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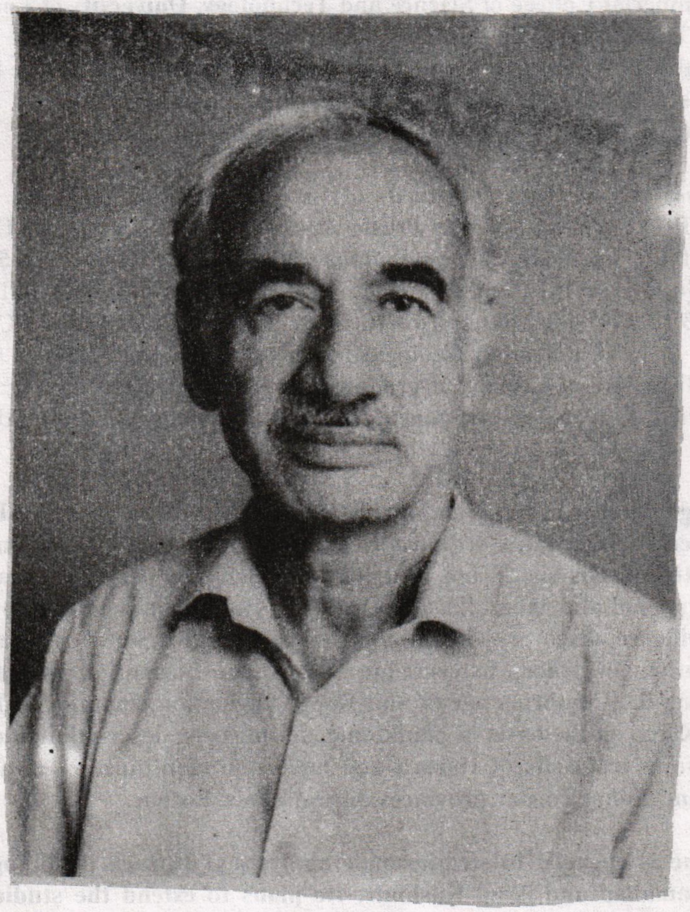
THIS VOLUME IS DEDICATED TO

PROF DR. M. A. LATIF
ON HIS RETIREMENT IN 1988



LIFE SKETCH OF PROF. Dr. M.A. LATIF

Professor Dr. MIR ABDUL LATIF was born at Jammu, Indian held Kashmir in 1928. He studied geology upto F.Sc. level at the Prince of Wales College, Jammu, the well known British India's Centre of Geology. After independence he studied geology at the Punjab University, Lahore for his B.Sc. and M.Sc. degrees in 1955 and 1957 respectively and was among the first batch of graduates in geology. On the basis of his academic performance, he was selected twice by UNESCO for higher studies, first from 1957 to 1959 and later 1967 to 1968. He completed his D.I.C. in 1958 and M.Sc. in 1959 both from the Imperial College of Science and Technology, University of London and his FPTC in 1968 from the University of Vienna. He was awarded the best student and best Scientist Certificates in 1959 and 1968 respectively. In 1969 he was awarded Ph.D. degree by the University of London, as external student, on the Geology of SE Hazara, parts of Islamabad and Muzzaffarabad district Azad Kashmir. He is the first Pakistani to have this unique honour.

He acted as Head of the Department of Geology in 1965, 1973 and 1974 and Director, Institute of Geology 1979 and 1980. He was President of the Punjab University Geological Society in 1955-56; President of the Imperial College, London/Pakistan Society in 1958-59; President of the Punjab Geological Society in 1977 and 1978; the Chief Editor, Geological Bulletin of the Punjab University from 1973 to 1977 for volume Nos.10 to 14 and the Chief Editor, Contributions to the Geology of Pakistan in 1980, a Punjab Geological Society publication. He was instrumental in the introduction of the discipline of Geology at graduate level at Muzzaffarabad Azad Kashmir in 1973 which later developed into a major component of Azad Jammu & Kashmir University under his honorary advice.

He has a large number of research publications to his credit a considerable number of which having been published in International journals of repute and have revolutionised the geology of South Asian Subcontinent. His significant contributions include a geological map of South Eastern Hazara, parts of Islamabad and Muzzaffarabad; redating the Abbottabad Group as Cambrian on he basis of new fossil evidence; discovery of economic deposits of phosphate in Hazara; discovery of pre Cambrian paleoglciation; evidences to correlate Salt Range Formation with Hazara Group and accordingly confirming the Cambrian age of Salt Range Formation; zonation of Paleocene-Eocene of oil rich area of D.G.Khan, on the basis of planktonic microfossils; description and zonation of Upper Cretaceous to Eocene microfossils of Hazara and lately the identification of a barrier separating basins of Sulaiman and Kohat Potwar provinces during Lower Eocene.

At present he is engaged in stratigraphic analysis of Hazara including adjacent parts of Margala Hills of Islamabad and Azad Kashmir. He plans to extend the studies to Kohat Potwar basin in future, specifically to find the inter relationship of the two areas.

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SERPENTINIZATION OF CUMULATE ULTRAMAFITES AND DEVELOPMENT OF HEAZLEWOODITE-PENTLANDITE-AWARUITE-MAGNETITE AND PENTLANDITE-CHAL COPYRITE-PYRRHOTITE-PYRITE ASSOCIATIONS IN ALPURAI AND KISHORA, SWAT, PAKISTAN

BY

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ABSTRACT:- Ultramafics of Alpurai & Kishora areas of Swat District have been found to occur as cumulates. These ultramafic bodies occur along the Main Mantle Thrust which marks the part of the suture zone between the Asian and Indo-Pakistan plates. The present study elaborates the classification of ultramafics of the two areas, their chemico-mineralogical composition, distribution of minor elements, ore microscopy and electron microprobe composition of some sulfides. The Alpurai rocks are found to be, stratigraphically upward, harzburgite, olivine websterite, wehrlite, dunite, wehrlite, websterite, dunite and lherzolite. All these members are altered variably to serpentine minerals. The Kishora rocks are dominantly a part of an ultramafic mantle tectonite i.e., a harzburgite which is overlain by dunite. All these rocks are pervasively serpentinized. In both Alpurai & Kishora areas nickel mineralization is present in two distinct ore mineral assemblages as heazlewoodite - awaruite - pentlandite -. magnetite and pentlendite chalcopyrite - pyrrhotite - pyrite associations respectively. These associations appear to have developed from hydrothermal alteration of ultramafic rocks by the introduction of water, sulfur and or carbon dioxibe. The Ni values found in the ultramfic rocks appear to be low i.e. 1500 to 2000 ppm. But most of Ni is in the form of nickel sulfides and alloy.

