate Formation.

(ii) Galdanian Formation represents an unconformity of Cambrian age which merges with the phosphate formation in the surrounding depressions and continental shelf environments laterally. (Fig. 7).

(iii) In the vertical extensions the Galdanina Formation changes over to quartzitic rocks, siltstone and clay rich siltstone but in open sea environments development of the latter is very evident (Hazira Formation).

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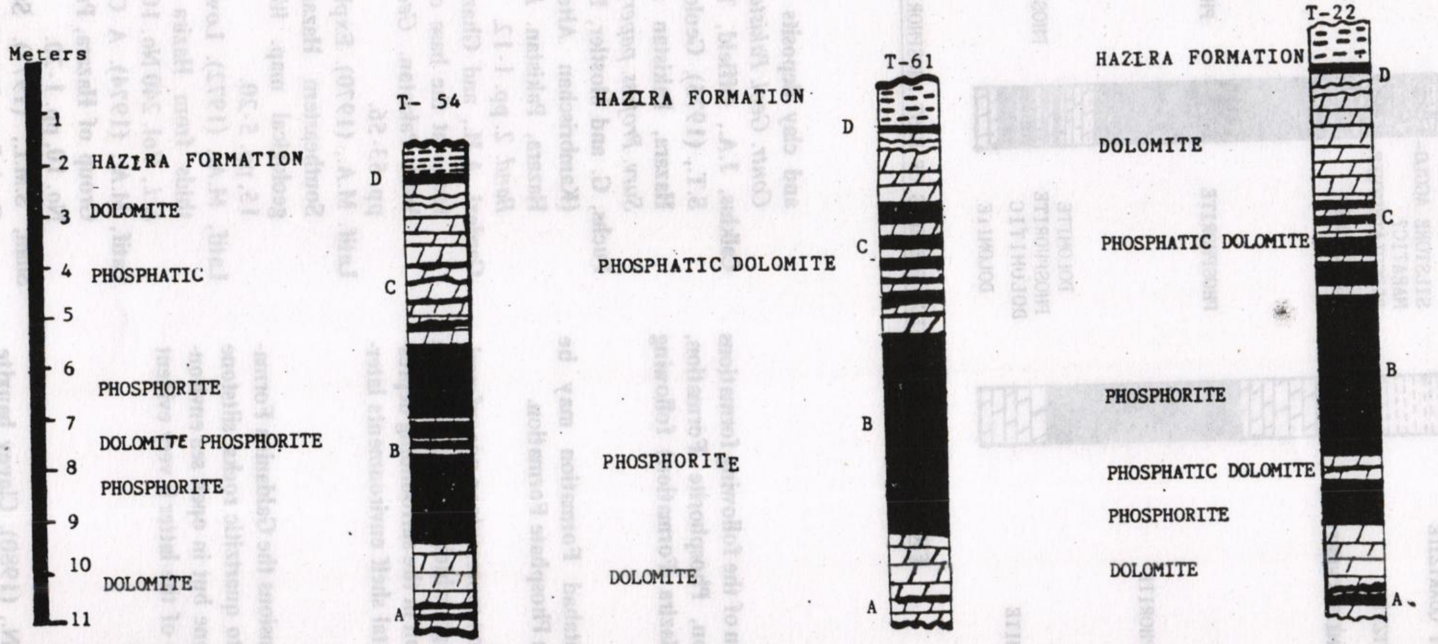

FIG.6 TRENCHES SHOWING VARIOUS PHOSPHATIC ZONES AND YOUNGER HAZIRA SILTSTONE OF LAGARBAN BATKANALA & SOUTH PHOSPHORITES

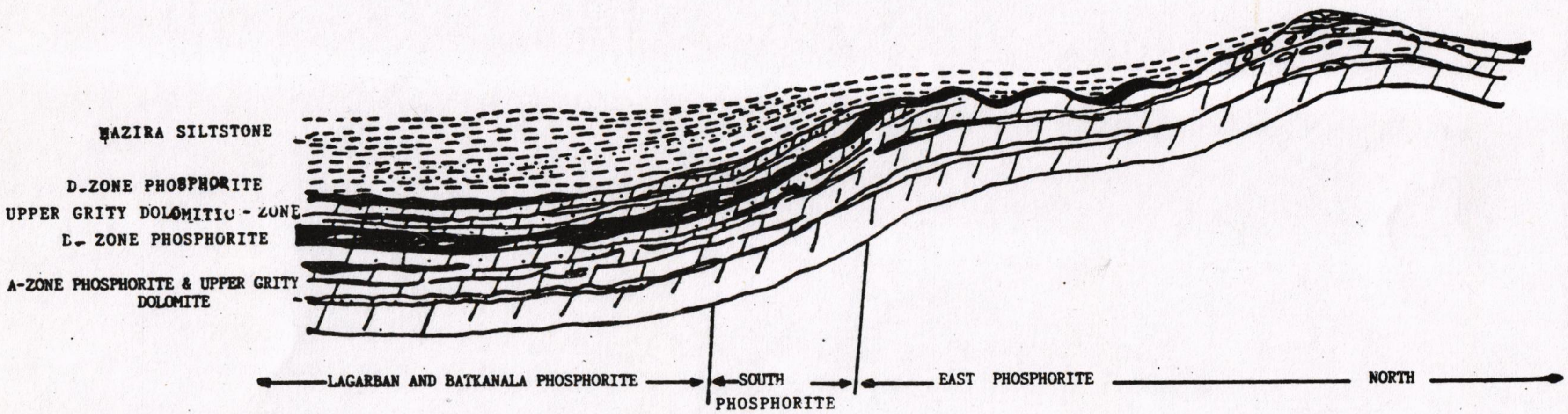

FIG.7 IDEALIZED DEPOSITIONAL ENVIRONMENTS OF PHOSPHOPITE
AND GALDANIAN UNCONFORMITY IN LAGARBAN TARNWAI AREA ABBOTTABAD. N.W.F.P.

MINERALIZATION ASSOCIATED WITH THE ALKALINE ROCKS AND CARBONATITES IN N.W.F.P. PAKISTAN

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ABSTRACT:– Nepheline syenite and associated alkaline rocks are known from north western part of Pakistan as an alkaline igneous province trending WSW-ENE. Important exposures so far known are at Loe Shilman, Warsak, Malakand, Shewa, Koga and Tarbela. The distribution of the alkaline magmatism in a narrow belt suggests a zone of crustal weakness during late Eocene/Oligocene in the Indian block and was caused by the influence of compression. Butt, Chaudhry and Ashraf (1980) proposed that while the leading edge of the Indian plate was being collided with Asian block, compressional features were produced within the zone of deformation, a complimentary zone of tension was created within Indian block. These tensional openings provided sites for intrusion of highly alkaline magmas.

The economically important alkaline magmatism is seen in Koga area as medium to coarse grained nepheline syenites, sodalite nepheline syenites, foyaites, litchfieldites and carbonatites. The first four rocks are prone to beneficiation to produce a product useful for the manufacture of colourless glass and quality ceramic wares. The carbonatites are quite interesting as they contain Ce (0.07%), Sr (0.9 to 2.46%), Y (0.005%) Ba (0.09%). The P_2O_5 contents are quite interesting as they range from 15 & 18% in two samples of carbonatites, 5 and 6% in fenite and lamprophyres.

Interesting occurrences of carbonatites were found by Ashraf & Chaudhry (1977) in Malakand. They occur as composite bodies having Nb (100-300 ppm). Sr (0.3%), V (0.01%), Y (100-200 ppm), Zr (0.01%), Sc (Traces), La (400 ppm) and Yt (3-5 ppm). P_2O_5 in the six samples studied is 5 to 11%.

Loe Shilman is also very interesting deposit regarding trace/rare earth elements and phosphate contents.

INTRODUCTION

The alkaline igneous rocks including nepheline syenite and carbonatite are rocks which are deficient in silica, high in alkalies and alumina in former case, and rich in carbonates, phosphate and rare-earths is the latter case. Nepheline syenite dominantly consists of feldspathoids (nepheline, sodalite etc..), microcline and albite. Varying but small amounts of mafic silicates and other accessary minerals are always present in these alkaline rocks. Carbonatities consists of calcite, dolomite, siderite, ankerite with minor amount of apatite and rare earths.

Nepheline syenite rocks are widely distributed through out the world but only in Canada, Norway, U.S.S.R., and United States deposits are worked commercially. Because of its low melting point and fluxing ability nepheline syenite is used mostly in glass and ceramic, and as extender

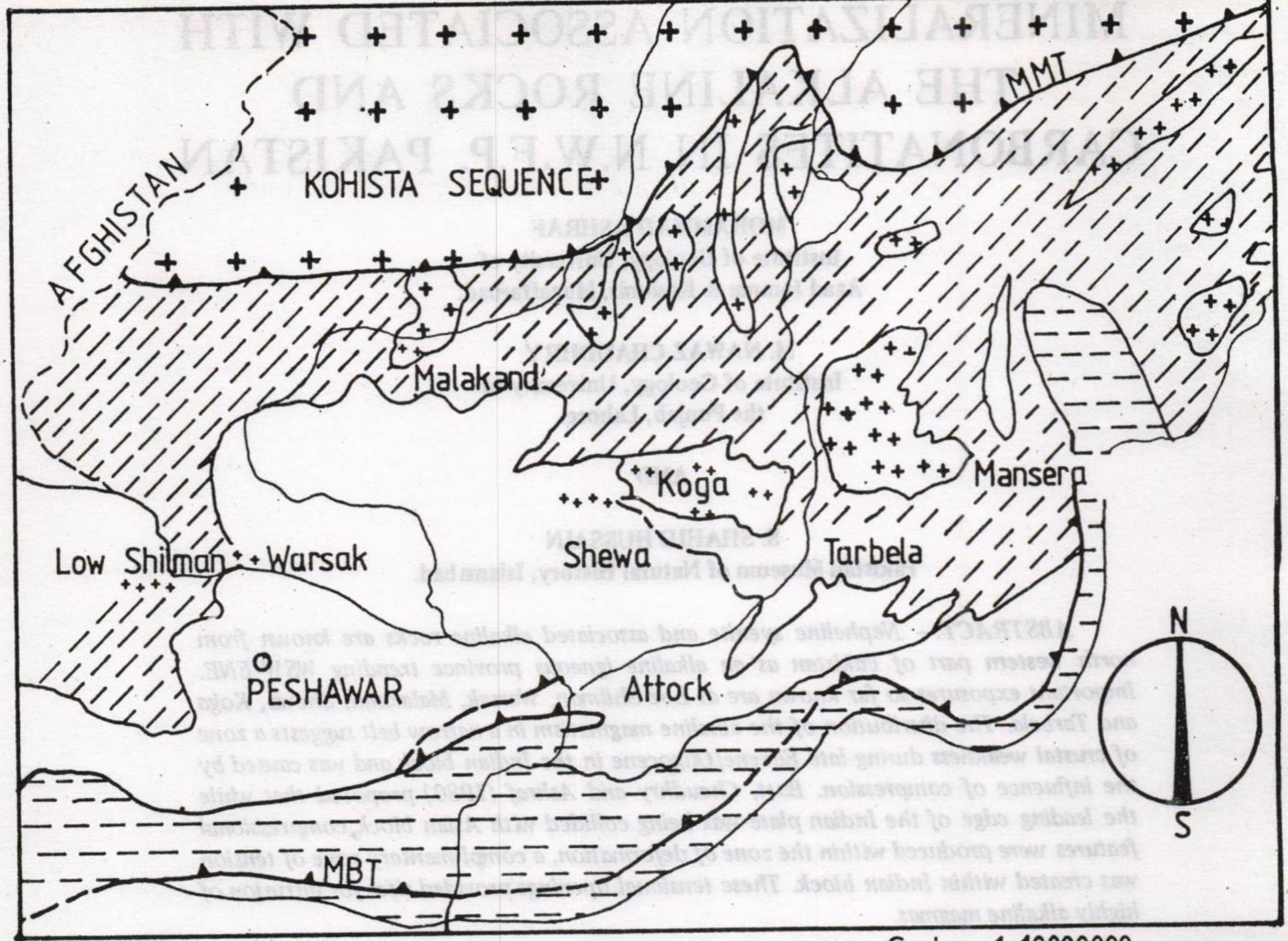
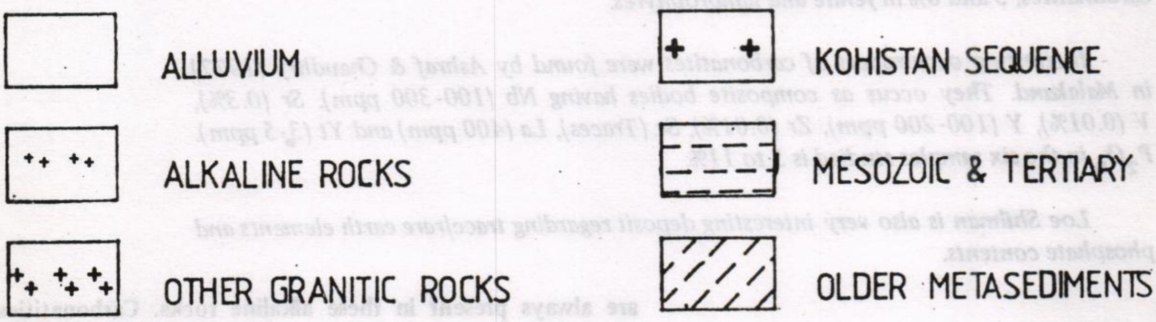


FIG: 1

GEOLOGICAL SKETCH MAP SHOWING ALKALINE AREAS

(After Tahir Kheli & Jan, 1978)



in pigments and fillers in paints, plastics and rubber. In Russia nepheline syenite is used in increasing quantities in the manufacture of alumina, alkali carbonates and portland cement and to a lesser degree in the manufacture of coloured container glasses.

Carbonatites are known as a source of rare-earth elements and a by-product apatite (phosphate fertilizer raw material).

GEOLOGY OF ALKALINE PROVINCE.

An alkaline igneous province was described and discussed by Kempe & Jan. (1970), Butt, Chaudhary and Ashraf (1980) and Chaudhry, Ghazanfar & Ashraf (1983, 84) based on their own work and publications of Siddiqui (1965, 1967), Siddiqui, Chaudhry and Shakoor (1968), Ashraf and Chaudhry (1977), Riaz & Ali (1977), Ahmed et al. (1983) and E.C.L., (1977 & 1979). Chaudhry & Shams (1983) described the mechanism of emplacment. The occurrences of the alkaline rocks in Loe Shilman, Warsak, Malakand, Shewa, Koga and Tarbela suggest the existence of a fairly extensive narrow alkaline igneous province in the Northern Pakistan trending WSW–ENE. The intrusive age of these rocks has been suggested to be early Tertiary (Fig. 1).

The alkaline province comprises of feldspathoidal syenites, syenites/nordmarkites, fenite/carbonatities, soda granites and soda porphyries.

The distribution of the alkaline magmatism in a narrow belt suggest a zone of crustal weakness during late Eocene/Oligocene in Indo-Pak plate. This zone is about 170 Km in length and is about 50 Km wide consisting of en-echelon planes of weakness. Marginal zone is composed of Precambrian to Paleozoic mata-sediments, older and younger granites, basic sills, dykes and minor bodies, rocks of the alkaline affinity and marginal minor tectonic slices. Butt, Chaudhry & Ashraf (1980), Chaudhry & Shams(1983) and Chaudhry et al. (1983) have suggested that zone of compression developed at the edge of Indo-Pak block during early Tertiary.

The compressional environment within the zone of plate interaction resulted in the development of a complimentary zone of tension, a zone of alkaline magmatism. Chaudhry & Shams (1983) have shown that the intrusive rocks along this zone developed from the melts generated at variable depths and emplaced along en-echelon weak planes of a zone which suffered intermittent and alternate periods of variable tension and compression. The alkaline rocks of this zone developed during periods of tension while the normal acidic rocks emplaced along this zone were formed during periods of compression.

The work carried out in the alkaline province by various authors show that economically important alkaline magmatism occurred in the following areas: –

1. *Koga Area.*– Medium to coarse grained nepheline syenite, sodalite nepheline syenite, foyaite, litchfieldite and fenite/carbonatite (Chaudhry, Ashraf & Hussain, 1980).

2. *Malakand Area.*–Sheet like carbonatites occur in Sillai Patti locality as titanomagnetite carbonatites and vermiculite carbonatite (Ashraf & Chaudhry, 1977).

3. *Loe Shilman Area.*– Five categories of carbonatites occur in the area. They are sovite, mica carbonatite, amphibole carbonatite, hornblende carbonatite and strontium carbonatite (Ahmed & Ali 1977).

KOGA NEPHELINE SYENITE COMPLEX

Nepheline syenite is associated with the Ambela granite and nordmarkite complex and lies in its middle. The nepheline syenite occurs as massive bodies and as dykes of various textures intruded in the nordmarkite. These rocks are generally grey to rusty grey and on fresh surface are light grey to dark grey with black specks of mafics. There prevails marked heterogenity both as regards texture and composition. These rocks have been, therefore, classified on the basis of texture and mineral composition(Fig. 2).

(a) *Textural Classification.*

- *(i) Fine-grained nepheline syenite*
- *(ii) Medium-grained nepheline syenite*
- *(iii) Coarse-grained nepheline syenite*

(b) *Compositional Classification.*

- *(i) Pulaskite*
- *(ii) Normal Nepheline syenite*
- *(iii) Sodalite nepheline syenite*
- *(iv) Litchfieldite*
- *(v) Foyaite*
- *(vi) Nepheline pegmatites.*

The nepheline syenite complex as a whole is medium to coarse-grained with fine-grained dykes at places. Chilling and coarsening of the rock is a common phenomenon. These rocks also show flow structures in some fine-grained dykes. Fine to medium grained nepheline syenite dykes are exposed to the west southwest and south of Koga nad Bibi Dheri and also south of Agarai and Sura. Medium to coarse grained dykes and bodies are, however, in the southern part of the complex (south of Koga, Agarai & Sura etc.).

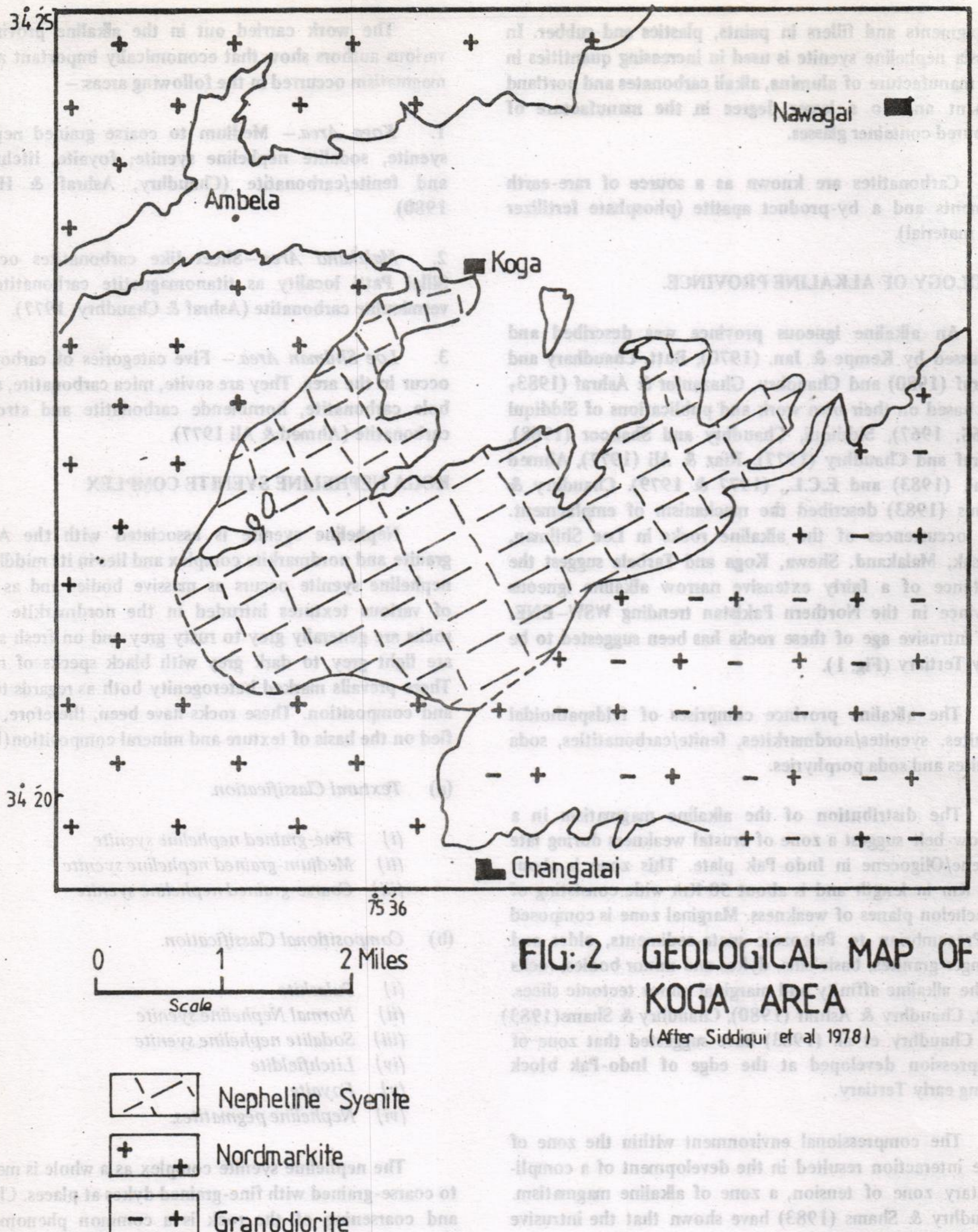


FIG: 2 GEOLOGICAL MAP OF KOGA AREA

(After Siddiqui et al 1978)

Minerals of nepheline syenite complex recognizeable in handspecimen are nepheline, microcline, albite, sodalite, pyribole, biotite, sphene, zircon, apatite, fluorite, magnetite and pyrite. The older dykes contain pyribole as dominant ferromagnesian minerals whereas younger dykes contain biotite instead of pyribole. Calcite is the essential mineral of nepheline syenite exposed near Naranji Kandao & Bagoch Sar. Fluorite in younger dykes is a common mineral. Pulaskite type nepheline syenite is found near Kharkai & Bagoch Sar whereas rocks near Landi Patao, south of Agarai and Miane Kandao are very rich in nepheline syenite.

Associated rock types are fenites, carbonatites, lamprophyres, acidic dykes etc. (Fig. 3).

Texturally the rokcs of Agarai, Landipatao, Miane Kandao and Shpala are mostly medium to coarse grained hypidiomorphic having grain size from 1.5 to 14 mm. The over all grain size including the mafics is generally from 0.1 to 8 mm. The associated, chilled portion in the coarser rocks are finer-grained from 0.1 to 1 mm having mostly granitoid (hypidiomorphic) and occasionally foliated structures. The intergrowth of finer-grained mafic minerals with the coarser grained feldspar/feldspathoid minerals is small to moderate. The mafics often occur as clotty aggregates and as discrete grains.

Mineralogically all types of rocks (Table – 1) consist of nepheline, microline, albite, sodalite, cancrinite, aegirine, arfvedsonite, biotite, muscovite calcite, apatite, zircon, sphene, ilmenite, garnet, haematite, magnetite, pyrite & epidote.

Chemically the rocks of the area are very close to nepheline syenites of Norwary & Canada as they have $Na_2O + K_2O$ = 13.92 to 15.53%, Al_2O_3 = 22 to to 24.7 and SiO_2 = 47 to 58 to 58% (Table – 3) and similarly the processed nepheline syenite is also very close to them as it contains $Na_2O + K_2O$ = 15.13 to 17.28%, Al_2O_3 = 22.09 to 24.98%, SiO_2 = 55.14 to 57.20% and Fe_2O_3 = 0.09 to 0.098% (Table – 4) Overall composition of the nepheline syenite rocks of Koga are presented in Table – 2.

Trace Elements in Alkaline Rocks

Granites & Nepheline Syenite: A total of twelve samples of Koga alkaline rocks including syenite and granite were analysed. Four samples belong to Babaji syenite and soda granite (Table – 5).

The Babaji syenite and granite are free of Li & Sr. Only 0.05% Cr is present in one sample. La is present in two samples (0.01% & 0.02%). Y(0.005%) is present in three samples. ZrO_2 (0.01%) is present only in one sample. Be, Cu, Pb. & Ba is 0.005%, 0.001%, 0.01% and 0.01% in the four samples respectively. V(0.01%) is present only in one sample. Mn is 0.05 to 0.02% and TiO_2 varies from 0.02 to 0.1% in the sample studied.

Out of eight samples of nepheline syenite two were taken from Kharkai, one from Landipatao, one from Shpala, two from Bagoch Sar, One each from Agarai & Miane Kandao.

Agarai sample (Ag-78-5-124) contains 0.005% each of La & Y & one sample (Bss-78-ASRM-100 of Bagoch Sar contains 0.02% and 0.005% each of La & Y.

Agarai sample contains 0.06% ZrO_2, Be (0.005%) occurs in one sample (KK3-78-SM-123) of Kharkai and in the sample of Miane Kandao. Agarai contains 0.004% Cu & all others have 0.001% Cu.

Pb (0.01%) is in all samples except those of Agarai and one of Bagoch Sar.

V is present is Kharkai sample (0.01%), Bagoch Sar (0.02%) and Agarai (0.05%).

Mn varies from 0.05 to 0.20% in all samples.

Sr is 0.5% in one sample of Bagoch Sar which contains calcite.

Ba in 0.01% in six samples and 0.5% in one sample of Bagoch Sar.

Sn, Ce, Mo. Nb, Ta, Co, Ni, Ag,.Au, Zn, Cs, & Ga were sought but not detected.

Bagoch Sar area appears to contain higher Sr & Ba. This area has had access to calcareous fluids which probably formed the carbonatite. But the Shpala area although rich in calcite seams poor in Sr & Ba.

Only Bagoch Sar and Agarai calcite bearing rocks contain La & Y.

No significant primary mineralized area (in constituents discussed) can be predicted on the basis of this analysis. However, secondary concentrations are definitaly warranted.

Koga Carbonatites:– The Koga carbonatite rocks are confined to the western part of the nepheline syenite body and occur near Naranji Kandao in the form of lenses, pockets and veins that vary from a few cm to about 45 m in width and length upto 120 metres. Carbonatites are coarse-grained and most of them lack foliation. The veins cut across the flow structure in the medium grained nepheline syenite. Majority of the veins are composed of massive

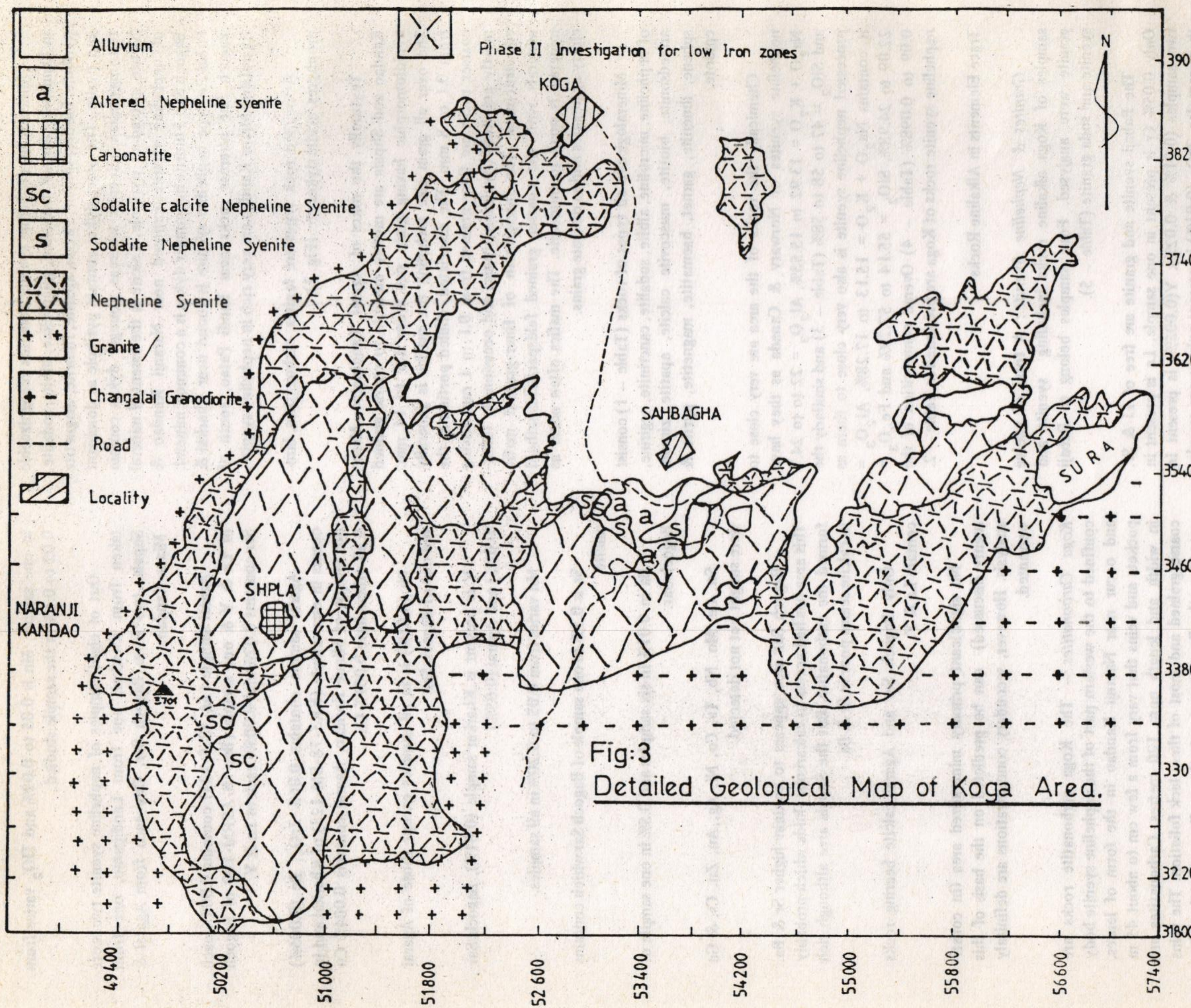


Fig: 3
Detailed Geological Map of Koga Area.

TABLE – 1

Mineral Composition of Nepheline Syentes of Koga, Swat.

No. of Samples	23	3	5	8	8	10
	Nepheline Syenite	Foyaites	Nepheline Syenite Dykes	Sodalite Nepheline Syenite	Litchfieldites	Nepheline Syenite Pegmatites.
Nepheline	19.74	51.06	24.92	14.68	19.05	5.49
Microcline	50.53	18.40	50.49	55.44	15.68	50.08
Albite	16.43	17.99	9.35	6.05	51.15	32.49
Sodalite	0.08	0.00	0.30	13.65	0.07	0.00
Cancrinite	0.94	5.51	3.20	2.46	3.12	0.07
Aegirine	3.71	0.05	0.37	0.00	1.00	2.86
Arfvedsonite	1.79	0.00	3.70	0.67	1.68	0.08
Biotite	2.12	4.98	3.57	4.35	1.91	1.95
Muscovite	1.01	0.00	0.60	1.12	1.00	2.06
Calcite	1.62	0.00	0.00	0.00	0.00	0.00
Apatite	0.01	0.00	0.40	0.00	0.25	0.00
Zircon	0.32	0.47	0.60	0.00	0.15	0.00
Sphene	0.78	0.51	0.87	0.12	1.00	0.50
Ilmenite	0.58	0.53	0.40	0.55	1.51	1.69
Garnet	0.38	0.00	1.18	0.00	1.25	0.50
Haematite	0.10	0.00	0.00	0.18	0.62	0.25
Magnetite	0.03	0.00	0.00	0.00	0.00	0.30
Pyrite	0.13	0.00	0.00	0.58	0.25	0.50
Epidote	0.16	0.00	0.26	0.12	0.00	0.10

TABLE – 2

Chemical Composition of Nepheline Syenites of Koga, Swat.

No. of Samples	32	05	12	05	07	05
	Nepheline Syenite	Foyaite Dykes	Nepheline Syenite Dykes	Sodalite Nepheline Syenites	Litchfieldites	Nepheline Syenite Pagmatites
SiO_2	57.31	55.65	58.50	55.92	58.90	61.65
TiO_2	00.23	—	—	00.13	00.01	00.14
Al_2O_3	20.75	22.72	20.08	23.46	21.84	21.01
Fe_2O_3	03.19	02.46	02.15	02.32	01.70	02.88
MnO	00.02	—	—	—	00.01	00.01
MgO	00.78	01.40	00.83	00.16	00.25	00.04
CaO	01.96	01.39	02.27	01.27	01.99	00.55
Na_2O	07.80	09.91	08.13	10.68	09.56	06.12
K_2O	06.23	05.34	06.77	04.97	04.70	06.97
P_2O_5	00.18	—	00.26	00.04	00.15	00.01
1/L	01.41	01.37	01.39	01.11	01.10	00.57
Total :–	99.86	100.24	100.38	100.06	100.21	100.37

TABLE – 3

Chemical Composition of Head Samples of Nepheline Syenite

	Agarai – 1	Agarai – 2	Landipatato –1	Landipatao – 2	Maine kandao	Bagoch Sar	Shapala.
SiO_2	55.54	54.55	58.16	56.80	56.74	47.95	54.02
TiO_2	0.60	00.20	tr	00.40	00.10	00.00	00.00
Al_2O_3	23.50	24.69	22.38	22.00	22.16	23.74	23.31
Fe_2O_3	02.06	01.88	02.70	03.14	02.68	00.87	01.18
MgO	01.00	01.20	00.83	00.94	00.38	00.72	00.43
CaO	01.85	02.50	01.40	01.59	10.61	05.75	03.01
Na_2O	10.63	09.94	09.98	08.21	10.37	08.98	09.45
K_2O	03.96	04.80	04.36	05.80	04.80	04.98	06.08
P_2O_5	00.00	00.02	00.00	00.00	00.00	00.00	00.00
1/L	01.00	01.19	00.79	01.19	01.03	06.78	02.67
Total:	100.14	100.43	100.60	100.07	99.87	99.73	100.15
Total Alkalies:	14.59	14.02	14.34	14.01	15.17	13.92	15.53

TABLE – 4

Chemical Analysis of Purifind Samples of Nepheline Syenite

	Agarai	Landipatao – 1	Landipatao – 2	Shpala
SiO_2	55.14	57.20	55.61	56.14
TiO_2	00.00	00.00	00.00	00.00
Al_2O_3	24.04	24.15	24.98	20.56
Fe_2O_3	00.09	00.098	00.096	00.09
MgO	00.86	00.85	00.99	00.47
CaO	01.81	01.20	01.90	03.36
Na_2O	12.37	10.57	08.83	09.37
K_2O	04.91	04.92	06.30	06.83
1/L	01.17	01.52	01.05	00.60
Total:	100.69	100.51	99.76	100.46
Total Alkalies:	17.28	15.49	15.13	16.20

TABLE – 5

TRACE ELEMENT COMPOSITION OF NEPHELINE SYENITE, NORDMARKITE AND SODA GRANITES

Sample	No.	AG-78-S-124	LP3-78-SM-53	MK3-78 AS-112	BS-78 RM-99	BS-78 ASRM-100	SH3-78 SM-185	KK3-78 SM-117	AK-78 SM-123	AK-78 AS-115	AK-78 AS-116	AK-78 AS-120	KG-78 AS-125
Li	(–	–	–		(Value of All Samples is 0.05 or Nil)					–	–	–	–)
La	%	0.005	–	–	–	0.02	–	–	–	0.02	–	0.01	–
Y	%	0.005	–	–	–	0.005	–	–	–	0.005	0.005	0.005	–
ZrO_2	%	0.06	–	–	–	–	–	–	–	0.01	–	–	–
Be	%	0.005	–	0.005	–	–	–	0.005	–	0.005	0.005	0.005	0.005
Cu	%	0.004	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Pb	%	–	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
V	%	0.05	–	–	0.02	–	–	–	0.01	0.01	–	–	–
Mn	%	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.5
Sr	%	Traces	–	–	Traces	0.5	–	–	–	–	–	–	–
Ba	%	0.1	0.1	–	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sn, Ce, Mo, Nb, Ta, Co, Ni, Ag, Au, Zn, Cs, Ga,					Sought But Not Found								
		F	SNS	F	Fe	Fe	NS	P	P	S	S	S	G

P : Pluskite, N.S. = Nepheline Syenite, S.N.S. = Sodalite Nepheline Syenite,
F : Foyaite, Fe = Fenite, S = Syenite, G = Granite

carbonates and silicate minerals. In handspecimen carbonates, microcline pyroxene and magnetite can be recognized. Fenetization has also taken place near the contacts of carbonatites and nepheline syenite.

The largest exposure near Naranji Kandao is at the contact of nepheline syenite with Babaji syenite. The carbonetite is 45 metres wide & 120 metres long. It is coarse-grained rock of carbonates with microcline and pyroxene. Pyroxene occurs as acicular crystals intergrown with carbonates in the form of radial to sub-radial and parallel to subparallel pattern mostly near contacts. Microcline occurs as coarse crystals at places.

Other carbonatite bodies have exposures of the following sizes near Naranji Kandao: 30mx 3 to 7.5m, 15 x 30 m, 1.5 x 6 m. Nearly all carbonatitic magma is regarded as the chief source of fenitizing solution. In the area of Naranji Kandao to Bagoch Sar & Shpala have fenitized nepheline syenite. Therefore the area may be regarded an ideal area for rare earths.

Texturally the rocks are coarse-grained and hypidiomorphic. They contain 58 to 60% carbonates, 6.0% each microcline, 7 to 10% aegirine augite, 7 to 11% arfvedsonite, 15 to 18% apatite and 0 to 1% ilmenite. The apatite contents are of interest.

One fenite sample & one lamprophyre sample contain 5 to 6 apatite respectively. The carbonatites are quite interesting as they contain Ce (0.079%), Sr (0.9 to 2.46%), Y (0.005%), Ba (0.09%) and similarly the P_2O_5 contents of about 10 to 12%.

MALAKAND CARBONATITES

The carbonatites of Malakand area accur near Silai Patti. Silai Patti is 30 Km from Dargai. The carbonatites occur as larger sheet like body and as sills in the pelitic psammitic schits of possibly Pre-cambrian age. They were first reported by Ashraf & Chaudhry (1977). The major body occurs as sheet divisibie into two major zones.

The basal part is vermiculite carbonatite while the upper half is of titanomagnetite carbonatite. In the subsequent traverses it was traced for about 1.5 Km distance from near Silai Patti Kandao to north – westwards. In this locality its thickness is about 15 to 20 metres. Other smaller occurrences have been found near south of Silai Patti Kandao, and between Silai Patti & Haspur.

The rocks are composed of carbonates, arfvedsonite, ilmenite, magnetite, vermiculite, apatite, chlorite and some feldspar. The minerals show uneven distribution and local seggregation. The rocks are coarse grained and porphyritic to subporphyritic.

Carbonates are the main minerals and range from 50 to 90% in most cases. Some siderite crystals are recognizeable at places.

Vermiculite occurs unevenly distributed and range in size from 1 to 3 mm and occasionly upto 9 mm in size.

Magnetite ilmenite are generally about 5%, however, at few places they may be as high as 50% (as pods & lenses). These occur from subhedral to anhedral crystals.

Arfvedsonite ranges from 2 to 25% of the rock. It forms subhedral to euhedral crystals.

Vermiculite and amphibole alter to chlorits at places.

K-feldspar ranges from 0 to 5%. It occurs as subhedral to anhedral crystals. It may be partly enclosed by the carbonates.

Trace element study was carried out on three samples with the following results:

Nb is present 0.01 to 0.03%
Sr occurs in three samples as 0.3% in each.
V is 0.01% in all samples.
Y is 0.01% to 0.02%
Zr is 0.0 to 0.01%
La is 0.04% in three samples
Sc is in traces.
Yt is traces to 5 ppm.

P_2O_5 values of some 15 samples collected varies from 5 to 11 % which is of special interest as it can be recovered as by product of rare-earth elements in the carbonatites.

This preliminary study shows that apatite is recoverable as it is 8 to 15% in the carbonatites under study. These days such rocks are being exploited by Brazil and Yougosalvia for the recovery and manufacture of phosphate fertilizer. Their cut off grade is 5% apatite and apart from this they also get concentrate of rare-earth elements.

LOE SHILMAN CARBONATITES

Loe Shilman occurs in eastern Khyber Agency near Landi Kotal. Carbonatites and associated alkaline rocks are present in Landi Kotal Formation.

Carbonatites occur as tabular body with a length of about 1950 metres and a thickness of about 100 to 200 metres or less at places running almost east west. Ahmed & Ali (1977) have classified the carbonatites into five types.

1. *Sovite (the pure carbonatite):*-- It is nearly pure

calcitic carbonate with a maximum of 10% other minerls. It is medium to coarce grained and tends to be heterogeneous. Magnetite is commonly found. Apatite is a common mineral and is present upto 9.5% in sovite.

2. *Mica Carbonatite:* -- It is fine to medium grained with abundant flakes of muscovite or biotite. This occurs near the contact with nepheline syenite. Apatite occurrence is relatively poor in this part of carbonatite.

3. *Amphibole Carbonatite:* -- It is fine to medium grained carbonatite with blue green amphibole. Apatite is more or less evenly distributed in the carbonatite. The highest P_2O_5 content was found to be 10%.

4. *Hemblende Carbonatite:* -- In this carbonatite hornblende is the prominant constituent. Biotite is the next dominant mineral. Phosphate is present throughout the body but with low percentage (below 4%).

5. *Strontium Carbonatite* -- Strontium is the important mineral of this part of carbonatite and chemical composition of the rock is rather dolomitic. Among other constituting minerals, aegirine and apatite are important which individually form upto 8% of the rock.

In the area Ahmed & Ali (1977) have taken average P_2O_5 content as 4.0% in the eastern portion and 5.5% in the western portion. The tonnage calculated of the ore is 200 million tonnes and that of phosphate as 10.4 million tonnes.

Qureshi, Beg & Babar (1980) studied these carbonatites at 100 metres interval on surface and found that they contain:

P_2O_5 0.90 to 4.7%, Nb 0.007 to 0.2%, Ta 0.006 to 0.01%, La 0.005 to 0.055%, Yt 0.004 to 0.006%, V 0.001 to 0.01%, Zr 0.001 to 0.07% in eight samples.

Qureshi, Beg & Babar (1980) also reported the results of 9 bore holes. According to them distribution of anomalous valuable was again irregular and no zone with richer grade of P_2O_5 or any other element was indicated. Results are as follows of the drill holes:

P_2O_5 2.04 to 4.08%, Nb 0.007 to 0.094%, Ta 0.002 to 0.004%, La 0.001 to 0.034%, Y 0.001 to 003%, V 0.002 to 0.005%, Zr 0.0 to to 0.032%.

Uranium mineralization is assoiated with amphibole carbonatite and it belongs to pyrochlore betafite occurrence.

Although the results are not discouraging as reported by Ahmed & Ali (1977) for phosphate and other veluables like Nb, Ta, La, Y, Zr etc. It is hoped that enriched zones are likely to occur and also a concentrate of the rare-earth can be obtained.

CONCLUSIONS

1. A fairly extensive zone of alkaline activity exist in the Peshawar plain extending for about 170 Km in length and 50 km in width consisting of en-echelon planes of weakness. Apart from the known 8 sites more are expected to be discovered in the subsurface/surface.

2. Koga area in swat is the most promising site as regards the occurrence of medium to coarse-grained nepheline syenite. This nepheline syenite is prone to beneficiation giving rise a product which is most suitable for use in glass and ceramic industry. The use of nepheline syenite has edge over feldspar due to higher contents of alkalies and alumina. Reserves of such material are 120 million tonnes.

3. The total reserves of 6,000 million tonnes of Koga nepheline syenite complex warrant establishment of industrial complex in the area for the manufacture of cement, alumina and alkalies and for the production of iron free nepheline syenite.

Carbonatites of Koga area are smaller and may not need immediate attention.

4. Malakand carbonatite having sheet like occurrence in pelitic psammitic rocks and gentle dip inward is 15 to 20 metres thick for extension of 1.5 km so far known, is very encouraging for explortation. Exploitation is possible due to higher amount of apatite (P_2O_5, 5 to 11%) and anomolous amount of Nb (0.01 to 0.03%), Sr (0.3%), V (0.01%), Y (0.0 to 0.02%), La (0.04%) etc.

In addition vermiculite about 3.5% and titanomagnetite about 5% can also be recovered.

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THREE STRATIGRAPHIC PROVINCES AT HAZARA-KASHMIR BOUNDARY, PAKISTAN.

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ABSTRACT:– A stratigraphic study of Hazara – Kashmir boundary in the region of Kaghan, Garhi Habibullah and Muzaffarabad indicates presence of three different stratigraphic sequences now tectonically juxtaposed. Two different stratigraphic levels are indicated for Tanols/Tanawals of Hazara and Kashmir.

INTRODUCTION

In the region of Hazara-Kashmir Syntaxis at the borders of district Mansehra (Pakistan) and Muzaffarabad (Azad Kashmir) three different sets of stratigraphic sequences occur close together. These represent three different basinal affinites which we may term as the Kashmir Basin, the Kohat-Potwar Basin and the Muzaffarabad Up-lifted Zone. At the Hazara Kashmir boundary parts of three stratigraphic sequence are truncated by faulting and some parts are not exposed. Still the exposures are sufficient to develop a comprehensive picture (mapl). Once the three different stratigraphic sequences have been indentified their close juxtposition emerges as most interesting. A somewhat similar relationship was first noted by Calkins et al. (1975). However, those writers ignored the Kaghan/Kashmir sequence while paying more attention to the Mansehra-Batgram-Tarbela area. Below we first outline the broad location and stratigraphic characteristics of each of the three stratigraphic provinces. A discussion of the correlation of the stratigraphy of the three provinces in different areas then follows. Finally there are comments on the Tanol/Tanawal controversy in the light of the present observations.

DESCRIPTION

Hazara Area

The rocks belonging to this area constitute the so-called Garhi-Habibullah Syncline (Calkins et al. 1975) and comprise a large area to its south and southwest including Abbottabad, Nathia-Gali, Murree, Islamabad, Khanpur, etc. The two roads Abbottabad – Murree via Nathiagali in the north and the Haripur-Ghora Gali road via Lora Maqsood in the south provide excellent traverses across this beautifully developed and extensively exposed stratigraphic sequence. Latif (1970) has described the stratigraphy of the rocks in this section at length.

This area is characterized by the development of a fairly complete stratigraphic section right from the Precambrian slates to the Pliocene-Pleistocene Siwalik Group of rocks with some important unconformities. Both Mesozoic and Tertiary are well developed but Late Lower Palaeozoic to Late Palaeozoic sequence is altogether absent in Hazara.

The Muzaffarabad Area

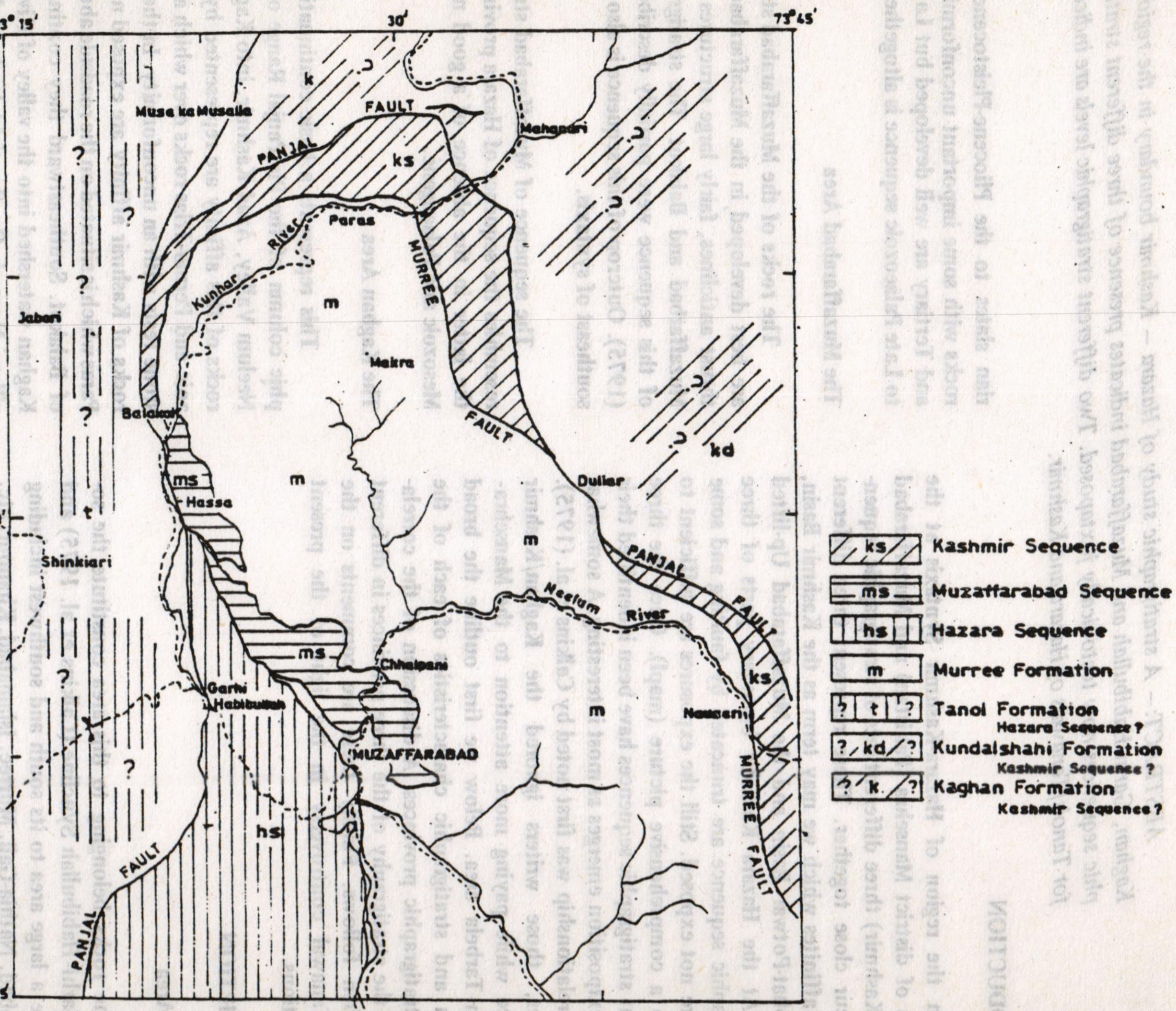
The rocks of the Muzaffarabad stratigraphic province are best developed in the Muzaffarabad and Balakot overthrust anticlines, fairly large structures developed between Muzaffarbad and Balakot. The stratigraphy and structure of this sequence were partially described by Calkins et al. (1975). Outcrop of this sequence is also seen at Kotli to the southeast of syntaxis.

The sequence of Muzaffarabad stratigraphic province resembles the sequence of Hazara province but differs from the latter in the absence of a good many formations of Mesozoic and Palaeogene.

The Kaghan Area

This represents a basic continuation of the stratigraphic column of the Pir Panjal Range of Kashmir, through Neelum Valley, Azad Kashmir, into Kaghan. In Kaghan the rocks of this affinity are represented by the Lower Palaeozoic and Permo-Trias rocks over which a foraminiferal limestone rests with an unconformity. In the Kaghan Valley the rocks of Kashmir affinity are exposed north of the town of Paras which is situated on the roadside about 25 km upstream of Balakot. Southeastward they continue across the great Kaghan watershed into the valley of River Neelum north of village Nauseri. On the right bank of River Kunhar these rocks bend westwards and then south to form the famous structure of western Himalaya, the Hazara Kashmir Syntaxis. This sequence in main is truncated and eliminated near Balakot where the two faults, the Panjal Fault and the Murree Fault coalesce for sometime only to reopean again near Hassa north of Garhi Habibullah.

The rocks of Western Kashmir affinity are characterized by a foraminiferal limestone and two volcanic series, Map.1. Three Stratigraphic Sequences at Hazara Kashmir Boundary with possible areas of extension



Geologic base adapted from Calkins J. A., Offield, T.W., Abdullah, S.K.M. and Ali, S.T., 1975 the Panjal Series and the Agglomeratic Slate Series (Wadia 1928, 1931, Calkins et al. 1975, Ghazanfar and Chaudhry 1984, Bossart et al., 1984). The Panjal Series comprises green coloured basic volcanics and associated limestone/ marbles. The Agglomeratic Slate Series includes volcanogenic material, conglomerates, graphitic schists and subordinate marbles. In the Kaghan Valley it is mainly sedimentary and has been called the Chushal Formation by Bossart et al. (1984). These two volcanic and sedimentary series overlie the Tanols (quartz mica schists and quartzites) which in turn are in faulted contact with the Kaghan Group (Ghazanfar and Chaudhry, 1985, 1986), a huge thickness of metamorphosed pelites, quartzites, marbles and clac-schists in the Kaghan Valley. The Kaghan Group overlies the Shadra Group of rocks (Ghazanfar, Baig and Chaudhry, 1983) or the so-called Salkhalas, which outcrop north of the Main Central Thrust (MCT) in the Upper Kaghan Valley, and the Neelam Valley. (Ghazanfar and Chaudhry, 1985, 1986, Ghazanfar, Baig and Chaudhry, 1983).

DISCUSSION

The Palaeozoic Sequence

See Fig. 1.

Hazara Province: The Palaeozoic and older sequence is best developed and is thousands of feet thick in the Hazara Province of the Kohat-Potwar Basin. The sequence is outlined as follows:

Age	Name of Unit	Principal Lithology
Cambrian	Hazira Formation –	Siltstones
Cambrian	Abbottabad Group	Cherty dolomites with shale and sandstone below and a conglomerate at the base.
Precambrian	Tanol Formation –	Quartzites and quartz mica schists.
Precambrian	Hazara Formation	Slates and quartzites

Muzaffarabad Province: In the Muzaffarabad Province the oldest rocks exposed are the cherty dolomites. Some slates have been reported by Ashraf and Chaudhry (1983), from the Kotli area. They correlated these with the Dogra Slates. However, it may be still premature to talk with certainty about the nature of units older than Abbottabad Group in the Muzaffarabad Province.

As far as the Abbottabad Group is concerned it is quite similar to that developed in Hazara but has its peculiarites. The lower part has arenaceous material and there are intraformational breccias in the Muzaffarabad area. In the Muzaffarabad area a black limestone has developed towards the top (Calkins et al. 1975). This limestone is not seen in Hazara area.

The cherty dolomite of the Muzaffarabad Province is more or less equivalent to the Sirban Formation of the Abbottabad Group of Latif (1974).

In the Hazara area the Hazira shales and siltstones overlie the cherty dolomite; not so in the Muzaffarabad area. Again in Hazara, the Hazira shales in one part are replaced by the Galdanian Formation which marks an unconformity. The surface of unconformity is overlain by a well developed Mesozoic succession. Now in the Muzaffarabad area, too, there is an unconformity after the cherty dolomite of the Sirban Formation but the gap in deposition is much longer, and it is directly overlain by a Tertiary sequence. Thus Hazira shales as well as the entire Mesozoic sequence above the unconformity are missing in the Muzaffarabad area.

Kaghan Province: In the Kaghan Province of the Kashmir Basin the sequence is as in Table below.

The Palaeozoic sequence of Kaghan is quite different from that of the other two adjoining stratigraphic provinces of Hazara and Muzaffarabad. The Carboniferous to Trias (the Agglomeratic and Panjal Series) are entirely missing in Hazara and Muzaffarabad. So far as the Tanawal Formation is concerned it is much better developed in the Neelam Valley than in Kaghan. These rocks in spite of lithologic similarities with Tanols of Hazara are stratigraphically closer to Tanawals of Kashmir. In the Kaghan Province these rocks have Ordovician to Devonian or even younger in Kashmir, as against the Precambrian age of Tanols of Hazara. For a variety of reasons the Tanols of Hazara in the past have been confused with Tanawals of Kashmir.

The Kaghan Group of Kaghan Valley again has similarities with the Hazara Slate Formation of Hazara in being mainly pelites and quartzites and in the presence of gypsum, though there are differences, too. One important difference is a larger proportion of clac-and graphitic material in the Kaghan Group.

So far as the Abbottabad Group and Hazira Shales are concerned these two are totally absent in the Kaghan Valley although in the past some limestones associated with the Panjal volcanics in Kaghan Valley have been confused and wrongly interpreted as dolomite of Sirban Formation (Abbottabad Group).

Tentative Age	Unit Name	Lithology
Cenozoic	Eocene limestone and Murree Formation	Foraminiferal limestone, shales. Red sandstone, shales.
Triassic	Malkandi Formation	Oolitic limestone with shales
Upper Carboniferous to Trias	Panjal Series	Metabasites and marbles.
Carboniferous	Agglomeratic Slate (Chushal Formation)	Quartz mica schist, graphitic schists, marbles, conglomerates, tillites.
Ordovician to Devonian/ Carboniferous	Tanawal Formation	Quartzites and quartz mica schists.
Upper Precambrian	Kaghan Formation	Pelitic schists, quartzites, calc-schist, graphitic schists, marbles
Precambrian	Shadra Group (Salkhala Formation)	Garnetiferous calcpelitic gneisses with sheet granites and amphibolites.

(After Ghazanfar and Chaudhry 1985 and Ghazanfar et al. 1986)

The Mesozoic Sequence

See Fig. 2

Hazara Province: The Mesozoic sequence again is best developed in Hazara where it comprises the following:

Thus the Mesozoic sequence in Hazara lacks Triassic and Lower and Middle Jurassic and comprises a nearly thousand ft. thick, fairly variegated sequence of sandstone, shale, limestone of stable shelf facies spanning Upper Jurassic to Cretaceous times. This sequence unconformably overlies the Cambrian Hazira Shales.

Age	Name of Unit	Principal Lithology
Cretaceous	Kawagarh Formation	Fine-grained limestone
Cretaceous	Lumshiwal Formation	Glauconitic sandstone
U.Jurassic/Cret.	Chichali Formation	Black shales
U.Jurassic	Samana Suk Formation	Oolitic limestone
Jurassic	Datta Formation	Sandstone and microconglomerates.

STRATIGRAPHIC CORRELATION OF PALAEOZOIC & OLDER

	Hazara	Muzaffarabad	Kaghan
Permian			Panjal Fm. Agglomeratic slate
Carboniferous			(Chushal Fm.)
Devonian			Tanawal Fm.
Silurian			Tanawal Fm.
Ordovician			Tanawal Fm.
Cambrian	Hazira Fm. Abbottabad Gp. Tanol Fm.	Abbottabad Gp. (base not exposed)	Kaghan Fm.
Precambrian	Hazara Gp. (base not exposed)		Sharda Group (Salkhala Fm.)

Fig. 1.

STRATIGRAPHIC CORRELATION OF MESOZOIC

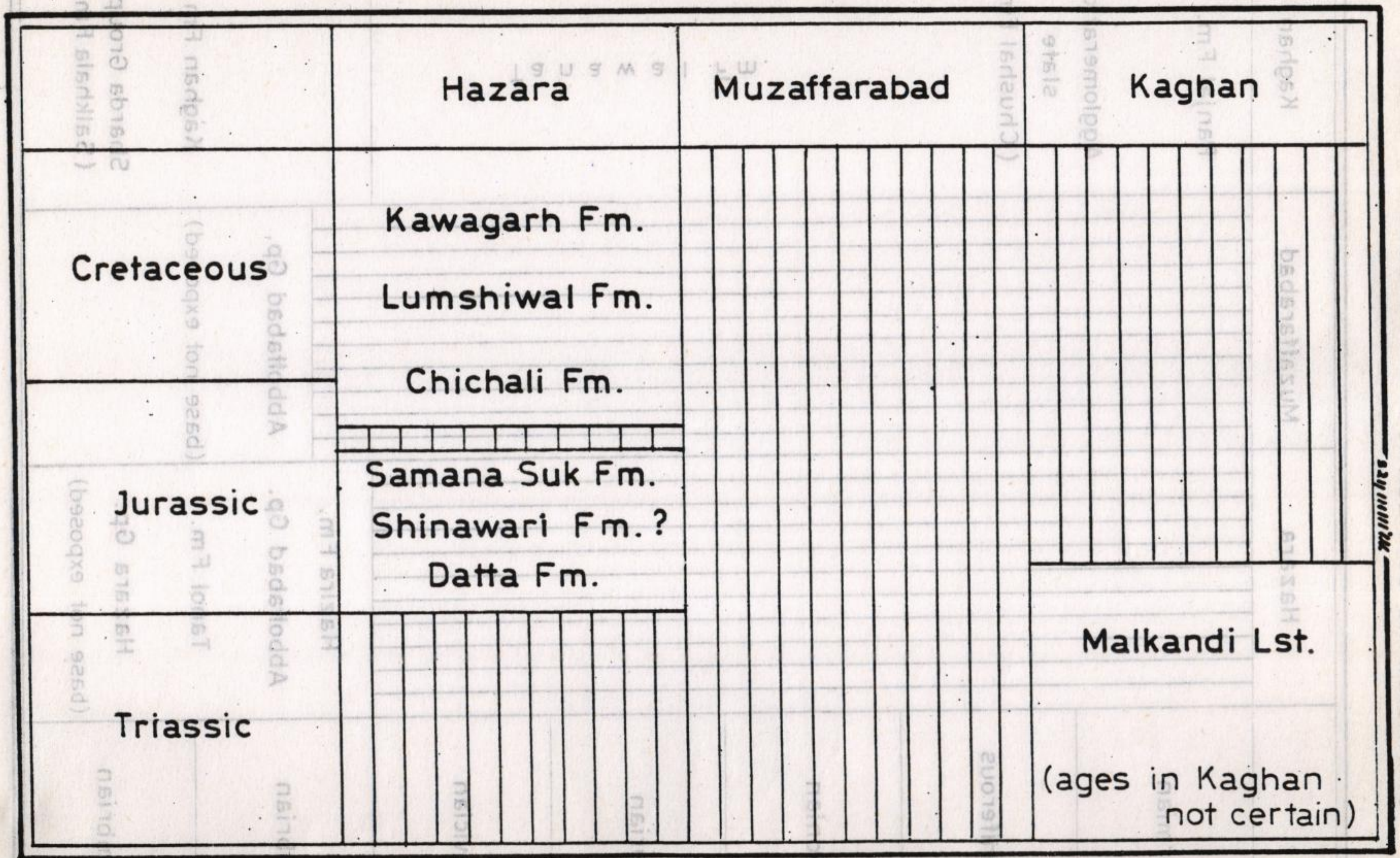


Fig. 2.

Muzaffarabad Province: In the Balakot-Muzaffarabad-Kotli area the whole of the Mesozoic era is marked by the absence of any deposits. The Cambrian dolomitic sequence of Sirban Formation is unconformably overlain by Hangu Formation of Palaeocene age. Obviously the Muzaffarabad area was uplifted land subject to erosion during the entire Mesozoic era.

Kaghan Province: In the Western Kashmir Basin exposed in the Kaghan Valley thrusting has obliterated normal relationship of the rocks and has obliterated at least part of the sequence. Between Mahandari and Paras in the Kaghan Valley the Mesozoic sequence is represented by Triassic oolitic limestone (Malkandi Fm. Ghazanfar et al. 1986) which is underlain by Panjal Series and overlain by an attenuated Tertiary sequence.

The age of the Panjal volcanics in Kaghan valley proper is not known with certainty. In Kashmir it is known to become progressively younger towards east and older to the west ranging from Upper Carboniferous to Triassic. On this basis the age of Panjal rocks in Kaghan may be presumed to range from Carboniferous to Permian but ending short of Mesozoic.

The Tertiary Sequence

See Fig. 3.

Hazara Province: The Tertiary sequence is best developed in the Hazara Province of the Kohat Potwar Basin where it comprises the following stratigraphic units:

Age	Name of Units	Principal Lithology
Pleistocene to Miocene	Siwalik Group	Sandstones, shales conglomerates
Miocene	Murree Formation	Sandstone, shales
Eocene	Kuldana Formation	Gypsiferous shales
Eocene	Chorgali Formation	Marls and shales
Eocene	Margalla Hill Formation.	Nodular limestone
Palaeocne/ Eocene	Patala Formation	Shales with limestone bands
Palaeocene	Lockhart Formation	Nodular limestone
Palaeocene	Hangu Formation	Sandstone, pisolitic claystone, laterite, etc.

The above listed Tertiary sequence specially the Neogene part is many thousands of feet thick. The deposition was nearly continuous except for a marked break in Lower Palaeocene and during the Oligocene period.

Muzaffarabad Province: The Tertiary sequence in the Muzaffarabad uplifted zone resembles that of Hazara area but is attenuated and some units have not developed.

The Chorgali Formation is absent. The Kuldana Formation is reported from the Muzaffarabad area (Ashraf, verbal communication)* but its extent is not known. The Siwaliks are not deposited, the area having been uplifted during post-Murree period.

Kaghan Province: The Tertiary sequence in Kaghan comprises mainly a foraminiferal limestone Paras Formation considered to be of Eocene age overlain by thick Miocene Murree rocks and underlain by a thin calcarenite quartzite and lateritic sequence Rosachcha Formation representing an unconformity (Ghazanfar et al. 1987).

The Tanol/Tanawal Controversy

The Palaeozoic rocks of both the Kaghan province (Kashmir Basin) and those of Hazara overlie the so-called "Tanol" or "Tanawal Formation". In Kaghan Valley rocks of "Tanol"/"Tanawal" Formation outcrop near Jared (Wadia 1931, Ghazanfar and Chaudhry 1985). the "Tanols"/ "Tanawals" here do not represent a fully developed sequence and at least their lower contact is faulted near Mahandri. The upper contact of Tanawal of Kashmir is gradational with Agglomeratic Slate (Wadia, 1957). Fossils reported from Agglomeratic Slates here place them as Devonian to Carboniferous. The upper contact of Tanawals in Kaghan, too, appears to be gradational with the Agglomeratic Slate sequence or the Chushal Formation (Ghazanfar and Chaudhry 1984). If it be so then "Tanols"/"Tanawals" of Kaghan have Kashmir affinity and represent a Middle to Upper Palaeozoic sequence. In such a case the "Tanols"/ "Tanawals" of Kaghan are not homotaxial with the Tanol Formation of Hazara. The latter underlies a Cambrian sequence (Latif, 1974) and is Cambrian to Precambrian in age. For the time being, we are therefore, calling the "Tanols"/"Tanawals" of Kaghan as the Tanawal Formation on the basis of its stratigraphic position and its affinity with

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STRATIGRAPHIC CORRELATION OF CENOZOIC

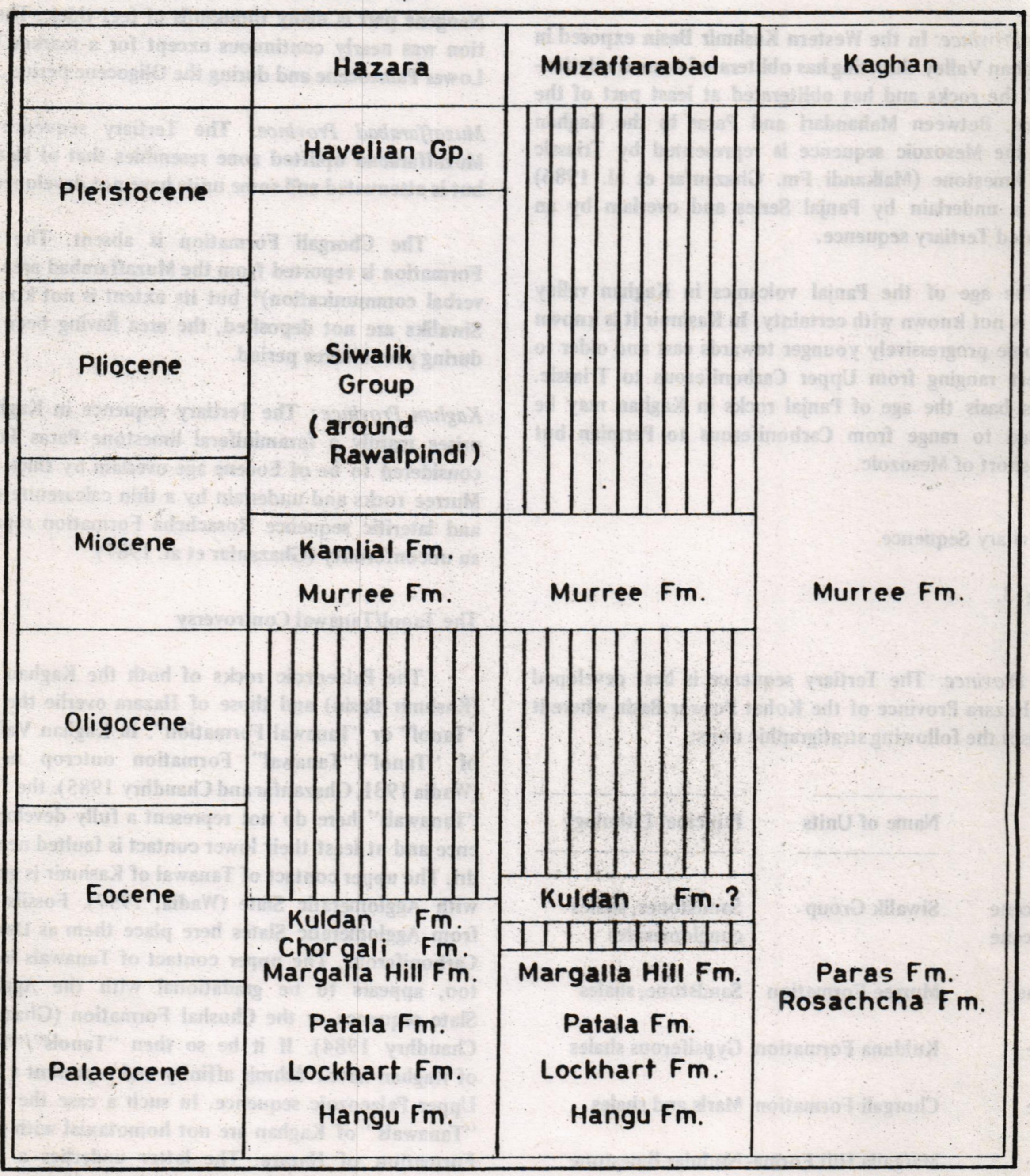

Fig. 3.

the Kashmir basin and to differentiate them from what may preferably be called the Tanol Formation of Hazara which is Cambrian or Infra-Cambrian.

The mistake of confusing the Ordovician to Carboniferous rocks of Kashmir with the Infra-Cambrian rocks of Hazara by giving them a single name had its roots in the days when the Sirban dolomite of Abbottabad Group in Hazara was considered Permian and was called Infra-Trias. Since the Tanol Formation in Hazara underlies the Abbottabad Group it was considered Middle to Upper Palaeozoic and, therefore, correlated with the fossiliferous Ordovician to Carboniferous sequence of Kashmir. Both were given a single name the Tanol or the Tanawal Formation. However, eversince the discovery of Cambrian fossils in Hazara Formation (Latif, 1974) overlying the Sirban dolomite the Tanol Formation of Hazara had definitely acquired a Cambrian to Infra-Cambrian age and cannot by any means be considered homotaxial with or related to the fossiliferous Tanawals of Kashmir which are Ordovician to Carboniferous in age. We are, therefore, presently using two names Tanawal Formation for Ordovician to Devorian/Carboniferous continental sequence in Kashmir and Tanol Formation for similar but Infra-Cambrian rocks in Hazara, Pakistan. The quartzites and quartz mica schists outcropping at Jared in Kaghan Valley (Wadia 1928, 1931; Ghazanfar and Chaudhry, 1985) are, therefore, to be correlated with the Tanawals of Kashmir.

SUMMARY

In a relatively small area at the Hazara-Azad Kashmir (district Mansehra – district Mazaffarabad) boundary three different stratigraphic sequences occur side by side. The sequence enclosed by the Murree and the Panjal Faults, that comprising the Balakot – Muzaffarabad anticlines and that between Murree and Abbottabad mark three different stratigraphic zones. At least two of these zones, the northern and the southern belong to different stratigraphic basins while the middle zone probably represents a variation of the southern. Without defining the limits of stratigraphic basins these zones are being called here three stratigraphic provinces, the Kaghan Province, the Muzaffarabbad Province and the Hazara Province.

The Kaghan province is marked by the development of Tanawal Formation, the Agglomeratic Slates (the Chushal Formation) and the Panjal Volcanic Series disconformably overlain by oolitic limestone of Malkandi Formation and an attenuated Tertiary sequence. On the other hand it is also marked by the absence of the Cambrian sequence like the Abbottabad Group and the Hazara Formation so characteristically developed in Hazara. The equivalents of these rocks are also not present. There is, however, some resemblence at the Upper Precambrian level between Hazara Slates and the Kaghan Formation (Ghazanfar and Chaudhry, 1985).

The southernmost Abbottabad-Murree zone or the Hazara Province represents a part of the Kohat-Potwar Basin and it marked by the development of a relatively complete sequence between Cambrian and Recent. There is, however, a complete absence of the Ordovician to Triassic sequence, represented by Tanawal Formation (of Kashmir), Chushal Formation (Agglomeratic Slates), the Panjal Series and the Triassic limestone so characteristically developed to the north in the Kaghan Valley.

The rock sequence in the Balakot-Muzaffarabad Zone or the Muzaffarabad Province now geographically somewhat in the middle is marked by the absence of a large part of Mesozoic and some Tertiary deposits. This area is also characterized by the absence of Chushal Formation (Agglomeratic Slates), Panjal Series and Triassic limestone, rock units that are so characteristically present in the north. Also rocks older than Abbottabad Group are not exposed in the Muzaffarabad Province.

The Muzaffarabad Zone was thus uplifted and exposed during much of the Palaeozoic and Mesozoic times. The Hazara area, too, during much of the Palaeozoic times was uplifted along with the Muzaffarabad area. However, since Jurassic period the Hazara area remained submerged for most of the time. In contrast the Kaghan area of the Kashmir Basin received sediments during Palaeozoic times but remained a land area during most of the Mesozoic as well as a fair period of the Tertiary times.

An understanding of the different stratigraphic affinities now points out two totally different stratigraphic horizons for the lithologically similar Tanols and Tanawal of Hazara and Kashmir. The Tanols of Hazara are older than Cambrian while the Tanawals of Kashmir are Middle Palaeozoic in age.

The Main Boundary Fault has played an important role in tectonically juxtaposing three different stratigraphic provinces in a small area on the Hazara-Kashmir boundry.

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SOME PETROPHYSICAL CONSIDERATIONS ABOUT THE FENESTRAL POROSITY IN CARBONATE ROCKS

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ABSTRACT:– The complexity in the pore space systems of the sedimentary carbonate rocks precludes a mathematical treatment in developing a general relationship between the formation resistivity factor and the rock porosity. Sedimentary carbonate rocks exhibit numerous porosity types, in which pore space pattern is completely dissimilar.

Fenestral porosity is a specific type of induced porosity prevailing in sedimentary carbonates. A mathematical model has been performed to simulate this porosity type. It reveals a plausible relationship between the formation resistivity factor and the porosity.

Thereby, the derived relationship gives close values of the formation resistivity factor to the measured values on sedimentary carbonate samples analysed by other investigators.

INTRODUCTION

Pore systems in sedimentary carbonates are generally complex in their geometry and genesis, and commonly differ markedly from those of sandstones.

For the assessment of the reservoir rocks, the porosity and permeability are the most important petrophysical data. On the other hand, the relationship between the rock porosity and the formation resistivity factor has a considerable importance to the oil industry for distinguishing hydrocarbons from water in formation pores. The formation factor thereby depends very strongly on the geometrical structure of the pore space system. This is the origin of an essential difficulty in representing a consistent relationship between porosity and formation resistivity factor to be fit for all types of sedimentary carbonates under certain fluid-phase conditions.

Various petrophysical models have been introduced by different investigators such as Wyllie and Spangler (1952), Cornell and Katz (1953), Carmen (1956), Wyllie and Gardner (1958), Rink and Schopper (1968), Schopper (1973), Clavier et al. (1977), Pape et al., (1982), and Bussian (1983) in order to simulate pore system in porous medium. Hence the aim of most of these is to replace some of the petrophysical parameters by quantities which can be directly and easily measured.

The classification of porosity in sedimentary carbonates introduced by Choquette and Pray (1970) has been recognized fifteen basic porosity types. Out of them, seven porosity types were abundant in sedimentary carbonates (fenestral, interparticle, intercrystal, intraparticle, moldic, fracture and vug), while the rest are more specialized types.

Fenestral porosity term was proposed by Tebbutt et al. (1965) for a primary gap in rock frame work, larger than grain supported interstices. Petroleum reservoirs formed of rocks containing fenestral porosity are a distinctive and important type of reservoir facies. Fenestrea occur as somewhat rounded features of spherical, lenticular, or more irregular zigzag shapes (Fig. 1a & b). Their large size in comparison to normal interparticle roofs and floors and

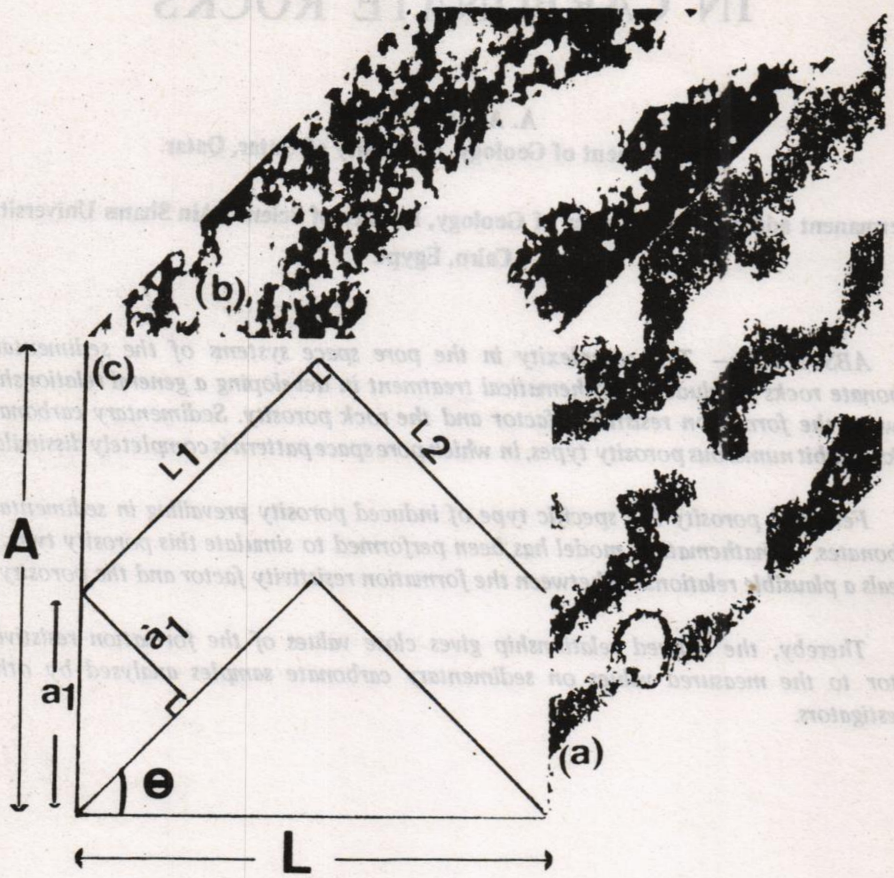

Fig.1. Zigzag Capillary Tube Model (a) limestone, belongs to Rus Formation in Qatar peninsula, shows fenestral fabric.(b) magnified part of capillary tube in photo(a).(c) proposed model.

other margins are key characteristics. The aim of the present paper is to simulate the fenestral porosity type and to study its relation to the formation resistivity factor.

PROPOSED MODEL

On the basis of the inclined capillary tube model of Cornell and Katz (1953), the so-called zigzag capillary tube model is developed. The essential property of this model is that it possess some structural features simulating fenestral fabric arises by means of zigzag capillary tube shape. The assumed form is simplified in such a way that a geometrical calculations can be easily performed (Fig. 1c). The angle between the two segments (L1 & L2) of the capillary tube is assumed to be right angle. There-in-after, the effective cross-sectional area of the pore space (A1) is assumed to be constant all over the tube length.

The inclination angle (θ) of the capillary tube relative to the bedding plane is measured on photograph (Fig. 1a). While, it is found to be approximately equal to 45 degrees. This photo exhibit limestone sample, partially dolomitic, belongs to the Rus Formation (Eocene) exposed at Dukhan area in Qatar Peninsula.

Therefore, the effective cross-sectional area of the zigzag capillary tube is calculated as follows:

$$A1 = A1 . \cos \Theta \quad (1)$$

where: $A1$ = cross-sectional area of the pore opening, cm^2.

$$\text{but, } A1 = A . \phi \quad (2)$$

where: ϕ = rock porsity %. and,
A = cross-sectional area of the sample, cm^2.

Therefore, from eq. (1) & (2):

$$A1 = A . \phi . \cos \Theta \quad (3)$$

The electrical resistivity (R_o) of a cube of rock 100% saturated with brine solution is theoretically calculated (Winn, 1955) as follows:

$$R_o = (R_w . L_e . A) / (L . A1) \quad (4)$$

where: (L_e / L) = is the tortuosity of the system defined by L_e, the effective distance current must travel, and (L) is the length of the rock sample. R_w = is the water resistivity, ohm. m.

By use of equation (4), therefore the formation resistivity factor (F) can be calculated as:

$$F = (R_o/R_w) = (L_e/L) . (A/A1) \quad (5)$$

where: $L_e = L1 + L2$ (on the model, Fig. 1c) Therefore, by use of eq. (3) & (5);

$$F = \frac{\cos \Theta + \sin \Theta}{\cos \Theta} . \frac{1}{\phi} \quad (6)$$

$$\text{Then } F = a . \frac{1}{\phi} = (\sqrt{T} / \cos O) . \phi^{-1} \quad (7)$$

$$\text{where: } a = \frac{\cos \Theta + \sin \Theta}{\cos \Theta}$$

= tortuosity of the present system.

It is worthwhile to mention that the multiplier (a) in equation (7) is found to be vary from $\propto$ to 1.0 since the inclination angle O equals 90 degrees and zero respectively (Fig. 2). The multiplier (a) equals 2.0 for the fenestral fabrics, while O equals 45 degrees. Thereby, the formation factor-porosity general equation which can be applied for sedimentary carbonates that possess fenestral porosity type is:

$$F = 2.0 \phi^{-1} \quad (8)$$

Figure 2., exhibits relationships between the inclination angle (Θ) and both of the multiplier (a) and the tortuosity (T). The multiplier (a) increases by the increase of the inclination angle (Θ). In addition, the tortuosity (T) increase, until it reaches its upper limit (T = 2.0), by the increasing the inclination angle (Θ = 45 degrees). Tortosity curve declines by further increasing of the inclination angle. The plot indicates that tortuosity of the present capillary tube model does equal values ranging from 1.0 to 2.0.

F – ϕ Monogram

In practical application, the equation (6) is used for constructing a simple graphical monogram (Fig. 3). This plot can be used for calculating the formation resistivity factor (F) at any value of known porosity (ϕ) measured for sedimentary carbonates having fenestral fabrics (Θ= 45°). Sample porosity (ϕ) can be measured either directly, on the cores during conventional core-analysis or indirectly by use of the wire-line long-porosity tools.