INTRODUCTION

Alpurai and Kishora are the two important localities where well exposed and easily accessible ultramafics occur in the Swat District of Pakistan. They occur at distances of about 50 and 30 Kms respectively from the district headquarters (Saidu) and can be reached by means of all-weather metalled roads.

The ultramafic bodies occur along the Main Mantle Thrust (MMT, Tahirkheli et al., 1979) which marks the part of the suture zone between the Asian and Indo-Pakistan Plates extending from Ladakh through northern Pakistan to eastern Afghanistan (1500 Kms long belt).

This work is a continuation of the earlier preliminary study of nickel mineralization in Swat, Pakistan (Chaudhry, Ashraf & Hussain, 1980). Their work was of a preliminary nature in which they mentioned the chemical distribution of nickel in basic/ultrabasic rocks. They have attempted to characterize the distribution and abundance of nickel in ultramafics.

Studies carried out by various workers in the world show that most magmatic nickel sulfide deposits are associated with komatiitic or tholeiitic rocks of greenstone belts or within large intrusions emplaced in stable cratonic areas. Mafic and ultramafic rocks in other environments host relatively few nickel deposits, and none are of large size (Foose et al., 1985).

The present study, however, presents rocks classification of ultramafics of the two areas, their chemico-mineralogical composition, distribution of minor elements, ore microscopy and electron microprobe composition of some sulfides.

The Ni values found in the ultramafic rocks of Alpurai and Kishora appear to be low, i.e., 1500 ppm to 2000 ppm. But most of the Ni is in the form of nickel sulfides and alloy. The extent of mineralization in both the areas is 12 square kilometres and 4 square kilometres, respectively, with average depth of 500 metres. The deposits are well exposed with minor or insignificant cover of soil. Taking into consideration that the price of Ni is about three times that of Cu, the present study has been undertaken.

GEOLOGICAL SETTING

The geology of the Alpurai-Kishora area containing the ultramfics is characterized by the Kohistan Complex which is overthrust to the south onto a folded and metamorphosed series (mainly consisting of pelites, psammites and carbonates hosting acidic plutons (Shams, 1969 and Ashraf, 1984) of mostly lower Paleozoic to pre-Paleozoic rocks. This under thrust series belongs to the northern margin of the Indian plate. The Kohistan Complex and Indian plate sequences have a clearly tectonic contact represented by the Indus Suture Zone (ISZ) or Main Mantle Thrust (MMT, Tahirkheli et al., 1979). The rocks of the Asian plate to the north and those of the Kohistan Complex are sutured by the Main Karakorum Thrust (MKT). These two sutures extend eastwards across Ladakh and join into the Indus-Zangbo Suture zone in south western Tibet (Thakur and Sharma, 1983). The investigations carried out in Kohistan and Ladakh suggest that the Kohistan Complex occupying region between the MKT and MMT represents a Cretaceous Island arc(s) that became Andean-type margins by the Early Tertiary (Tahirkheli et al., 1979, Klootwijk et al., 1979, Bard et al., 1980, Jan and Asif, 1981 & 1983, Coward et al., 1982 and 1987). The Kohistan Complex consists of (north to south) i) the Cretaceous Yasin Group of volcaniclastic and clastic sediments, ii) Late Jurassic calc-alkaline volcanics named the Chalt volcanics or greenstone complex (Ivanac et al. 1956), iii) Early Eocene to Middle Tertiary calc-alkaline plutons with screens metasediments and metavolcanics (of Chalt) known as Kohistan-Ladakh granitic belt, iv) the Early Cretaceous Chilas mafic complex; and v) the Cretaceous to Late Jurassic Southern Amphibolite belt of mainly metavolcanics (Coward et al., 1986).

Ultramafic rocks occuring in the southern part of the Kamila Group; Kohistan sequence are either at the contact or as klippen much southwards. Their affinity with the Kohistan island arc is very obvious and they occur as ophiolites (as in Dargai-Utmankhel; Awan, 1987 and Hussain et al., 1984) or as parts of the upper mantle, which have obducted as dismembered blocks and pieces.

The geological relations of the Alpurai-Kishora ultramafics (Fig. 1) is discussed briefly with respect to their exposures and tectonic setting. According to Kazmi et al. (1984), the area consists of three melanges: (i) Mingora-Alpurai melange, (ii) Charbagh Greenschist melange, and (iii) Shangla blue schist melange. The formation of different melanges in the area from north of Alpurai to Mingora is due to three major thrust faults: the Shangla thrust, the Makhad thrust, and the Kishora thrust. The ophiolite melange in the area between Alpurai and Kishora consists of tectonized blocks and clasts of serpentinites, talc-carbonate schist, greenstone metabasalt, greenschist, metapyroclasts, metagabbro, metasediments, and metachert.

Details of ultramfics of the two areas are given in the following.

ALPURAI AREA:- The ultramfic rocks are mainly serpentinites with minor associated talc-carbonate-serpentinites. The rocks are light green, dark green, and greenish grey in colour and are highly jointed and sheared. The serpentinization is extensive in the sheared zones and along joint surfaces, giving a yellowish green colour to the rock at those places. In the serpentinized rocks relics of olivine and pyroxene with disseminated grains of magnetite and chromite can be recognized.

The magnetite occurs as disseminated grains and within veinlets. Small chromite lenses and pods are present in Kuz Kotkai, Barmachar, Kandogai and Zarogai. At a few places small bodies of gabbro, anorthosite, rodingite and dolerite are found.

KISHORA AREA:- The ultramafic body of Kishora is the southwestern extension of Alpurai in the Mingora ophiolitic melange. Near Kishora the serpentinites are highly sheared and fractured, which may particularly be due to the interaction of the Kishora and Makhad Thrusts. The rocks are greenish grey to greyish green in colour. The ultramafic rocks are so thoroughly serpentinized that it is difficult to find relics of olivine and pyroxene, and even the ore grains are hardly visible. Alteration to talc-carbonate is also found at some places in the ultramafics.

The ultramafics of Alpurai appear to consist of a basal mantle tectonite that grades upward into ultramafic cumulates. However, the rocks of Kishora are mantle tectonites consisting of harzburgite and minor dunite overlying the hazburgite.