Pressure solution, cementation, and recrystallization of sedimentary carbonates are complex processes because they take place over a period of time. They affect rock fabric and subsequently rock pore space by either elimination or creation. The value of inclination angle (Θ) varies, while it depends on the rock framework. Thereupon, pressure solution and chemical leaching could be the plausible mechanisms responsible for diminishing the value of inclination angle (Θ), while cementation and recrystallization, on the other hand, are the possible causes of increasing the inclination angle of the present model.

WORKED EXAMPLE

Enter with ϕ = 10% and Θ = 45 degrees,
By use of the monogram (Fig. 3), therefore F = 20.

FL – FM RELATIONSHIP

Some values of laboratory estimated formation resistivity factor (FL ranges from 4.0 to 128, Fig. 4.) measured by different investigators for sedimentary carbonate samples of various geologic ages (Lower Cretacous – Recent) in different countries are compared to the corresponding values that are estimated by use of the present monogram (Fig. 3). The angle of inclination (Θ) is considered to be between 45 to 55 degrees, that because some of the used sample data do not possess fenestral fabrics.

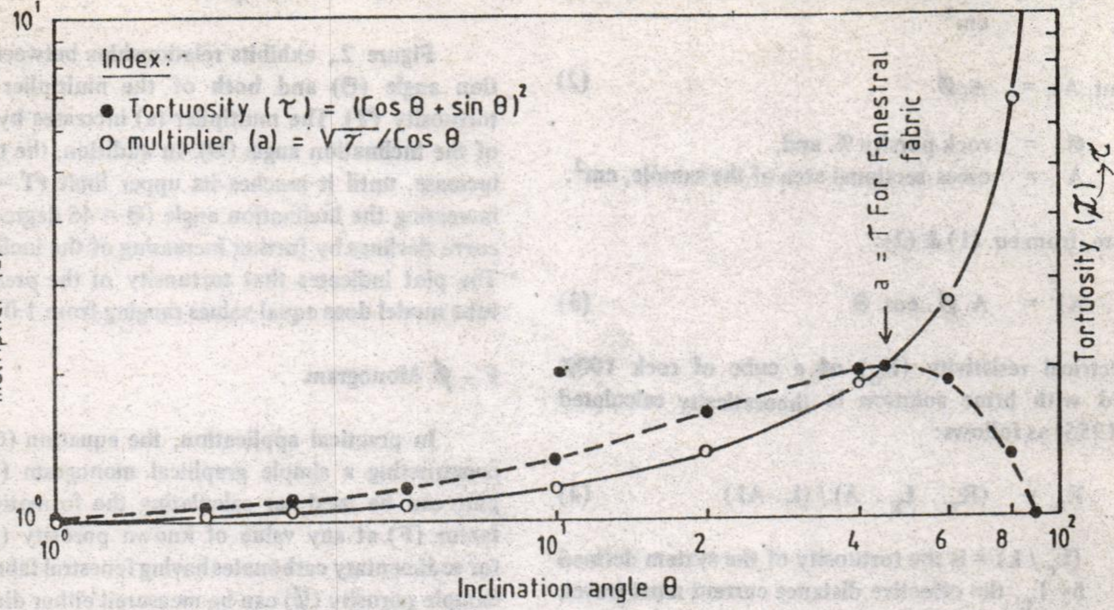

Fig.(2) Inclination angle (θ) VS. Tortuosity & multiplier (a)

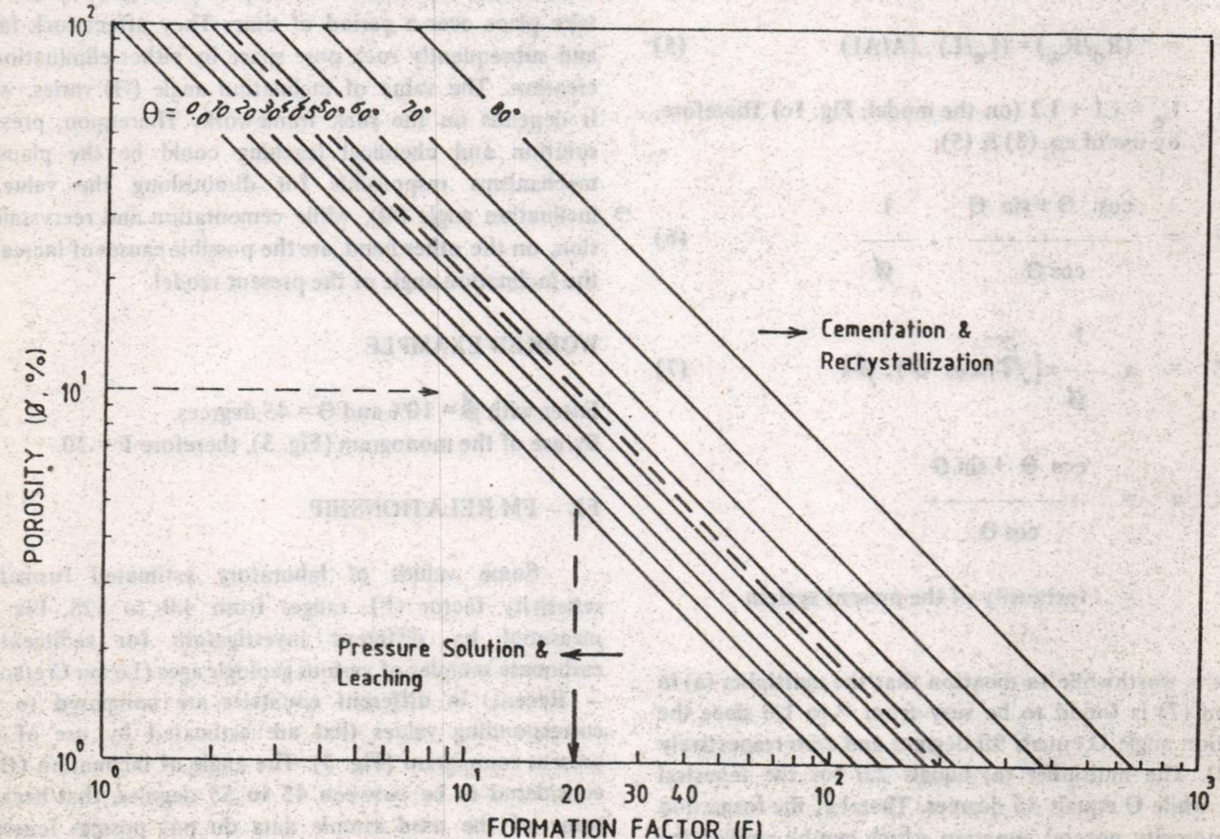

Fig.(3): Formation Factor- Porosity Relation

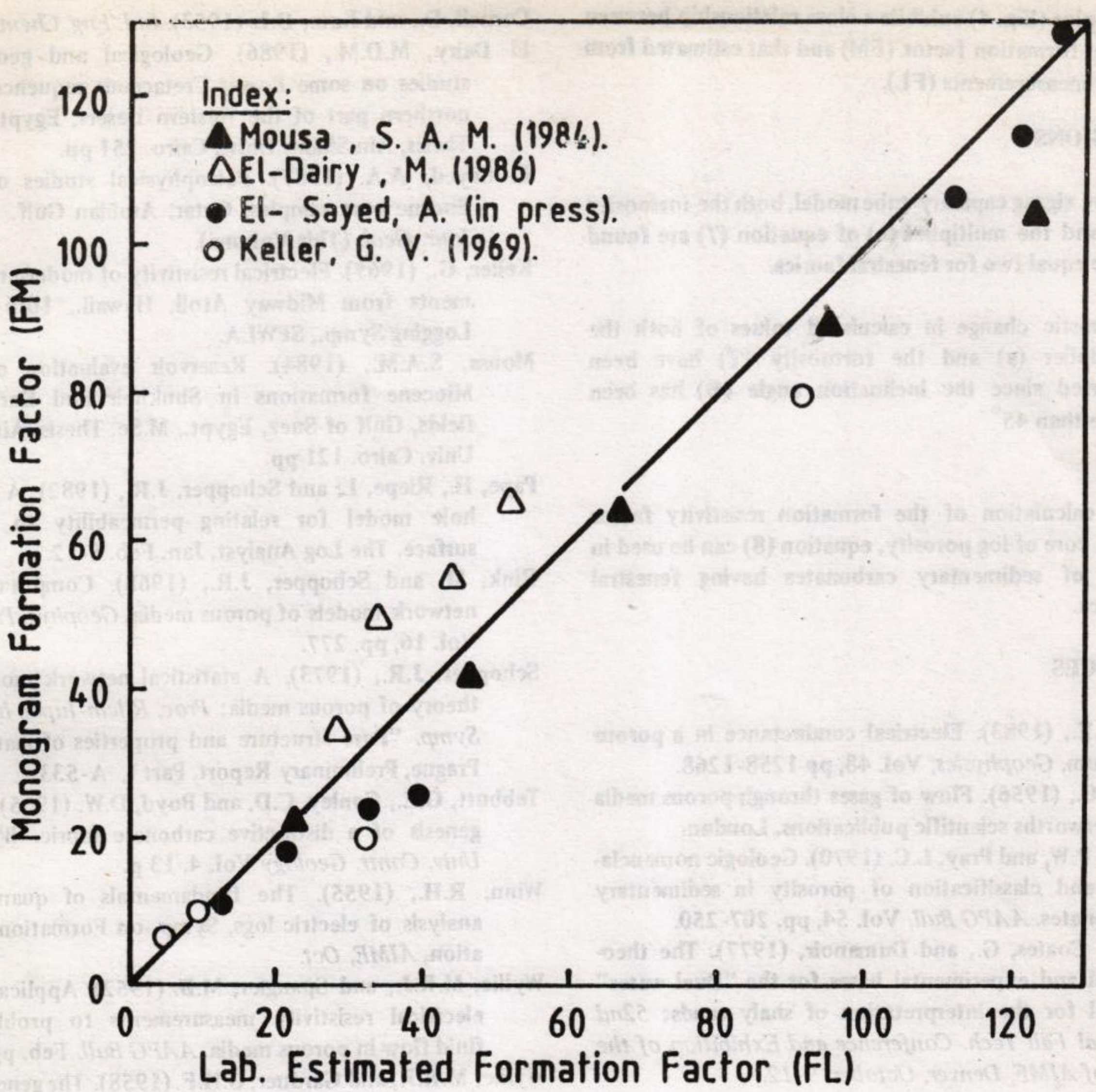

Fig.(4): FM versus FL.

The plot (Fig. 4) exhibits a close relationship between the derived formation factor (FM) and that estimated from laboratory measurements (FL).

CONCLUSIONS

1. In the zigzag capillary tube model, both the tortuosity (T) and the multiplier (a) of equation (7) are found to be equal two for fenestral fabrics.

2. A drastic change in calculated values of both the multiplier (a) and the tortuosity (T) have been reported since the inclination angle (Θ) has been more than 45°

3. For calculation of the formation resistivity factor from core of log porosity, equation (8) can be used in case of sedimentary carbonates having fenestral fabrics.

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INFLUENCE OF PORE GEOMETRY ON THE HYDROCARBON RESERVOIR QUALITY

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ABSTRACT: A critical study of a reservoir pore space geometry is very helpful to divide a heterogeneous reservoirs into zones that make sense both from the geological point of view and from the production engineering aspects.

Different reservoir rock genetic types are studied, for instance, to show how one can relate rock porosity to permeability and pore diameter by combining SEM studied with mercury injection data.

INTRODUCTION

The scanning electron micrographs are used extensively to provide qualitative informations of the rock pore geometry either directly (Timur, et al., 1971; El-Sayed, 1981; and Abdel-Wahab, 1984) or indirectly through the examination of pore casts (Wardlaw, 1976; and Swanson, 1979).

In sandstone reservoirs, clay with associated micropores may occur as detrital laminae or authigenic materials giving a specific pore space pattern. However, in carbonate reservoirs, dolomitization; recrystallization; cementation; and replacement processes mainly affect pore space geometry.

Both clay and carbonate minerals of sizes less than 5 um may occur in a reservoir rock pore spaces as pore filling; pore lining; and fracture filling or displacement Wilson, et al., 1977). Pore radius and geometry are functions of both sedimentation history and post-depositional processes.

The object of the present study is to clarify the interrelationships among reservoir rock porosity, permeability, and pore entry radius in combination with pore geometry revealed by scanning electron micrographs.

METHODS AND TECHNIQUES

Core samples used, in this work, have been selected from different genetic rocks type encountered in some drilled wells in Algyo field (Hungary). They were of Pliocene and Miocene in age.

The full-diameter cores were drilled into small plugs of 5.0 cm length and 2:5 cm in diameter for petrophysical measurements. In addition, small cylinderical samples of 1.0 cm length and 1.5 cm in diameter were prepared for SEM studies. Prior to laboratory measurements, hydrocarbon residual fluids have been completely removed by use of distillation-extraction technique (Keelan, 1972). Samples were dried to a constant weight and cooled in a moisture free atmosphere for further laboratory measurements.

Sample porosity was measured by use of Carlo-Erba porosimeter, while the experimental technique employed is outlined by Taylor, et al. (1975). The pore entry radius is measured by forcing mercury into the evacuated core sample at low pressure (starting with 1.0 kg/sq. cm) level. The volume of mercury entering the sample at this pressure level is recorded. The process is repeated through a range of pressures, while the recorded volume of mercury injected with each pressure increment step is used for calculating directly the percentages of total pore spaces which can be saturated. By increasing the pressure level from 1.0 to 2000 kg/sq. cm, the fractions of the pore entry radius accounted for by all pore sizes between 75000 and 37 A are calculated by use of equation:

$$V_p\% = \frac{H(P\text{-}Max) - H(Pr)}{\text{---}}$$

$$V_p\% = \frac{H(P\text{-}Max) - H(Pr)}{H(P\text{-}Max)} \times 100.$$

where: H(P-Max) = corrected value of mercury level displacement in mm at maximum pressure.

H(Pr) = corrected value of mercury level displacement in mm at a pressure step recorded.

The methodology of pore statistics has been borrowed from graphical measures used in grain size analysis by Folk and Ward (1957).

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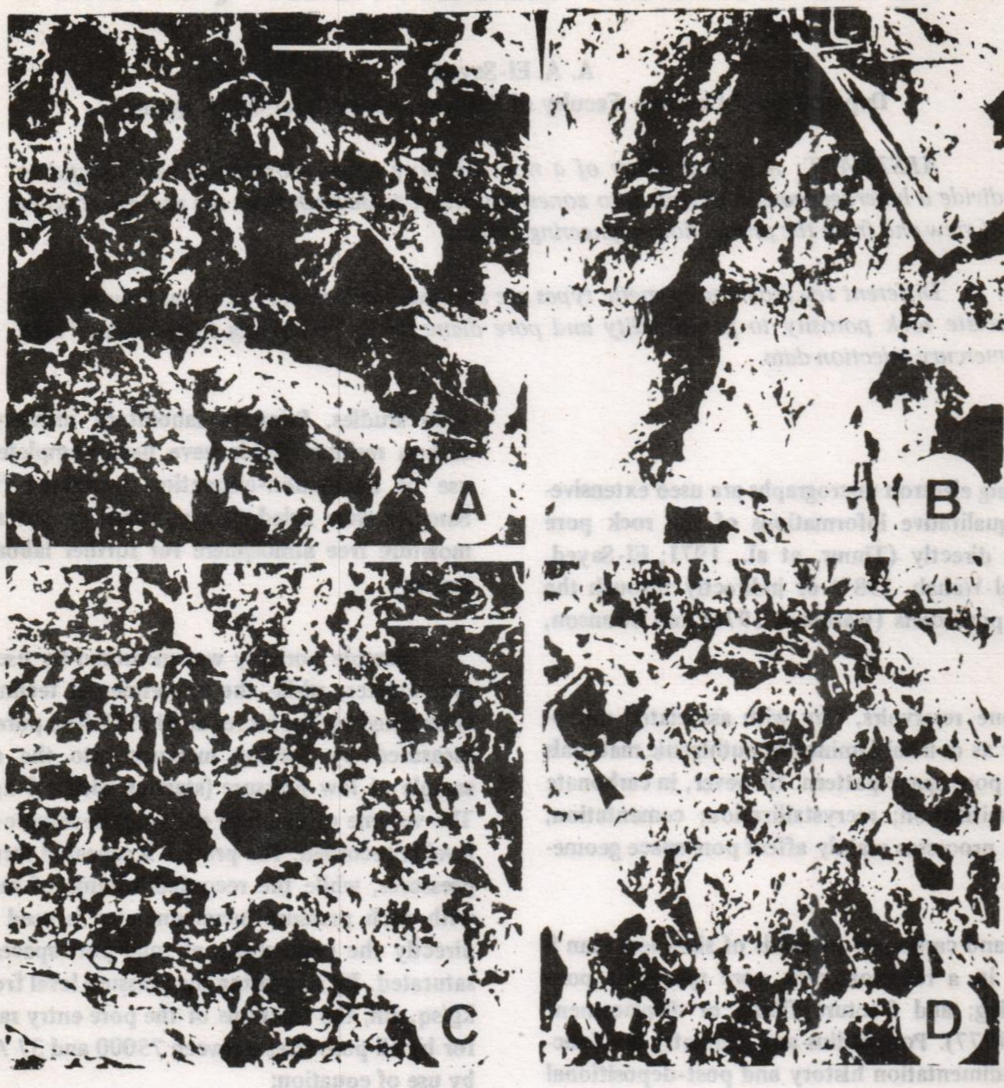

Plate-1. SEM micrographs for different reservoir rock genetic types. A. barrier bar sandstone of Algyo-2 reservoir, at Algyo field (Hungary), sample is from well No. 210, core No. 2/3, from the depth interval 1928.41 to 1928.64m, cementing materials are kaolinite and illite, with crystals of dolomite (arrow head). B. sandstone of distributary channel rock type, sample is from well No. 314 at Algyo field, core No. 1/a, from the depth interval 1925.27 to 1925.42 m, clean sandstone with large quartz crystals. C. deltaic fringe sandstone of Algyo field, well No. 149, core No. 1/13, depth interval 1951.00 to 1951.40 m, kaolinite perhaps the most common authigenic clay forms well crystallized books (arrow), micropores in clays are common (arrow head). D. shaly sandstone of deltaic fringe rock genetic type, from Algyo field, well No. 339, core No. 3/2, depth interval 1948.85 to 1949.04 m, rhombohedral dolomite is present as small (arrow) and large crystals (arrow head). Scale line equals 10 um.

Scannng electron micrographs are made by use of a Jeol-JSM 35. The microscope general discription, principles, operation, and applications are discussed by Hashimoto, et al. (1973). The scanning electron microscope provides several unique advantages to the geologists or engineers when compared with other types of microscopes. It has different advantages such as great magnification range (15x to 40,000x) three dimensional image; non-destructive rock sample study; great depth of field under examination and ease of sample preparation.

RESULTS AND DISCUSSION

The first example is of the Algyo-2 sandstone of Algyo field, which is a fine grained sandstone with intergranular porosity. Plate-1A shows a SEM micrograph of this type. It belongs to a deltaic barrier bar depositional origin (El-Sayed, 1981). The rock has 29.39% porosity and 0.412 um^2 of permeability.

Figure-1(a) exhibits the mercury injection curve of the deltaic barrier bar sandstone. It reveals very large(Mz = 7.11 phi), very poorly sorted, lepto- kurtic and nearly symmetrical skewness pore aperatures exhibiting desirable characteristics for a very good reservoir rock. The sample has quartz over-growths and pore lining clays. Clay minerals are mainly kaolinite and illite. In addition, very small amounts of dolomite crystals exist in the rock formation fines (less than 5/um in size) as cementing materials. A scanning electron micrograph (Plate-1A) shows that the pores are interconnected in a three dimensional net-work.

The solid curve (Fig. 1B) is for an Algyo"-2 sandstone (Plate-1B) of a deltaic distributary channel rock genetic type. It indicates a relatively coarse interconnected pore system that permits a reasonably higher permeability than that of the deltaic barrier bar type. The calculated statistical parameters of pore throat size for sample-314C.1/A(Fig.1B) indicates that it has large (Mz = 8.25 phi), very poorly sorted, leptokurtic and positive skewness pore aperatures. Both SEM micrographs (Plates 1A&B) and pore throat size distribution curves (Figs. 1A&B) reveal features of a good quality sandstone reservoirs.

The next example is represented by two shaly sandstone samples. They are attributed to the Algyo"-2 deltaic fringe rock genetic type (El-Sayed, 1981). The rock sample (Fig. 2A) has 12.52% porosity and $0.0007/um^2$ permeability. Most of the porosity is non-effective microporosity among the clay particles (Plate-1C). Intergranular porosity is filled by clay minerals, which have reduced pore aperatures. The mercury injection curve depicted by the dotted line indicate that the break in the curve is at about 15.5 phi. Even though the rock has reasonable porosity (12.52%), the rock permeability is extremely low and the pore throat mean size is very small (Mz = 14.0 phi). This particular rock did not yield hydrocarbons. Such rock had high water saturation due to the presence of irreducible water in the clay film coating rock grains.

In order to enhance this particular sandstone to become a reservoir rock, irreducible water would have to be displaced by hydrocarbons and the rock to be fractured either naturally or artificially.

The solid curve (Fig. 2B) is for a sandstone sample It belongs to the Alygo"-2 deltaic fringe rock genetic type. It is obtained from a productive interval. The curve shows that the pore mean size is larger (Mz = 9.59 phi) than that of the dotted curve. It has also higher permeability, although the porosity is lower. Both of them (Figs. 2A&2B) has an abundant authigenic clay minerals and few dolomites as cementing materials that reduce pore aperatures. However, its frequent occurrence is completely different. Clay pore filling characterizes the sample illustrated by the SEM micrograph (Plate-1C). Scanning electron micrograph (Plate-1D) reveals both authigenic clays and quartz overgrowths occuring as pore lining.

Plate-2A, shows a SEM micrograph of a limestone sample. It belongs to the Nukhul Formation of Miocene age (Gulg of Suez, Egypt.) The limestone sample has 7.01 % porosity and $0.0048/um^2$ permeability. Most of the porosity is intercrystalline type. However, calcite and dolomite microcrystals are filling the rock intercrystalline pores. This example contrasts the effect of calcite-dolomite pore fillings on both porosity and permeability. The rock has large pore apearatures, Mz = 8.52 phi), however, most of them are disconnected.

Plate-2B, exhibits a SEM micrograph of a shaly sandstone sample. The sample belongs to the Belayim Formation of Miocene age (Gulf of Suez, Egypt). The rock sample has 4.30% porosity and $0.0021/um^2$ permeability. The study of the scanning electron micrograph indicates that the rock porosity is mostly due to existent micropores among the detrital and authigenic clay minerals. Either clays filled pore spaces or coated rock grains have participated effectively in both rock porosity and permeability reduction. Such types of reservoir rocks have very low fluid storage capacity and low productive capabilities.

The above mentioned cases are good examples of how pore geometry controls fluid flow and immobile water saturation. The scanning electron micrographs (Plate-1A&B) indicate large intergranular pores. Such type of pores maight hold mobile fluids such as gas; oil and water. Contrarily, scanning electron micrographs (Plates-1C&2B) reveal micropores which can hold immobile and irreducible water that constricts pore space pattern and confuses wire-

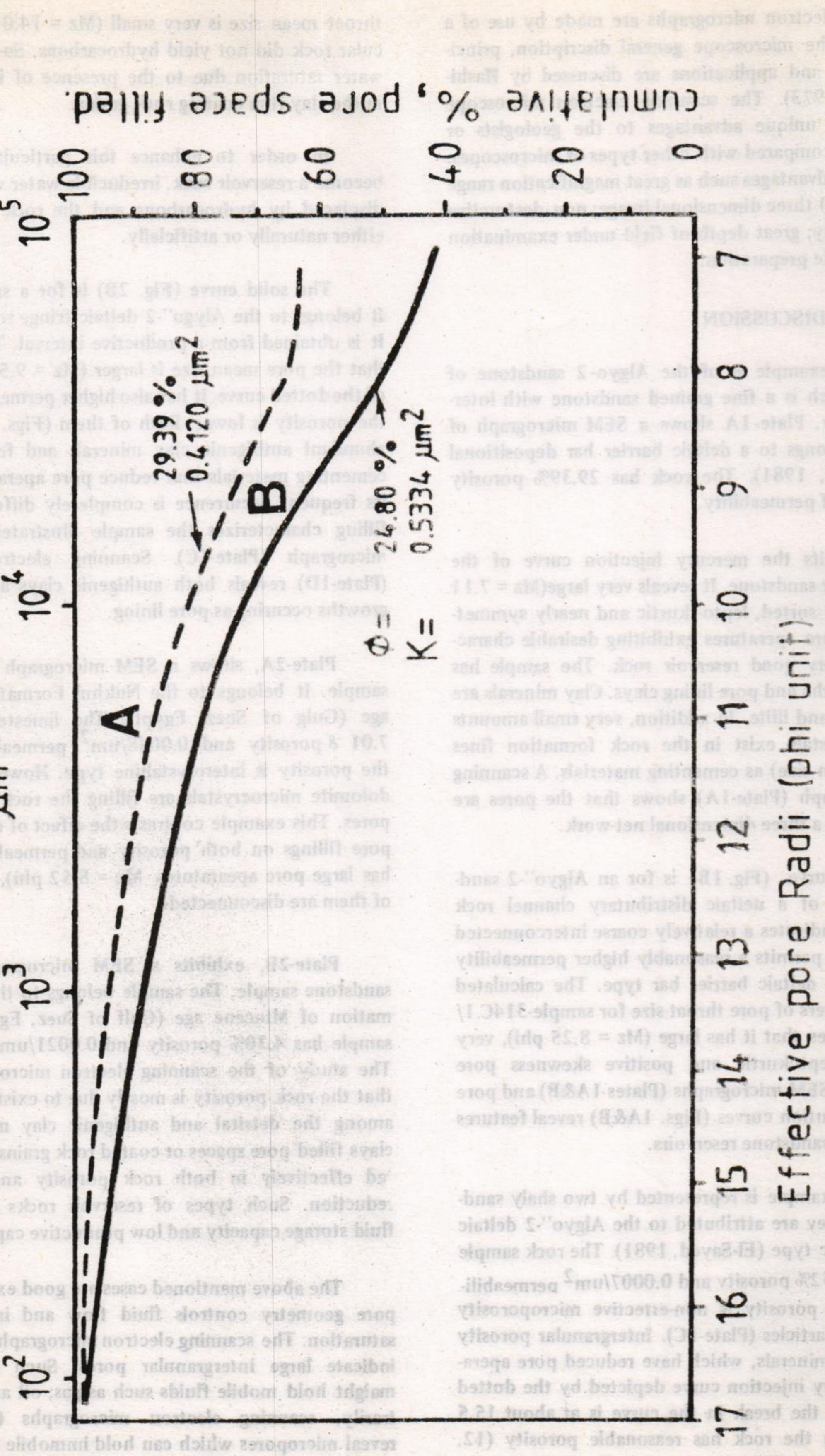

Fig. 1 Mercury injection curves of good sandstone reservoirs.

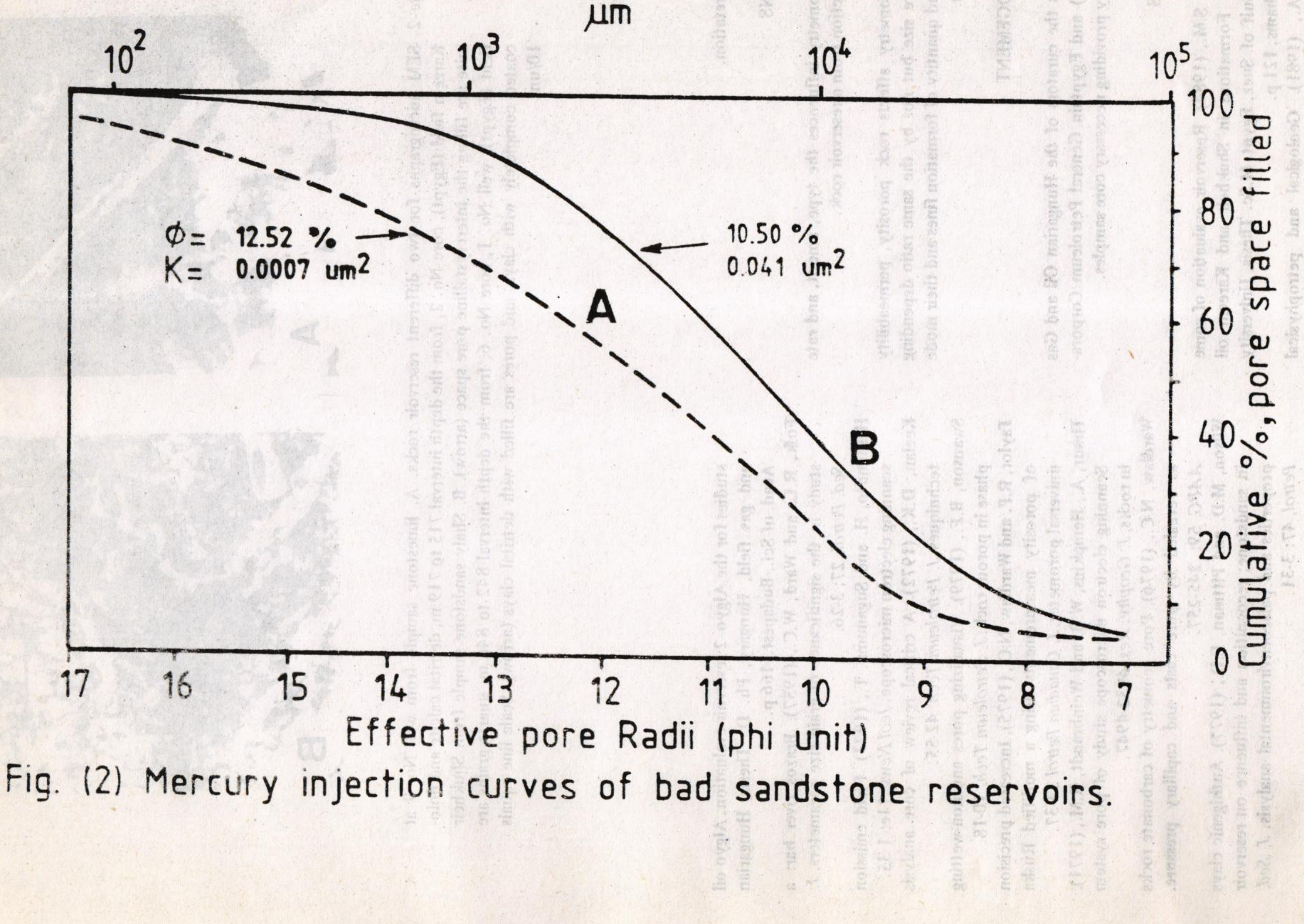

Fig. (2) Mercury injection curves of bad sandstone reservoirs.

Plate-2. SEM micrographs for two different reservoir rocks. A. limestone sample from well No. 9 at Kareem field (Egypt), core No. 2, from the depth interval 715 to 719 m, detrital calcite and dolomite are filling the intercrystalline pore space (arrow). B. Shaly sandstone sample from Shukheir field (Egypt), well No. 1, core No. 6, from the depth interval 842 to 846 m, quartz grains are coated completely with clays, and pores are filled with detrital clays (arrow). Scale line equals 10/um.

line log interpretation.

CONCLUSIONS

1. Pore geometry influences the type, amont, and rate of fluid production from a reservoir rock.

2. Pore geometry affects rock porosity, permeability as well as pore size but not by the same ratio depending on the type and quantity of formation fines and their mode of occurrences.

ACKNOWLEDGEMENT

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A NEW BUNODONT SUID FROM SIWALIKS OF PAKISTAN

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ABSTRACT:– Three mandibular rami bearing low crowned and bunodont artiodactyle teeth and an isolated bunodont tooth have been recovered from various localities of Middle and Upper Siwaliks of Punjab, Pakistan. This new material is described as Dicoryphochoerus mirkhalensis sp. n. It was a fairly gigantic suid and was porbably the culminating species of the genus.

INTRODUCTION

Genus *Dicoryphochoerus* was erected by Pilgrim in 1926. He included nine species in this genus which are *Dicoryphochoerus chisholmi, D. haydeni, D. instabilis, D. robustus, D. titan, D. titanoides, D. vinayaki, D. vagus* and *D. durandi.* According to Colbert (1935), the species *D. chisholmi* and *D. instabilis* are represented by quite insufficient material and their validity is uncertain. He also questioned the validity of the species *D. vagus.* About *D. titanoides* he remarked that it is very much allied to the species *D. chisholmi.* Among the remaining species, *D. titan* is the largest. After Colbert (op. cit), little attention has been paid to the studies of the large bunodont suids of the Siwaliks by any worker. The present study is based upon the three fairly preserved mandibular rami bearing P_4 and the molars and an isolated molar from the various localities of the Middle and Upper Siwaliks. A detailed study has revealed that a specific distinction occurs between the said material and the species *Dicoryphochoerus titan.* This new species is designated as *Dicoryphochoerus mirkhalensis* after the name of the type locality.

SYSTEMATIC ACCOUNT

Order	ARTIODACTYLA Owen
Suborder	SUINA Gray
Superfamily	SUOIDEA Cope
Family	SUIDAE Gray
Subfamily	SUINAE Zittel
Genus	*DICORYPHOCHOREUS* Pilgrim, 1926.

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*Punjab University Palaeontological collection stored in Zoology Department at Lahore. Pakistan.

DICORYPHOCHOERUS MIRKHALENSIS new species

TYPE

P.U.P.C*. No. 68/111, a right madibular ramus bearing P4, M_1 and M_2.

TYPE LOCALITY

Mirkhal, district Chakwal, Punjab, Pakistan.

HORIZON

Dhokpathanian of the Middle Siwaliks and Tatrotian of the Upper Siwaliks.

HYPODIGM

1. P.U.P.C. No. 68/111, the type specimen.
2. P.U.P.C. No. 67/5, a left mandibular ramus bearing M_{1-3} from Bhandar, district Jhelum, Punjab, Pakistan.
3. P.U.P.C. No. 69/237, a right mandibular fragment bearing an M_2 from Dhok Gaal, district Jhelum, Punjab, Pakistan.
4. P.U.P.C. No. 69/362, a right mandibular fragment bearing M_1-3 from Tatrot, district Jhelum, Punjab, Pakistan.

DIAGNOSIS:

Metaconid bifurcated into two widely separated inner and outer conelets. Two accessory cusps present between the metaconid and the talonid. M_1 and M_2 with large hypoconulid. M_3 with very large heel.

DISTRIBUTION:

Mirkhal, district Chakwal, Dhok Gaal, Tatrot and Bhandar, district Jhelum, Punjab, Pakistan.

DESCRIPTION: (Fig. 1):

P_4

The tooth (P.U.P.C. No. 68/111) is very well preserved and is inserted into the right mandibular ramus. It is subhypsodont with moderate crown height. In a lateral view, the tooth appears to be pyramidal with the highest central cusp slopping anteriorly as well as posteriorly. The protoconid, metaconid and talonid are well defined. Protoconid and talonid are equally high (Table 1). Protoconid is a single tubercle with a shallow valley posterior to it. Anterior to it there is a small papilla which is the cingular growth. Metaconid is conspicuously bifurcated into two strong pillars of equal thickness. Of these, the outer one is anterior in position than the inner one. The inner tubercle is comparatively high vertically. The outer surface of the buccal cusp shows two weak vertical styles. The anterior face of the lingual cusp is simple and rounded whereas the posterior face is bifurcated due to posteriorly directed shallow groove. Posterior to the metaconid, there are two small accessory tubercles. Talonid or heel is quite thick and just touched by wear. It is unituberculated with two anterior and two posterior ridges. The posterior ridges are continuous with the posterior cingulum.

TABLE – 1

Measurements (in mm.) of P_4 in *Dicoryphochoerus mirkhalensis* **new species.**

Length	26
Width	19
Width/Length index	73
Height of Protoconid	16
Height of Metaconid	22
Height of talonid	16.5
Height/Width index	110

TABLE – 2

Measurements (in mm.) of M_1 in *Dicoryphochoerus mirkhalensis* **new species.**

	P.U.P.C. No. 68/111	P.U.P.C. No. 67/5	P.U.P.C. No. 69/362
Length	28	26	26
Width (anterior half)	19	20	22
Width (posterior half)	19	21	20
Width/length index	70	81	85
Preserved height	14	13	12
Reconstructed height	20	20	20
Height/Width index	105	95	100

M_1 (Figs. 1, 2&4):

Of the three lower first molars, the specimen P.U.P.C. No. 68/111 is well preserved. All the teeth are brachyodont with varying degree of wear. Enamel layer is thick, simple and shining. Cingulum is well-marked at the posterior and outer faces. At the outer side, it blocks the median transverse valley by the formation of a thick tubercle or pillar. Anterior end of the tooth is transversely linear whereas the posterior contour is almost rounded due to fairly developed hypoconulid. Enamel layer is thick. The major cusps are produced into a cross "X-like" structure due to the anteroposterior and transverse vertical grooves. The anteroposterior grooves are more prominent in the inner conids than the outer conids. The median conulid is low and is of moderate size. In all the three teeth, it is worn and its dentinal islet has become contiguous with that of the hypoconid. The dentinal islet of principal conids are still isolated.

M_2 (Figs. 1,2,3&4):

All the teeth are well preserved except the P.U.P.C. No. 68/237 in which the metaconid is slightly damaged at the anterior side. Teeth are elongated and brachyodont (Table 1). Enamel layer is thick and somewhat rugose at the lingual side. Cingulum can be seen at the anterior, posterior and at the outer side. At the outer side it produces a small-sized tubercle in between the outer cusps. median accessory conulid is fairly large. Metaconid is the largest of all the principal cusps both in height as well as

Fig. 1a

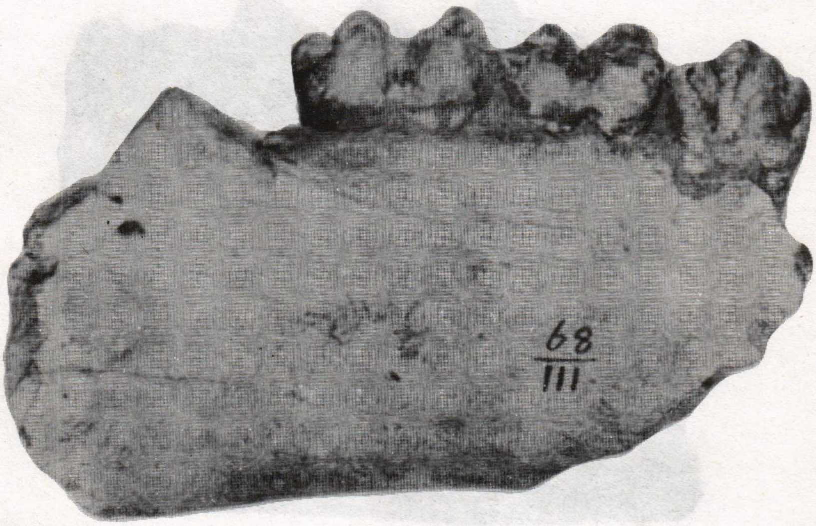

Fig. 1b

Fig. 1c

Fig. 2a

Fig. 2b

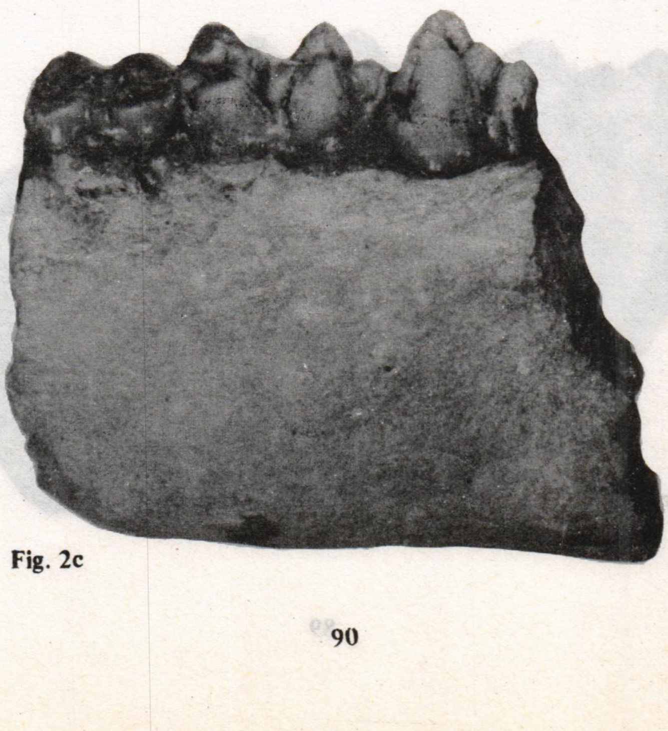

Fig. 2c

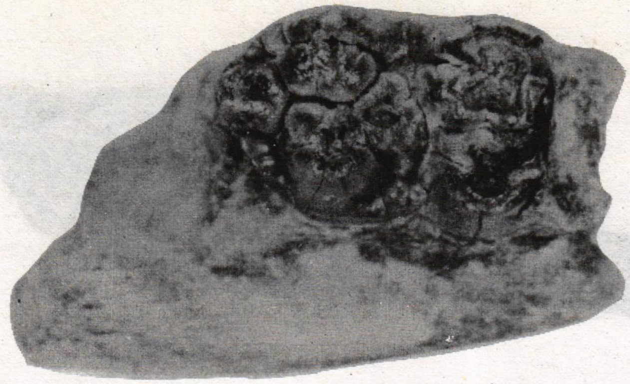

Fig. 3a

Fig. 3b

Fig. 3c

Fig. 4a

Fig. 4b

Fig. 4c

TABLE – 3

Measurements (in mm.) of M_2 in
***Dicoryphochoerus mirkhalensis* new species.**

	P.U.P.C. No. 68/111	P.U.P.C. No. 67/5	P.U.P.C. No. 69/237	P.U.P.C. No. 69/362
Length	36	37	39	37
Width (Anterior half)	26	25	26	27
Width (posterior half)	25	26	25	26
Width/Length index	66	70	66	72
Preserved height	19	22	19	20
Reconstructed height	23	–	23	26
Height/Width index	88	85	88	98

TABLE – 4

Measurements (in mm.) of M3 in
***Dicoryphochoerus mirkhalensis* new species.**

	P.U.P.C. No. 67/5	P.U.P.C. No. 69/362
Length	–	64
Width (anterior half)	30	32
Width (posterior half)	–	29
Width/Length index	–	50
Preserved hegith	26	27
Reconstructed height	–	34
Height/Width index	87	107

in diameter. Heel is fairly developed in all the four molars.