Small bodies of gabbros and rodingites are associated with the Kishora complex as dismembered blocks tectonically intercalated with ultramafics.

PETROGRAPHY

ALPURAI AREA:- The serpentinized rocks of the Alpurai area were stuided in thin and polished sections under the microscope. Stratigraphically, the

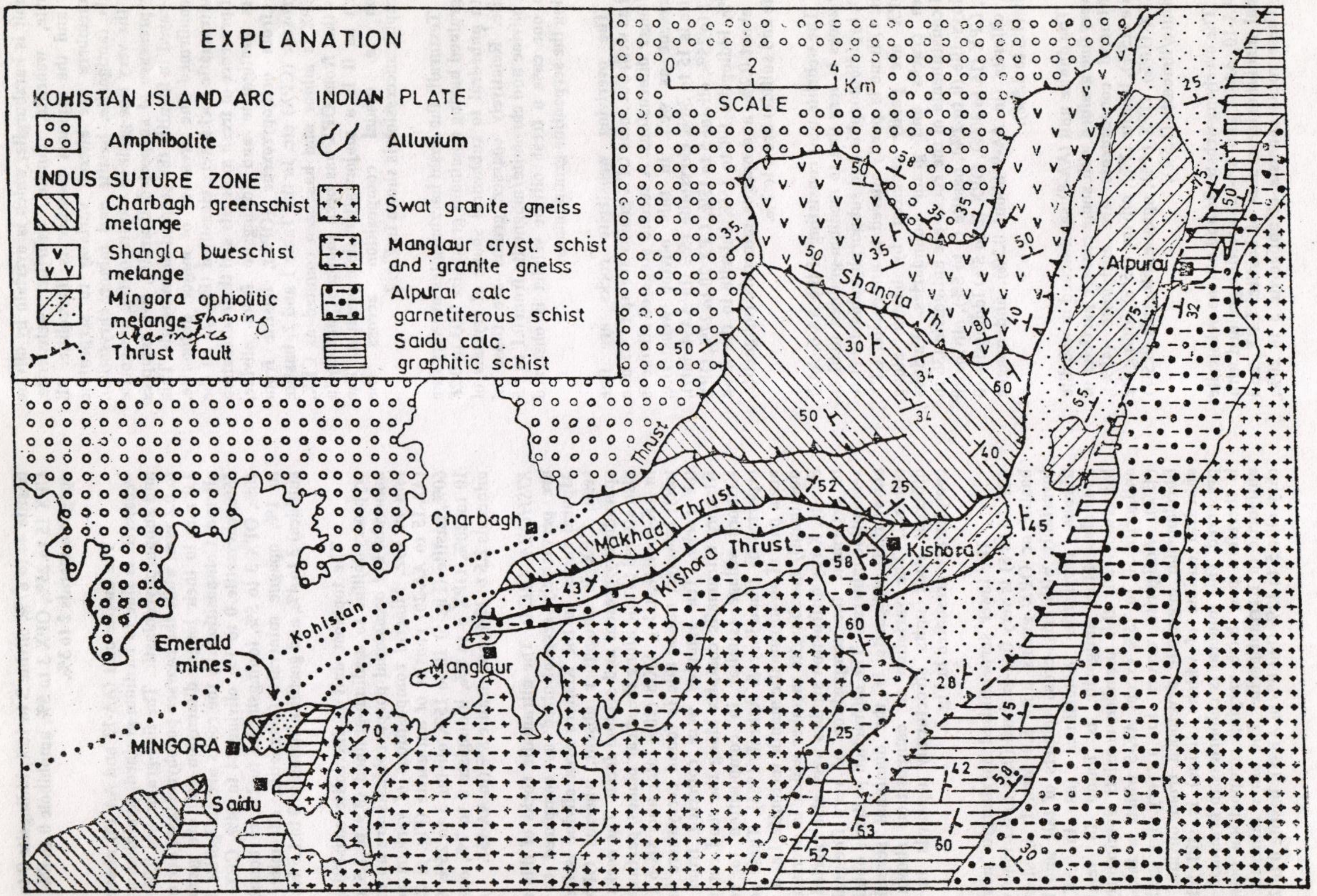

Fig:1 Geological map of the Kishora-Alpurai area. After Kazmi et al.1984 basal unit is harzburgite, which is overlain by olivine websterite, wehrlite, dunite, wehrlite, websterite, dunite, and the topmost member is lherzoliite. All these members are altered variably to serpentine minerals (antigorite, bastite and minor chrysotile). Due to the very fine-grained nature of the antigorite and/or presence of suspected lizardite, five samples were X-rayed to identify the serpentine minerals. This study confirmed the presence of major antigorite. These ultramafic rocks were classified (Fig. 2) on the basis of presence of fresh minerals and their alteration products (antigorite and iddingsite from olivine, bastite from orthopyroxene (OPX), bastite from clinopyroxene (CPX) etc. In the Table 1 and 2, bastite from CPX is minor and has been counted as CPX, whereas that from OPX has been shown separately in as much as it is a major alteration product. The variation in modal composition across the stratigraphic succession is shown in Fig. 2.

Texturally the basal harzburgites are very fine to fine-grained having dominant grain size 0.03 to 0.25 mm with anhedral to subhedral shape of crystals of antigorite. Relatively coarser grains are those of bastite, olivine and chromite/magnetite from 0.1 to 2.5 mm. In one case a fresh olivine veinlet is observed traversing the serpentine groundmass.

The overlying websterite rocks are fine grained as well, but some CPX grains are up to 4.5 mm in the longer dimensions. A second stage of olivine is also present as well. In this olivine websterite, antigorite is 15 to 30%, chrysotile 15% (in AA-4 only), bastite 7 to 25%, olivine 5 to 15%, CPX 20 to 27%, OPX 8 to 10%, iddingsite 1.0 to 15%, chlorite in the AA-4 zone is about 0.2%, and opague minerals (magnetite, chromite and sulfide) are 4 to 7%.

The wehrlite unit consisting of the AA-6, AA-7 & AA-9 zones is very fine to medium-grained (0.01 to 1.0 mm), hypidiomorphic and subporphyroblastic (1 to 1.5 mm). Olivine is partly altered to antigorite, CPX and OPX are partly replaced by bastite along cleavages cracks and grain boundaries. Various mineral constituents of the rocks are antigorite (36 to 70%), chrysotile (0 to 2%), bastite (1 to 5%), olivine (0 to 30%), CPX (16 to 30%), OPX (2 to 5%) iddingsite (0 to 3%), chlorite (in AA-9 about 0.2%), and opague minerals (1.5 to 2.5%).

The dunite unit (AA-8) sandwiched in wehrlite is also very fine grained with some coarser particles of CPX. Mineral constituents are antigorite (45%), chrysotile (15%), bastite (2%), olivine (15%), iddingsite (8%), CPX (10%), OPX (4%), opague minerals (0.5%) and goethite/limonite (1.5%).

The overlying websterite and olivine websterite zones (AA-10, AA-11 and AA-12) are fine-grained with occasional medium-size grains of bastite, CPX, and olivine. These rocks consists of antigorite 3 to 20%, bastite 44 to 67%, olivine 3 to 15%, iddingsite 0 to 8%, CPX 15 to 25%, OPX 3 to 5%, amphibole 0 to 8%, and opague minerals 2 to 3%.

The dunite unit (AA-13 and AA-14) above the websterite is fine to medium-grained, hypidiomorphic and subporphyroblastic. The fine-grains are 0.05 mm to 0.2 mm, while the coarser porphyroblasts are up to 3.0 mm in their longer dimension and are generally altered. Compositionally the rocks are antigorite 45 to 55%, chrysotile 0 to 1%, olivine 24 to 44%, CPX 0 to 10%, OPX 3 to 5%, iddingsite 1.5 to 2%, carbonates 0 to 1%, opague minerals (magnetite, chromite and sulfides) 3 to 4%, and goethite/limonite 0 to 1.5%.

The topmost unit is lherzolite consisting of cryptocrystalline to medium-grained (0.9 to 2.5 mm) minerals, but occasional porphyroblasts are up to 4.5 mm in size. Mineral compositions of various zones (AA-15 to AA-20) consist of antigorite (Fig. 4) 25 to 60%, bastite (Fig. 5) 10 to 15%, olivine 3 to 25%, CPX 10 to 20%, OPX 5 to 8%, iddingiste 0 to 7%, opague minerals 2.5 to 12%, and uralite 8% (in AA-15).

KISHORA AREA:- The ultramafic rocks of this area are pervasively serpentinized as compared to the Alpurai rocks. In the Kishora area olivine is hardly seen, CPX is altogether absent, whereas OPX is sporadically present and seldom fresh. The rocks are also altered to talc along the shear planes, particularly in AK-5 (45%, talc), AK-8 (20% talc) and AK-6 (16% talc); however, minor talc is found everywhere in all the rocks. Ten samples were collected from the Kishora ultramafic complex along the road cut near Kishora village (similar in composition to rocks reported by Chaudhry & Ashraf, 1986). These rocks are a part of an ultramafic mantle tectonite, i.e., a predominantly harzburgite member which is overlain by dunite. X-ray diffraction studies were also carried out to determine the composition of very fine-grained serpentine minerals. The diffraction patterns obtained show that antigorite is the dominant serpentine mineral. The variation in composition shown by different rock units structurally upwards in the complex are presented in Fig. 3.

The lower serpentinized harzburgite member (AK-10 to 5) is very fine-grained (0.01 to 0.2 mm) with bastite or OPX grains upto 5.0 mm. It is sheared invariably, with criss-cross veinlets of talc and long fibrous chrysotile. Sometimes (as in AK-10) anomalous-blue antigorite is found in veinlets. Mineralogically this member consists dominantly of antigorite 50 to 75% except AK-5 which is talc-rich (45%). Antigorite occurs in a very fine-grained fibrolamellar aggregate developed from olivine. The anhedral outline of which (olivine) is still faintly preserved. This mineral is colourless to brownish and is therefore may have varying composition between antigorite to ferriantigorite. The other minerals are chrysolite 5 to 12% (but 0% in AK-5), bastite 0 to 20%,