M_3 (Figs. 2&4):

The last lower molar is much elongated. It is damaged in P.U.P.C. No. 67/5 but complete and excellently preserved in P.U.P.C. No. 69/362. Cingulum is present at the anterior and posterior sides. At the outer side, it can be seen at the entrance of the transverse valleys. Like the anterior molars, its metaconid is also high and thick. Median accessory cusp completely blocks the transverse valley. The hypoconulid present between the posterior cusps and the talonid is even stronger than the actual median accessory cusp. Talonid is a very strong structure and in vertical height it almost approaches the posterior cusps. It comprises a very large outer and a very small inner cusp. The outer cusp is in line with the outer principal cusps of the molar series. Posteriorly, the talonid is completely encircled by the tuberculated cingulum.

DISCUSSION

The mandible is quite gigantic in all the specimens. P_4 is fairly large and robust with prominent bifurcation of the central cusp. The two cusps are not in line but rather outer and inner in position. However, the inner of the two stands somewhat posterior to the other. The central cusp is not bifurcated in the genera *Conohyus, Sivachoerus* and *Propotamochoerus* (Pilgrim, 1926) and *Tetracondon* (Falconer, 1868). Teeth of the genus *Propalaeochoerus* and *Sus* show resemblance with those of the specimen under study. A detailed study, however, shows that more simplicity may be seen in the teeth of the genus *Propalaeochoerus* (Stehlin, 1929). Moreover, P_4 in the present specimens is comparatively much robust. It is bifurcated in the genera *Sus* (Colbert, 1935), *Hippohyus* (Falconer and Cautley, 1847), *Hyosus* (Pilgrim, 1926), *Sivahyus* (Pilgrim, 1926) and *Sanitherium* (von Meyer, 1866). Thus it resembles the P_4 of the specimens under study. However, a close examination indicates that anterior and posterior ends in P_4 are more elevated in P.U.P.C. No. 68/111 than in those of the above said genera. Thus, it makes differentiation between the two. P_4 of the specimens under study when compared with that of the genus *Dicoryphochoerus* indicates that the two cannot be separated. The overall size and morphology of the principal cusps of *P4* in P.U.P.C.

TABLE – 5

Comparative measurements (in mm.) of teeth in *Dicoryphochoerus mirkhalensis* n.sp. and *D. titan*

	Dicoryphochoerus mirkhalensis			*Dicoryphochoerus titan*		
	Width	**Length**	**Width/ Length index**	**Width**	**Length**	**Width/ Length index**
P_4	19	26	73	16	19	84
M_1	19-22	26-28	70-85	22	25	87
M_2	26-27	36-39	66-72	26	32	80
M_3	30-32	64	50	36	60	59

No. 68/111 is entirely the same which has been cited as the characteristic features of the genus *Dicoryphochoerus* by Pilgrim (1926).

There are two accessory cusps between the central bifurcated cusp and the talonid in P_4. This feature alone is sufficient to exclude the specimen under study from the known material of the species of the genus *Dicoryphochoerus* in which the accessory cusp is either single or absent (Pilgrim, 1926).

Large size of the hypoconulid in first molars of the specimen, P.U.P.C. No. 68/111, 67/5 and 69/362 is noteworthy. Due to its large size, the posterior end of molars has become conical. Such a structure is normally met with the last molars. First molars are comparatively elongated than those of the species, *Dicoryphochoerus titan* (Table 5). In *D. titan,* these teeth are broad (Lydekker, 1884).

Second lower molars are also like the first molars. They also exhibit the characters of the same nature. They are also elongated than those of the species, *Dicoryphochoerus titan* Table 5).

Last molar is very much elongated. Its heel is enormously bigger and wider than that of the species, *Dicoryphochoerus titan.*

Accessory cusps found in P_4, the presence of large hypoconulid in M_1 and M_2, the large heel in M_3 and the width/length indices of the molars do not allow the inclusion of the specimens under study in any of the known species of the genus *Dicoryphochoerus* and rather warrant the erection of a new species. This new form is named as *Dicoryphochoerus mirkhalensis* after the name of the type locality.

Hypoconulid may be seen even in the palaeodonts such as *Antiacodon* (West, 1984). It was initiated in Palaeogene and culminated in the suid genera like *Dicoryphochoerus* and *Sus.* The presence of hypoconulid in the intermediate molars, longer heel in last molar and the two accessory cusps in P_4 had made the cheek teeth much more complicated and efficient grinding mills than those of the other species of the genus *Dicoryphochoerus.* On the basis of this advancement of cheek teeth, it became possible for this species to continue to survive to a fairly late date i.e. Tatrotian of the Upper Siwaliks.

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A NEW SIVATHERINE GIRAFF FROM PABBI HILLS OF POTWAR PAKISTAN

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ABSTRACT: *A large-sized giraffid upper second molar has been described. A thorough investigation has revealed that it may be included in the genus Bramatherium but as a new species, Bramatherium geraadsi.*

INTRODUCTION

At present giraffes are only found in the Aethiopean region (Beaufort, 1951) but they were widely distributed in Neogene of Asia (Colbert, 1935; West, 1981), Europe (Geraads, 1977) and Africa (Churcher, 1979; Geraads, 1985). Siwaliks are well known for the fossil giraffes and have yielded a number of specimens. These have been worked out by different workers such as Falconer and Cautley (1836), Falconer (1845), Lydekker (1876), Lydekker (1878), Pilgrim (1910, 1911), Matthew (1929) and Colbert (1935). All the three subfamilies of the family giraffidae are known from the Siwaliks. The subfamily Sivatheriinae is known by 7 genera of which 6 known from the Siwaliks. The present specimen which is an upper second molar was procured from the upper Siwalik beds exposed near Sardhok, District Gujrat, Punjab, Pakistan. It represents a new species of the genus *Bramatherium*. The name *Bramatherium geraadsi* has been assigned to this new species.

Abbreviations used are as follows:–

Brit. Mus.	British Museum of Natural History.
H.	Crown height.
L.	Anteroposterior length of the corwn.
l.	Left.
P.U.P.C.	Fossil collection stored in the zoology Department, Punjab University, Lahore, Pakistan.
r.	Right.
W.	Transverse width of the crown.

SYSTEMATIC ACCOUNT

Order	ARTIODACTYLA	Owen
Suborder	RUMINANTIA	Scopoli
Infraorder	PECORA	Linnaeus
Superfamily	GIRAFFOIDEA	Simpson
Family	GIRAFFIDAE	Gray
Subfamily	SIVATHERIINAE	Zittel
Genus	BRAMATHERIUM	Falconer

BRAMATHERIUM GERAADSI new species

(Figs. 1)

TYPE

P.U.P.C. No. 86/24, an upper second molar of the left side.

HYPODIGM

Type only.

TYPE LOCALITY

Sardhok, District Gujrat, Punjab, Pakistan.

HORIZON

Pinjorian of the Upper Siwaliks.

DIAGNOSIS

Probably the largest of the known Sivatherines. Protocone L-shaped. Medium folds of the outer cusps isolated. Medium ribs of the outer cusps well pronounced.

DESCRIPTION

The tooth, P.U.P.C. 86/24 is quite gigantic. In general contours, it is square-shaped with almost equal length and width of the crown (Table 1). It is nicely preserved except for the antero-internal side. The tooth was in early stage of wear which is indicated by the partial unworn surface of the posterior cusps. The overall contours of the molar tooth indicate that it was inserted into the left maxilla. The presence of a weak pressure mark at the posterior face of the tooth indicates that it was not the last of the molar series. Since the anterior half is fairly bigger than the posterior half, the tooth can be labelled as the second molar of the series. Cingulum can be seen anteriorly, posteriorly as well as outwardly. The inner face of the protocone is damaged but even then it can be said that a weak cingulum was present at the inner side of the tooth. It is inferred from the inner face of the metaconule and the opening of the transverse valley. Anterior cingulum is weaker than the posterior one, however, it covers the whole surface. To the outer side, it runs upwards to meet the parastyle. Inwardly, it slopes down to the crown base. The overall shape of the posterior cingulum is also the same but being comparatively stronger, it produces a sort of shelf at the middle length. Outwardly, the cingulum covers only the paracone where it is crenulated and folded structure. Anterior half of the tooth is narrower longitudinally than the posterior one.

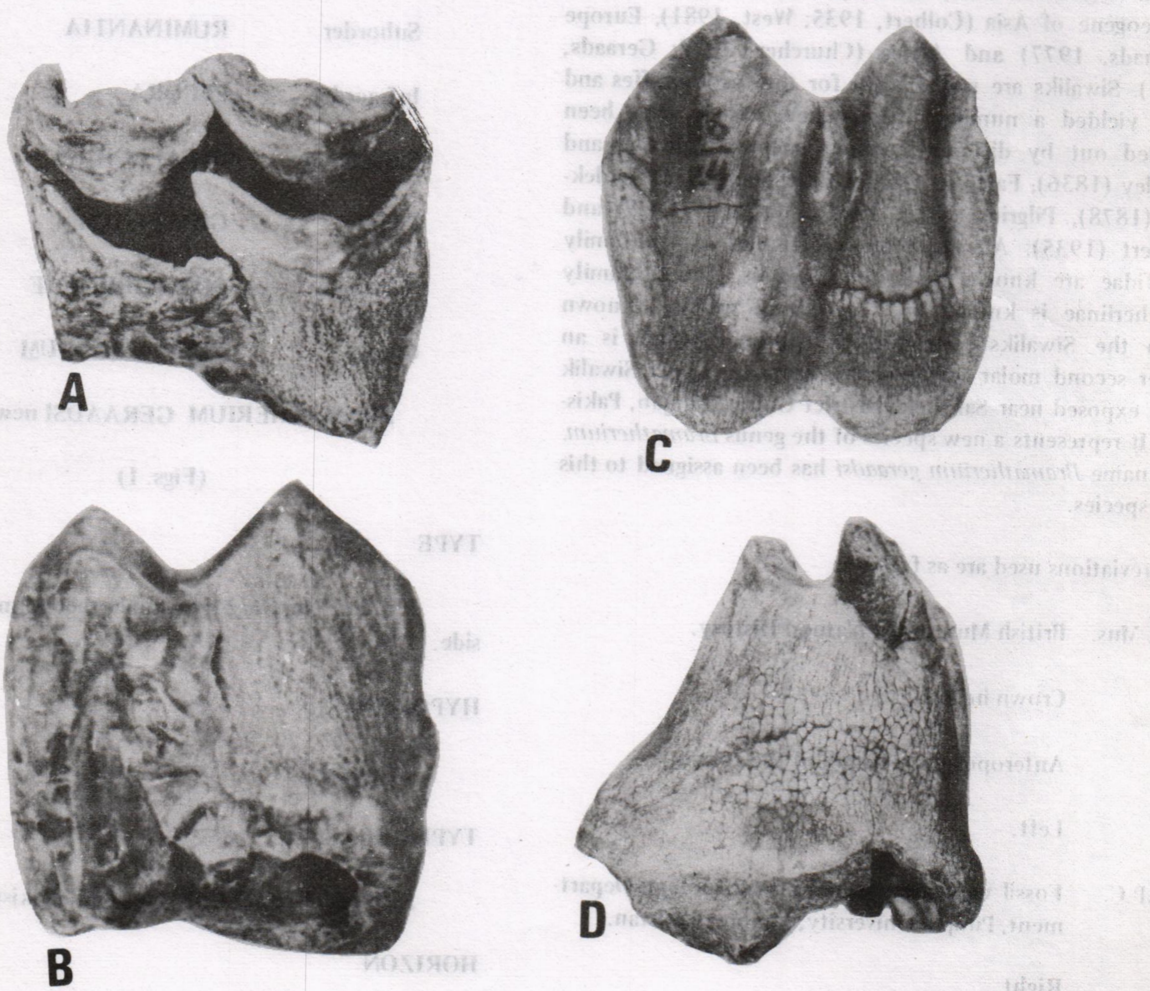

Fig. 1 Type specimen (P.U.P.C. No. 86/24) of *Bramatherium geraadsi* n. sp. A crown view: B, inner view. C, outer view. D. Posterior view. Natural size.

Protocone is damaged at the inner face. The damaged face gives the detail of the tooth structure. Enamel layer is moderately thick, the pulp cavity extends far up in the crown of the cusp. Protocone is L-shaped with the posterior limb comparatively longer than the anterior one. The posterior limb is free for the most of the vertical depth. However, it is so much close to the metaconule that it completely blocks the longitudinal valley at the lingual side. Looking at its worn surface, a vertical ridge can be seen close to the posterior and towards the longitudinal valley. This limb slopes abruptly towards the metaconule. It remains equally thicker throughout its length. The anterior limb gradually reduces in thickness towards the outer side. It gently slopes anteriorly where ultimately it is connected with the paracone through a shallow nnd narrow ridge. The anterior face of the cusp is somewhat corrugated. At present, the protocone is low in vertical crown height than the paracone.

Paracone is excellently preserved and is much folded anteriorly, posteriorly and in the middle producing thereby parastyle, mesostyle and the median rib. Paracone is spindle-shaped with maximum thickness in the middle, where it produces a median rib at the buccal side and a buldging in the longitudinal valley. The anterior side is much folded. This vertical fold or parastyle becomes stronger and stronger towards the crown apex. Towards the apex, it overlaps the outer surface of the cone to some extent. The outer surface of the cusp is highly corrugated. The cusp is highest in the middle, sloping down towards the anterior and posterior ends.

Like the anterior end, the posterior end is also highly folded. For the small distance, it is free from the metacone, however, they are so close together that they appear to be fused. The posterior end of the paracone and the anterior end of the metacone form a vertical loop known as mesostyle. Metacone plays a major role in the formation of mesostyle. The longitudinal valley between the anterior cusps is transversely narrower anteriorly than posteriorly. Posteriorly, it becomes fairly wide and is continuous with the valley present between the posterior cusps through a narrow channel.

Metacone is comparatively much longer than the paracone. Its enamel surface is as much corrugated as that of the paracone. Towards the crown base, its longth is the same as that of the paracone. The overall shape of the metacone is like that of the paracone. However, its anterior and posterior folds are comparatively less worn than the paracone. The crescent of this cusp is highest in the middle with anterior and posterior slopes. Like paracone, metacone is also spindle-shaped with maximum thickness in the middle of the cusp. The median rib is comparatively blunt and rounded. The posterior wing of the metacone is very slightly worn with little exposure of its dentinal material. Posteriorly, it becomes much narrow to form a shallow ridge. This shallow ridge is connected with the hypocone through a narrower rounded loop. The inner enamel border of the cusp is simple and rounded. The valley present between the posterior cusps of comparatively shallower. It remains uniform in transverse diameter throughout its extent.

Metaconule is typically crescentic with anterior and posterior wings of equal dimensions. It is maximum high in the centre with gentle slopes at either sides. Outer margin o of the cusp is vertical whereas the inner or lingual side is sloping with conspicuous rugosity. The outer border is not simple, rather it is folded. A vertical fold of moderate size can be seen in the centre of the cusp and a weak one close to the posterior end. This posterior fold is developed at both borders of the cusp at the same point.

DISCUSSION

The specimen being a very large selenodont tooth with rugose enamel may be referred to the family Giraffidae. Simpson (1945) divided the family into 3 subfamilies i.e. Palaeotraginae, Giraffinae and Sivatheriinae. The subfamily Palaeotraginae includes the primitive ancestral forms, Giraffinae includes smaller giraffes and the extant species and the Sivatheriinae includes the larger giraffes (Colbert, 1935). Since the specimen under study is a fairly large tooth, it may be referred to the subfamily Sivatheriinae. Subfamily Sivatheriinae is known by 7 genera. Of these, 6 are known from the Siwaliks. These are the genera *Sivatherium* founded by Falconer and Cautley (1836), *Bramatherium* described by Falconer (1845), *Vishnutherium* described by Lydekker (1876), *Hydaspitherium* reported by Lydekker (1878), *Indratherium* reported by Pilgrim (1910) and *Helladotherium* erected by Gaudry (1861). *Helladotherium* is also known from Europe (Piveteau, 1961). The non-Siwalik form is the genus *Griquatherium* known from Africa (Haughton, 1922). In the genus *Sivatherium* the protocone is truely crescentic and its posterior limb is projected backwardly (Falconer and Cautley, 1836), whereas it is L-shaped in the specimen under study. In the genus *Vishnutherium* the molars are with truely crescentic inner cusps (Lydekker, 1876), hence different from the L-shaped inner cusps of the specimen under study. According to Geraads (1986), the genus *Vishnutherium* is not a valid genus and may be included under the synonymy of the genus *Sivatherium*. Like the specimen under study, the members of the genus *Hydaspitherium* were also gigantic giraffid. Regarding size, it is comparable with the members of the genus *Hydaspitherium*. However, the two differ in the structure of protocone which is crescentic in *Hydaspitherium* (Lydekker, 1880) but L-shaped in P.U.P.C. 86/24. Gerad's opinion (1986), the genus *Hydaspitherium* is not differentiated from the genus *Sivatherium* and it may be

TABLE – 1

MEASUREMENTS (in mm) OF M^2 (P.U.P.C.86/24) IN *Bramatherium geraadsi* NEW SPECIES

L	56
L (anterior half)	27
L (posterior half)	32
W	53
W (anterior half)	38
Reconstructed width of the anterior half	56
W (posterior half)	53
W/L index	95
H	56
H (reconstructed)	60
H/W index	112
Enamel thickness	2

TABLE – 2

COMPARATIVE MEASUREMENTS (in mm) OF THE IM^2 IN VARIOUS GENERA OF LARGER GIRAFFIDS AND *Bramatherium geraadsi* NEW SPECIES

	L	W	H	W/L index	H/W index
Hydaspitherium	38	40	–	107	–
Helladotherium	44	44	42	100	96
Vishnutherium	45-49	41	–	4-92	–
Sivatherium	55-56	52-56	41	95-100	74-79
Bramatherium perimense	42	39	–	94	–
Bramatherium geraadsi	56	58	57	95	112

placed under the synonymy of the genus *Sivatherium*. The molars in the genus *Indratherium* are similar to those of the species *Hydaspitherium grande* (pilgrim, 1911), hence cannot be compared with the specimen under study. In the genus *Helladotherium*, the molars are provided with an enamel island in the hypocone (Gaudry, 1861), whereas, there is no such development in the molar under study. Moreover, *Helladotherium* was comparatively a smaller form (Table-2). In the genus *Bramatherium* the protocone is not V-shaped and its posterior limb is rather L-shaped (Falconer, 1845). It is therefore, advisable to regard the specimen under study as congeneric with *Bramatherium*. The genus is known by a single species i.e. *Bramatherium perimense*. This species is known from Perim Island, India. The last upper molar of this species is too small to be compared with the specimen under study (Table 2 .!The tooth, P.U.P.C. 86/24 is quite gigantic with highly pronounced medium rib of the outer cusps. It is comparatively weaker in the type specimen (Brit. Mus. No. 48933) of the species *Bramatherium perimense*. Being different from *B. perimense* the specimen under study is referable as a new species. It is being designated as *Bramatherium geraadsi* which is in recognition to the excellent work of Denis Geraads on the phylogeny of the family Giraffidae.

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A GIANT TETRACONODONT SPECIES FROM MIDDLE SIWALIKS OF DUDIAL, AZAD KASHMIR, PAKISTAN

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ABSTRACT:– A very large-sized Tetraconodont maxilla bearing last two molars, roots of first molar and root impression of the last premolar has been described from the Middle Siwalik beds exposed along the River Punch near Dudial, Azad Kashmir, Pakistan. Its comparison with the known species of the genus has proved it to be a new species. Regarding size, it happened to be the largest of the known tetraconodonts. The name, Tetraconodon dudialensis, has been proposed for this new species.

INTRODUCTION

Genus *Tetraconodon* and the genotypic species, *T. magnus* was founded by Falconer (1868) on the evidene of a maxillary fragment bearing ultimate and penultimate molars. The specimen was in the Bakr and Durand's collection and appears to have been lost and no other specimen was discovered till the Lydekker's report (1876) of a fragmentary mandible from Hasnot (Punjab, Pakistan). The mandible is characterised by the premolars of considerably large size and broad molars. Lydekker (op. cit.) included it in the species *T. magnus.* In 1926, Pilgrim described two new species i.e. *T. minor* and *T. mirabilis.* In the species, *T. minor*, he included three specimens from Irrawaddy Series of Burma. In the species, *T. mirabilis*, he included two specimens, one from Haritalyanger and the other from Jammu. In 1935, Colbert reported a maxillary fragment (Amer. Mus. No. 19750) of *T. minor* from Bhandar Bone Beds of district Jhelum, Punjab, Pakistan. Abubakr and Akhtar (1987) described a number of suids from the Siwaliks but described not even a single specimen of the genus *Tetraconodon.* Thus, there is no report of the genus from anywhere else subsequent to the Colbert's (op. cit.) work. The specimen, P.U.P.C. 88/2, being described here, consists of Excellently preserved last two molars, roots of the first molar and the root impression of the last premolar. It was procured from the Dhokpathanian of Dudial exposed along the River Punch, Azad Kashmir, Pakistan. It is the first record of the tetraconodonts from Azad Kashmir area. In size, it surpasses all the known members of the genus.

The abbreviations used are as follows:

Amer. Mus.	American Museum of Natural History
Ind. Mus.	Indian Museum, Calcutta.
P.U.P.C.	Fossil collection stored in the Zoology Department, Punjab University, Lahore. Pakistan.

SYSTEMATIC DESCRIPTION

Order Artiodactyla Owen

Suborder Suina Gray

Superfamily Suoidea Cope

Family Suidae Gray.

Subfamily Tetraconodontinae Simpson

Genus *Tetraconodon* Falconer

Tetracondon dudialensis new species

(Figs. 1)

Holotype:

P.U.P.C. 88/2, a left maxillary fragment bearing M^{2-3}, roots of M^1 and root impression of p^4.

Hypodigm:

Type only.

Locality:

About two kilometers east of Dudial, Azad Kashmir, Pakistan.

Horizon:

Dhokpathanian of the Middle Siwaliks.

Diagnosis:

A form larger than *Tetraconodon magnus.* P^4 abnormally large. M^1 much broader than longer. M^2 also broader than longer but less than the preceeding tooth. Last molar triangular, abruptly narrowing posteriorly. Heel in M3 almost rudimentary.

DESCRIPTION

Anterior face of the maxillary fragment bears a very large concave and round impression of the root fang supporting the metacone of the last premolar tooth. Transversely it is much broad and projecting out to the buccal side. It proves that the last premolar was quite a robust and gigantic tooth.

The first molar is represented only by the roots. Roots of the para-, meta- and hypocones indicate that the tooth was much abbreviated anteroposteriorly than the second molar. However, it was equally broad transversely.

The second molar is anteroposteriorly abbreviated but transversely wide. It is a well worn, thick enamelled tooth. A well developed crenulated cingulum covers the outer side of the tooth. Cingulum may also be seen at the anterior side where it mostly covers the protocone. Due to the deep wear, the anterior cusps and the anterior cingulum or the fore-talon have formed a common transversely elongated dentinal plate. Towards the inner side, the transverse valley between the anterior and posterior cusps is in the form of a small cleft. Towards the outer side, it is wide and open. Paracone is comparatively less worn than the other main cusps. Due to the less wear, it is high vertically than the others. Towards the anterior side, its dentinal matter is contiguous with that of the hypocone. Hypocone is well worn and has become V-shaped. Its V-shaped enamel figure indicates the presence of an anterior and a posterior accessory conule.

The last upper molar is a subhypsodont triangular tooth. It is broader transversely and much abbreviated anteroposteriorly. Enamel is thick and highly rugose at the outer side. A very strong tuberculated cingulum may be seen at the anterior side of the protocone. Its outermost tubercle, which lies on the median longitudinal line, is the largest. Due to this cingular growth, the protocone is backwardly placed as compared to the paracone. Protocone is almost rounded and is lined by rugose enamel layer. Paracone is as large as the protocone but is somewhat elongated transversely. The longitudinal valley between the anterior cusps is just marked by a small cleft. At the outer surface of the paracone, a weak tuberculated cingulum may be noticed. Metacone is separated from the paracone by an open wide valley. Metacone is somewhat anteroposteriorly elongated cusp. Its enamel lining is also rugose all around. The longitudinal valley between the posterior cusps is so much appressed that it is difficult to mark anteriorly, the two cusps are separated anteriorly by a large highly compressed triangular accessory conule. This accessory conule has completely blocked the transverse valley. The hinder pair of principal cusps is separated posteriorly by a relatively smaller but highly compressed triangular accessory tubercle. Metacone is less worn than the anterior cusps but more than the hypocone. The three principal cusps i.e. proto-, para- and meta- cone has each formed a rounded dentinal iselet. Like the meta-cone, the hypocone is also somewhat elongated anteroposteriorly. A small cingular tubercle may be seen at the inner entrance of the transverse valley between the proto- and hypocone. Hypocone is slightly worn and has formed a minute rounded dentinal islet. Hind talon is a poorly developed, unituberculated structure. It is abbridged anteroposteriorly but somewhat wide transversely.

TABLE 1.– Measurements (in mm.) of the type specimen of *Tetraconodon dudialensis* new species and its comparison with the upper M^{2-3} of *T. mirabilis.*

	Tetraconodon dudialensis (P.U.P.C. 88/2)	*Tetraconodon mirabilis* (Ind. Mus. B 675)
Length of the molar Series	106	95
Length of M^2	37	30
Width of M^2	44	33
Width/Length index of M^2	119	110
Preserved height of M^2	10	
Reconstructed height of M^2	22	–
Height/Width index of M^2	50	
Length of M^3	44	40
Width of M^3	40	31
Width/Length index of M^3	91	77
Preserved height of M^3	17	–

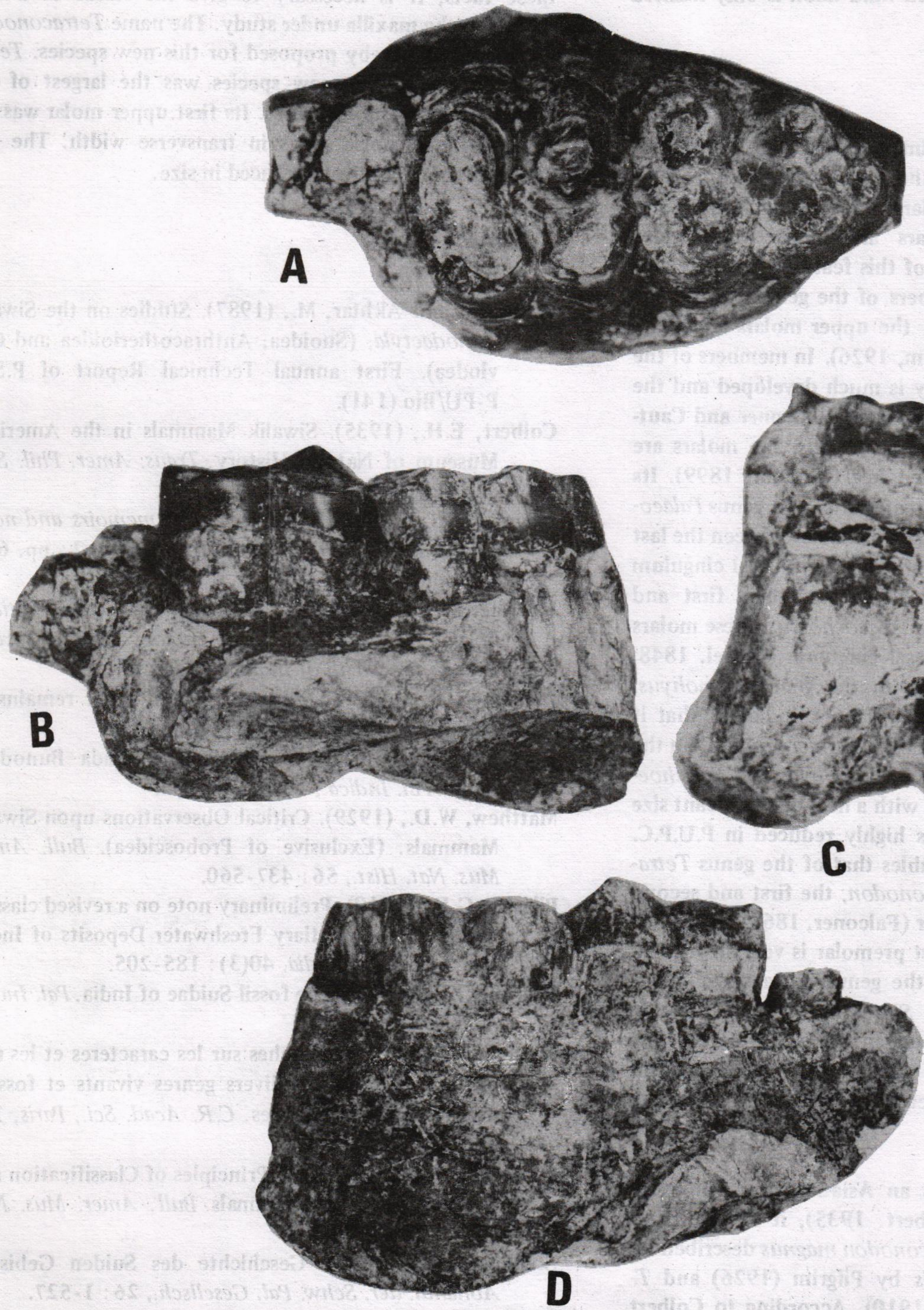

Fig. 1. Type specimen (P.U.P.C. No. 88/2) of *Tetraconodon dudialensis* n. sp., A. crown view; B, inner view; C, anterior view; D, outer view. x0.8.

Reconstructed height of M^3	22	–
Height/Width index of M^3	55	–

It is just touched by wear and its dentinal matter is not yet exposed. Two small unworn cingular tubercle may be seen anteriory but outer to the hind talon. Transverse valley anterior to the unituberculated hind talon is only marked by a small cleft.

DISCUSSION

Molar teeth of the specimen P.U.P.C. 88/2 are differentiated from the genera of the *Potamochoerus* lineage in having broad and short molars. In *Potamochoerus* and *Propotamochoerus,* the molars are longer than wider Pilgrim, 1926). On the basis of this feature, these are also differentiated from the members of the genera of the *Sus* lineage. In *Dicoryphochoerus,* the upper molars are somewhat longer than wider (Pilgrim, 1926). In members of the genus *Hippohyus,* choerodonty is much developed and the cusps are anteroposteriorly elongated (Falconer and Cautley, 1846). In members of the genus *Sus,* the molars are elongated with much elongated heel(Stehlin, 1899). Its comparison with the relevant material of the genus *Palaeochoerus* shows that there is a resemblance between the last upper molar of the two. In both there is a basal cingulum with much abbreviated heel. However, their first and second molars differ greatly. In *Palaeochoerus,* these molars are longer than wider with basal cingulum (Pomel, 1848; Zittel, 1925). A comparison with the genera *Conohyus, Tetraconodon* and *Sivachoerus* offshoot indicates that it resembles the members of the genus *Tetraconodon* than the others. In members of the genera *Conohyus* and *Sivachoerus,* the last molar *is* provided with a heel of significant size (Pilgrim, 1926) whereas, it is highly reduced in P.U.P.C. 88/2. In this respect it resembles that of the genus *Tetraconodon.* In the genus *Tetraconodon,* the first and second molars are broader than longer (Falconer, 1868) just as it is the case in P.U.P.C. 88/2. Last premolar is very strong and heavily built in members of the genus *Tetraconodon* but not in those of the genera *Sivachoerus* and *Conohyus* (Matthew, 1929). In the specimen under study, the last premolar is not preserved but the size of the root nourishing the metacone can very easily be estimated from the anterior face of the specimen.

Genus *Tetraconodon* is an Asiatic genus (Simpson, 1945) and according to Colbert, 1935), it is known by three species. These are *Tetraconodon magnus* described by Falconer (1868), *T. mirabilis* by Pilgrim (1926) and *T. minor* reported by Pilgrim (1910). According to Colbert (1935), *T. mirabilis* is synonymous with the species, *T. magnus.* A fractured cranium (Ind. Mus. B675). of an adult individual of *T. mirabilis* drawn by Lydekker (1948) consists of molars smaller than the specimen under study Table I). The outer cingulum is stronger in the Indian Museum specimen than in P.U.P.C. 88/2. Last molar is damaged in the former but its root show an elongated heel. It is readily distinguished from the highly abbreviated heel of P.U.P.C. 88/2. *Tetracondon minor* is still a smaller species with comparatively smaller premolars and a comparatively larger heel in the last upper molar. In view of these facts, it is necessary to give the status of a new species to the maxilla under study. The name *Tetraconodon dudialensis* is hereby proposed for this new species. *Tetraconodon dudialensis* new species was the largest of the known *Tetraconodon* species. Its first upper molar was the largest of the molar series in transverse width. The last molar was comparatively reduced in size.

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ELECTRICAL RESISTIVITY SURVEY FOR SUBSURFACE GEOLOGY IN AZAD JAMMU AND KASHMIR UNIVERSITY CAMPUS CHELLA BANDI AREA MUZAFFARABAD.

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ABSTRACT :– Electrical resistivity surevey was carried out in the New University Campus Area to give a suitable site for the multistorey buildings. Eighteen observation stations were selected by using Wenner Configuration, applying resistivity metre Strata Scout R-40C. The apparent resistivity values were obtained by using apparent resistivity formula. These values were plotted on logrithmic graph paper of modules 62.5 mm to obtain the field resistivity curves. The results obtained after the interpretation of these curves reveal that deeper foundation would be necessary for civil engineering projects.

INTRODUCTION

The area under study was selected for the purpose of investigation to know the suitability for multistorey buildings at the New University Campus site Muzaffarabad. The area 1000x400 metres is about 1.5 Km from the main city of Muzaffarabad. Eighteen suitable points were located in the area and electrical resistivity method was applied for subsurface investigation of the soil, as shown in fig. 1. Vertical electrical sounding was executed with resistivity metre Strata Scout R-40C using Wenner electrode configuration. Eighteen probes were run in the area out of which sixteen were selected for evaluation and interpretation. The common depth of exploration was nearly 30 metres. The area under study is located between the longitude 34° 24′ 0″E and latitude 73° 30′ 40″ N and is connected with Muzaffarabad city by a metalled road. On the basis of true resistivity values, evaluated by quantitative interpretation, subsurface geology has been classified into four distinct zones which are low, low medium, medium and medium high resistivity zones. The top most two metres of the soil consist mostly of clay with silt in the northern part where resistivity values are low. In the south eastern and south western parts resistivity values are medium high which indicate that after clay bed, gravels, boulders and sand are present. Bed rock in the area is highly fractured which increases the porosity of the rock. Water lavel in the area varies from 7-12/meters. Probable depth of bed rock indicates that deep foundation would be necessary for multistorey buildings. The investigation which is first of its kind on scientific lines is considered to be highly essential for project of this magnitude.

INTERPRETATION

The field curves were subjected to various processes which are as under:–

a) Interpretation of vertical electrical sounding curves by Orllana method (1966).

b) Subsurface true resistivity zoning (Dobrin, 1976, Patra & Mallick, 1980).

c) Subsurface geological cross-section based on true resistivity values (Sharma, 1986).

QUANTITATIVE INTERPRETATION

The quantitative interpretation is based on finding out or evaluation of the true resistivity values and thickness of different subsurface layers from the field sounding curves by comparing them with the set of ideal curves. Evaluation has been carried out by Orllana method.

Evaluation by two layers:– The procedure by curve matching by two layers ideal curve is as follow:–

a) Make the segment of the field curve at points where the trend of the curve is changing.

b) The curve is superimposed on the set of standard curve of two layers.

c) The segment of the field curve are matched with one of the theoretical curves by displacing the field curve horizontally and vertically during which the axis are kept parallel.

d) The cross of the standard two-layers curve on the logrithmic graph paper gave the values of apparent resistivity of Ist layer (P_1). The ratio of P_2 P_1 is given at the end line of each standard curve of two-layers. By replacing the values of P_1 from cross reading we can find out the values of second layer P_2 e.g. $P_2/P_1 = x$ so $P_2 = P_1$ x after taking value of P_2 draw a line along this value and again match the third segment of the field curve with standard curve and obtain the value of P_3. Fig. 2 shows the interpretation of three layers field curve.

SUBSURFACE TRUE RESISTIVITY ZONING OF THE AREA:

On the basis of true resistivity values of the area evaluated by quantitative interpretation, subsurface geological units have been classified into four distinct zones which are as follows:–

a) Low resistivity zones (0-60 ohm.m)
b) Low Medium resistivity zone (60-160 ohm.m)
c) Medium resistivity zone (160-700 ohm.m)
d) Medium-High resistivity zone (above 700 ohm.m)

The different type of material in different zones in the area under study is as follows:–

Low Resistivity Zone :– In this zone the subsurface material having the true resistivity values ranges from 0-60 ohm.m; indicates the presence of clay, silty clay and shale. Low resistivity values represent the subsurface water bearing horizon.

Low-Medium Resistivity Zone:– The zone indicates the presence of interlayering of clay, sandy clay, sand and small size gravels. It also indicates the presence of water bearing horizon. Which consist of highly fractured and porous sandstone and claystone, etc.

Medium-Resistivity Zone:– This zone represents interlayering of small and large size gravels.

Medium-High Resistivity Zone:– This zone indicates the presence of large size gravels and boulders.

INTERPRETATION BASED ON SUBSURFACE GEOLOGICAL CROSS-SECTION

The resistivity lines namely B–B′, A–A′, A′–E, D–E–C and C′–B′ in the area, which cover nearly all the resistivity probes. The interpretation of these lines are as follows:–

1. *Resistivity Line (B–B′):–* Low resistivity value has been observed at probe site No. 2. This low resistivity value shows the clay and silty clay increases in north eastern side. Therefore the clay decreases towards B' (See the map attached) and at probe site No. 5 it is completely absent. Low-medium resistivity values have been observed at probe site No. 5 and probe site No. 12 which indicates the presence of sand and small size gravels. Below this zone medium resistivity values have been observed, these values indicate the occurrence of gravels mixed with sand.

The thickness of this material is only 1.5 metres at probe site No. 16 and increases toward probe site No. 12. The admixture of clay increases toward B and the thickness of this material at probe No. 12 is nearly 12 metres. Below this zone at probe site No. 16 medium high resistivity value has been observed, which indicates the presence of large size gravels and boulders. Remaining depth throughout the resistivity line shows the low resistivity values, which indicate the water bearing horizon, as shown in fig. 3a.