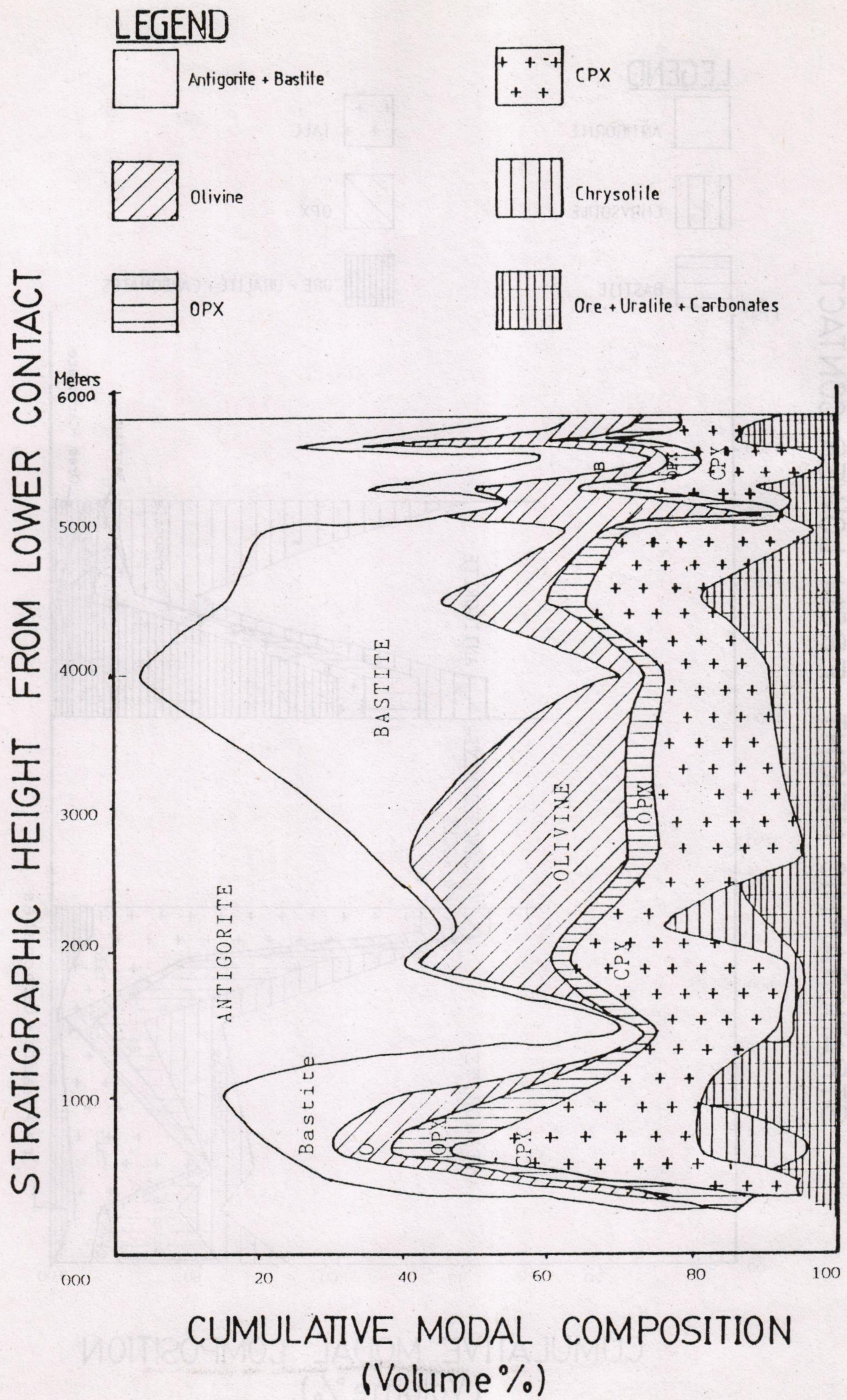

Fig. 2 **Variation in modal composition across the stratigraphic succession of Alpurai ultramafic complex**

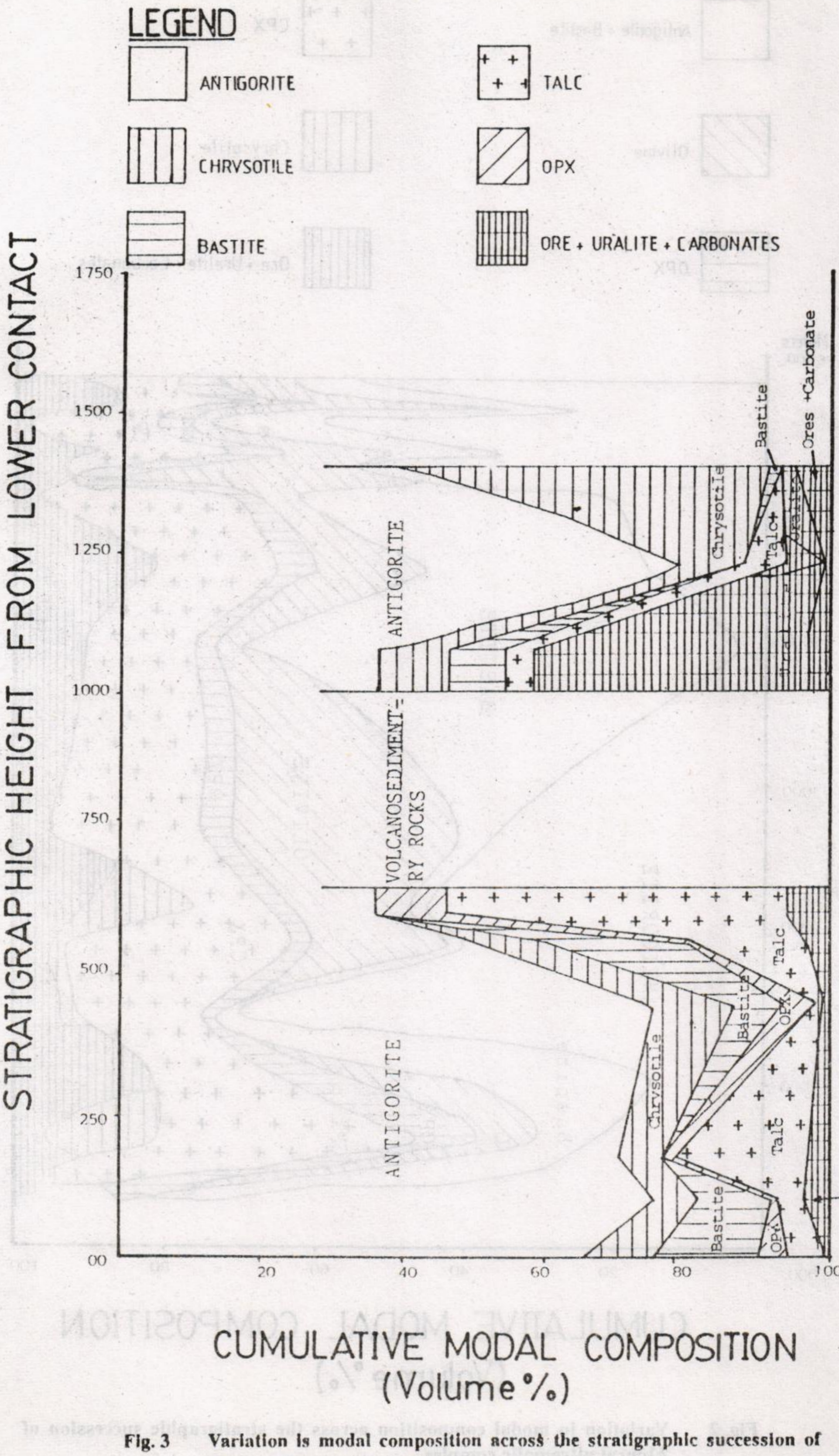

Fig. 3 **Variation is modal composition across the stratigraphic succession of Kishora ultramafic complex.**

Fig. 4 **Olivine altering to antigorite (AA-17 dunite rock), field width 1.0 mm.**

Fig. 5 **Olivine altering to antigorite and (CPX to bastite, (AA-19), field width 1.0 mm.**

Fig. 6 **Heazlewoodite (white), and magnetite ring around chromite in serpentinized dunite (AA-13), field width 1.0 mm.**

Fig. 7 **Pentlandite well laminated while massive portion is of chalcopyrite, field width 1.0 mm.**

OPX 1 to 10%, talc 1 to 45%, carbonates 0 to 5%, and ore minerals (0.5 to 1.5).

The upper member (AK-1 to 3) in the Kishora ultramafites is predominantly dunite which is also pervasively serpentinized and uralitized. The rocks are also very fine grained (0.01 to 0.2 mm) with coarser grains of bastite and OPX but their concentrations are very small. The rocks are less talcosed and contained slightly more ore minerals (1.5 to 3%). Table 2 may be consulted for details.

CHEMISTRY

Chemical analyses on rocks from both the areas were performed on 15 samples which showed higher amount of nickel sulfide in the polished thin sections irrespective of the various rock types determined by petrographic methods.

The analyses were carried out by the ACME analytical Laboratories Ltd., Vancouver, B.C, in Canda. In their procedure, 0.1 g sample was fused with 0.6 g $LiBO_2$ and then dissolved in 50 ml HNO_3 and analysed by ICP. The results are presented in tables 3 & 4. Sulfur was determined by LECO infrared spectroscopy and sulfide and metallic Ni & Cu by acid leaching and A.A.

***ALPURAI AREA*:- From this area chemical analyses of the basal harzburgite (AA-2), olivine websterite (AA-3) and upper lherzolite rocks (AA-15 AA-16 AA-17, AA-18 AA-19 & AA-20) were carried out because they showed anomalous amounts of nickel sulfide minerals. The harzburgite (AA-2) is characterized by MgO 44.66 (volatile-free basis, subsequent description is also on volatite-free basis), SiO_2 44.79%, Al_2O_3 0.75%, Fe_2O_3 0.60%, Cao 0.72% and Cr_2O_3 0.45% The rest of the elements are insignificant. In olivine websterite (AA-3) MgO is 46.85%, SiO_2 43.02%, Al_2O_3 8.05%, CaO 0.58 and Cr_2O_3 0.38%. In the lherzolite rocks MgO varies from 43.18 to 46.58%, SiO_2 42.94 to 45.14%, Fe_2O_3 6.40 to 9.08%, CaO 0.76 to 4.32% and Cr_2O_3 0.38 to 0.48%. Other oxides such as Na_2O, TiO_2, P_2O_5, and MnO are insignificant. The loss on ignition (LOI) in all the above mentioned rocks is 6.70 to 10.20%.**

CaO-Al_2O_3-MgO, and (Na_2O + K_2O)-FeO-MgO diagrams (figs. 4 & 5) were used to classfy the rocks. It was found that these rocks mostly fall in the tectonite zone while one or two rocks fall in the ultramafic cumulate zone. Which is all due to more or less uniformity of the rocks.

MgO/(MgO + FeOt) ratios vary from 0.93 to 0.94, except in one sample (0.91), showing the uniformity of the original silicate composition.

Ni, Co, and Cu are the trace elements which show interesting values. Total Ni in harzburgite is 1692 ppm, in olivine websterite 1878 ppm and in lherzolite from 1479 to 1915 ppm. Co is 75 to 114 ppm in all the rocks and Cu is 25 to 64 ppm.

Ni, Co, and Cu were also determined in the sulfide fraction of these ultramafics by agua regia leach extraction. Ni is 1253 to 1580 ppm, Co 44 to 62 ppm, Cu 13 to 64 ppm. S in these rocks is 0.02 to 0.04% (Table-4A). These results appear to be encouraging and indicate that sulfur metasomatism during metamorphism of the rocks has helped to extract Ni from sillcates to combine with S to form Ni-fulfide and Ni-Fe alloy minerals in the Alpurai area. If further studies are carried out it may be possible to locate some better disseminated and segregated sulfide-rich zones.

***KISHORA AREA*:- In the Kishora area two rock types are identified by petrographic study, i.e., harzburgite and dunite, both of which are thoroughly serpentinized. This classification corresponds with chemical analyses presented in Table-4. In this table analyses AK-9, AK-7, AK-6 and AK-5 are of harzburgite, while AK-8, AK-3 & AK-2 are of dunite. AK-8 lies within harzburgite, and two dunites overly the harzburgite zone.**

The harzburgite is characterized by MgO 38.72 to 42.39 volatile free basis, subsequent analyses described are also on water free basis), SiO_2 45.50 to 50.01%, Al_2O_3 7.47 to 8.86%, CaO 0.12 to 0.50%. The hydrated and carbonated dunite rocks have MgO 40.88 to 42.76%, SiO_2 46.91 to 51.29%, Al_2O_3 0.56 to 0.92%, CaO 0.23 to 0.28 and Cr_2O_3 0.32 to 0.59%.

CaO-Al_2O_3-MgO and (Na_2O + K_2O)-FcO-MgO variation diagrams were also constructed but it was found that these rocks also fall in tectonite zone which show uniformity in composition to a large extent. MgO/(Mg + FeOt) ratios vary from 0.91 to 0.94 which are considerably not great showing, however, unformity in composition of rocks and part of ultramfic tectonites.

Trace elements of some interest found in these rocks are Ni, Co & Cu. Ni in the harzburgite zone is 909 to 1723 ppm, Co 76 to 105 ppm and Cu 10 to 53 ppm. In the dunite zones Ni is 1487 to 2182 ppm, Co 77 to 126, and Cu 10 to 11.

Ni, Co, & Cu determined in the sulfide fraction of the rock are: Ni 745 to 1559 ppm, Co 54 to 63 ppm & Cu 1 to 56 ppm in the harzburgites. In dunite Ni is 1026 ppm, Co 41 ppm and Cu 3 ppm.

NICKEL MINERALIZATION

In the Alpurai and Kishora areas nickel mineralization is present in two distinct ore mineral assemblages. Apparently from field evidence

ultramafics of both the areas are part of the same ophiolitic melange. But polished thin section microscopy, ore microscopy and electron microprobe investigations reveal that they are possibly not equivalent in age and in composition. The Kishora ultramafics are harzburgite tectonites, whereas the Alpurai area has a lower peridotite tectonite member and an upper ultramafic cumulate member.

Nickel minerals in both cases occur in the shape of blebs, stringers and skeletons and are characterized by nickel-& cobalt-rich sulfide assemblages of heazlewoodite-awaruite with closely associated magnetite; and pentlandite as major nickel mineral with associated chalcopyrite, pyrrhotite & pyrite. The latter minerals never form a significant part of the sulfide assemblages. Heazlewoodite-pentlandite-magnetite and pent-landite-chalcopyrite-pyrrhotite- pyrite are described with respect to areal distribution and lithologic association.

Heazlewoodite Pentlandite-Awaruite-MagnetIte Association

Alpurai Area:- The heazlewoodite-pentlandite-awaruite-magnetite association is found in Alpurai area. In the following ore microscopic description is given first with respect to petrographic units identified and at the end electron probe analyses are given of the nickeliferous ore minerals in Alpurai ultramafic rocks.