2. *Resistivity Line (A–A′):–* Low Resistivity values have been observed at the probe site No. 1,2,3, and are absent at probe site No. 14·Low resistivity values are due to clay silt and fine sand. Thickness of low resistivity material at the probe site No. 1 is 0.9 m, and at probe site No. 2 and 3 it is nearly 1.5 m. Below this zone medium resistivity values have been observed which are due to the interlayering or admixture of sand and gravels, the thickness of this material at probe site No. 1,2,3, and 14 are 9.5, 10.9, 10.9 and 11 metres respectively. Below medium resistivity zone again low and low medium resistivity values have been observed

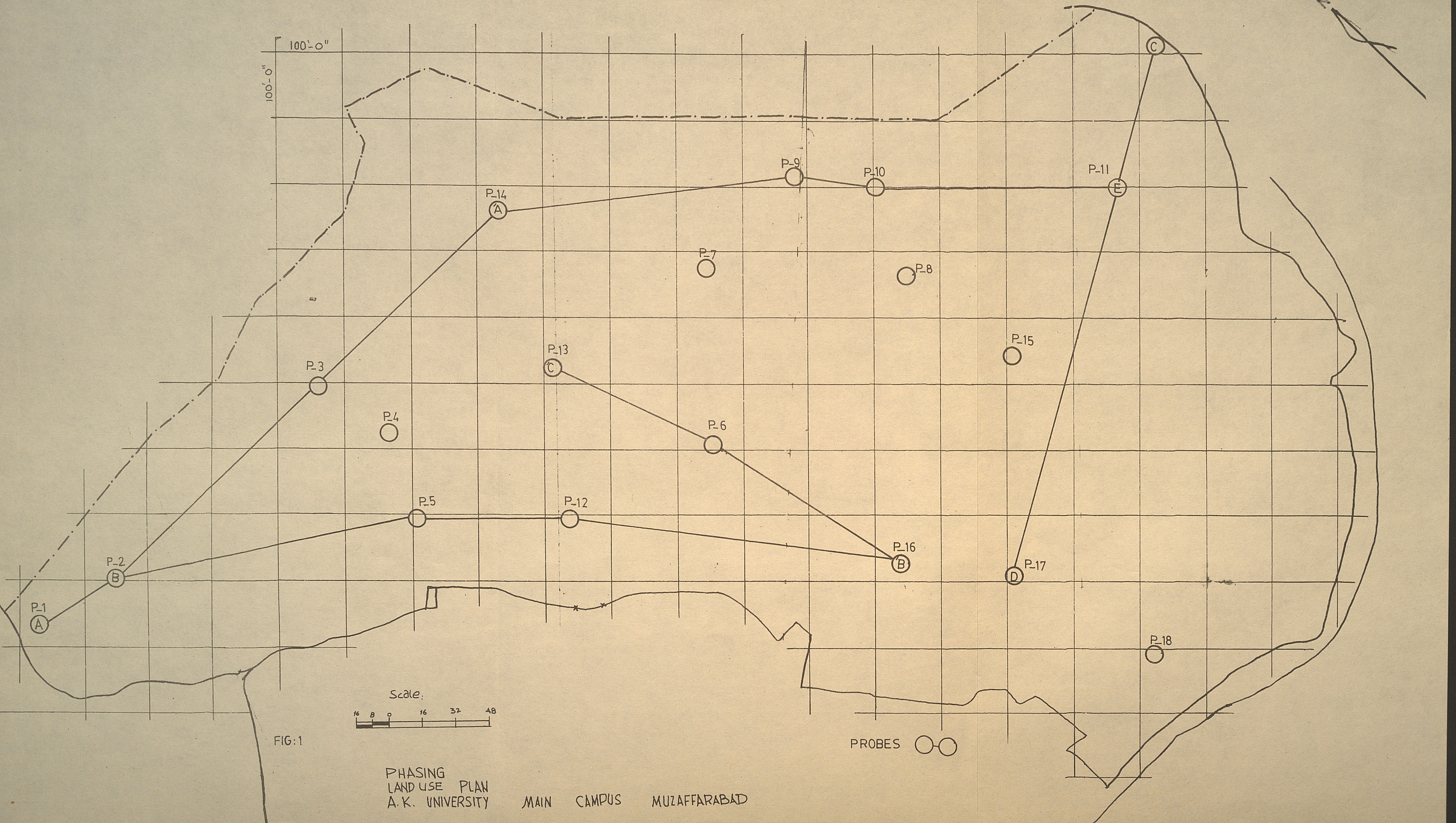


FIG: 1

PHASING
LAND USE PLAN
A.K. UNIVERSITY MAIN CAMPUS MUZAFFARABAD

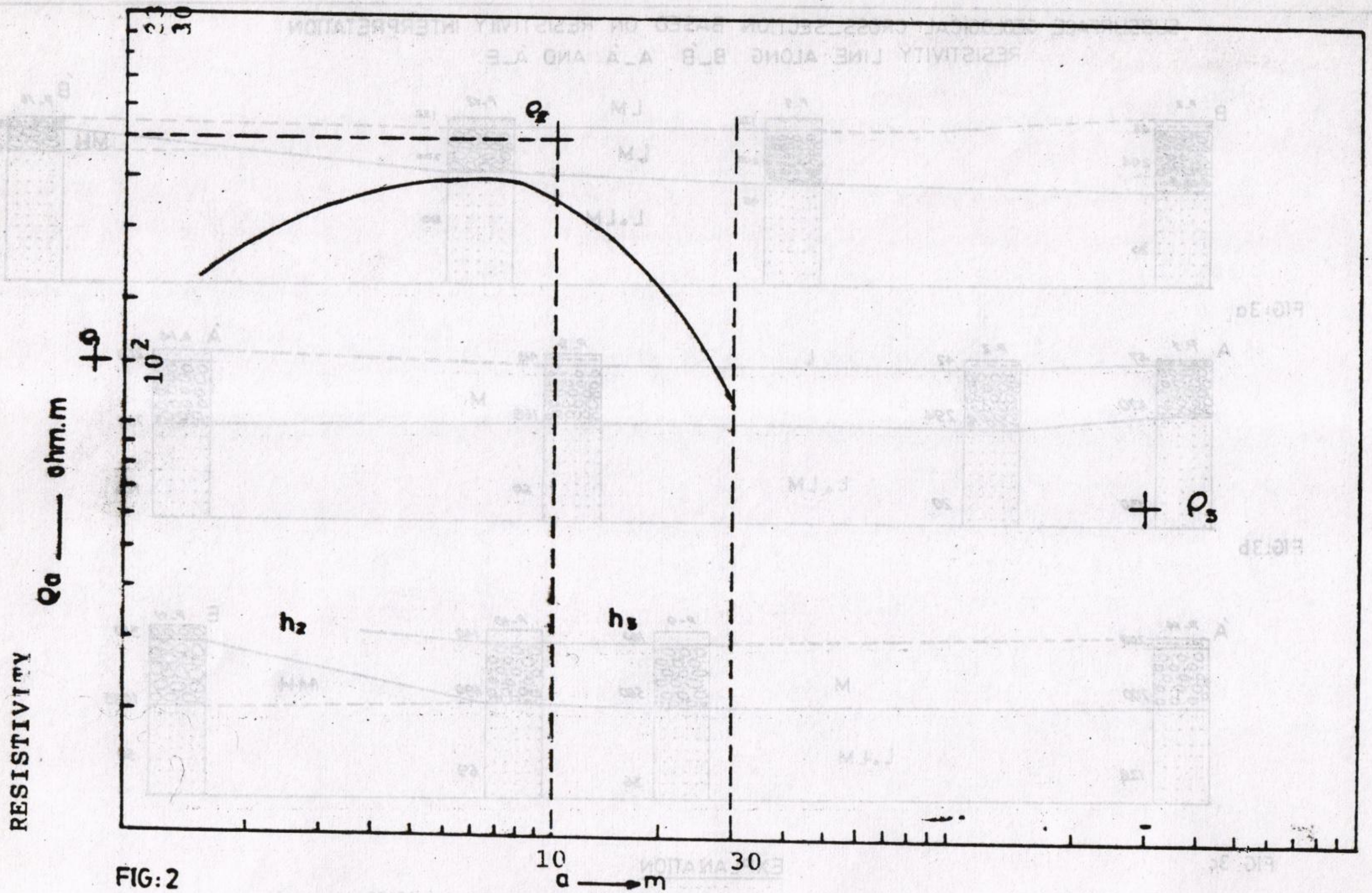
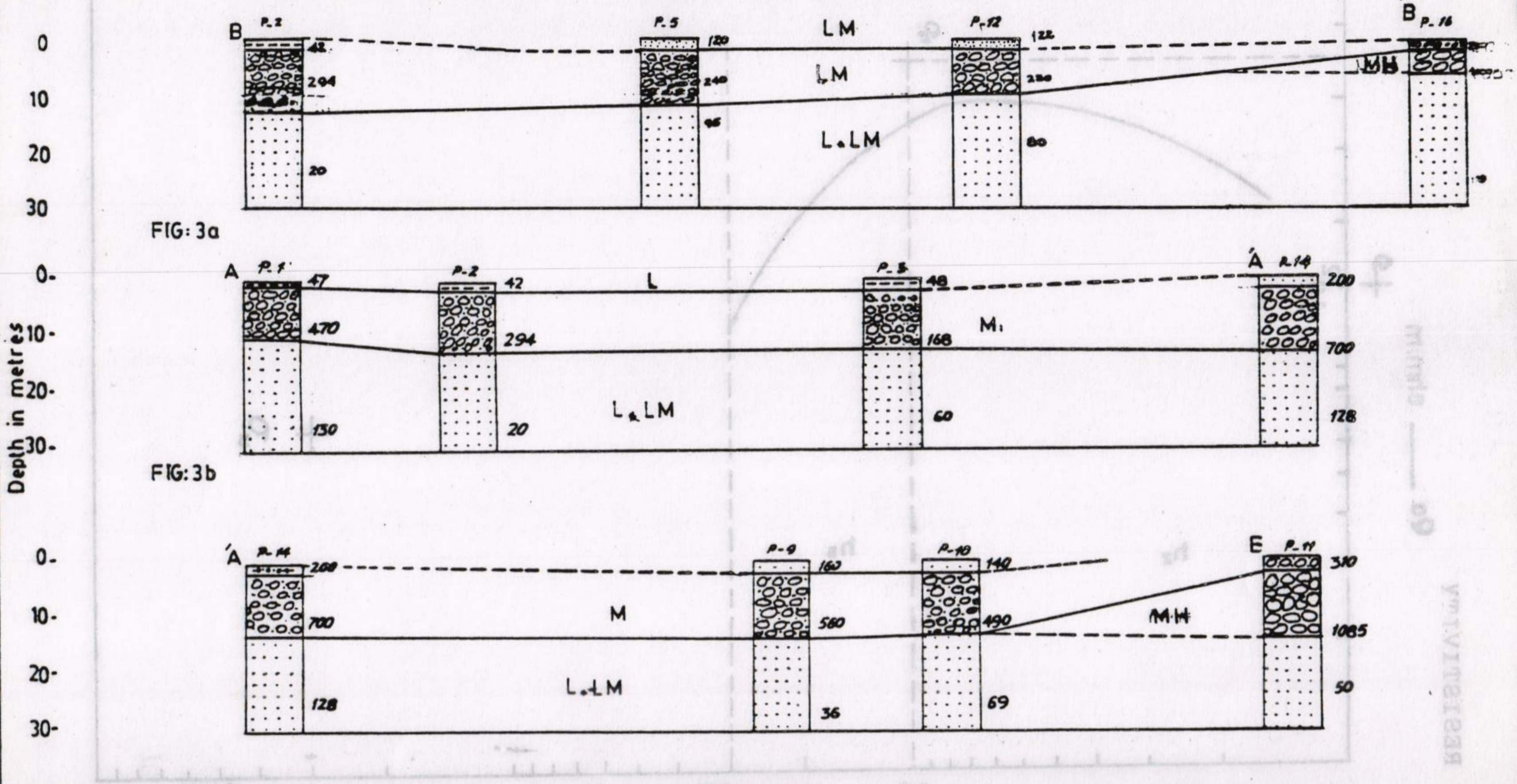


FIG:2

ELECTRODE SPACING (Metre) h= Thickness of layer

SUBSURFACE GEOLOGICAL CROSS_SECTION BASED ON RESISTIVITY INTERPRETATION
RESISTIVITY LINE ALONG B_B́ A_Á AND Á_E.



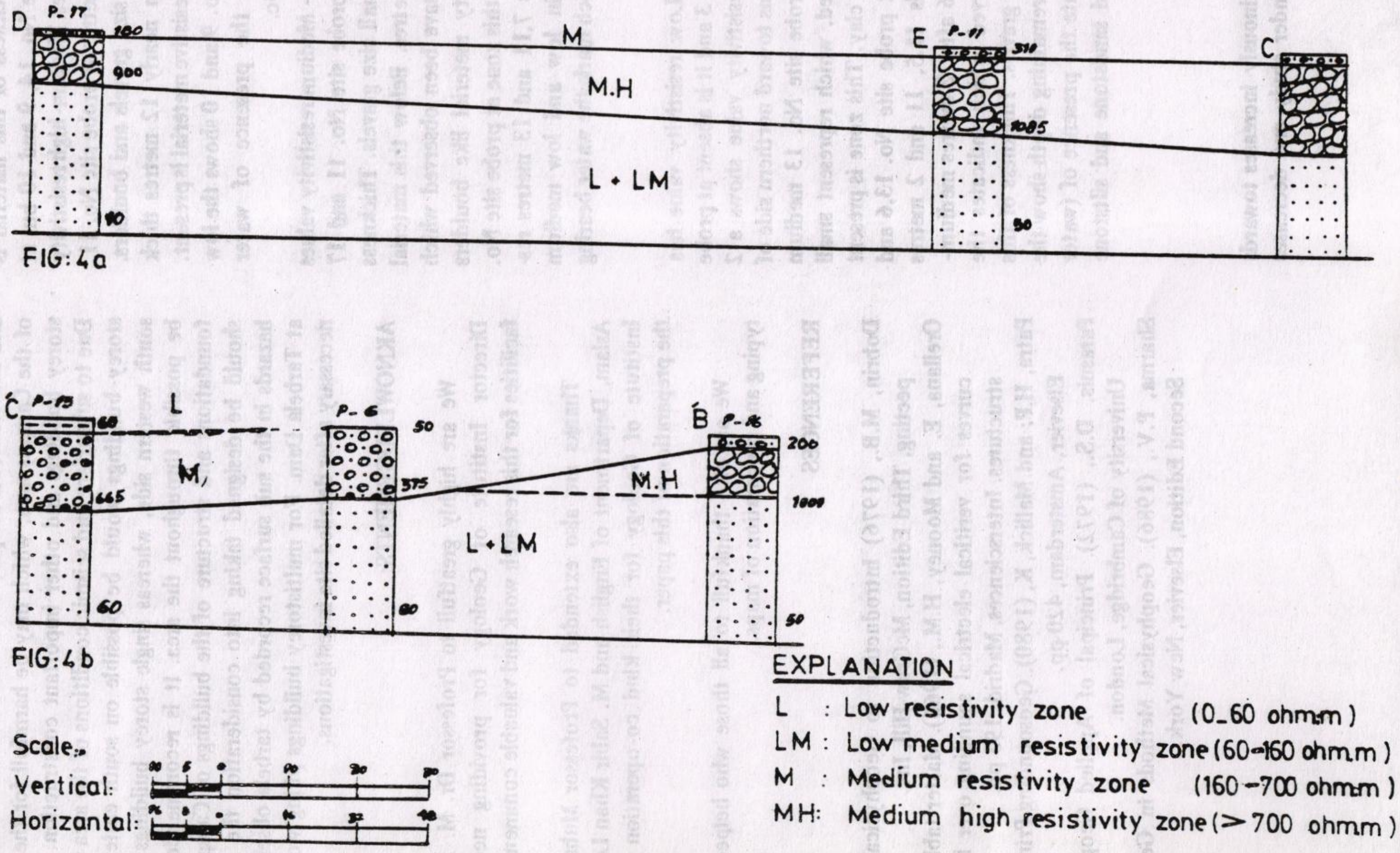
EXPLANATION

L : Low resistivity zone. (0_60 ohm.m)
LM: Low medium resistivity zone. (60_160 ohm.m)
M : Medium resistivity zone. (160_700 ohm.m)
MH: Medium high resistivity zone (> 700 ohm.m)

SCALE

Vertical: 10 5 0 10 20 30 metre
Horizontal: 16 8 0 16 32 48 metre

SUBSURFACE GEOLOGICAL CROSS SECTION BASED ON RESISTIVITY INTERPRETATION
RESISTIVITY LINE ALONG D_E_C AND Ć_B́.



which represent water bearing horizon, as shown in fig 3l.

3. *Resistivity Line (A′–E):–* Low-medium resistivity value were observed at the probe site No. 14, 9 and 10 which show the presence of silt, and sand. Thickness of this meterial is nearly 1-2 metres. Below low medium resistivity values, medium resistivity values were observed throughout the resistivity line. These values are due to medium resistivity material. Thickness of this material is nearly 11-12 metres at probe site No. 14, 9 and 10 but at probe site No.11 it is only 2 metres. Medium-high resistivity value has been observed after 2 metres at probe site No. 11. This value may be due to large size gravels and boulders. These gravels and boulders form nearly 12 metres thick layer, below this layer again low resistive meterial is present. Remaining depth at probe site No. 9 and 10 shows the low resistive values, which indicate the presence of water bearing horizon, as shown in fig. 3c.

4. *Resistivity line (D–E–C):–* Medium resistivity values observed at control point (C), probe site No. 11 and 17 show the sand is mixed with small size gravels. Thickness of this material is nearly 1-2 metres. Below this material medium high resistivity values have been observed which mark the medium-high resistivity meterial like boulders mixed with gravels. Thickness of this zone at probe site No. 17, 11 and control point (C) is 7,11 and 13 metres respectively. Below this zone again low and low medium resistive values were observed which mark the water bearing horizon as shown in Fig. 4a.

5. *Resistivity Line (C′–B′):–* Low resistivity value has been observed at probe site No. 13 and it is absent at probe site No. 6 and 16. This low resistivity value shows a 2 metres thick layer of clay thickens toward northern side of the area. Below this layer at probe site No. 13 medium resistivity value has been observed, which represent small size gravels mixed with sand and clay. This zone is present throughout the resistivity line at probe site No. 13,6 and 16. Thickness of this material is 11.5, 11 and 2 metres respectively. At probe site No. 16 after 2 metres medium-high resistivity value was observed which indicates the presence of boulder mixed with gravels. Thickness of this material is nearly 7 metres. This remaining depth show the low resistive values, which indicate the presence of (water bearing horizon) highly fractured sandstone and siltstone etc. as shown (Fig. 4b).

CONCLUSIONS

The thickness of clay continously increases towards north eastern side of the area under study and decreases towards south eastern side and south western side. The thickness of boulders, gravels and sand continously increases in south eastern and south western side. Highly fractured sandstone and siltstone are present at a depth of 7-12 metres throughout the area and also mark the water bearing horizon.

The main boundry fault is running in the near by area and the offshoots are present in northern and southern part of the Campus area, which may be harmfull for the multi-storey buildings and other important construction works. Due to subsurface and seismic conditions of the area double storey buildings would be possible on south eastern and south western side, whereas single storey buildings would be possible throughout the area. It is recommended that foundations and structure of the buildings of Campus site should be designed taking into consideration the seismic hazards in the sub surface recorded by tarbela observatory at Tarbela Dam. For multistorey buildings piling would be necessary after detailed site investigations.

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STRUCTURE AND THE HISTORY OF YASIN GROUP OF ROCKS IN HUNZA VALLEY, NORTHERN PAKISTAN

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ABSTRACT: Yasin Group of metasedimentary rocks lies on the northern extremity of Kohistan Island Arc. F_1 (recumbent folds), F_2 (upright folds), F_3 (Intrafolial and Kink folds), F_4 (minor folds) and F_5 (crenulation observed in oriented hand specimens) are the type of folds that can be studied in addition of slickensides, veins, dykes, foliation, lineation and shear zones. Average trend of dominant axial plane foliation of F_2 folds is WNW and the inclination is almost vertical. Veins of different age and origin had been of substantial help in this study. The most recent deposit travertine probably relates to a major fault.

INTRODUCTION

Indus suture zone towards west is bifurcated into two branches where its northern extension is named as Main Karakoram Thurst (Tahirkheli et al. 1979). Structural studies south of Chalt on the underthrusted group of metasediments that inturn ride over Rakaposhi Volcanics along a faulted unconformity make them intensively complicated rocks. Imprints of different episodes of deformation are unevenly distributed depending upon competency of rock. Traces of first deformational episode are very sole. F_2 folds reveal second deformation and are commonly observed in slates, quartzites and marly crystalline limestone but towards north in schists, they are not observable. Here foliation predominates. Kink folds, minor folds and crenulations are suggested to be produced as a result of a later disturbance. Well developed poikiloblasts of calcite with inclusion of other minerals and imprints of earlier deformation reveals static recrystallization. Rock and structures of Chalt Ophiolitic Melange (Tahirkheli, 1979) are studied in detail by Amjid & Saqib (1982) and Zahid & Shahbaz (1983) in Sikandarabad and Chalt respectively. Observations along faults reveal them to be inactive.

Previously many workers contributed to the geology of the area on local & regional scale (Hayden, 1915; Desio, 1964; Gansser, 1964; Ivanac, 1965; Tahirkheli, 1979; 1979a, 1982; Tahirkheli & others, 1976, 1979; Powell, 1979; Bard & others, 1980, Coward & others 1982). Present work is the first attempt towards the detailed structural analysis on mesoscopic and microscopic scale on the metasedimentary rocks of Yasin Group in Chalt. These rocks lying as a linear belt all along the Main Karakoram Thrust (Tahirkheli, 1982) constitutes the northern extremity of Kohistan Island Arc and are directly involved in the continental collision.

STRUCTURES

Foliation:

To record all the variation in the attitude of foliation about 250 readings of dip and strike were treated on the stereonet (Pl. 1A). Contoured diagram indicates an average trend of foliations as N75°W with steep (almost vertical) inclinations toward the south-west (Pl. 1B). Scatter in the point diagram reflects, variation in the attitude of the foliation. The distinct single maximum of poles to foliation gives a pole diagram that is an example of axial symmetry.

Folds:

Folding is the most obvious, complex and pronounced feature observed in the area. Five deformational episodes reflected by these structures of different generation are as follows:

F1 (Recumbent Folds): F_1 occur only as relic structures and are only discernible at a few places; as these are greatly obliterated or obscured by later folding. These can be observed in the areas where S_0 and S_1 are preserved. These are very tight folds in which S_1 parallel to S_0 is now deformed along S_0. The distance measured between the adjacent limbs never exceeds 1 m where seen. The fold axes and the axial plane measured in the field indicate that these were of recumbent type. The trend of the fold axes is dominantly EW. The bedding (S_0) although locally observed has commonly been transposed into S_1 which has later been affected by subsequent folding (F_2) giving rise to the most prominent foliation (P1. 2A-B). The transposition of S_0 to S_1 and later S_1 to S_2 can be observed in slate and quartzites towards south while towards north the rocks are more schistose and even S_1 is not visible. Again these are folded very tightly in slates as compared to the quartzites.

F2 (Upright Folds); These are the most prominent folds of the area. These are formed by the folding of S_1 as a result of the second phase of deformation (D2). The degree of tightness varies with the mechanical behaviour of the rock. These are less tight in quartzite, moderately tight in marly crystalline limestone and very tight in slates. In the real schist what is seen is only S_2. Where F_2 folds are oppresed beyond discernible. It is here that no trace of S_1 is left. The wavelength is observed to be as much as 2.5 m. The stereographic analysis shows the character of F_2 folds, as almost tight upright or even isoclinical and moderately plunging. The angle of plunge is small and non-consistent. The fold axes either plunge east or west and thus there is no definite plunge direction. The similar trend of the axial plane of the F_2 folds and foliation, indicates it (S_2) as an axial plane foliation of F_2 folds.

F3′ Intrafolial and Kink Folds): Third episode of deformation is inferred from the presence of intrafolial and kink folds. Intrafolial folds are comparatively a larger structure and measured about 10 m in wavelength width in slates. The axis is nearly parallel to S_2. A quartz vein that probably formed parallel to S_2 is clearly seen to be involved in the folding of this phase of deformation (D_3). The kink fold in biotite schist provides additional evidence for this band of deformation. Trend of kink bend boundary is N65°W/90 with subhorizontal fold axis that plunge 40° to S65°E. The kink zone is 40 cm thick. These are suggested to be produced as a result of a subsequent deformational period (D_3) which is responsible for the folding of major foliation (S_2).

F4 (Minor Folds): These were commonly observed in quartz and qtz-siderite veins that vary in size from a few cm to as much as 30 cm in wavelength. The F_4 folds are determined to be related to a phase of deformation younger than F_3 because of their distribution on a small scale in younger veins. Generally their fold axes and axial planes are of the same orientation as of earlier folds. From a stereographic projection following trend have been determined, F.A = 8°, S78°E, A.P = 79° N 79°W . The folds are assymetrical, moderately plunging and are of a tight nature. In the southern part of the area they are mostly overturned.

F5 (Crenulations Observed in Hand Specimens): Fifth episode of deformation (D_5) was inferred by the study of oriented hand specimens (P1. 2D). Most of these folds are found to have quite surprising orientation of their planes that is a NS direction which is parallel to the regional stress direction (P1. 2E). Their axes are steeply plunging and are usually stretched by NS shortening. As such there are as a result of an eastwest anomolous compression acting simultaneously with the regional tectonic forces. F_5 folds characterised by an unusual orientation of their axes, micro-scale and rare occurrence are emplaced in a still younger phase of deformation (D_5).

CONCLUSIONS DRAWN FROM THE FOLDS

1. F_1, F_2, F_3, F_4, and F_5 are inferred to have formed as a result of five different episodes of deformation D_1, D_2, D_3, D_4, and D_5).

2. F_1 (recumbent folds) are obscured by the later folding except in very rare locations in the quartzite and slates.

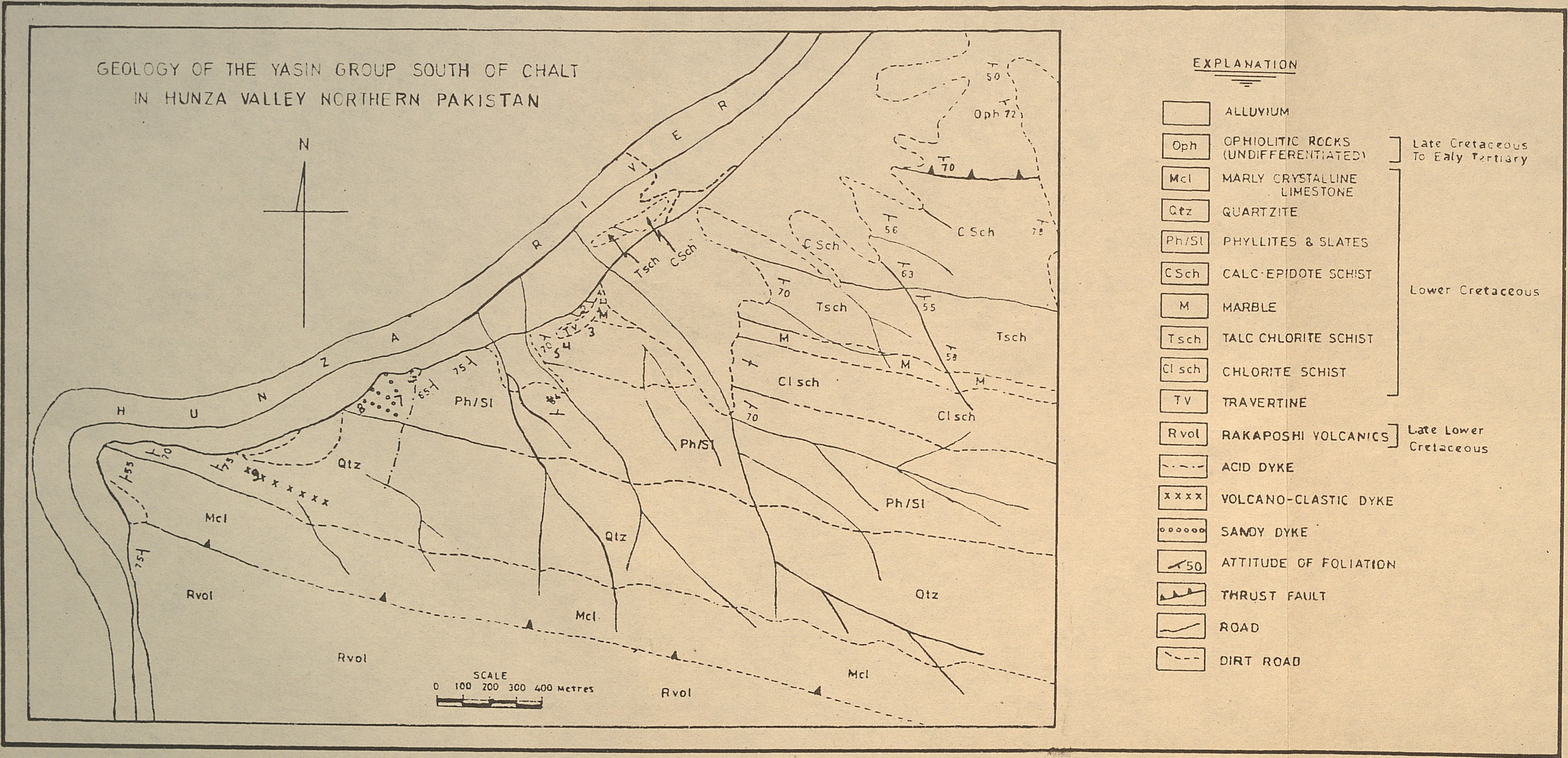
3. F_2 folds are relatively abundant and formed as a result of a major deformation. The prominent foliation in the rocks is in fact the axial plane foliation (S_2) of these folds.

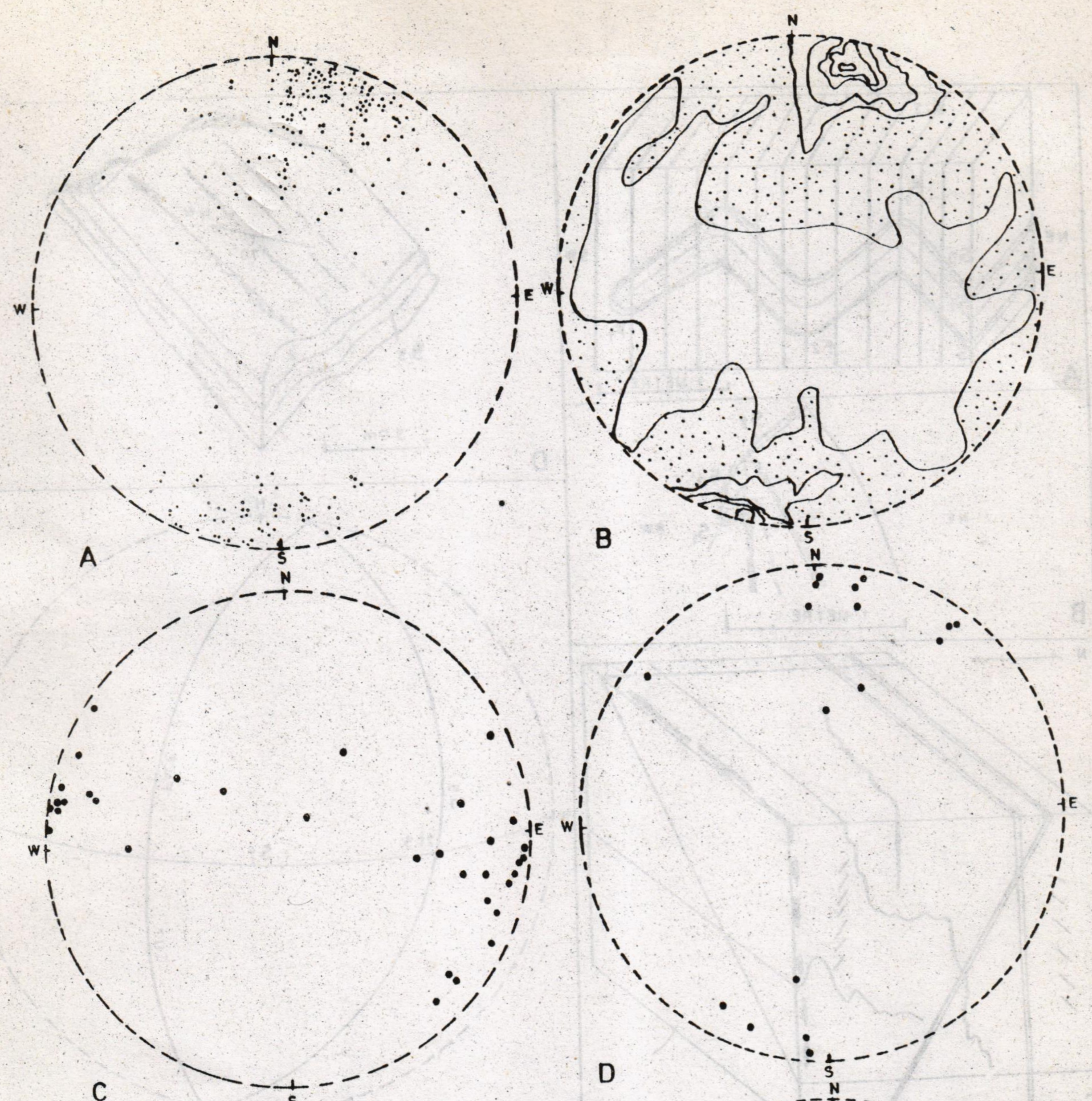
4. F_3 and F_4 may have developed as a result of continuous push from north and by thrusting of Yasin Metasediments over Rakaposhi volcanics.

5. The most interesting relationship between F_1, F_2, F_3, and F_4 is that while their axial surfaces may or may not have similar orientation and their axes are almost parallel. This feature is very significant in the area as it points towards consistency in the orientation of causitive forces.

6. F_5 (crenulations) are the youngest structures of this kind with a surprising orientation of the axial surfaces (NS). These are stretched by the regional compression.

7. It is probable that F_5 are formed as a result of stresses during the emplacement and cementation of a 40-60 m exotic block of magmatic geneisses and garnet stanrolite schist, located 600-650 m above Jaffarabad


GEOLOGY OF THE YASIN GROUP SOUTH OF CHALT
IN HUNZA VALLEY NORTHERN PAKISTAN
N
HUNZA RIVER
Rvol
Mcl
Qtz
Ph/Sl
Tsch
CSch
Cl sch
M
TV
Oph 72
SCALE
0 100 200 300 400 Metres
EXPLANATION
ALLUVIUM
Oph OPHIOLITIC ROCKS (UNDIFFERENTIATED)
Late Cretaceous To Ealy Tertiary
Mcl MARLY CRYSTALLINE LIMESTONE
Qtz QUARTZITE
Ph/Sl PHYLLITES & SLATES
CSch CALC-EPIDOTE SCHIST
M MARBLE
Tsch TALC CHLORITE SCHIST
Cl sch CHLORITE SCHIST
TV TRAVERTINE
Lower Cretaceous
Rvol RAKAPOSHI VOLCANICS
Late Lower Cretaceous
ACID DYKE
VOLCANO-CLASTIC DYKE
SANDY DYKE
ATTITUDE OF FOLIATION
THRUST FAULT
ROAD
DIRT ROAD



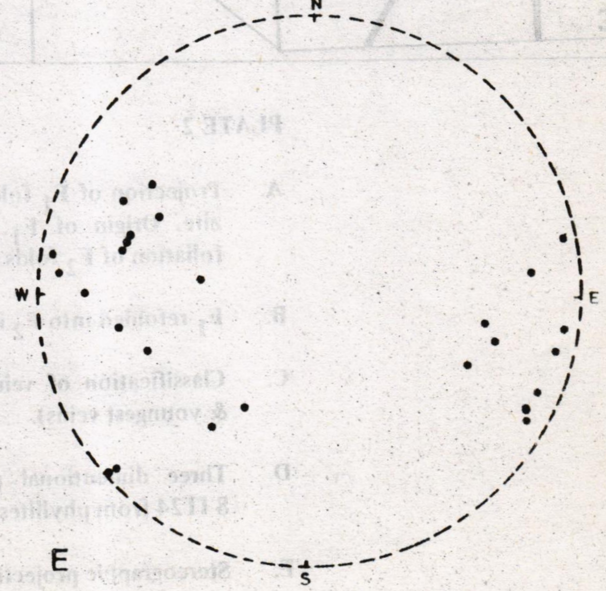


PLATE 1

A. **Poles to foliation**

B. **Projection of P1. 1-A, contoured and shaded. Contours at 0%, 4%, 8%, 12%, 14% and 16%.**

C. **Point diagram of 30 fold axes.**

D. **Point diagram of 19 poles to axial planes.**

E. **Point diagram of slickensides.**

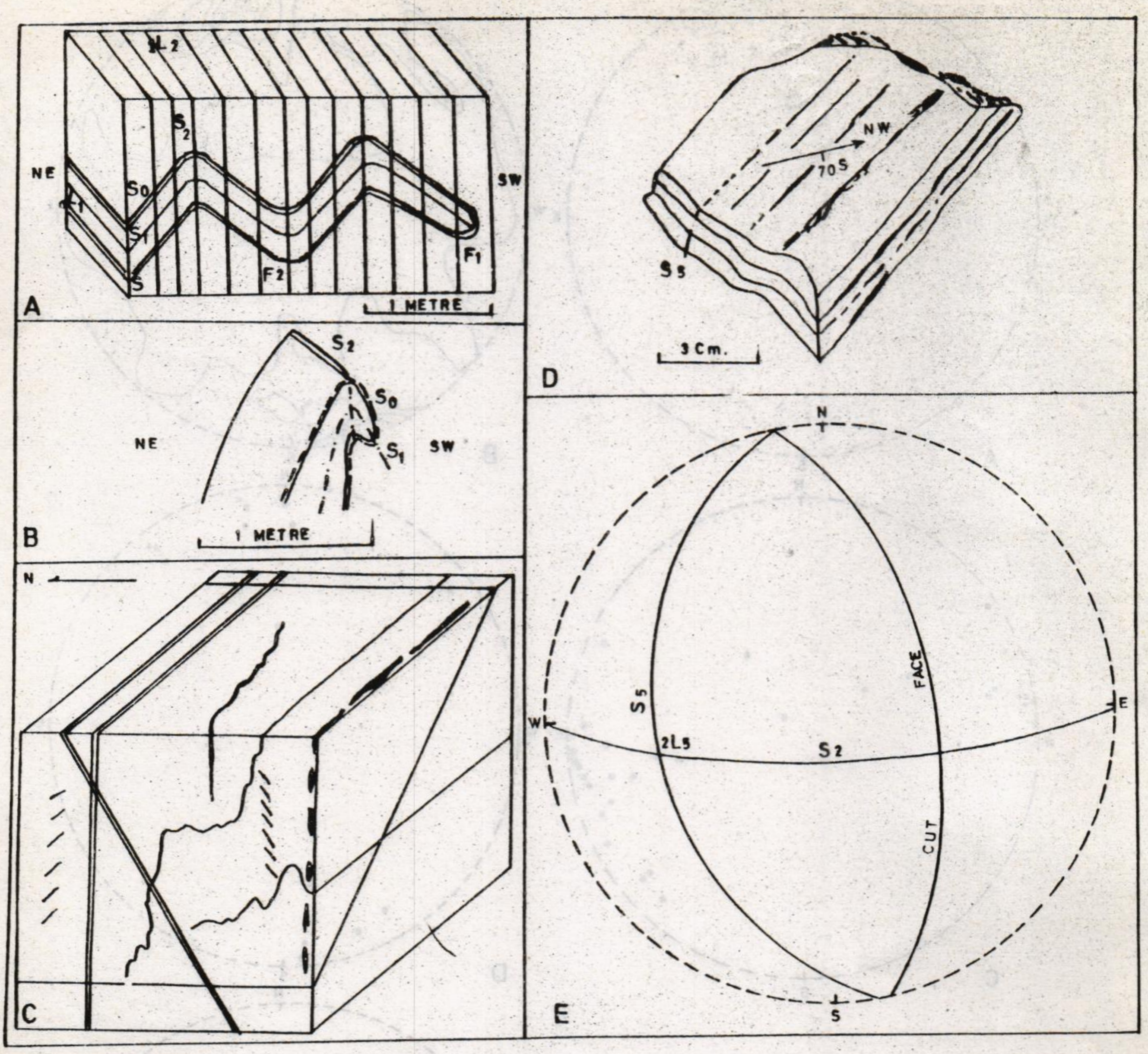


PLATE 2

A. **Projection of F_1 folds and present foliation in quartzite. Origin of F_1, oL_1, S_1, S_2 and axial plane foliation of F_2 folds is interpreted.**

B. **F_1 refolded into F_2 in slates.**

C. **Classification of veins in the area (oldest, younger & youngest veins).**

D. **Three dimentional projection of oriented sample 8 IT24 from phyllites.**

E. **Stereographic projection of P1. 2-D.**

village along a steep nala 8-10 km upstream of Chlat, near the contact between Yasin and Rakaposhi volcanics, either derived from the Eurasian marginal mass (Minapin Formation) or from the area of Nanga Parbat-Haramoh loop (Tahirkheli 1982).

8. Absence of large scale folding is suggested, by the absence of major repetition in rocks.

TRACE OF THE MAJOR FAULTS

Yasin Group is bounded by large faults. On the south it has a thrust contact along an unconformity with the Rakaposhi Volcanics and on the north it is subducting under the Eurasian plate along the Chalt Ophiolitic Melange.

The southern contact along which the Yasin Group moved up over the greenstone is in very rugged, largely inaccessible terrain and could only be examined locally. This fault can be seen about 400 m downstream of the main Hunza River bend across from Chalt. It is in a steeply sloping nala that is terminated in a cliff about 40 m above the road. A 4 m thick zone of mylonites and blastomylonites was observed at the contact. The elevation of this exposure is 1653 m. It is seen that competant material of Rakaposhi Volcanics is more deformed than that of the Yasin Group. Direction of vergence of parasitic folds and clockwise sense of movement in the shear zones, along and near the contact coincides with thrust. Effects of cataclasism are well preserved in the mylonitized zone. The trend of the fault is N72°W, 79°NE.

The northern margin of Yasin Group, where schistose rocks are in direct contact with the Main Karakoram Thrust (MKT) is quite distinct and accessible. Although it is a tectonic contact, it is not abrupt.

Travertine the most recent deposit with a cross cut relationship to the host rocks probably resulted from Holocene activity and relates to a major fault. Undulations seen in this rock are of depositional nature. Angular fragments of host rocks incorporated in travertine during its formation are a characteristic feature.

MINOR FAULTS AND SICKENSIDES

Minor faults with normal and reverse sence of slip are obviously the youngest feature of its type and can directly or indirectly be related to the last regional stress orientations or a period of an ease, during which the stresses were released.

Stereographic analysis of 24 fault plane with marked slickansides (P1. 1E), represent them as a set of strike and dip slip faults. Sedimentary dykas are observed with reverse offset. Similar dykes in the vicinity are gravity faulted.

VEINS

Quartz and quartz siderite veins have a wide distribution in the area. They vary in thickness from a few mm to 20 cm. These are developed at different times in different directions and can be divided into three age groups.

En-echelon quartz veins are the oldest. These may have been developed parallel to S_0 and later by F_1 folding were stretched and by F_2 folding rotated and arranged themselves in an en-echelon pattern.

The middle age group veins, had diversity in orientation. Some of these developed parallel to S_2 and during the deformation were only stretched and boudinaged. Those developed oblique to S_2 were, however, folded into different pattern. Crenulation in very thin veins by D_5 are also included in this group.

The youngest group of veins which have not been subjected to deformation remains planer. The oldest of these are thin veins trending EW with vertical dips. These were cut by later inclined veins, in which two distinct sets have been observed. One set composed of quartz-siderite strikes EW and dips 60°S. These veins displace the vertical set but developed earlier than the other set which trends N10°E, 65°W. These are commonly developed in phyllites and chlorite-schist (P1. 2C).

LINEATIONS

The common lineations in the area are the axes of folds of different generations (P1. 1C). The most prominent lineations are ${}_0L_1$, ${}_1L_2$ which are parallel to each other. Among the minor lineations ${}_2L_4$, ${}_2L_5$ have been indentified. The former are subhorizontal while ${}_2L_5$ are generally steeply inclined perpendicular to the major folds.