Ore minerals in the harzburgite unit occur as fine-grained disseminations, veinlets, aggregates and as coarser grains (of chromite mostly). Grain size varies from 0.05 to 2.3 mm. Zoning is found in some grains having a chromite core surrounded by magnetite (Fig. 6). Dusty grains are partly in the basal zone where no sulfide minerals have been found. Sulfides in the upper harzburgite member (AA-2) occur as fine disseminations (0.05 to 0.09 mm), subhedral to euhedral (around 0.05 mm), whitish & very light creamish anhedra are of awaruite. Magnetite is light grey to whitish as compared to the grey chromite, which is fractured and altered along fractures.

In olivine websterite (AA-3 & AA - 5) ore minerals are mostly fine discrete and skeletal grains in serpentine and as exsolution product of CPX & OPX. Grain size varies from 0.1 to 1.5 mm. Chromite (picotite) occurs as subhedral grains with overgrowths of magnetite. Magnetite is found as anhedra (very fine to 0.2 mm) along cleavages and in veinlets. Sulfide grains are principally heazlewoodite, mostly 0.05 to 0.5 mm in size, while in sample AA-4 grains are very fine (around 0.01 to 0.03 mm) and are discrete skeletal to tabular in shape. Heazlewoodite is yellowish cream to yellow in colour, anisotropic, and grey to yellowish with crossed nicols. Pentlandite is very fine grained and closely intergrown with major heazlewoodite which is the predominant phase.

Ore minerals in the wehrlite (AA-9, the upper part of the zone) were also studied. They occur mostly as disseminated euhedra to anhedra with a range of grain sizes from 0.1 to 0.6 mm. Chromite grains are fractured & cloudy, show poor polishing, and are rounded to subrounded in shape. The sulfide grains are 0.01 to 0.1 mm in size and finely disseminated in the rock with euhedral to subhedral shape and look like heazlewoodite, having light yellow colour and slight anisotropy. Intergrowth of pentlandite in heazlewoodite was found by electron microprobe study.

The dunite member (AA-13 & AA-14) contains ore minerals 0.2 to 1.5 mm in diameter, subhedral to anhedral, and discrete & skeletal aggregates. Heazlewoodite (Fig. 6) is the only sulfide mineral with yellowish cream to yellowish colours and cleavage traces, with grain size of 0.05 to 0.15 mm. Magnetite is mostly associated with serpentine with grain size 0.1 to 0.6 mm and dendritic habit. Magnetite also occurs as an outer shell growth on chromite (0.3 to 1.5 mm). The latter is distinctly greyer than magnetite which is found along fractures in chromite.

The lherzolite member (AA-15 to AA-20) is the uppermost member of the ultramafic complex. In this zone sulfides are acicular & tabular). The grains are mostly 0.05 to 0.3 mm in size, but proportionately the larger grains are dominant. The heazlewoodite appears to be very weakly anisotropic, with well defined cleavage traces. A relatively more anisotropic phase, possibly millerite, is developed on the cleavage planes. At places some fine grains of awaruite appear white as compared to heazlewoodite. Magnetite is coarser grained-up to 0.8 mm-and occurs as discrete grains or as exsolution aggregates and rims around chromite grains. The chromite grains are distinctly darker grey than magnetite.

The heazlewoodite of the Alpurai area is rich in Ni (71.29 to 75.43%) and S (25.31 to 26.94%). Other elements are Fe (0.05 to 0.5%) and Co (0.01 to 0.03%) in most cases except AA-17/C-6 which has 1.47% Co). Cu is <.01% in all the samples.

Awaruite of the samples AA-13 & AA-16 show Ni 74.71 & 81.78% and Fe 14.87 & 22.86%. Co is interestingly high varying from 0.43 to 1.88%. S is insignificant from 0.01 to 0.05% and Cu is 0.62 to 2.33%.

Pentlandite-Chalcopyrite-Pyrrhotite-Pyrite Association

Kishora Area:- Ore minerals occur in smaller amounts in the harzburgite (serpentinized) member of Kishora as mentioned above, i.e., 0.5 to 1.5%. Their grain size varies from 0.1 to 0.9 mm. Chromite as well as magnetite occurs as discrete grains, and no zoning is found. The sulfides, however, occur in discrete grains as well as in aggregates (Fig. 7) mostly of pentlandite, chalcopyrite, pyrrhotite, pyrite and magnetite as minor phases; however, limonite occurs as an alteration product of sulfides. Pentlandite appears to replace chalcopyrite/pyrite having brighter yellow colour. The pentlandite is pale bronze to whiter cream in colour with well developed cleavage. It appears to be replaced by magnetite, and the veining appears to be of genetic significance and could be interpreted as hydrothermal oxidation of pentlendite ($Ni_6 Fe_3 S_8 + 12O - 2Ni_3S_2 + Fe_3O_4 + 4SO_2$).

The mineral association found in the Kishora rocks includes pentlandite, chalcopyrite and pyrite. They are found in serpentinites, and the minerals containing elements such as Ni, Cu, Fe & S may have eguilibrated to the P-T conditions of serpentinization.

SERPENTINIZATION & SULFIDE MINERALS

The Alpurai and Kishora ultramafic complexes are composed of ultramafic tectonites and cumulates and, as discussed in the previous section, are variably altered to serpentinites. The Alpurai complex is partially to completely serpentinized locally while the Kishora body is pervasively serpentinized throughout. The Alpurai ultramafics as a whole appear to be massive and to have been serpentinized in oceanic environments, but the peripheral parts were extensively serpentinized and sheared in syntectonic environments. The Kishora rocks appear to have been completley metamorphosed before emplacement and are modified by two thrusts (the Kishora & Makhad, Fig. 1).

Hydrothermal alteration of ultramafic rocks involves introduction of excess H_2O and/or CO_2. H_2O is usually available in sufficient amounts from the convecting sea water or from sediments or metasediments to convert ultramafic rocks into serpentinites having minerals such as antigorite or lizerdite/chrysotile. This process of serpentinization reconstitutes the metallic ions Fe, Cr. Ni, Co, Cu etc. present in the lattice of olivine, pyroxene or chromite or as discrete grains to form nickel sulfides, nickel-iron alloy, Fe-Ni-Cr oxides, Cu-Fe-sulfides, Fe-sulfides etc. But the process of serpentinization is stil complex. That is why for more than half a century people are still working to understand this process (Du Reitz 1935, Cooke 1937, Hess 1955, Sosman 1938, Bowen & Tuttle 1949, Francis 1956, Winkler 1976, Johannes 1968, Petrenko et al. 1974, Ramdohr 1967, Wenner & Taylor 1971, Donaldson 1981, Barrret et al. 1976, Peacock 1987 and many others.