Shears and joints are not uncommon. Dykes of different composition, extent and age are also observed.

CONCLUSION

Yasin metasediments suffered multiple deformation whose prints are rendered in the rocks. Five different phases of intense and mild deformations have been inferred. The first four episodes are the result of regional NS compression. The last phase however, appears to be entirely different because during the development, forces were oriented EW. The axes of folds produced during this phase of deformation are generally steep and almost perpendicular to the main fault. Absence of large scale folding is suggested, with the absence of any major repetition in lithologies. Faults are inactive whereas post-tectonic recrystallization is proposed on the basis of petrographic studies carried out on calcite porphyroblasts.

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COMPUTER PROGRAMME FOR SANDSTONE MINERAL ANALYSIS.

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ABSTRACT:– A computer programme has been prepared for the calculation of certain sandstone minerals from the results of chemical analysis. In this method chemical composition of the sandstone minerals and the molecular weight/molecular ratios of their components have been used. This programme can help in the quick calculation of the percentages of different sandstone minerals only by feeding the amounts of the components. Basic language has been used in this programme.

INTRODUCTION

Using the 'Molecular ratio method' a computer programme has been prepared for the computation of certain sandstone minerals from the results of chemical analysis. In this method it is necessary that one has a satisfactory chemical analysis of a rock. If the thin section shows certain

minerals to be present, the

chemical analysis of a rock. If the thin section shows certain minerals to be present, the percentage amounts of these minerals may be determined by calculations. It is essential to know the chemical composition of the minerals present and the molecular – ratios of their components. The molecular ratio is obtained by dividing the amount of certain component by its molecular weight. (Krumbein and Pettijohn, 1938; Brian, 1966; Chaudhry and Ashraf, 1981).

In this method it is necessary that the sandstone specimen be treated with dilute HCl to drive out all the calcite/dolomite, before the chemical analysis. But if the percentages of calcite and dolomite are to be determined, then HCl treatment should not be done.

The computer programme included in this paper is based on the original work. However, Krumbein and Pettijohn (1938) gave an idea of molecuratio method.

CASIO programable calculator, Model No. Fx 702 P has been used for testing the results of this method. This is a portable computer, have 176 grams weight and is run on BASIC language (Akhtar, 1986).

DISCUSSION

Mineral analysis of a sandstone specimen of Nagri Formation of Rawalpindi district (Table – 1) has been taken as an example to describe mineral calculation method. The specimen contains quartz, orthoclase/microcline, albite, anorthite, magnetite, muscovite, kaolin, chlorite, and rutile (Bajwa, 1984; 1985 a,b,; 1986)

Orthoclase/microcline (K-Feldspar) K(Al Si_3 O_8) K_2O Al_2O_3 6 SiO_2 : It is observed that all K_2O is in the orthoclase/microcline. So, molecular ratio of K_2O (0.009) has been taken as a unit for fixing the molecular ratios of the components of this mineral, as described below:

	K_2O	Al_2O_3	6 SiO_2
	1 :	1 :	6
Molecular ratio	0.009	0.009	6 x 0.009
x Molecular weight	x94.20	x101.96	60.08
= % age amount	0.85	+ 0.92	+ 3.24
= 5.01 Or/mi			

Albite (Plagioclase) Na (Al Si_3O_8) ≡ Na_2O. Al_2O_3. 6 SiO_2. It is clear that all Na_2O is in the albite. So, molecular ratio of Na_2O (0.010) has been taken as a unit for fixing the molecular ratios of Na_2O Al_2O_3 SiO_2 as 1 : 1 : 6. The calculations are same as in the case of orthoclase.

Anorthite (Plagioclase) Ca(Al_2 Si_2O_8 ≡ CaO. Al_2O_3. 2 SiO_2. It is clear from the composition that all the CaO is in Anorthite. So, molecular ratio of CaO (0.011) has been taken as a unit for fixing the molecular ratios of CaO Al_2O_3. SiO_2 as 1 : 1: 2. The calculations are similar to that of orthoclase.

---

1. BASIC means, Beginners All-purpose Symbolic Instructor Code.

Magnetite (Iron oxide) $Fe_3O_4 \equiv FeO\ Fe_2O_3$: **It is noted that all the Fe_2O_3 is in the magnetite. So, the molecular ratio of Fe_2O_3 (0.032) has been used as a unit for fixing the molecular ratios of FeO. Fe_2O_3 as 1 : 1. The calculations are similar.**

Amesite (Chlorite) **2 H_2O. 2 MgO. Al_2O_3. SiO_2: It has been observed that all the MgO is in amesite. So, the molecular ratio of MgO (0.019) has been used as a unit for fixing the molecular ratios of the components of amesite. But, MgO and H_2O are double in amount than Al_2O_3 and SiO_2. So, the mol. ratios for Al_2O_3 and SiO_2 will be reduced to half ($0.019 \div 2 = 0.0097$). The rest of the calculations are same.**

Ferroantigorite (Chlorite) **2 H_2O. 2 FeO. 2 SiO_2: Some of the FeO has been used in magnetite. So, that very amount will be subtracted from the total amount of FeO, then the mol. ratio will be calculated by dividing it with the mol. weight of FeO, that is $(3.82 - 2.29)\ 71.85 = 0.021$. The rest of the calculations are as under:**

TABLE – 1

SANDSTONE MINERAL ANALYSIS

Sandstone Specimen: Nagri Formation: Location: Wadala Kas, 43 C/15
District: Rawalpindi; Collected & Studied by: M. Saleem Bajwa

				FELDSPAR				CHLORITE		CLAY		
Elements	% age	Mol. Wt.	Mol. Ratio	An	Ab	Or.	Mag.	Ferant	At.	Kaolin	Qz	Rut.
SiO_2	78.92	60.08	1.217	1.32	3.78	3.24	–	0.85	0.58	2.95	66.20	–
Al_2O_3	06.60	101.96	0.065	1.12	1.07	0.92	–	–	0.99	2.50	–	–
Fe_2O_3	05.10	159.69	0.032	–	–	–	5.10	–	–	–	–	–
FeO	03.82	71.85	0.053	–	–	–	2.29	1.53	–	–	–	–
MgO	00.78	40.31	0.019	–	–	–	–	–	0.78	–	–	–
CaO	00.62	56.08	0.011	0.62	–	–	–	–	–	–	–	–
Na_2O	00.65	61.98	0.010	–	0.65	–	–	–	–	–	–	–
K_2O	00.85	94.20	0.009	–	–	0.85	–	–	–	–	–	–
Ti_2O	00.67	79.90	0.008	–	–	–	–	–	–	–	–	0.67
H_2O	01.49	18.01	0.103	–	–	–	–	0.26	0.35	0.88	–	–
Total	99.50	–	–	3.06	5.50	5.01	7.39	2.64	2.70	6.33	66.20	0.67
Including		Cal.	Dol.									
Calcite &		21.59	12.79	2.00	3.59	3.27	4.83	1.72	1.76	4.13	43.25	0.67
Dolomite		34.38			8.86			3.48				
Modal-Analysis		35.02			8.20		4.18	3.04		4.03	44.03	1.00

Analysis at G.S.P. Labs, by M.S. Bajwa and M. Anwar

Abreviations: **Quartz (Qz); Orthoclase (Or); Albite (Ab); Anorthite (An); Ferroantigorite (Ferant); Amesite (At); Magnetite (Mag) & Rutile (Rut).**

$2\,H_2O$	$3\,FeO$	$2\,SiO_2$
2/3 x 0.021	0.021	2/3 x 0.021
x 18.02	x 71.85	x 60.08
0.26	+ 1.53	+ 0.85 = 2.64 Ferrant

Kaolin (Clay) $2\,H_2O.\,Al_2O_3.\,2\,SiO_2$: The used Al_2O_3 will be subtracted from its total amount and then divided by molecular weight to get the molecular ratio. (6.60 – 4.1) 101.96 = 0.0245. The ratios will be fixed with H_2O, Al_2O_3 and SiO_2 as 2 : 1 : 2. The calculations are same as in the previous cases.

Quartz SiO_2 : In order to calculate the percentage of quartz, the amount of used silica will be subtracted from the total amount. (78.92 – 12.71 = 66.20 Quartz).

Rutile TiO_2 : In the present example no ilmenite or some other titanium bearing mineral has been observed, so the percentage of rutile will be same as that of TiO_2.

Calcite $CaCO_3$: and Dolomite $CaMg\,(CO_3)_2 = Ca.\,CO_3.\,MgCO_3$: A separate analysis of the same sandstone specimen indicated 15.98% and MgO 2.78%. Calculations for calcite and dolomite are as under:

Ca O
Molecular weight 40 + 16 = 56
Percentage amount 15.98

CO_2
12 + 32 = 44
= 44/56 x 15.98
= 12.56 CO_2
12.56 + 15.98 = 28.64 $CaCO_3$ ---a

Mg O
Molecular weights 24 + 16 = 40
Percentage amounts 2.78

CO_2
12 + 32 = 44
= 44/40 x 2.78
= 3.06 CO_2
03.06 + 02.78 = 05.84 $MgCO_3$ ---b

$MgCO_3$
Molecular weight 84
Percentage amounts 05.84

$CaCO_3$
100
100/84 x 5.84 = 06.95 $CaCO_3$ --c
Calcite (a – c) = 21.59
Dolomite (b + c) = 12.79

COMPUTER PROGRAMME NO. 1 : (Calcite & Dolomite)

```
05  PRT "CALCITE – DOLOMITE"
10  INP "% OF CaO =", A
20  INP "% OF MgO =", B
30  P = A* 0.79 + A
40  Q = B* 1.1 + B
50  R = Q* 1.19
55  SET F 2
60  PRT "CALCITE ="; P –R
70  PRT "DOLOMITE ="; Q+ R)
80  GOTO 10
```

Computer programme by Javed Akhtar

COMPUTER PROGRAMME NO. 2 : (Other minerals)

```
05  PRT "ANALYSIS OF SANDSTONE"
10  INP "% OF CaO =", A
20  INP "% OF Na2O =", H
30  INP "% OF CaO = ", K
40  INP "% OF Fe2O3 =", O
50  INP "% OF FeO =", R
60  INP "% OF MgO =", U
70  INP "% OF Al2O3 =", B
80  INP "% OF SiO2 =", C
90  D = 94.2: E = 101.96: F=60.08: L=A/D
100 I = 61.98: J = H/I: M = 56.08: N = K/M
110 P = 159.69: Q = 71.85: T = 18.02: V = 40.31
120 S = ABS (R – O/P * Q) / Q
130 W = ABS (B-(L* E + J * E + N * E + U/(2 + V)*E))
140 X = ABS (C-(L*6*F + J*F*6 + N* F* 2 +2/3* S*
    F + U/(2 * V) * F + W / E * 2 * F))
150 PRT "ORTHOCLASE ="; L * D + L * E + L * 6 * F
160 PRT "ALBITE ="; J * I + J * E + J * F * 6
170 PRT "ANORTHITE ="; N * M + N * E + N * F * 2
180 PRT "MANETITE ="; 0 + 0 / P * Q
190 PRT "FERRANT (CHLO) ="; 2/3 * S * T + S * Q +
    2/3 * S * F
200 PRT "AMESITE (CHILO) ="; U/V * T + U + U/(2 *
    V) * E + U / (2 * V) * F
210 PRT "KAOLIN ="; W/E * 2 * T + W + W/E * 2 * F
220 PRT "QUARTZ ="; X
230 GOTO 10
```

Computer programme by Javed Akhtar

CONCLUSIONS

A computer method, convenient for sandstone analysis has been described, that provides a practical and time-saving alternative to lengthy hand processing methods. In this programme molecular weights, molecular ratios and amounts of different mineral components have been used.

Percentage amounts of different sandstone minerals are obtained simply by feeding the amounts of different components, i.e. CaO, Na_2O, K_2O. This programme can be executed on any BASIC language computer. However this programme has been run on a pocket programmable calculator, weighing 176 grams. The programme is especially useful for the persons working on sandstone petrography.

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* * * *

SHORT COMMUNICATIONS ABSTRACTS AND REVIEWS

A REVIEW OF "EVIDENCE OF AN INCIPIENT PALEOZOIC OCEAN IN KASHMIR, PAKISTAN" By K. A. BUTT, M. N. CHAUDHRY & M. ASHRAF

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ABSTRACT.– Geochemical data presented in the paper under review in shown to be erroneous. Severe overestimation of Al_2O_3 and underestimation of TiO_2 and MnO, with evidently altered alkali and silica contents, render the analyses invalid for proposing a new tectonic model. The treatment does not prove the stated conclusion that the Panjal basalts are MORB, and cannot even prove whether the rocks are tholeiitic, alkaline or otherwise. Finally, the rocks are claimed to be primitive, which we do not agree with.

INTRODUCTION

In several recent papers, Butt, Chaudhry & Ashraf (1985) and Ghazanfar & Chaudhry (1984, 1985, and in prep.) have proposed a controversial setup of the geology of Hazara, Kashmir and the adjoining regions. In the proposed setup, the region between the MMT and the MBT is considered to be a micro-continent with associated rift and subduction-related magmatism. Field and geochemical data have been used to support the model. The discussions are not well-referenced with respect to previous work. The model is full of tectonic and regional geological inconsistencies, e.g. all magmatism associated with the tectonic cycle, from rifting to subduction and ophiolite emplacement, is attributed to the Panjal basalts and the agglomeratic slates. The model and supporting data presented by Butt et al. (1985) are criticised here, but this criticism applies broadly to Ghazanfar & Chaudhry (1984, 1985, and in prep.) as well.

The geochemistry of the basalts of Pir Panjal Range, Kashmir, has been used to indicate a rift – to ophiolite-stage mafic magmatism (Butt et al., 1985). The paper, following the style of Radhakrishan et al. (1984), consists of 1. chemical analyses, 2. a treatment of the analyses to prove a mid-ocean ridge basaltic (MORB) affinity for the Panjal traps, and 3. discussion of the tectonic implications. We propose to discuss these individually.

The presence of pillow lavas and intercalated marine sedimentary rocks is well-documented (Honegger et al., 1982; Gupta et al., (1983) from the Panjal basalts, but pillow lavas have been reported from basalts in all tectonic settings including continental flood basalts (Fodor & Vetter, (1984). Honegger et al. (1982) state that the Panjal basalts were erupted "under subaerial, marginal marine to terrigeneous conditions". Then, the authors conclude from their petrography that the absence of olivine indicates that the rocks are tholeiites. Their concusion is presumbaly based upon a misreading of Laurent et al., (1980).

THE CHEMICAL ANALYSES

The "Geochemistry" and "Magma Genesis" sections are misleading. It is clearly evident that the twenty three analyses presented by Butt et al. (1985) suffer from an overestimation of Al_2O_3 (upto 25%) and underestimation of TiO_2 (less than 0.5% in 18 analyses) and MnO (0.0 in 10 analyses); an impossible range of K_2O (0.00-6.18) and Na_2O (0.21-4.97) for basaltic rocks; sum totals that deviate from 100%; and incompleteness (P_2O_5 and volatile contents have not been determined). This alone is sufficient to invalidate the analyses.

In Figs. 8 & 9 the analyses badly scatter instead of defining neat fractionation trends. This is further indicative of the invalidity of the analyses for other elements as well. The analyses as such cannot be used for proposing a new tectonic model. Despite this, we shall consider how the authors use the data at hand to arrive at their conclusions.

THE TREATMENT

In Fig. 2, the norms plot from the olivine apex to well into the quartz field, an unusual variation for basaltic rocks. Not apparent from the plots is the presence of excess corundum, nepheline, magnetite and orthoclase, and absence of diopside in many of the norms. These unusual normative compositions (see Appendix) are the product of erroneous analysis. Further, our calculated CIPW norms plot quite differently (see Fig. 1). More surprisingly, they show 34 plots for 23 analyses. In some other diagrams also the number of plots and the positions of some of these do not match the analyses.

The "Geochemistry" section and Figs. 3-6 are devoted solely to demonstrate whether the basalts are tholeiitic, alkaline or calc-alkaline. The results are clearly

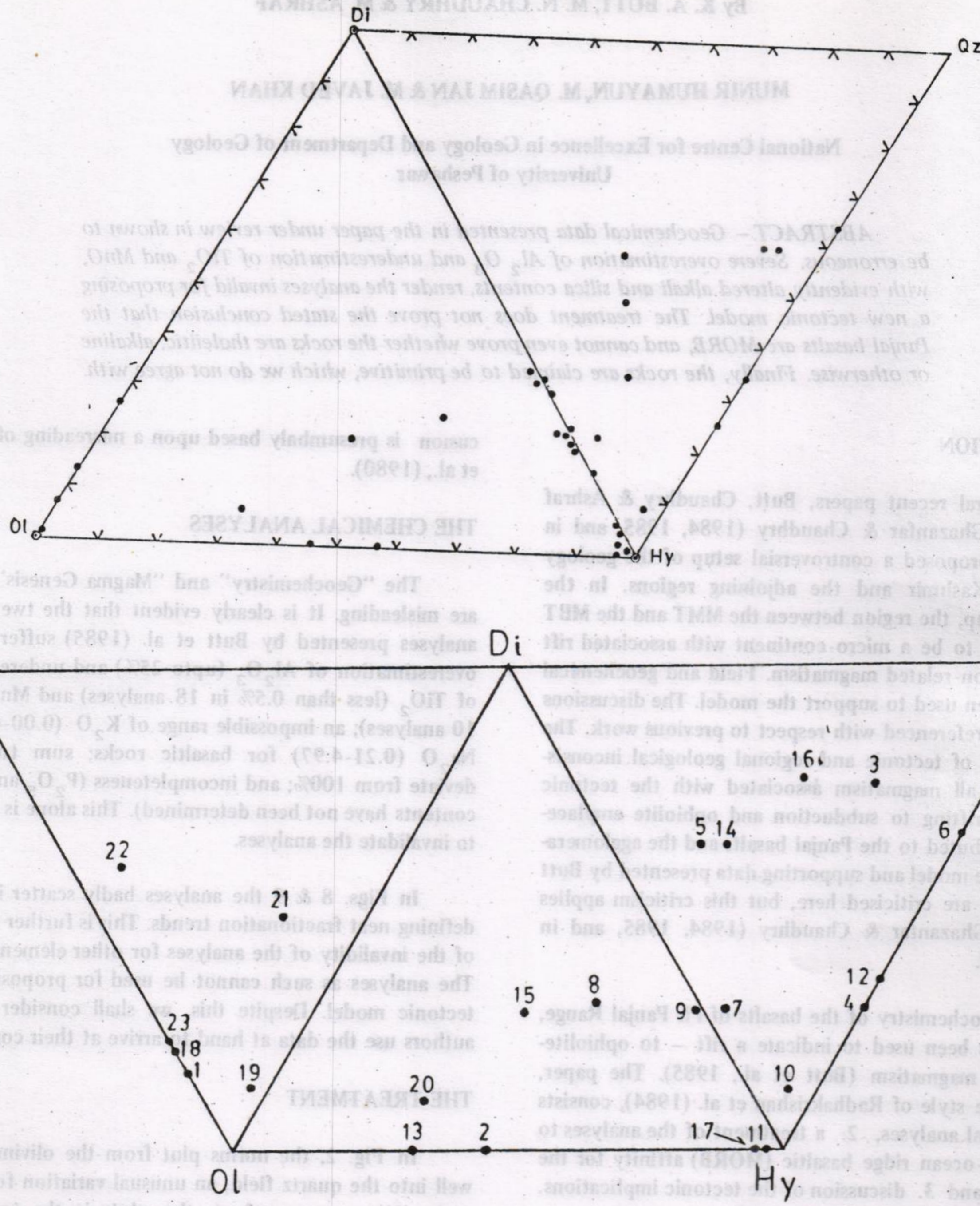

Fig.1 Normative plot of the 23 analyses in terms of quartz hypersthene-diopside-olivine-nepheline component (below) as compared to that of Butt et al., 1985 (above).

Appendix Table of CIPW norms of the analyses in But et al. (1985)

	1	2	3	4	5	6	7	8	9	10	11
Q	0.00	0.00	19.77	11.51	5.85	19.16	1.36	0.00	0.00	1.79	0.00
or	3.20	1.72	1.39	6.85	0.68	0.85	1.75	1.07	1.39	3.71	2.54
ab	21.73	39.88	5.01	1.85	16.76	14.76	13.98	18.71	21.13	15.41	27.44
an	43.71	21.37	52.35	38.41	42.68	45.12	44.17	41.42	38.19	49.29	39.64
lc	—	—	—	—	—	—	—	—	—	—	—
ne	3.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
c	0.58	4.99	0.00	4.85	0.00	3.27	0.00	0.00	0.00	0.00	1.94
cpx	0.00	0.00	7.65	0.00	16.07	0.00	8.48	10.19	9.42	1.47	0.00
hy	0.00	12.06	9.06	27.08	12.87	10.40	24.05	17.01	22.73	23.19	21.74
ol	19.9	14.03	0.00	0.00	0.00	0.00	0.00	6.16	0.44	0.00	0.69
mt	6.05	5.55	4.78	6.99	4.58	4.81	5.13	4.76	5.60	5.13	5.64
il	0.87	0.40	0.00	1.74	0.51	1.61	1.08	0.67	1.10	0.00	0.37
—			—								

12	13	14	15	16	17	18	19	20	21	22	23
15.87	0.00	4.55	0.00	22.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.11	0.55	0.74	10.41	0.00	8.72	3.00	2.23	10.95	7.82	17.26	2.20
10.60	32.64	27.86	19.85	4.07	28.41	28.03	29.56	26.70	24.38	0.00	25.12
29.45	36.26	49.41	30.52	36.08	30.27	30.36	36.31	32.51	28.88	15.31	41.16
—	—	—	—	—	—	—	—	—	—	14.48	—
0.00	0.00	0.00	0.00	0.00	0.00	5.93	0.84	0.00	4.79	22.29	4.86
6.81	0.63	0.00	0.00	0.00	4.92	4.93	0.00	0.00	0.00	0.00	3.53
0.00	0.00	8.87	9.33	18.32	0.00	0.00	2.60	2.25	10.43	4.33	0.00
29.62	7.87	7.82	12.54	12.33	20.88	0.00	0.00	6.66	0.00	0.00	0.00
0.00	16.11	0.00	10.64	0.00	1.18	21.89	22.57	13.50	15.76	18.46	15.76
4.10	5.52	5.54	6.39	6.95	5.37	5.87	5.54	6.82	7.46	7.53	7.09
1.45	0.42	0.30	0.32	0.12	0.26	0.00	0.35	0.62	0.48	0.33	0.27

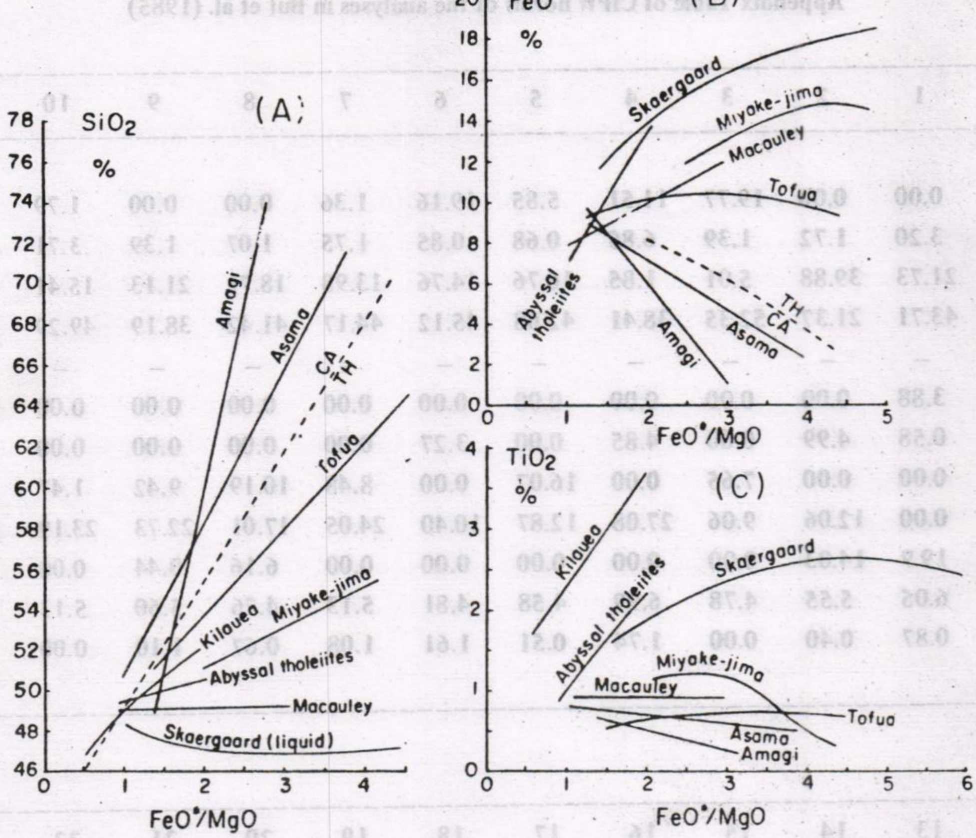

Fig.2 Distinction between the tholeiitic (TH) and calc-alkalic (CA) series in volcanic and related rocks in terms of the variation of SiO_2, FeO* and TiO_2 with increasing FeO*/MgO. FeO* means total iron as FeO. The rock series of the Skaergaard intrusion (Greenland), Macauley Island (Kermadecs) abyssal tholeiites (mid-oceanic ridges), Miyake-jima (Izu-Bonin), Kilauea (Hawaii) and Tofua Island (Tongas) belong to the TH series, whereas those of Asama and Amagi Volcanoes (Japan) belong to the CA series. (Photo-copied from Miyashiro, 1975 , p. 251).

ambiguous. In the first two paragraphs on p. 90, they alternately find that the Panjal basalts are tholeiitic to calc-alkaline, then tholeiitic to alkaline, then dominantly alkaline, and lastly, dominantly tholeiitic. It is evident that there is a severe problem with the analyses.

In Na_2O+K_2O vs. SiO_2 the analyses scatter with a negative correlation in all fields. This effect is typical of rocks which have undergone extreme alteration. This effect is typical of rocks which have undergone extreme alteration. This also effects the norms and, therefore, DI (Differentiation Index) vs. SiO_2 (Fig. 5) must be discarded. The same applies to any other diagram involving alkalies such as Fig. 6. Thus, it cannot be determined from the available data whether the Panjal basalts are tholeiitic or alkaline in affinity. The authors have paid little attention to the effect of alteration on the alkali contents of the rocks.

In Fig. 4 of the authors, the boundary between calc-alkaline and tholeiitic rocks is wrongly drawn in FeO* and TiO_2 against FeO*/MgO. It appears that these have been adapted from Radhakrishna et al. (1984) rather than from the original paper. The actual figures of Miyashiro (1975) are given in our Fig. 2 for comparison.

The affinity of the Panjal traps has not been proved in the paper which contains ambiguous statements such as "high Al_2O_3, low TiO_2 and low K_2O [6.18%] with a paucity of more sliceous associates [andestic and rhyolitic rocks are known]. . . . " and "Low TiO_2 content of pillowed lavas suggests these rocks to be ocean tholeiites erupted in a midocean ridge environment. TiO_2 content of Panjal volcanic is too low for mid ocean ridge basalts" which is self-contradictory. Note how Al_2O_3, TiO_2, and alkalies (their most unrealistic data) are used to make the most crucial agruments. Had these been determined correctly they would have been spared from generating much of the controversy. The interested reader is asked to consult their Table 2 for a comparison of their analyses with other basaltic rocks.

At the end of the "Geochemistry" section the reader will still not be able to find where the authors succeed in their purpose "to define their tectonic environment" by the "petrological-geochemical character of these volcanics". In fact they never had the data (minor, trace, RE elements) to even consider the tectonic environments. It is, therefore, unfortunate to see them claim an oceanic origin of tholeiitic to alkaline affinity in their discussion.

Following their uncovincing treatment of the data in the last section, they proceed to "Magma Genesis". Here figure for figure, word for word, and error for error, Butt et al. (1985) follow Radhakrishna et al. (1984). The interested reader is requested to obtain a copy of this paper for comparison.

The authors use two arguments, both invalid, to insist that the Panjal basalts are primitive. First, the Mg/(Mg+Fe) ratio which for primitive basalts is 0.70 to 0.60. From their analyses, we have calculated the ratios to range from 0.52 to 0.09 with the majority being among the most fractionated rocks. This is far from primitive. Thus, the rocks are not eligible for plotting on the next diagrams, following Sun et al. (1979). However, since the authors did not, apparently, read the reference, but instead relied on Radhakrishna et al. (1984), their plots reach maxima of $Al_2O_3/TiO_2=220$ and $CaO/TiO_2=180$, ten times the maximum (chondritic) limit for basaltic rocks. This is entirely the fault of their much too high Al_2O_3 and much too low TiO_2. The result is the sock-like distortion of Fig. 7.

In the end they state that a "strong olivine fractionation" was involved (which contradicts the primitive character which they claim) and that this indicates a MORB affinity. Olivine is involved in the fractionation of virtually every basalt, and nowhere do Perfit et al. (1980) claim this to be a MORB characteristic. We repeat again that Butt et al. analyses are not adequate to divulge a new model for the Hazara-Kashmir region. Before attempting to make such sweeping conclusions it is absolutely essential to have a good set of chemical analyses, with minor, trace and, preferably, RE elements.

Furthermore, previous geochemical studies (Honegger et al., 1982; Gupta et al., 1983; Pareek, 1983) indicate a continental flood basalt origin for the Panjal traps.

CONCLUSIONS

It is now evident that:

1. The chemical analyses are invalid, and some of the diagrams are erroneous.
2. The treatment is faulty and the authors did not have adequate data to prove their conclusions. Thus, the results are based on their personal opinion.
3. There is no scientific evidence to maintain the notion of a Hazara-Kashmir microcontinent, a third suture along the MBT, or some other conclusions stated in the paper of Butt et al. (1985).

Finally, the interested reader is referred to the papers of Andrews-Speed & Brookfield (1982), Honegger et al. (1982), and Trommsdorff et al. (1983), for a factual account of the classical Panjal basalts, the continental plateau basalts of a widely documented Permo-Carboniferous rifting episode.

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EVIDENCE OF AN INCIPIENT PALAEOZOIC OCEAN IN KASHMIR, PAKISTAN – A REPLY

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ABSTRACT:– Geochemical data presented in the paper Butt et al. (1985) is shown to be comparable to the data published by other authors on Panjal volcanics. Repeat analysis of 40 rock samples (to be published elsewhere) confirm high Al_2O_3 and low to moderate TiO_2 and low MnO_2 values.

The treatment certainly does not prove that Panjal basalt are MORB and the same was never claimed. Similarly the problem of these rocks being tholeiitic, alkaline or otherwise is also apparent from data of Gupta et al (1983) and Pareek (1983). Istead a transitional nature of these basalts was suggested which may have formed in an incipient ocean. The first stage in the evolution of an ocean is widely accepted to be an "Intracontinental rift" and successive developmental stages from a rift to and oceanic environment must involve an evolutionary process of development of oceanic crust between these too end members. The transitional nature of these basalts was proposed in this study.

INTRODUCTION

The controversial set-up proposed by Butt et al. (1985) has been contested by Hymayun et al. (this vol.) According to these authors the model proposed is full of tectonic and regional geological inconsistancies. They have suggested faulty analyses by refering to Gupta et al (1983), Pareek (1983) and Honegger et al (1982), faulty treatment to prove Panjal basalts to be MORB and therefore faulty tectonic interpretation. In this paper we intend to show that the chemical data presented by Butt et al. (1985) is not much different than that of Gupta et al. (1983), Pareek (1983) and Honegger et al. (1982). As for the contention that Butt et al. (1985) failed to prove Panjal basalts as MORB it is to be reiterated that Butt et al. (1985) never intended to prove an MORB for the basalt but rather suggested the formation of an incipient ocean. However, we would like to comment on the criticism of chemical analyses, treatment of analyses and discussion of the tectonic interpretation separately.

THE CHEMICAL ANALYSES

Hymayun et al. (this vol.) intuitively consider analyses to suffer from an overestimation of Al_2O_3 and under estimation of TiO_2 and MnO, since they do not present any data of their own to demonstrate it. Since they rely heavily on Gupta et al. (1983), Pareek (1983) and Honegger et al. (1982) to support these contensions, it would be of some interest to present a comparasion of analyses of these authors to those presented by Butt et al. (1985). Such a comparsion is given in Table-1.

It is obvious from Table-1 that the range of analytical values given by Butt et al. (1985) are comparable with other authors especially Gupta et al. (1983) and Pareek (1983). We however, regret the printing error where 0.00 was printed instead of a dash which represents "Not determined". As for the incompleteness of the analyses, it was never claimed that our analyses are complete but incompleteness of analyses does not invalidate the data by any means. Geochemical literature is full of such instances where many workers have relied on "incomplete" analyses for their interpretations.

Hymayun et al. (this vol.) stated that in Fig 8 & 9 of Butt et al (1985) there is a bad scatter of plots.The scatter is due to data presented therein and compared above with data on similar rocks from other areas. Such scatters need interpretations and we may or may not have been at error in interpreting such a scatter but this does not necessarily mean that the data is invalid. It is a common misconception in the geological literature that a neatly defined trend supports certain models specially fractiona-

tion. Neatness of fractionation trends in a lot of diagrams suffer from co-variance i.e. the plotting of an element or oxide. It would, in a way, amount to plotting a parameter against the same parameter which would certainly result in a straight line and the departures from this straight line being caused by involvement of other parameters on one of the ordinates. The point, however, is that if the data does not fall on a "neatly defined trends" it is to be interpretted as such but this should in no way invalidate the data which Humanyun et al. (this vol.) so strongly advocated.

Furthermore now we have another set of 40 analyses (to be published elsewhere) which do not deviate much from those reported in Butt et al. (1985). The following is a summary of this unpublished analytical data:

1. Average P_2O_5 is 0.10% which is lower than continental flood basalt.
2. Average MnO_2 is 0.11%.
3. TiO_2 range now obtained is 0.43 – 1.98%.
4. K_2O content is variable but generally much lower than continental flood basalts. However due to adularisation it rises sharply at place.

THE TREATMENT

The unusual variation of chemical analyses will most certainly be reflected in the unusual normative composition which Humayun et al. (this vol.) have contested. As demonstrated in the previous section, our analyses are comparable with those published by other authors. The unusual normative compositions are therefore not a product of erroneous analyses as contented by Humayun et al. (this vol.) but unusual compositions. The error in Fig. 2 is, however, regretted.

Humayun et al. (this vol.) refering to Figs. 3-6 of Butt et al. (1985) stated that they have failed to demonstrate tholeiitic, alkaline, a calc alkali nature of these basalts. In this connection we would like to cite the following.

Pareek (1983) page 2 para 4. "The Panjal traps fall in the tholeiitic field deficient in silica and alkalies, in the gradational zone and in the alkali basalt field.

Gupta et al. (1983) Page 12 para 2 line 2. "In this variation diagram it is clear that the spilitized members (of Bafliaz volcanics) fall near the marginal zone of alkali series and calc alkali series. The keratophyre displays high value of $Na_2O + K_2O$ suggesting increasing tendency towards alkali rock series during the course of differentiation (Gupta 1973). This clearly points towards alkali character of the rocks. For Panjal traps of Thannamandi area (autochthonous zone) the alkali-silica variation indicates that these rocks are tholeiitic in character as all these points are restricted to the tholeiitic field but the intrusives associated with the Panjal volcanics comparatively show high $Na_2O + K_2O$. The Ralakung volcanics however, show a slight gradation between the tholeiitic and alkali olivine basalt. The $Na_2O + K_2O$ do not show any trend of increase or decrease with SiO_2 in the case of Panjal trap of Kashmir but it is mostly restricted to tholeiitic field".

Honegger et al. (1982) page 25 para 3. "Mineralogically and chemically (Table – 1 and Fig. 3) the volcanics belong to the tholeiitic and alkali series. Most basalts are silica saturated (quartz normative) or nephline normative".

Since Humayun et al. (this vol.) have such faith in the above stated three authors we have quoted from these authors and leave the reader to judge the difference between our conclusions about tholeiitic, alkali or calc alkali nature of these basalts to those advocated by these authors.

Humayun et al. (this vol.) at the out set (abstract) declare that our analyses suffer from severe overestimation

TABLE – 1

Oxides	Butt et al. (1985)	Pareek (1982)	Gupta et al. (1983)	Honegger et al. (1982)
Al_2O_3	13.39 – 24.82	9.02 – 20.17	12.03 – 20.46	12.06 – 19.66
TiO_2	0.13 – 0.88	0.30 – 3.30	0.12 – 2.25	1.08 – 2.49
MnO	0.06 – 0.33	0.13	0.06 – 0.37	0.15 – 0.27
K_2O	0.09 – 6.18	0.13 5.56	0.06 – 4.49	0.14 – 2.06
Na_2O	0.21 – 4.97	0.43 – 3.20	0.37 – 6.32	1.31 – 3.58

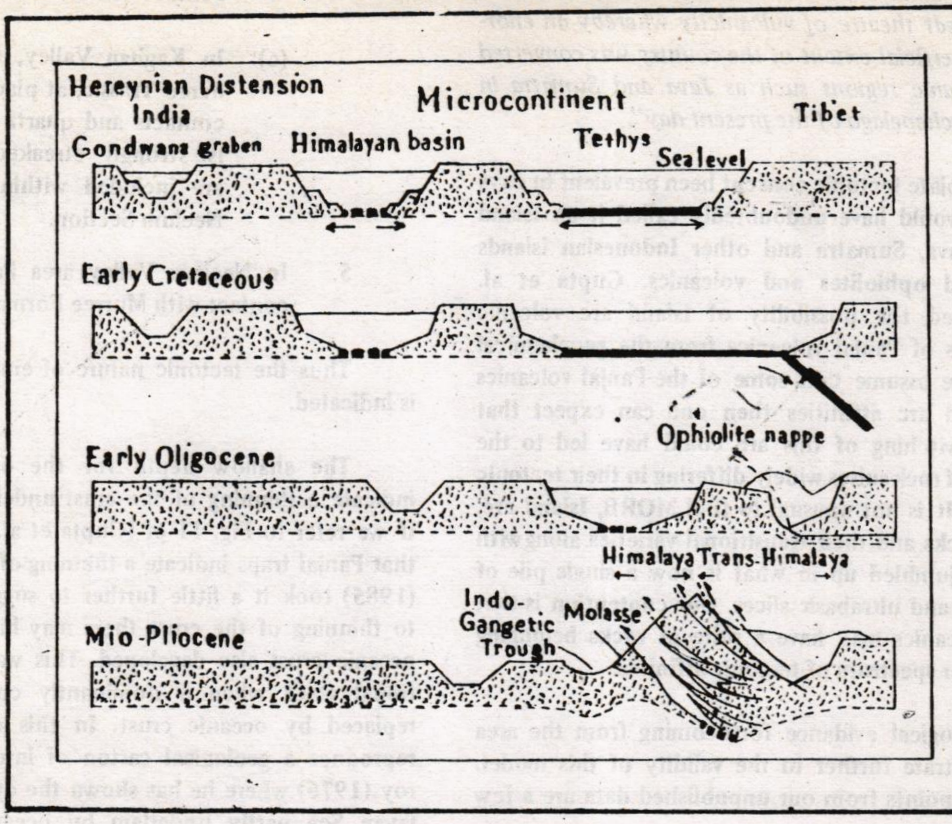

Plate tectonic cartoon showing the evolution of the Himalaya with the involvement of microcontinent (after Sinha Roy 1976)

of Al_2O_3 and underestimation of TiO_2 and MnO. However, under the heading "The treatment" para 5 they find the statements of higher Al_2O_3 and low TiO_2 and low K_2O as ambiguous. We are at a loss to understand what is ambiguous about stating high Al_2O_3 and low TiO_2 for these rocks based on our analyses.

In para 6 of "The treatment" Humayun et al. (this vol.) have declared that we never had the data to discuss the tectonic environment since our data lacked minor, trace and REE elements. In this regard the reader is once again referred to the conclution of Gupta et al. (1983) and Pareek (1983) upheld by Humayun et al. (this vol.) which are also based on major elements not withstanding the fact that the interpretation based on trace and rare earth elements are more reliable.

It would be evident by the above discussion that Humayun et al. (this volume) have only argument that the analyses are faulty and most of their other arguments are nothing but corollaries of the same. It has been amply demonstrated with reference to their favourite authors on Panjal volcanics that our data may have sufficient similarities with that of their's.

In the end, once again refering to Honegger et al. (1982), Gupta et al. (1983) and Pareek (1983), Humayun et al. (this vol.) stated that these authors have indicated a continental flood basalt origin of the Panjal traps. In this regard we once again quote from these authors.

Gupta et al. (1983) page 16 line 11 quoting Sharma et al. (1976 in press) have pointed out that the Panjal volcanics with their predominant andesitic character are of a nature of volcanicity along the continental margin. The predominace of pyroclastics alongwith volcanics in some of the sections may suggest island arc conditions as well.

It is, therefore, obvious that the conclusion "extracted" by Humayun et al. (this vol.) from Gupta et al. (1983) for Panjal basalts being continental flood basalts is not the only conclusion stated in their paper. They have also indicated the possibility of associated Island arc conditions.

In this context it would not be out of place to quote Wadia (1966) on panjal volcanics.

"During the last of deposition of the Fenestalla Shale Beds, the physical geography of the Kashmir area underwent a voilent change and what was before a

region of quite marine sedimentation was converted into a great theatre of vulcanicity whereby an enormous superficial extent of the country was converted into volcanic regions such as Java and Sumatra in Malaya archepelago of the present day".

Had the plate tectonic concept been prevalent in days of Wadia, he would have undoubtedly called it an Island arc such as Java, Sumatra and other Indonesian islands with associated ophiolites and volcanics. Gupta et al. (1983) indicated the possibility of Island arc volcanic nature of parts of Panjal volcanics from the geochemical approach. If we assume that some of the Panjal volcanics do have Island arc affinities then one can expect that orogenic sandwitching of this arc could have led to the juxtaposition of rock suites widely differing in their tectonic environments. It is not unusual to find MORB, Island arc, ocean floor rocks and their transitional varieties alongwith ultrabasics all jumbled up in what is now a single pile of basic volcanics and ultrabasic slices. Our contention is that the Panjal volcanics may have a suite of rocks belonging to a much wider spectrum of tectonic affinites.

The geological evidance forthcoming from the area would demonstrate further to the validity of this model. The following points from our unpublished data are a few such examples :–

1. **Ultrabasic bodies such as altered peridotites are present south of the Panjal volcanics in Kotli Distt. They cut the Cambrian dolomites. Due to late tectonic remobilization these ultrabasics have been moved up into the Terttiaries. These are located 20-30 km south of Panjal volcanics but are hundreds of Km south of MMT. In addition, several talc schist horizons (not related to siliceous dolomites) in Hazara may well represent ultrabasics related to Panjal complex.**

2. **Some of the gravity highs along parts of MBT in North Panjal and Peshawar plain may be due to subsurface, hitherto unexposed ultrabasic bodies.**

3. **Nickliferous ultrabasics from south of Panjal volcanics in Hazara are now know and are being investigated by one of us (Ashraf).**

4. **Panjal volcanics have peculiar contact relations:-**

   (a) **In occupied Kashmir the panjal volcanics are in contact with Silurian to Triassic rocks.**

   (b) **In Poonch – Kotli area they are in contact with Eocene limestone.**

   (c) **In Kaghan Valley, the limestone considered Trassic, at places show mylonitized contacts and quartz in impure limestone is strongly streaked. These limestones are included within Panjal in Reshian-Neelum Section.**

5. **In Neelum Valley area Panjal volcanic are in contact with Murree Formation also.**

Thus the tectonic nature of emplacement of Panjals is indicated.

The shallow depth for the outpouring of spilite indicate a thinning of the crust under oceanic conditions. If we refer to Fig. 11 of (Gupta et al. (1983) it is evident that Panjal traps indicate a thinning of the crust. Butt et al. (1985) took it a little further to suggest that in addition to thinning of the crust there may have been areas where oceanic crust also developed. This was probably a transitional stage when a dominantly continental crust was replaced by oceanic crust. In this connection we here reproduce a geological carton of interpretation by Sinha roy (1976) where he has shown the development of Himalayan Sea partly underlain by oceanic crust. Such was prbably the nature of the marginal sea which separated the Gondwanaland and its microcontinents.

In this connection it would be of some interest to the readers if we quote Sinha roy (1976).

At page 118 para 2 Sinha roy (1976) states "The suggestion that the Himalaya is essentially a Hercynide fold belt is also relevant in this connection. It is likely that Hercynian distension caused either opening or widening of the embryonic Tethys and that during this process rifting of the northern edge of India took place, so that a cluster of microcontinents came into existence between the main continnents of India and Tibet (Fig. 2). This distension was responsible for the Gondwana graben system in India and Upper Palaeozoic sedimentary volcanic sequence in Tibet. As this process continued, the oceanic separation between the microcontinent and the Tibetan shield increased to give rise to what may be designated as the Mesozoic Tethys. In the initial stages, the Himalayan basin was a rift system and an embryonic ocean, which as indicated by Upper Palaeozoic basic volcanics in Kashmir and Eastern Himalaya, contained mantle reaching fractures. Major and trace element geochemistry of these volcanics from a part of the Eastern Himalaya (unpublished data of the author) suggests that they are transitional between ocean floor and 'within plate' *basic rock suite. Most probably, continued rifting and distension caused appreciable thinning of the continental crust and at a late stage, formation of an intermediate or oceanic crust in this basin. Rift tectonics are amply demonstrated by lateral inconsistency and temporal heterogeneity in Upper Palaeozoic and Mesozoic stratigraphy which ranges from marine, platform to even continental types. Local intermingling of Gondwanic fauna with the Eurasian types in the sediments of the Himalayan basin would suggest that the microcontinent did not behave a solid barrier between the Tethys proper and the Himalayan basin. There might have been a few isthmuses".*

The transitional nature of upper Palaeozoic basic volcanics is also indicated in this study of Sinha roy (1976) which also includes geochemistry. The central crystalline zone of Indian Hamalayas are essentially a Precambrian-Proterozoic rock suites and there is some isotopic evidence that Nanga Parbat Harmosh massif may be as old as Proterozoic (Pers. Comm Dr. Qasim Jan). There is also some stratigraphic evidence that the gneissic rocks of Nanga Parbat-Haramosh massif and its probable counterparts exposed in Kaghan, Neelum and Reshian valleys may have formed the basement on which Precambrian sediments of Salkhala series were deposited. All this points towards the fact that NP-H massif may represent Pakistani counterpart of "Central crystalline zone" which Sinha roy (1976) considers to be a "Microcontinent".

CONCLUSIONS

1. Analyses are not invalid because independently reported analytical data of Gupta et al. (1983) and Pareek (1983) has comparable values.

2. Treatment is not faulty but we certainly do not claim to have finally proved the nature of Panjal basalts but merely advanced a plausible hypothesis for which field evidence in conjunction with chemical data (incomplete) was presented.

3. Whether the notion of Hazara-Kashmir microcontent is to be maintained or not only further work will tell. At this stage a working hypothesis to this effect can, however certainly be advanced.

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BASIC PROGRAMMING FOR MAGNETIC CALCULATIONS FROM VERTICALLY POLARIZED BODIES OF SIMPLE GEOMETRICAL SHAPES

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ABSTRACT:– The present paper deals with conversion of basic magnetic formulae by Nettleton (1976) into BASIC language, convenient for interpretation in the field. Software has been prepared for a sphere, horizontal, vertical and circular cylinders, vertical fault (approximated by a horizontal sheet), vertical sheet and two diamensional slab polarized vertically. Hypothetical data evaluations, presented in this paper, proves the efficiency of the method.

INTRODUCTION

Magnetic prospecting, the oldest method of geophysical exploration, is used to explore for both oil and minerals. It maps variations in the magnetic field of the earth which are attributable to changes of structure or magnetic susceptibility in certain near surface rocks. Sedimentary rocks exert such a small magnetic effect compared to the igneous rocks below them that virtually all variations in the magnetic intensity measurable at the surface are associated with topography or lithologic changes in the basement. In mining exploration, the method is used to prospect for magnetic minerals directly and in some instances for non-magnetic minerals where structures controlling their accumulation can be mapped because of associated magnetic minerals (Dobrin, 1960 and Paranis, 1979).

Attempt has been made to translate the magnetic formulae of simple geological structure into BASIC (Beginners all purpose symbolic instruction code) language for first approximation of the geophysical interpretation of magnetic anomalies in the field. Casio programmable calculator, model No. Fx 702 P having calculation range of $\pm 1 \times 10^{-99}$ to $9.999999999 \times 10^{99}$ has been used for these programs. It has 1680 steps with 26 memories and the memories can be expanded upto 226 by the reduction in the number of steps. Its portability can easily be judged by its weight of 176 grams (Butt 1985).

DISCUSSION

The magnetic effects are discussed only for the vertical field component from vertically polarized bodies. Hypothetical data evaluations caused by bodies of simple geometrical shapes are shown in Table – 1. These cases, of course, are greatly simplified over actual occurrences in nature where, in general, the magnetizing field is not vertical. However, they approximate actual conditions closely enough to be useful in indicating the approximate magnitude and general shape of expected effects as ordinarily measured with the vertical megnetometer.

Using the nomenclature given in the list of symbols, the mathematical formulation and computer implementation for magnetic calculations from vertically polarized bodies of simple geometrical shaps are given by Nettleton (1942, 1976).

List of Symbols

X = horizontal distance on ground surface from the point above the center of the disturbing body to the point at which the effect is calculated.

Y = depth from ground surface to the upper surface of the disturbing body.

Z = depth from ground surface to the lower surface or center of the disturbing body.

R = radius of the disturbing body.

T = thickness of the disturbing body (for lamellar forms).

L = length of the disturbing body.

K = magnetic susceptibility contrast in c.g.s units.

H = Vertical component of the earth's magnetic field in c.g.s. units and is determined from magnetic charts.

V = calculated magnetic effect in gammas.

A & C= Starting and end stations on x - axis.

TABLE NO. 1

CALCULATED MAGNETIC ANOMALIES IN GAMMAS FOR SIMPLE GEOLOGICAL STRUCTURES

Parameters	Sphere	Horizontal cylinder.	Vertical line Element.	Vertical fault.	Vertical sheet.	Vertical circular cylinder a) finite depth.	Vertical circular cylinder b) Infinite depth.	Two Dimensional slab.
Susceptibility, K		0.0059	0.0059	0.0059	0.0059	0.0059	0.0050	0.0059
Magnetic Strength H	0.339	0.339	0.339	0.339	0.339	0.339	0.330	0.339
Thickness	–	–	–	50	25	–	–	–
Radius, R	100	100	100	–	–	100	100	–
Length, L	–	–	–	–	–	–	–	400
Upper Surface Depth, Y	–	–	200	–	100	100	200	100
Lower or Centre Surface Depth, Z	200	200	–	200	200	200	–	200
Distance + 500	– 3.14	– 31.38	+ 8.05	+ 34.48	+ 3.85	– 12.41	+ 28.38	– 55.46
+ 400	– 3.75	– 37.70	+ 14.05	+ 40.00	+ 5.88	– 16.43	+ 41.50	– 87.47
+ 300	– 1.37	– 37.18	+ 26.81	+ 46.15	+ 10.00	– 20.62	+ 64.35	+ 235.20
+ 200	+ 18.51	– 0.00	+ 55.54	+ 50.00	+ 20.00	– 11.10	+ 103.83	+ 257.40
+ 100	+104.90	+ 150.80	+ 112.40	+ 40.00	+ 50.00	+ 64.35	+ 157.09	+ 235.20
0.00	+209.40	+ 314.16	+ 157.08	+ 0.00	+100.00	+ 128.71	+ 185.47	+ 87.47
– 100	+104.90	+ 150.80	+ 112.40	– 40.00	+ 50.00	+ 64.35	+ 157.09	– 55.46
– 200	+ 18.51	0.00	+ 55.54	– 50.00	+ 20.00	– 11.10	+ 103.83	– 66.06
– 300	– 1.37	– 37.18	+ 26.81	– 46.15	+ 10.00	– 20.62	+ 64.35	– 51.54
– 400	– 3.75	– 37.70	+ 14.05	– 40.00	+ 5.88	– 16.63	+ 41.50	– 39.22
– 500	– 3.14	– 31.38	+ 8.05	– 34.48	+ 3.85	– 12.41	+ 28.38	– 30.04

$$V = \frac{4\pi R^3 I}{3}(2Z^2 - X^2)(Z^2 + X^2)^{-5/2}$$

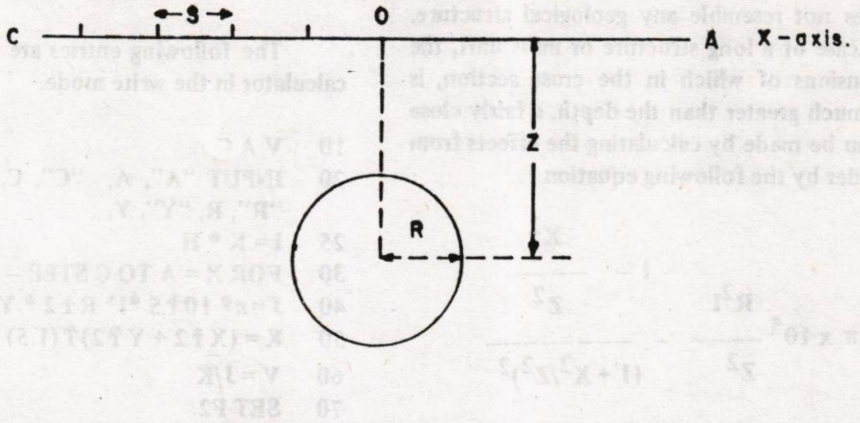

FIG. 1. Sphere

S = Station interval.

1. *SPHERE:*– The sphere is the simplest geometric form for which geophysical effects can be calculated. Of course, masses in nature for which magnetic effects might be derived are never spherical, but in any case where the horizontal dimensions of the body, being considered, are substantially less than the depth, surpirsingly close approximations to the magnetic effects can be made on the basis of its approximation as a sphere. The principal applications are to plugs or intrusions. The vertical component of magnetic effect caused by a spherical body is calculated by the following equation (Fig. 1).

The following entries are made in the programmable calculator for this equation in write mode.

```
10   V C A
20   INPUT "A", A, "C", C, "S", S, "K", K, "H", H,
     "R", R, "Z", Z,
25   I = K * H
30   Fox x = A to C STEP – S
40   V = 4/3 *π* R ↑ 3 * I * 10 ↑ 5 *(2* Z ↑ 2 – x ↑ 2)/
     (Z ↑ 2 + x ↑ 2) ↑ (2.5)
50   SET F 2
60   PRINT "X = "; X; "ANOMALY"; V
70   NEXT X
```

In the run mode, the calculator will ask successibely for A ? C and S. ? These are the positions on x-axis, from the starting station "A" to end station "C" for the calculation to be made with station intervals "S" "K" will be magnetic susceptibility contrast, "H", is the vertical component of earths magnetic field, "Z" will be for the depth to the centre of the sphere model, "R" entry will be for radius of the model sphere.

Suppose we want to find out anomaly caused by a spherical body of radius 100 meters, with its centre at a depth of 200 meters from surface and having magnetic susceptibility contrast of 0.0059 cgs units, vertical component of the earth's magnetic field is 0.339 oersted and calculations are required from 500 meters from one side of the body to 500 meters on the other side of the body with station interval of 100 meters. The entries will be –

A	?	500
C	?	– 500
S	?	100
K	?	0.0059
H	?	0.339
R	?	100
Z	?	200

The display will be

X	=	500	Anomaly	–	3.14
X	=	400	Anomaly	–	3.75
X	=	300	Anomaly	–	1.37
X	=	200	Anomaly	+	18.51
X	=	100	Anomaly	+	104.90
X	=	0.00	Anomaly	+	209.40
X	=	–100	Anomaly	+	104.90
X	=	–200	Anomaly	+	18.51

X	=	–300	Anomaly	–	1.37
X	=	–400	Anomaly	–	3.75
X	=	–500	Anomaly	–	3.14

2. *HORIZONTAL CYLINDER:–* **An infinite horizontal cylinder also does not resemble any geological structure. However, in any case of a long structure or mass unit, the horizontal diamensions of which in the cross section, is less than or not much greater than the depth, a fairly close approximation can be made by calculating the effects from a horizontal cylinder by the following equation :**

$$V = 2\pi \times 10^5 \frac{R^2 I}{Z^2} \frac{1 - \frac{X^2}{Z^2}}{(1 + X^2/Z^2)^2}$$

The following entries are made in the programmable calculator in the write mode.

```
10  V A C
20  INPUT "A", A, "C", C, "S", S, "K", K, "H" H, "R",
    R, "Z", Z.
25  I = K *H
30  For x = A to C step – S
40  V = 2* π* R I 2* I* 10 I 5* (Z I 2 – X I 2)/ (Z I 2 +
    X I 2) I 2
50  SET F2
60  PRT "X"; X; "ANOMALY"; V
70  NEXT X
```

The procedure for running this program is the same as that of a sphere mentioned previously.

3. *VERTICAL LINE ELEMENT:–* **Vertical line element can be used to approximate a vertical cylinder for which the horizontal dimension is considered less than the vertical dimension. The formula is given for the cause, in which the bottom of the cylinder is at infinite depth (Fig. 2).**

The following entries are made in the programmable calculator in the write mode.

```
10  V A C
20  INPUT "A", A,  "C", C, "S", S, "K", K, "H", H,
    "R", R, "Y", Y,
25  I = K * H
30  FOR X = A TO C STEP – S
40  J = π* 10↑5 *I* R↑2 * Y
50  K = (X↑2 + Y↑2)↑(1.5)
60  V = J/K
70  SET F2.
80  PRT "X"; X; "ANOMALLY"; V
90  NEXT X
```

4. *THE VERTICAL FAULT:–* **(approximated by a horizontal sheet).**

The magnetic effect of a semi infinite horizontal layer of finite thickness (the edge of which corresponds to a vertical fault) can be expressed quite simply on the assumption that the material is condensed into a thin sheet at a central plan of the body, and is given by the equation Fig 3.

The following entries are made for this equation in the programmable calculator in the write mode.

$$V = \pi R^2 Y I / (X^2 + Y^2)^{3/2}$$

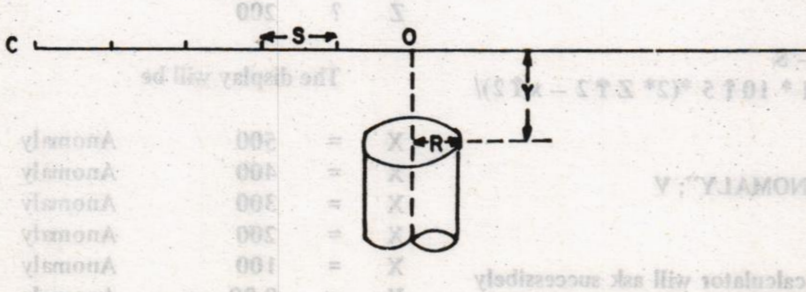

FIG. 2. Vertical Line Element.

$$V = 2\,I\,T\,X\,(x^2 + z^2)^{-1}$$

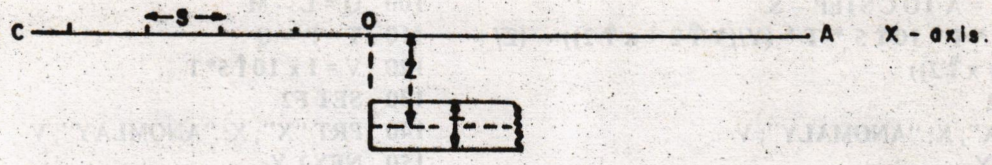

FIG. 3. Vertical Fault

```
10   V A C
20   INPUT "A", A, "C", C, "S", S, "K", K, "H", H,
     "Z", Z, "T", T,
25   I = K * H
30   FOR X = TO C STEP – S
40   V = 2 * 10↑5 *I* T* X/(X↑2 + Z↑2)
50   SET F2
60   PRT "X", X; ANOMALY"; V
70   NEXT X
```

5. *VERTICAL SHEET:–* **Expressions for a vertical sheet are useful in approximating effect which might be caused by vertical dikes. The geometry of the body is shown in the figure-4, and the formula for calculating magnetic effect is**

$$V = 2\,I\,T\,((Y/R\,1^2) - (Z/R\,2^2))$$

The following steps are to be entered in the calculator in write mode–

$$V = 2\,I\,T\,((\;Y\;/R\;1^2) - (\;Z\,./R\;2^2))$$

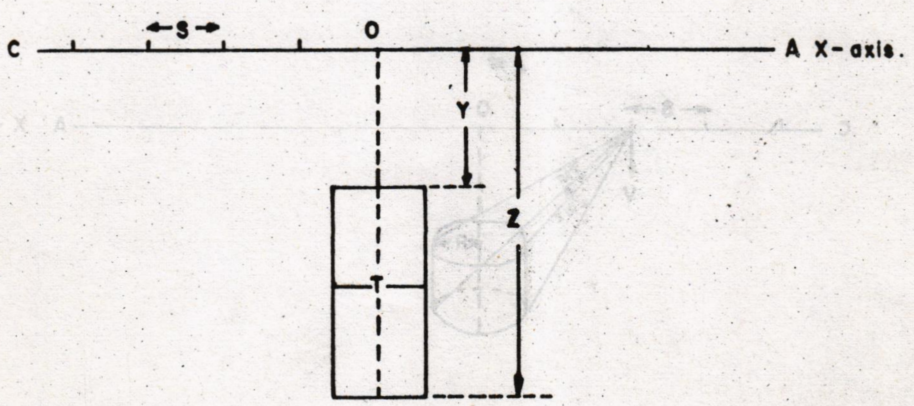

FIG. 4 . Vertical Sheet

```
10   V A C
20   INPUT "A", A, "C", C, "S", S, "K", K, "H", H,
     "T", T, "Y", Y, "Z", Z,
25   I = K * H
30   FOR X = A TO C STEP – S.
40   V = 2 * I * 10↑5 * T * (Y/(Y↑2 + x↑2)) – (Z/
     (Z↑2 + x↑2))
50   SET F2
60   PRT "X"; X; "ANOMALY"; V
70   NEXT X
```

6. *VERTICAL CIRCULAR CYLINDER:–*

a) *Finite Depth:–* The vertical component of the magnetic effect caused by vertical circular cylinder of finite depth (Fig 5) is calculated by the following equation:-

$$V = I \times 10^5 \times (W1 - W2)$$

Where W1 = Solid angle substended by the upper face.
W2 = Solid angle substended by the lower face.

The following entries are made in the programmable calculator for this equation in RADIAN MODE.

```
10   V A C
20   INPUT "A", A, "C", C, "S", S, "K", K, "H", H,
     "R", R, "Y", Y, "Z", Z
30   I = K * H
40   FOR X = A TO C STEP –S
50   J = ATN     ((X + R)/Y)
60   K = ATN     ((X – R)Y)
70   L = ATN     ((X + R)/Z)
80   M = ATN     ((X – R)/Z)
90   P = J – K
100  Q = L – M
110  T = P – Q
120  V = I x 10↑5*T
130  SET F2
140  PRT "X"; X; "ANOMLAY"; V
150  NEXT X
```

b) *Infinite Depth:–* The vertical component of the magnetic effect caused by vertical circular cylinder of infinite depth (Fig. 6) is calculated by the following equation:

$$V = I \times 10^5 \times W$$

The following entries are made in the programmable calculator for this equation in RADIAN MODE.

```
10   V A C
20   INPUT "A", A, "C", C, "S", S, "K", K, "H", H, "R",
     R, "Y", Y
30   I = K * H
40   FOR X = A TO C STEP – S
50   T = ATN ((X + R)/Y) – ATN ((X- R)/Y)
60   V = I * 10↑5 * T
70   SET F2
80   PRT "X"; X; "ANOMALY"; V
90   NEXT X
```

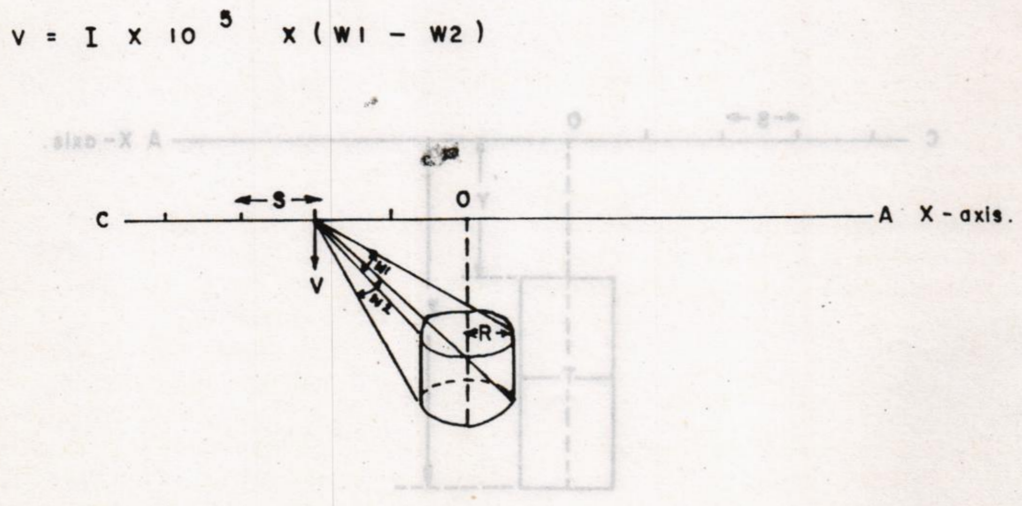

FIG. 5a. Vertical Circular Cylinder – Finite Depth

$$V = I \times 10^{5} \times W$$

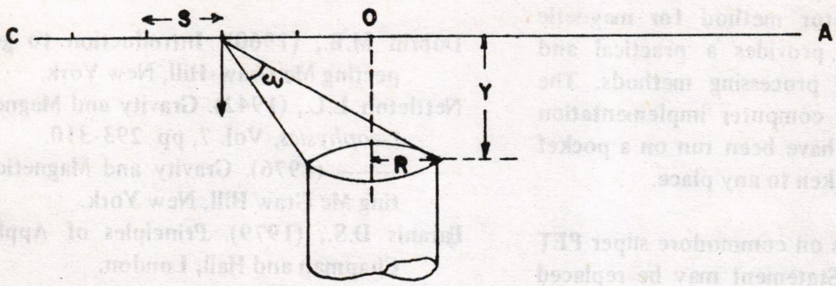

Fig. 5b. Vertical Circular Cylinder–Infinite Depth.

$$V = 2 \times I \times 10^{5} (\theta_1 - \theta_2).$$

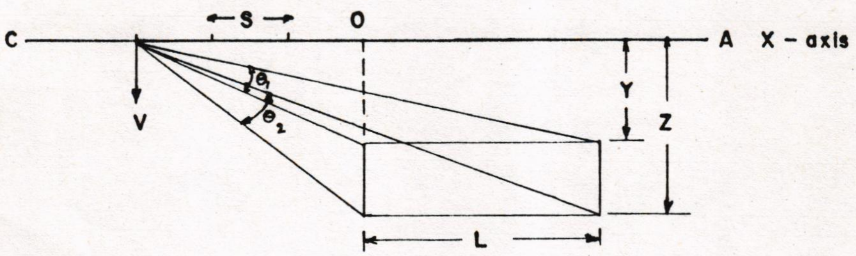

Fig. 6. Two Diamensional Slab.

7. *TWO DIAMENSIONAL SLAB:–* For a horizontal plate of finite width and infinite length (Fig. 7), the solid angle is simply W = 20 where – is the angle (in radians) substended by the edges of the slab. This gives the simple formula

$$V = 2 \times I \times 10^{5} (01 - 02).$$

The following entries are made in the programmable calculator in RADIAN MODE.

```
10  V A C
20  "A", A, "C", C. "S", S, "K", K, "H", H, "L", L,
    "Y", Y, "Z", Z
25  I = K * H
30  FOR X = A TO C STEP – S
40  IF L < X; GOTO 90
50  IF X = L; T = ATN (L/Y) – ATN )L/Z)
60  IF X > L; GOTO 110
70  IF X = o; T = ATN(L/Y) – ATN (L/Z)
80  IF X < O; GOTO 130
90  P = ATN (X/Y) + ATN ((L–X)/Y)
100 Q = ATN (X/Z) + ATN ((L–X/Z): GOTO 150
110 P = ATN ((X–L)/Y) – ATN (Y/X)
120 Q = ATN ((X–L/Z) – ATN (Z/X): GOTO 150
130 P = π – ATN (Y/(L–X) – π + ATN (Y/(–X))
140 Q = π – ATN (Z/(L–X)) – π + ATN (Z/(–X))
150 T = (P – Q)
```

```
160  V = 2 * I * 10↑5 *T
170  SET F2
180  PRT "X", X; "ANOMALLY); V
190  NEXT X
```

CONSLUCION

A programmable calculator method for magnetic calculation is described that provides a practical and economic alternative to hand processing methods. The mathematical formulation and computer implementation is presented. The programmes have been run on a pocket computer which can easily be taken to any place.

To use these programmes on commodore super PET SP–9000 computer the VAC Statement may be replaced by CLR statement, SET F2 statement used in these programmes should be deleted, and each assignment should have LET statement.

AKNOWLEDGEMENTS

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BASIC PROGRAMMING FOR MEASURING STRATIGRAPHIC SECTIONS

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and

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ABSTRACT:– A programmable calculator method for correcting stratigraphic sections from apparent thickness to true thickness and vice versa is presented that allows field geologists to work through problems that formly may have been done on a pocket calculator, but with much more flexibility, speed and accuracy. Hypothetical data evaluation presented in this paper proves the efficiency of the method.

INTRODUCTION

Measuring and describing stratigraphic sections with accurate fossil location are used to interpret geologic history, to solve the complexity of structures, to establish lithologic and thickness variations and to help to solve regional problems. The approach towards completion of stratigraphic work in any outcrop study is largly a function of the number of sections measured, studied and analysed. Regardless of the procedure employed, a measured section is useful only if it yields the data required on lithology, paleontology, stratigraphic relations and thickness of the measured stratigraphic section (Lahee, 1961 and Compton 1962).

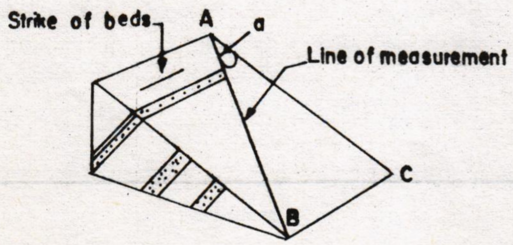
A programmable calculator method is desired that provides a practical and economic alternative to hand processing methods for calculating true thickness from slope distances for interpretting stratigraphic sections in the field. Casio programmable calculator No. Fx 702 p using Basic language and having calculation range of ± 1 x 10^{-99} to 9.999 x 10^{-99} has been used for this programme. It has 1680 steps with 26 memories can be expanded upto 226 by the reduction in the number of steps. Its partability can easily be judged by its weight of 176 grams. The programme can be run on another programmable calculator utilizing Basic Language with little or no modification (Akhtar, this Volume).

DISCUSSION

Unless the true thicknesses are measured directly, as with the jacob's staff, they must be calculated from the slope distances. If the measured slope distance is oblique to the dip of the beds, it must be corrected by the formula based on the notation as shown in Fig. 1.

The true thickness is then calculated by one of the formulas shown is Fig. 2, the choice depending on the relation between the ground slope and the dip.

To calculate a reverse situation of true thickness from dip and apparent thickness, as in a well with a dipmeter survey, the calculation is:



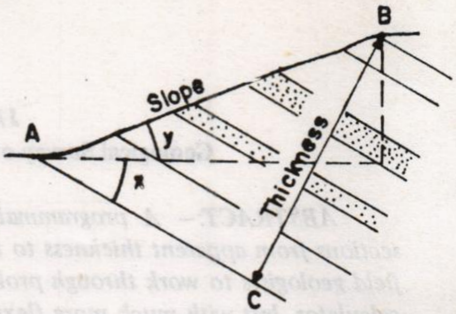
AC = AB Cos a

True thickness = Apparent thickness x Cos (Dip angle)

Fig. 1 : Correction of Slope distances as measured oblique to dip of the beds.

a. Slope and dip are opposed and angle of slope (y) plus angle of dip (x) is < 90°

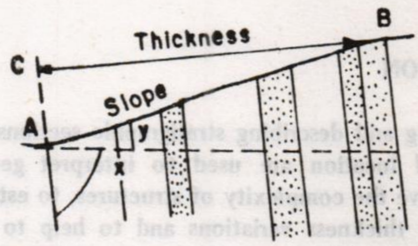
$$BC = AB \sin(x + y)$$



b. Slope and dip are opposed and angle of slope plus angle of dip is > 90°

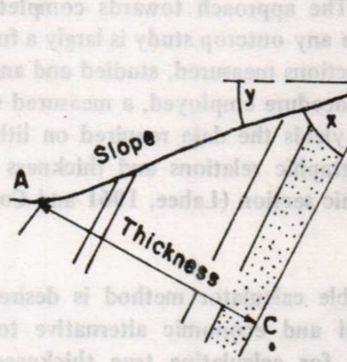
$$BC = AB \cos(x + y - 90°)$$

Or $$BC = AB \sin\left[180° - (x + y)\right]$$



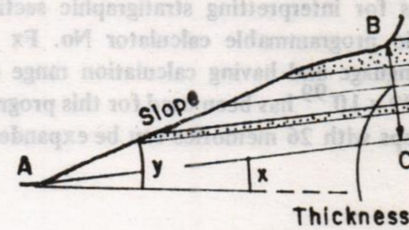
c. Slope and dip are in the same direction, with dip > slope

$$AC = AB \sin(x - y)$$



d. Slope and dip are in the same direction, with dip < slope.

$$BC = AB \sin(y - x)$$



Drafted by : S.N. Siddiqui

Fig. 2. Formulas used for the various possible combinations of direction and amount of ground slope and dip of beds. (Ref. Robert R. Compton, P. 241)

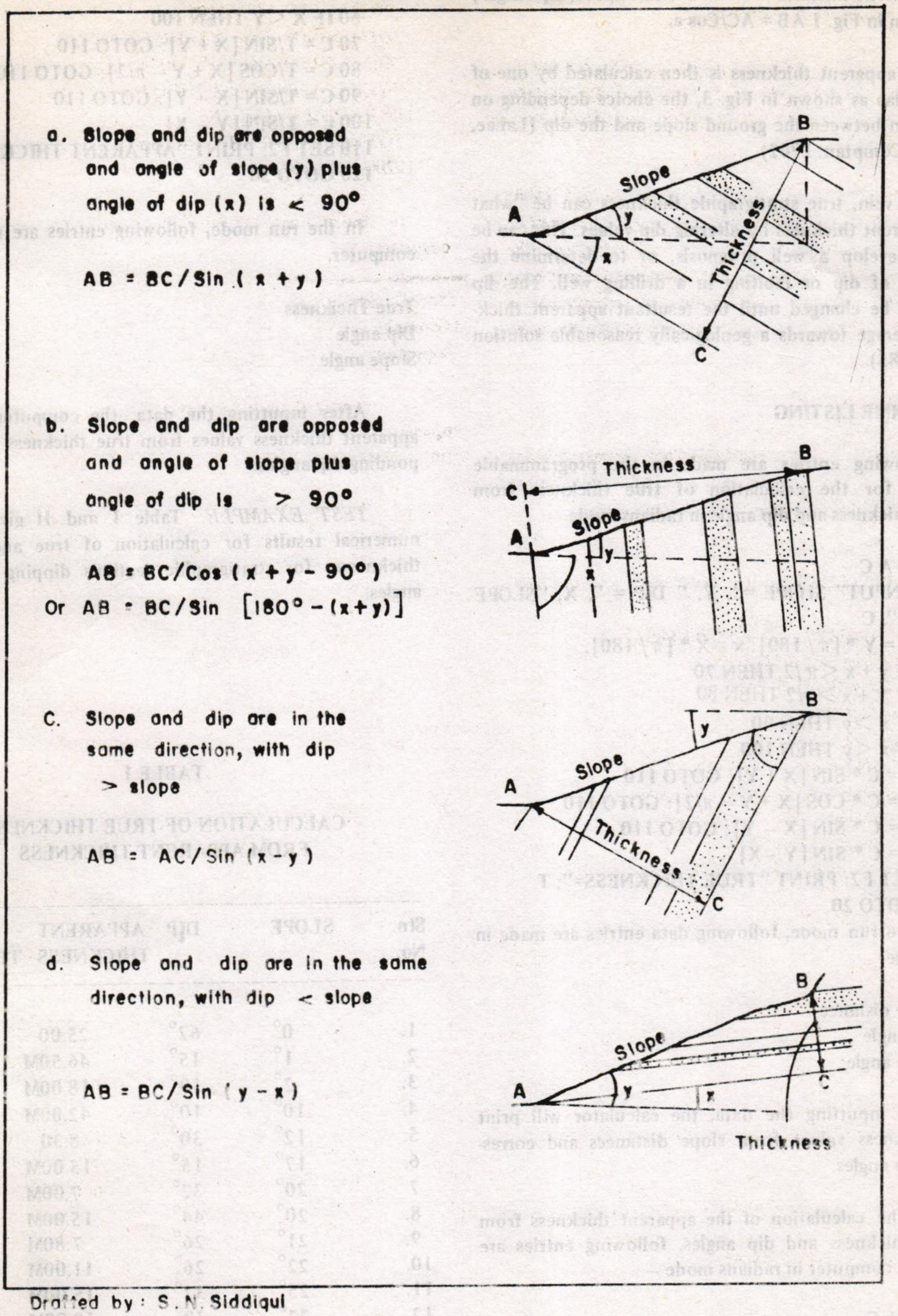


Fig. 3. Formulas used for the various possible combinations of direction and amount of ground slope and dip of beds. (Ref. Robert R. Compton, P. 241)

Apparent thickness = True Thickness/Cos[dip Angle] or as shown in Fig. 1 AB = AC/Cos a.

The apparent thickness is then calculated by one of the formulas as shown in Fig. 3, the choice depending on the relation between the ground slope and the dip (Lahee, 1961 and Comptan, 1962).

In a vein, true stratigraphic thickness can be "what ifed" apparent thickness by altering dip values. This can be used to develop a well prognosis, or to determine the magnitude of dip or faulting in a drilling well. The dip values can be changed until the resultant apparent thicknesses coverage towards a geologically reasonable solution (Smith, 1985).

PROGRAMME LISTING

Following entries are made in the programmable calculator for the calculation of true thickness from apparent thickness and dip angle in radians mode –

```
10 V A C
20 INPUT" SLOPE =", Y, " DIP = ", X, "SLOPE DIS=", C
25 Y = Y * [π / 180]: x = X * [π / 180].
30 IF y + x <π /2 THEN 70
40 IF Y + x >π/2 THEN 80
50 IF x >y THEN 90
60 IF x <y THEN 100
70 T = C * SIN [X + Y]: GOTO 110
80 T = C * COS [X + Y – π/2]: GOTO 110
90 T = C * SIN [X – Y]: GOTO 110
100 T = C * SIN [Y –X]
110 SET F2: PRINT "TRUE THICKNESS="; T
120 GOTO 20
```

In the run mode, following data entries are made in the computer

1. Slope distance
2. Dip angle
3. Slope angle

After inputting the data, the calculator will print True Thickness values from slope distances and corresponding dip angles.

For the calculation of the apparent thickness from the true thickness and dip angles, following entries are made in the computer in radians mode –

```
10 V A C
20 INPUT">Slope =", Y," Dip = ", x, "True Thick=", T
25 Y = Y * [π/180]: x = X * [π/180].
30 IF Y + X <π/2 THEN 70
40 IF Y + X >π/2 THEN 80
50 IF X >Y THEN 90
60 IF X <Y THEN 100
70 C = T/SIN [X + Y]: GOTO 110
80 C = T/COS [X + Y – π/2]: GOTO 110
90 C = T/SIN [X – Y]: GOTO 110
100 C = T/SIN [Y – X]
110 SET F2: PRINT "APPARENT THICKNESS="; C
120 GOTO 20
```

In the run mode, following entries are made in the computer.

True Thcikness
Dip angle
Slope angle

After inputting the data, the computer will print apparent thickness values from true thickness and corresponding dip angles.

TEST EXAMPLE: Table I and II gives detailed numerical results for calculation of true and apparent thicknesses for stratigraphic sections dipping at various angles.

TABLE 1

CALCULATION OF TRUE THICKNESS FROM APPARENT THICKNESS

Stn. No.	SLOPE	DIP	APPARENT THICKNESS	TRUE THICKNESS
1.	0°	62°	25.00	22.07
2.	1°	15°	46.50M	12.82M
3.	2°	10°	18.00M	3.74M
4.	10°	10°	42.00M	14.36M
5.	12°	30°	8.30	5.55M
6.	17°	15°	15.00M	7.95M
7.	20°	32°	7.00M	5.52
8.	20°	44°	15.00M	13.48
9.	21°	26°	7.80M	5.70
10.	22°	26°	11.00M	8.17
11.	25°	32°	15.00M	12.58
12.	27°	30°	19.00M	15.93
13.	28°	32°	19.00M	16.45
14.	38	15°	2.70M	2.16M

TABLE 2

CALCULATION OF APPARENT THICKNESS FROM TRUE THICKNESS

Stn. No.	SLOP	DIP	TRUE THICKNESS	APPARENT THICKNESS
1.	0°	62°	22.07M	25.00M
2.	1°	15°	12.82M	46.50M
3.	2°	10°	3.74M	18.00M
4.	10°	10°	14.36M	42.00M
5.	12.°	30°	5.55M	8.30M
6.	17°	15°	7.95M	15.00M
7.	20°	32°	5.52M	7.00M
8.	20°	44°	13.48M	15.00M
9.	21°	26°	5.70M	7.80M
10.	22°	26°	8.17M	11.00M
11.	25°	32°	12.58M	15.00M
12.	27°	39°	15.93M	19.00M
13.	28°	32°	16.45M	19.00M
14.	38°	15°	2.16M	2.70M

CONCLUSIONS

The mathematical formulation and computer implementation for calculation of true thickness from apparent thickness and slope angle or vice versa is presented, that provides a practical and economical alternative to hand processing methods. Field geologists will find these programmes useful and can apply the same in the field using handheld programmable calculators.

AKNOWLEDGEMENTS

We wish to express our gratitude to Mr. S. Habib Abbas, for providing a careful review of an earlier draft of this manuscripts and to the Deputy Director General for permission to publish this paper.

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GENESIS OF PETROLEUM AND ITS IMPLICATIONS IN OIL AND GAS EXPLORATION

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INTRODUCTION

Seemingly inherent in the man's intellectual make-up is the urge to understand and explain his own origin, that of the world in which he lives, and of the things he finds in the world.

Arabs were not behind among the first to formulate hypotheses about the orgin of petroleum. Quoting Forbes (1958), a famous Arab hypothesis formulated about 850 AD says:

> *Water (spirit) and Air (soul) were matured by the action of Fire and produced "fiery sulphur" and "watery mercury". These two secondary elements admixed with more or less Earth and subjected to certain temperatures formed the minerals found in the earth including the bituminous substances such as naft (from the Greek "naptha") and qir (asphalt) which, because they had a high air and oil content, were easily liquified and highly inflammable ...... how the condensation of "mercury" and "sulphur" in the crevices of mountains produce naft and qir like "coagulated dew".*

Until the chemical nature of petroleum was known, hypotheses on origin of petroleum were pure speculation. In the eighteenth century speculation centred around an origin by distillation of coal with some authorities arguing for an origin from animal remains. In the middle century most popular were the hypotheses on an inorganic origin, where inorganic chemical reactions deep in the earth in the presence of supposed hot alkalies and/or hot carbide reacted with carbon dioxide in one case, or water in the other. These hypotheses owed their ascendancy more to the great names of their authors – M. Berthelot and Dimitri Mendeleef, than to their intrinsic merit and fell into general, though not complete, disrepute by the end of the century.

Many variations and modifications of these inorganic hypotheses were proposed, principally by the chemists.

At the same time, geologists began severely to question the validity of conclusions based on purely theoretical occurrences of source materials which did not accord with geological facts.

ORGANIC ORIGIN

Tremendous advances in organic chemistry and bio-chemistry during the last half century, and more recently in organic geochemistry, have provided a ful' comprehension of the chemical nature of organic matter and its decomposition, and of petroleum. In the minds of vast majority of geologists and geochemists the organic hypothesis is now firmly establihsed as a theory.

It has been established since long ago that the majority of marine sedimentary rocks consist of organic matter in different proportions, which varies in composition, properties and form of occurrence. Various kinds of organic matter may form 85-90% of organic carbon and 8-10% of H in the rocks.

FUNDAMENTAL FORMS OF ORGNANIC MATTER:

Dispersed organic matter exists in two fundamental forms in the rocks as organic mineral complex and in detrital form.

1. *Organic-mineral complex:* it results on account of release of the active surfaces of rocks from water and thus includes; mineral mass of the rocks & adsorbed layer of organic mater. Adsorbed layer is formed on account of components of organic matter capable of dispersion in water. The layer consists of heterogeneous polymolecular structure, representing the capability of individual components of organic matter to adsorption.

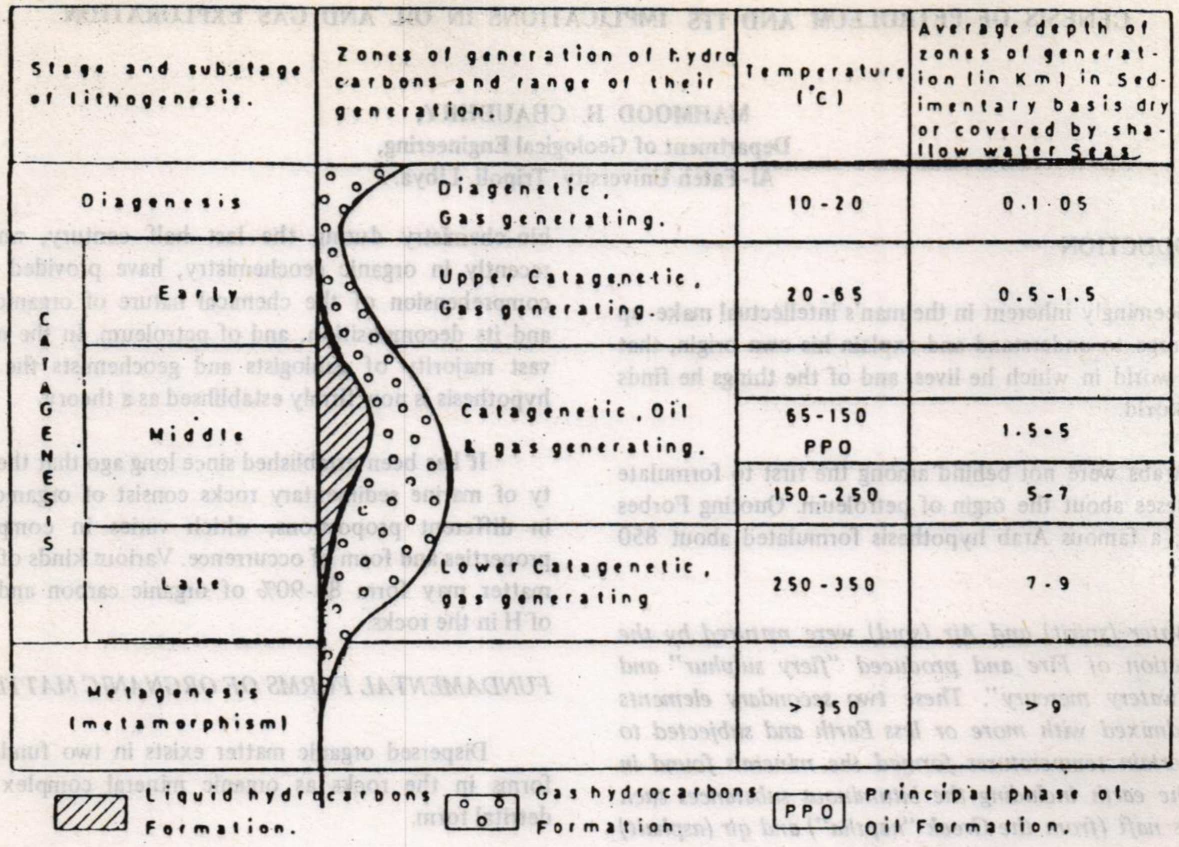
The most active adsorbents are pelitic rocks, first of all clays, much lesser – carbonate sediments and almost insignificant – sandy rocks.

2. *Detrital organic matter:* it is represented by carbonised vegetable remains, which to some extent have preserved the structure of initial organic matter.

Detrital organic matter is usually transported from land and, therefore, is an allochthonous element. It is usually disposed along the surface of beds as lens like veins, patches etc. Detrital form of occurrence of organic matter is mostly characteristic for oil shales and for highly bituminized carbonate rocks.

TYPES OF ORGANIC MATTER BASED ON COMPOSITION OF THE INITIAL SOURCE MATTER:

Composition of the initial organic matter permits to distinguish two basic types of dispersed organic matter in the rocks.



Scheme of evolution of dispersed organic matter, enclosed in the sedimentary rocks.

1. *Sapropelic organic matter:* It accumulates in clayey and carbonate-clayey marine sediments in reducing geochemical environments. The initial materials are components of lower plants and animal plankton. Sapropelic type of organic matter is principally a structureless (more than 85%), reworked substance, which has lost resemblance with the initial material.

2. *Humus organic matter:* Accumulates principally in the shelf and lake environments in the sandy-silty sediments in the sandy-silty sediments in weak reducing and oxidising conditions. The intial organic material is mostly lignitic-cellulose part of the higher plants and carbohydrate components of the lower plants. Humus substance is composed of the same group of micro components which take part in the structure of coals (vitrinite, fusinite, etc.).

However, the most widespread is organic matter of mixed type: humus-sapropel or sapropelic-humus. Pure sapropelic matter is possible only in marine rocks of late Proterozoic and early Paleozoic.

Genetic type of organic matter may be reliably worked out at its early stages of transformation. In the course of lithogenesis the differences in the composition of humus and sapropelic type become less distinct.

EVOLUTION OF DISPERSED ORGANIC MATTER:

Dispersed organic matter in the rocks is subjected to continuous change on account of its own internal chemical energy. This change has a character of conjugated process of oxidation – reduction, where one part of the substance is oxidised (enriched in oxygen) and other part is recuced (enriched in hydorgen). External factors (surrounding minerals, temperature, pressure) are principally, either stimulants, or they slow down the continuous action of internal energy.

The process is irreversible exothermic chemical reaction. It is directed towards lowering down the free energy and is accompanied, on one hand – by the permanent formation and separation from organic matter of combinations with little reserves of energy (CO_2, H_2O and others) and on the other hand – formation of comparatively smaller amounts of energy rich new combinations, hydrocarbons, which are more as compared to the earlier ones, in temperature-pressure and geochemical conditions of the taking place reaction. These reactions take place in conditions of changing properties of the environment in which organic matter is located (porosity, water saturation, composition, sorbtion and catalytic activation of the rocks) different forms of occurrence of organic matter (in solution colloid or adsorbed state) and variable intensity of action of various physical agents on the organic matter (temperature, pressure.)

The end product of transformation of organic matter is graphite.

FACTORS OF TRANSFORMATION OF DISPERSED ORGANIC MATTER:

The most important factors are bacterial activity, temperature, catalysts and hydrogenation. These factors act at various stages of occurrence of organic matter, substituting each other, or acting simultaneously with variable time length.

STAGES OF EVOLUTION OF ORGANIC MATTER:

Different stages of evolution of organic matter varying in degree of transformation and composition of generatéd products are distinguished. These correspond to different stages of coalification of organic matter and lithogenesis.

1. *Stage of accumulation of organic matter (accumulation of sediment):* During settling of organic matter (till it reaches the bottom sediments) characteristic are oxidational processes, which take place on account of molecular oxygen and aerobic heterotrophic bacteria, touching the less stable components of organic matter.

2. *Stage of diagenesis:* As a result of short duration of the stage of sedimentogenesis, unstable components in oxidational conditions, such as carbohydrates and proteins, during the process of settling does not succeed to get completely decomposed. As a result, sediments receive initial components of organic matter (proteins, carbohydrates, lipoids, lignin and others) and also their decomposition products (aminoacids, fatty acids, humic acids, etc).

Water content in the sediments is sharply reduced at this stage. Oxidational environment is replaced by reductional. Availability of free oxygen in the sediment is limited or almost absent and the available free oxygen is actively consumed by the microorganisms. Part of the organic matter is thus oxidized, consuming free oxygen. At this stage reduction of some components of mineral matter takes place in anaerobic conditions. Oxide forms of iron and sulphates are subjected to reduction, which transform into $FeCO_3$ (siderite) and FeS_2 (pyrite). The availability of oxide or sulphide forms of Fe determines the geochemical environments of diagenesis as oxidizing or reducing.

Capability of organic matter to oxidation is determined by the intensity of its initial oxidation. In case of a higher starting oxidation of organic matter, the level of reduction of geochemical environment is decreased. Correspondingly, organic matter of sapropelic type provides the best reducing conditions in the sediments.

After entering the bottom sedimetts, organic matter is subjected to short lived becterial activity. Significant part of organic matter, probably, is concentrated as heterogeneous miscible complexes, composed of various partly decomposed components of organic matter (carbohydrates amino acids, lipoids) and products of its initial transformation which are interconnected by sorbtion forces. Complexes formed in this way are not capable of further significant changes at this stage.

It is generally accepted that the stage of diagenesis takes place up to 500 m. depth and within temperature range of 10-20°C.

3. *Stage of protocatagenesis:* This stage is characterised by the increasing action of temperature on organic matter, which may reach at the end of this stage up to 65°C. The depth range of this stage is adopted up to 1,500 m. A new agent of transformation of organic matter – microcatalysis appears at the end of this stage.

4. *Stage of mesocatagenesis:* For this stage of transformation of organic matter, characteristic temperatures are from 65-250°C. and depth up to 7,000 m. Most active agent of transformation is thermocatalysis. Heterogeneous microcatalysis results on account of removal of adsorbed water from active surfaces of rocks and their replacement by the components of organic matter, existing in miscible complexes. Transformation of organic matter here, as a whole, takes place in adsorbed layer and is accompanied by the breakdown of molecules and redistribution of hydrogen with the formation of hydrocarbons, not only gaseous, but also liquid, having different group composition.

Adsorption balance is dynamic – molecules of the adsorbate, as a result of molecular forces and thermal flow are continuously renewed. As such, a continuous redistribution of substances occurs in accordance with their sorbtion properties. In particular, fatty acids, asphaltenes, etc. are concentrated within the inner side of the adsorbed layer, and hydrocarbons – in the external; successively – aromatic, napthenic, and most weakly held – paraffinic. 5. Stage of apocatagenesis; last and the rigorous stage of transformation of organic matter starts at depths exceeding 7000 m. and is characterized by high values of temperature (250-350°C.) and pressure, and weak catalytic activity of surrounding minerals. Residual organic matter, after thermocatalysis, at these depths is highly coalified and poor in hydrogen. Hydrocarbons and particularly methane at this stage can form, probably, on account of hydrogen.

GENETIC ZONATION OF PETROLEUM FORMATION:

Stages of transformation of organic matter and formation of hydrocarbon result in the appearance of (in the Earth's crust) a definite zonation of hydrocarbons of varying composition and phase state, which are capable of migration.

There are four fundamental genetic zones: biochemical gaseous; thermolytic gaseous; thermocatalytic oil and gaseous and lower gaseous pyrohydrogenation.

1. *Biochemical gaseous zone:* Corresponds diagenetic stage of transformation of organic matter (peat stage of

coalification). The principal hydrocarbon product is methane.

2. *Thermolytic gaseous zone:* Corresponds early stage of catagenesis of sedimentary rocks and lignitic stage of coalification of organic matter. Generation of methane continues and also appear its homologues. Formation of gas takes place under the effect of temperature, which may reach at the end of this zone up to 65°C. and depth may range up to 1.5 Km.

3. *Thermocatalytic oil and gas zone:* Corresponds to middle stage of catagenesis of sedimentary rocks and bituminous coal stage of coalification of sedimentary rocks and bituminous coal stage of coalification of organic matter. It is characterised by the increase in gas generation and appearance of liquid hydrocarbons. At this stage a sudden increase in the generation of liquid hydrocarbons. At this stage a sudden increase in the generation of liquid hydrocarbons takes place from the mother rocks. Temperature at the end of this zone may reach 250°C. The depth of this zone may extend up to 6 or even 7 Km.

The lower half of this zone having a temperature range of 150-250°C is characterised by the decrease in the quantity of generation of liquid hydrocarbons as a result of exhaustion of lipoidic components of organic matter. However, gas continues to form in large quantities (wet gas).

4. *Lower gaseous pyrohydrogenation zone:* Corresponds to late stage of catagenesis of sedimentary rocks and anthracite coal stage of coalification of organic matter. It is disposed below 7Km. with temperatures above 250°C. The zone is characterized by the generation of hydrocarbon gas from organic matter. In the upper portions of the zone are formed gaseous homologues of methane and in the lower – only dry methane. Liquid hydrocarbons are not formed.

The disposition of the above considered zones and their thickness in the section of an oil and gas basin will, naturally, vary and may be accounted by the following factors:

(a) Genetic type of organic matter – domination of organic matter of humus type increases the thickness of upper gaseous zone and lowers the border of oil and gas zone. As such the position of genetic zones of oil and gas generation will be different in basins represented by only continental rocks or only by marine rocks or alternations of these rocks.

(b) Value of geothermal gradient – with the increase of the geothermal gradient, thickness of genetic zones is increased. Thus in the basins represented by older rocks, whole of the genetic series will lie higher, than in the younger basins.

Vertical zonation in the formation of hydrocarbons is also reflected in the vertical distribution of accumulations of hydrocarbons of variable composition and phase state. However, significant effect on this distribution is caused by the time and intensity of removal of hydrocarbons from source rocks, time and mechanism of formation of traps and also the history of the formed accumulations, which depends upon tectonic movements. All these variables change the picture of distribution of accumulations of hdrocarbons within the rock section, against the expected correspondence with the sequence of vertical zonation.

Thus hydrocarbon composition in the reservoir depends upon a complex of basin factors coarse material, conditions of deposition and burial and coincidence between stages of organic diagenesis and conditions favourable for accumulation.

While concluding, it may be said that ideas about the generation of hydrocarbons, and likewise many others, are the lifeblood of the science of petroleum. Quoting from Park A. Dickey (1958)–

> "We usually find oil in new pools with old ideas. Sometimes also, we find oil in an old place with a new idea, but we seldom find much oil in an old place with an old idea. Several times in the past we have thought that we were running out of oil, whereas actually we were running out of ideas."

Careful study of the process of generation of hydrocarbons and responsible factors in every definite basin is an important and essential stage in the study of its oil and gas bearing and provides the possibility to work out its prospects on a more firm basis.

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STRATIGRAPHIC TRAPS AND THEIR STATUS IN PETROLEUM EXPLORATION

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INTRODUCTION

Search for petroleum in a producing region generally follows a rough chronological order. Structural traps being the more readily located are drilled first. Information gained from drilling them is used to locate traps in combination with structures. Finally, when the remaining structures are small and obscure, emphasis is on finding sand patches, reefs, shoestring sands, and other typical stratigraphic phenomena. These stages grade into one another. Much of the Middle East is, perhaps, still in the stage of exploration of structural traps.

However, increasing demand for oil and gas to satisfy the world's energy needs and, simultaneously, to keep recurring domestic reserves of the producing countries, the petroleum industry is forced to give greater attention to stratigraphic traps, as primary exploratory objects.

Facies changes, unconformities with resulting truncated beds, and buried erosional or constructive surfaces such as reefs, hills, channels, barrier and sand bars, and other related phenomena, forming the basic requirements for the creation of stratigraphic traps are observed in most of the sedimentary basins. Because of the relationship of stratigraphic traps with older geologic surfaces, unconformities, and lateral lithologic changes within and adjacent to stratum, their formation generally proceeds the structural traps. Thus, if migration of hydrocarbons through a particular region were to take place before structural movements, all of the petroleum trapped during this early migration would be in these subtle traps. Constantly recurring depositional patterns in a sedimentary basin, which usually precede, or may be associated with structural movements, may result in a larger number of stratigraphic traps than structural traps. Although much petroleum has migrated into structural traps, possibly more has accumulated in the early formed stratigraphic traps. The latter then stands a good chance of contributing to the domestic reserves of oil and gas, and, therefore, a purposeful search for the stratigraphic traps must form an essential part of the exploration programme.

The exploration strategy for finding stratigraphic traps depends upon the development of an understanding of the depositional and structural framework within which the traps are formed. The approach proceeds from data collection, through data analysis and formulation of an exploration hypothesis, for the testing of the latter by drilling.

STAGES OF THE EXPLORATORY PROCEDURES

a) *Determination of the type of depositional basin and its structural framework:* while proceedings to work in an absolutely virgin area, it is particularly important to define the prevailing characteristics of the basin under study. The exploratory procedure may include – i) defining the lateral boundries of the basin, e.g., a vertical uplift, an orogenic belt, a shield area or an ocean deep. ii) Determination of the structure and nature of the basement of the basin. iii) Determination of the basin type, as symmetric, asymmetric, intermontane, etc. iv) Location of prominent structural features such as hinge zones, shelf areas, and central platform areas.

b) *Establishing the time-stratigraphic framework:* an interpretation of the time-synchronous strata or boundries in a basin provides the fundamental skeleton for detailed correlation, definition of unconformities, structural interpretation, and distribution of facies, which are all important in predicting stratigraphic traps. The stage involves construction of cross sections and correlation of various rock units over the basinal territory, as aided by good palaeontological record, quality seismic lines, electric and sample logs, etc. While analyzing the data care should be exercised to detect the surfaces of unconformities, for a surface of unconformity may contribute to the development of stratigraphic traps in many ways. Angular unconformities commonly form stratigraphic traps by truncation and later burial of dipping reservoir strata. Onlapping reservoir rocks may terminate against an unconformity; deltaic reservoirs may develop on an unconformity or carbonate rocks may have porosity and permeability induced as a result of weathering and erosion associated with an unconformity.

c) *Interpretation of environments of deposition of various rock facies;* an understanding of the environemnts of deposition of facies is of particular significance. Because stratigraphic traps commonly are a function of the character of reservoir rocks, therefore, an interpretation of the latter through environmental analysis is an important phase of work, and should result in providing information on the distribution, size, shape, trend, and quality of reservoir deposits.

Environmental-facies analysis requires knowledge in all fields of geology, sedimentology, stratigraphy, petrology, geochemistry, gemorphology, hydrogeology, oceanography, and palaeontology. The method may include the following basic steps; i) determination of vertical sequence of environment facies from cuttings, cores, or outcrop samples to establish the basic data points. ii) determination of lateral environmental facies relations along cross sections. iii) development of local three-dimensional environmental facies framework in areas of interest. iv) regional interpretation – relating to the basin form, determination of source of reservoir material, etc.

d) *Reconstruction of paleogeography;* exploration data cannot be used properly and effectively unless they can be placed in paleogeographic setting. For example, knowing that a potential reservoir is a barrier–island sandstone is of little help unless the explorationist can interpret where ancient shoreline was, in which direction it trended, and where in the basin such facies were most likely to develop. Many reservoir deposits have a probable primary preferential direction and trend with respect to depositional strike and the related source-transport-depositional-side continum, as well as a preferred area of development with respect to basin structure and the time-stratigraphic framework.

Most reservoir deposits have a preferred or more probable orientation with respect to the direction of the shoreline or to the depositional slope. A useful tool for determining ancient depositional strike or shoreline direction is the isopach map. If such maps were constructed to represent two time-stratigraphic boundries or an upper time-stratigraphic boundary and a lower unconformity, the gross direction or trace of the isopach contour lines will represent approximate depositional strike and will parallel ancient shorelines.

Petrographic analysis of rock fragments in coarse-grained clastic beds commonly can aid in paleogeographic reconstruction, particularly where alluvial-deltaic systems are involved. If enough information is available concerning the characteristics of the potential source-area terrain, specified rock types in clastic facies may be traced back to unique areas which are their probable source. This method is helpful in determining the trend and extent of alluvial-deltaic clastic systems.

e) *Predicting the location of stratigraphic traps;* a successful completion of the above metnioned stages will lead to form general ideas concerning the distribution, location and type of stratigraphic traps that may be present in the basin. Creative thought and alternative ideas and interpretations are essential at this stage in procedure. Some helpful steps while predicting the location of stratigraphic traps may include– i) in each time-stratigraphic unit, the environmental facies of the expected reservoirs should be predicted. This may include telling the expected thickness, primary porosity and permeability, structural attitude, potential lateral distribution, most probable trend and fluid content. ii) analysis of the major unconformities, geomorphology of the surface and the onlapping or covering processes. iii) analysis of the paleogeographic maps for areas of gross stratigraphic accumulations, such as embayments, deltaic masses, zones of abrupt facies change, anomalous change in depositional strike, and favourable patterns on subcrop maps.

f) *Drilling for stratigraphic traps;* It is usually necessary to drill more wells in testing stratigraphic-trap prospects than are needed for a purely structural interpretation. However the data available from the dry holes should be studied carefully to make adjustments in interpretations for alternate drilling locations.

A successful application of the above mentioned procedure may result in finding new oil and gas bearing traps in mature as well as virgin areas. Surely, the exploration hypothesis is to be tested by drilling and additional data are to be used to accept, modify or reject the original interpretations.

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"COMMENTS ON SOME NEW EARLY JURASSIC MIOSPORES FROM DATTA FORMATION; WESTERN SALT RANGE PAKISTAN" BY DR. ASRAR M. KHAN

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I have gone through the comments of Dr. Khan. I as one of the co-authors accept that there are certain typographic mistakes such mistakes are quite common in the published letter of Dr. Asrar Khan. Thanks for his comments like ;

> "The reason for this may be lack of literature available to the authors, lack of comprehension of descriptive terminologies, and a critical eye to compare the grains with illustrations.
>
> It was painful to read the descriptions of miospores. The *test* is full of mistakes which include typographic, descriptive, spelling and even references are wrongly cited".

In response to his above mentioned statement I wish to inform that I have more than 3000 palaeobotanical research articles apart from classic literature in my personal collection. Furthormore, sufficient literature is stacked in the libraries of Botany Department and Institute of Geology, Punjab University, Lahore. Palaeobotany museum of Punjab University contains a collecton of over 10,000 slides, 1500 peep sections and over 1000 samples of palaeobotanical materials. Apart from M.Sc. research students I am supervising three Ph.D Research Scholars when Dr. K. Rass Masood one of the co-author was awarded Ph.D. degree in 1984, Dr. Masood's thesis was evaluated by leading and reputed Palynologists/Palaeobotanists of Britain and U.S.A. Still we consider ourselves not competent as compared to the workers in the foreign countries. Mistakes may crop up which can be rectified by writing more research papers.

For instance, Sitholey in 1946 collected a sample from the variegated shales of Nammal Gorge, Salt Range. It was investigated by Sah (1955) and Jain and Sah (1969) and by so many others. The material was time and again investigaated adding more information. The Indian workers were not haunted by any confusion while our article has created confusion in Dr. Khans opinion.

How does Dr. Asrar think without any validity that the identification at generic level in our paper is incorrect? I welcome him to provide the correct version by going through our prepared slides relating to our article.

It is very wrongly quoted by Dr. Khan that :

> *"Procedure for naming of new species does not follow the set rules of Botanical Nomenclature. Very seldomly names are erected after persons but the authors have named nine species after the author himself. As a rule if a species is named after a person, that person should be a well known scientist in the field Where as none of these persons is a palynologist."*

I wish to explain that procedure of naming has been completely followed the rules of Botanical Nomenclature (cf. International Code of Nomenclature, Seattle 1969). Furthermore, there is no rule that the naming of a species should be after a well known scientis in the field. It may be named after a person, after a place or after its self explanatory morphological details. The described 30 species in our article have the following split up.

(a) 18 species were named on morphological characters.
(b) 3 species were named after known places.
(c) 9 species were named after persons.

I do not want to go in greater details of all the 9 species but to refer the following :

1. *Leiotriletes naumovaensis:* (Dr. Naumova is known for her excellant work on Devonian Palynology of Russia)
2. Divisisporites *balmensis:* (Dr. Balme is reputed Australian Palynologist)
3. *Microreticulatisporites bharadwajii:* (Dr. Bharadwaj was the Director, Birbal Sahni Institute of Palaeobotany Lucknow, India).

The above mentioned statements of Dr. Asrar Khan are now self explanatory. If Dr. Khan does not know the names of Drs. Naumova, Balme and Bhardwaj I do'nt know what to comment?

The principal author Dr. Khan Rass Masood worked day and night for five years and submitted his Ph.D. thesis which was refereed by reputed experts from Britain and U.S.A. The comments of the foreign referees were excellant due to which he got a Ph.D degree in 1984. This article is the part of Ph.D work I as supervisor accept certain errors made in the publication because Dr. Rass submitted the paper for publication without having my comments otherwise his Ph.D thesis reference would have been made.

In response to Dr. Khan's last paragraph I have full faith in the Editorial Board of Kashmir Journal of Geology because I know that each and every paper is refereed. The authorities of the journal are worth congratulating by publishing their journal regularly and the brought up of the journal is excellant.

In the last I welcome Dr. Asrar Khan to have Jurassic samples from me for further investigations or he may collect himself from the localities mentioned or he may study the prepared slides in my possession. I shall appreciate if Dr. Khan writes an article of the same localaties, after investigation, rectifying our mistakes. It would be better and proper way.

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A STUDY OF FOLDED STRUCTURES WEST OF HAZARA KASHMIR SYNTAXIAL BEND, IN SOUTH EASTERN HAZARA, SOUTHERN HIMALAYAS.

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and

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Structural complexity of the area of Hazara Kashmir syntaxial bend has been identified by many workers (Wadia, 1931; Latif, 1970; Calkins et al., 1975; Seeber et al., 1979, 1981; Bossart et al., 1984; Coward & Butler, 1985). Data of folds from an area of 25 sq. km. between Donga Gali, Kuza Gali and Ayubia is briefly discussed here.

Folds of variable intensity, commonly from open to tight are present in the area. An intriguing feature in tight folds is the prevalence of anticlines over synclines (Fig. 1).

The axes of the folds plotted on the stereonet show a scatter; nevertheless two distinct sets can be identified. One set of axes represents ENE-WSW trending non-plunging to subhorizontally plunging folds, whereas the other set reveals generally moderately plunging folds in the northeast direction. Dip of the axial planes is subvertical in NW or SE direction (Fig. 2).

Classification based on the geometrical interrelationship of axial surfaces and hinge line reveals the majority of folds as subhorizontal to gently plunging, steeply inclined to upright; followed by moderately plunging, steeply inclined folds (Fig. 3). Besides these two major types subvertical to steeply plunging, upright folds occur.

As such we identify two discrete group of folds. Younger ones represented by commonly upright, subhorizontal to gently plunging in ENE-WSW direction and the older folds represented by steeply inclined moderately plunging folds in NE direction. We believe that the older group of folds were produced prior to the development of the Hazara Kashmir syntaxis. At that time they were most likely similar to the younger generation of folds recognized in this study and attained their present character (moderate to steep plunge) during the formation of the syntaxial structure.

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	T	C	O	G
An	9	3	3	0
Syn	2	7	4	1

Fig:-1

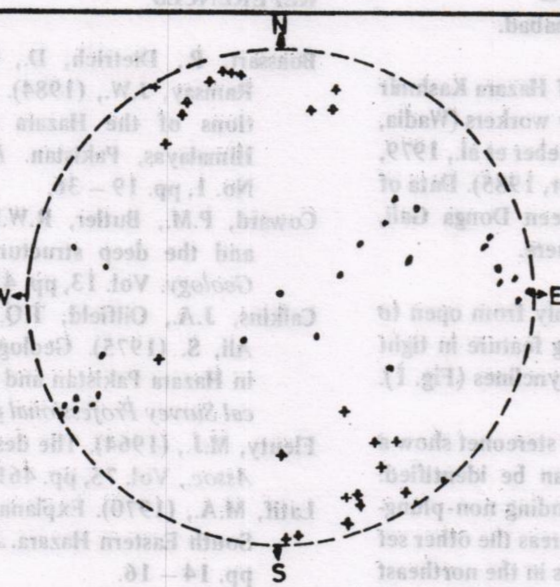

Fig:-2

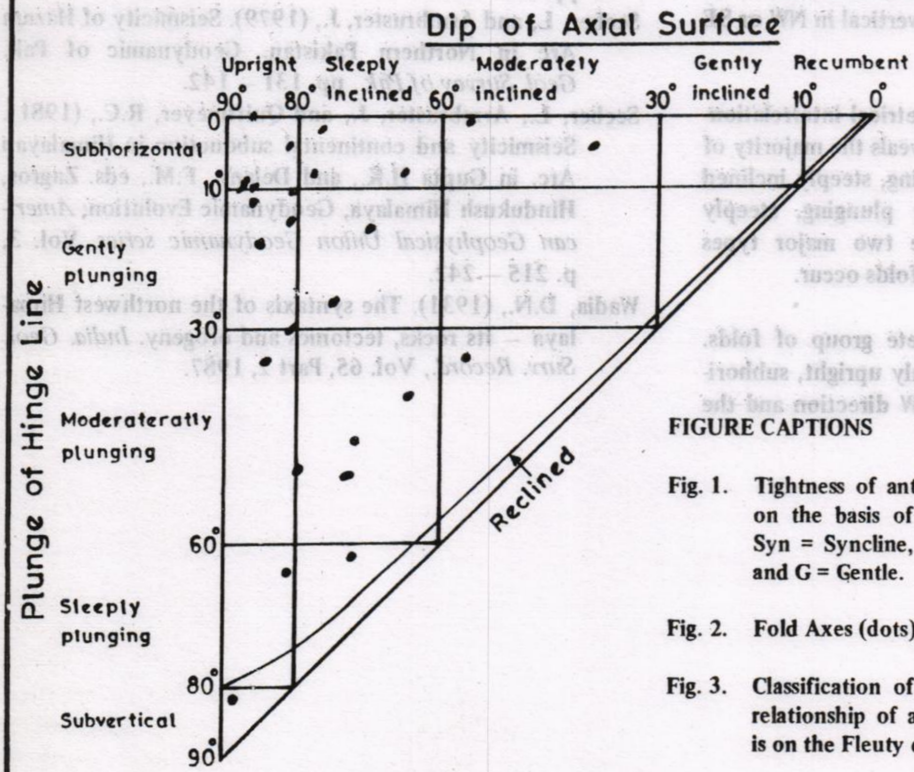

Fig:-3

FIGURE CAPTIONS

Fig. 1. **Tightness of anticilines as compared to synclines on the basis of interlimb angle. An = Anticline, Syn = Syncline, T = Tight, C = Close, O = Open and G = Gentle.**

Fig. 2. **Fold Axes (dots) and poles to Axial Planes (crosses)**

Fig. 3. **Classification of folds on the basis of geometric relationship of axial surface and hinge line. (Plot is on the Fleuty diagram).**

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ELECTRICAL RESISTIVITY SURVEY FOR GROUND–WATER IN ISLAMGARH TOWN DISTRICT MIRPUR AZAD KASHMIR.

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ABSTRACT:– Sixteen electrical resistivity measurements were carried out using Wenner Electrode Configuration for probing the subsurface lithologies, suitable for tubewell instalation. Field resistivity curves were interpreted, using the partial curve matching technique. On the basis of true resistivity values, supplemented by surrounding geological information, the area has been classified into three zones.

INTRODUCTION

The purpose of this investigation was to mark suitable sites of groundwater aquifers. Islamgarh is situated at a distance of 30 Kms. NE of Mirpur. The area lies between grid reference 110000-110100 and 35920000-35970000. on Topo Sheet No. 43 G/16. Sixteen vertical electrical sounding were executed in the area with Gish Rooney type of instruments applying Wenner Configuration. Out of the sixteen, probes fourteen were selected for interpretation and evaluation. The average depth of exploration ranges from 150 feet to 500 feet. The depth of water table in the town ranges from 75 feet to 140 feet. This variation in the water table suggests that water table follows the general trend of topography. However, perched water may also exist in the town. Therefore, on the basis of true resistivity values, subsurface hydrologic units have been classified into three distinct zones, which are low, medium, and high resistivity zones. The true resistivity values ranging from 0 to 25 Ohm-m has been marked the low resistivity zone, whereas the resistivity values ranging from 25 Ohm-m to 45 Ohm-m indicate the medium resistivity zones. Similarly the resistivity values greater then 45 Ohm-m mark the high resistivity zone. PH values of the groundwater obtained from the aquifer in the area under investigation varies from 7.3 to 8.4.

PRINCIPLES AND EQUIPMENT

In the electrical resistivity survey we used the Wenner Electrode Configuration. Four electrodes (two outer current electrodes and two inner potential electrodes) were placed in a straight line on the ground. The distance between the potential electrodes was one third of the distance between the current electrodes. For field work Gish Rooney resistivity set (1925) has been used. It consists of milliammetre potentiometre and a double commutator. Current from the battery was passed *Via* power unit into the ground, through the two outer current electrodes. The resulting potential difference between the inner elctrode was measured by the potentiometer.

The formula used for claculating the apparent resistivity is:–

$$Pa = 2\pi A \frac{V}{I}$$

Where:–

π = Constant.

V = Potential difference in millivolts.

I = Current in milliamps.

A = Separation distance between the electrodes

Pa = Apparent resistivity in Ohm-m.

INTERPRETATION AND PRESENTATION OF TRUE RESISTIVITY DATA

The field curves were interpreted by using 2 and 3 layers theoratical curves with auxilliary point charts of Orellana and Moony. The matching of the field curves with a standerd curve help in determining the resistivities of the subsurface layers and their approximate depths from the surface. A columnar vertical resistivity section showing the interpreted layers, i.e. their depths from the surface and true resistivities values. This section has compared with the geological information available in the surrounding area. On the basis of true resistivity values, obtained by quantitative interpretation of the field curves, hydrological units have been classified as follows:

a- Low Resistivity Zone (0-25 Ohm-m)
b- Medium Resistivity Zone (25-45 Ohm-m)
c- High Resistivity Zone (>45 Ohm-m)

Low Resistivity Zone: The low resistivity zone indicates the presence of argillaceous material i.e. clay, silty clay, with intercalation of sandstone & gravels. The thickness of this zone ranges from 1 meter to 300 meters (fig. 1). The ground Water potential of this zone is low. This saline zone starts from 165 metre to 400 metre depth from surface. The low resistivity zone is predominant at probe site No. 3,5,8,12 and 14. It is present dominantly throughout the town but interlayered by material of other resistivity zones. The blank portion of the columns indicates the low resistivity zone (fig. 1). This zone may yield very little ground water.

Medium Resistivity Zone: This zone indicates the presence of argillaceous material i.e. clay, silty clay, interlayered by arenaceous material, like sandstone or gravels of limited vertical extension. The resistivityvalues range from 25 to 45 Ohm-m. This zone is dominant at the probe sites No. P-2, 4,6,8, and 12, due to the intercalation of impervious material. The shaded parts of the column indicate the medium resistivity zone (fig.1). This zone may yield limited supply of ground water, due to intercalation of impervious material.

High Resistivity Zone: The true resistivity values greater than 45 Ohm-m mark the high resistivity zone. This zone indicates the high resistivity material like arenaceous material i.e. sandstone or gravels, intercalate with small quantity of silt, silty clay and shale. The dotted parts of the columns indicate the high resistivity zone (fig. 1). This zone has been demarcated at the probe site No. P-1, 11, 13 and 14. The high resistivity zone may yield limited to fair supply of ground water.

CONCLUSION

The high resistivity zone consists of arenaceous material. This zone has been marked at the probe site Nos.1, 11,13 and 14, which are the most promising for groundwater development. The north eastern side of the area is recommended for tubewell installation. The quality of groundwater in the area is alkaline and at places in south western side it is acidic.

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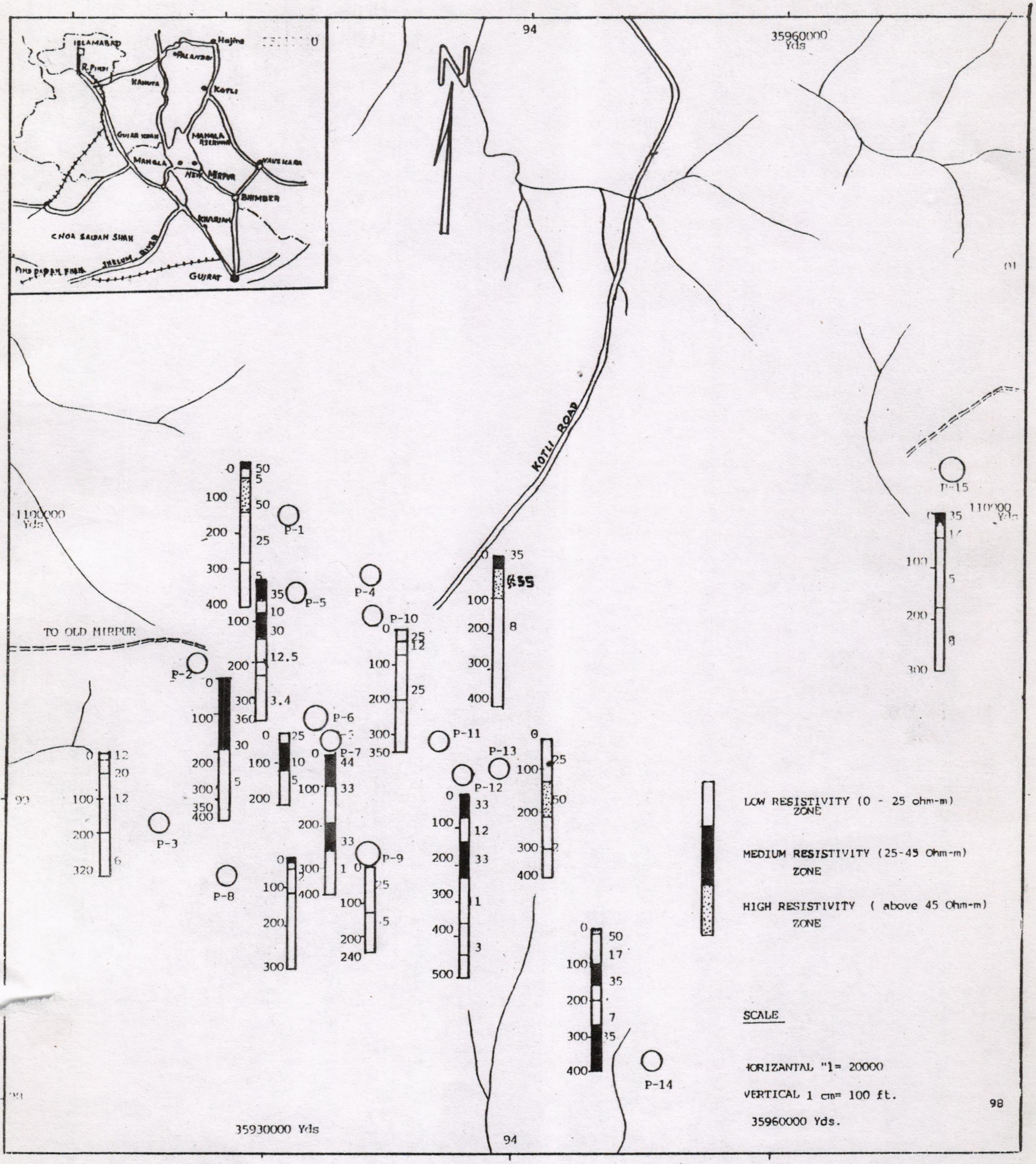

FIG 1 COLUMNAR VIEW OF SUB-SURFACE HYDROGEOLOGIC UNITS BASED ON TRUE RESISTIVITY VALUES OF ISLAMGERH MIRPUR (A.K).

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The Kashmir Journal of Geology is devoted to the publication of original research in the field of geology including geophysics, geochemistry, geomorphology and paleontology. Review articles, short papers and abstracts are welcomed. The articles should deal with some aspects of the geology of Pakistan or should pertain to significant advancement of geological knowledge of international importance.

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The articles should be written in English accompanied with adequate abstract, type written (double space) on one side of the foolscap paper, with wide margin and should be submitted in duplicate. The illustrations (figures, diagrams, and maps) should be drawn in black ink on tracing paper with allowance for reduction in final print. Lettering should be preferably done with stencil. Colour photo prints can be arranged on payment. All tables, illustrations, maps and photographs should be self - explanatory. International symbols should be used on maps as far as possible. In all maps and illustrations linear scale should be used. The maximum length of the articles including diagrams should generally be around 20 foolscap pages. A copy of the book to be reviewed in the Kashmir Journal of Geology may be made available well in time for reference.

References should be arranged as follows:

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