It is thought that chrysotile begins to form when olivine and or orthopyroxene completely alter to lizardite (Prichard, 1979), and antigorite forms from lizardite in the presence of hydrothermal solutions at higher temperature (500-550°C). The textural study of the Alpurai ultramafics shows that antigorite was directly developed from olivine. This is evident from Pseudomorphous textural relics, i.e., dendrites and skeletons of olivine and development of fibrolamellar needles and bladelets of antigorite. X-ray diffraction patterns were obtained of a large number of samples to differentiate between antigorite and lizardite (typical large peaks of antigorite & lizardite occur at 7.3 A and 2.5 A, but the third large peak of antigorite was found at 3.6 A and similarly a third large peak should be present at 4.6 A for lizardite, but they were of small size, which clearly indicates little or no lizardite. Alteration of OPX is to bastite with well-shaped pesudomorphic forms. Moreover, typical mesh and hourglass textures are not developed in these rocks. The Kishora rocks are thoroughly sheared and mylonitized, so the order of formation of serpentine minerals cannot be deduced with certainty, but may essentially be antigoritic, contemporaneous formation of the pentlandite-chalcopyrite-pyrrhotite-pyrite association at temperatures ~ 325°C.

In the Alpurai ultramafic body, development of unfoliated antigorite directly from olivine and orthopyroxene at temperature <500°C and contemporaneously with sulfides in the absence of deformation suggests that their serpentinization and mineralization occured in response to hydrothermal convection of seawater through the oceanic crust and upper most mantle in a spreading ocean ridge tectonic setting. Seawater convection into the ocean upper mantle in an ocean ridge setting has been established by oxygen isotope studies of the Samail ophiolite (in Oman by Gregory & Tylor, 1979). In the Kishora body and locally within the Alpurai Complex, some additional serpentinization may have accompanied ductile deformation during tectonic emplacement as overthrust sheets.

The chemical processes by which the ultramafic and mafic rocks are hydrothermally altered and mineralized by sea water can be represented schematically by generalized reactions involving the molecular components of the various fluid and solid solutions. The ferrous-iron components of olivine and pyroxene solid solution are altered to magnetite plus agueous silica and hydrogen by reaction of the type.

$$3Fe_2SiO_4 + 2H_2O = 2Fe_3O_4 + 3SiO_{2(aq)} + 2H_{2\,(aq)} \quad (1)$$

which is the principal reaction responsible for development of strongly reducing condition. Seawater sulfate is probably the principal source of sulfur for sulfide mineralization and is reduced by reaction with ferrous silicate components.

$$13Fe_2SiO_4 + 2SO^{2-}_{4(aq)} + 4H^+_{(aq)} = 2FeS + 8Fe_3O_4 + 13SiO_{2(aq)} + 2H_2O \quad (2)$$

The pyrrhotite formed by reaction (2) is typically associated with pentlendite, which may form

TABLE I

PETROGRAPHIC COMPOSITION OF ALPURAI SERPENTINIZED ULTRAMFICS

	AA-1 Harzburgite	AA-2 Harzburgite	AA-3 Olivine Websterite	AA-4 Olivine Websterite	AA-5 Olivine Websterite	AA-6 Wehrlite	AA-7 Wehrlite	AA-8 Dunite	AA-9 Wehrlite	AA-10 Websterite
Antigorite.	75.00	60.00	30.00	23.00	15.00	70.00	40.00	45.00	36.00	3.00
Chrysotile.	–	–	–	15.00	–	1.50	2.00	15.00	–	–
Bastite.	10.00	10.00	25.00	7.00	25.00	3.00	1.00	2.00	5.00	67.00
Olivine.	–	8.00	5.00	8.00	15.00	–	20.00	15.00	30.00	3.00
CPX.	–	7.00	25.00	20.00	27.00	16.00	30.00	10.00	20.00	15.00
OPX.	–	10.00	10.00	8.00	10.00	2.00	2.00	4.00	5.00	3.00
Iddingsite.	3.00	0.30	0.30	15.00	0.00	–	3.00	8.00	1.00	2.00
Limonite/Goethite.	2.00	–	–	–	–	–	–	0.5	–	–
Chlorite.	0.00	–	–	0.20	–	–	–	–	0.2	–
Carbonates.	6.00	–	–	–	–	–	–	–	–	–
Uralite.	2.00	–	–	–	–	5.00 from CPX	tr	tr	–	5.00
Oreminerals.	2.00	5.00	5.00	4.00	7.00	2.5	1.5	0.5	1.5	2.0

TABLE 1 (Continued)

	AA-11 Olivine Websterite	AA-12 Olivine Websterite	AA-13 Dunite	AA-14 Dunite	AA-15 Lherzolite	AA-16 Lherzolite	AA-17 Lherzolite	AA-18 Lherzolite	AA-19 Lherzolite	AA-20 Lherzolite
Antigorite	15.00	20.00	45.00	55.00	35.00	50.00	60.00	25.00	45.00	50.00
Chrysotile.	–	–	1.00	–	–	–	–	–	–	–
Bastite.	30.00	44.00	–	–	15.00	15.00	15.00	10.00	15.00	8.00
Olivine.	15.00	5.00	44.00	24.00	14.00	9.00	3.00	25.00	10.00	10.00
CPX.	16.00	25.00	–	10.00	18.00	18.00	15.00	20.00	10.00	20.00
OPX.	5.00	3.00	3.00	5.00	7.00	5.00	5.00	6.00	8.00	5.00
Iddingsite.	8.00	–	2.00	1.5	–	–	–	2.00	7.00	1.00
Limonite/Goethite	0.5	–	–	1.5	–	–	–			
Chlorite.	–	–	–	–	–	0.1	0.1	–	–	–
Carbonates.	–	–	1.00	–	–	–	–	–	–	–
Uralite.	8.00	–	–	–	8.00	–	–	–	–	–
Ore Minerals.	2.00	3.00	4.00	3.00	3.00	2.5	2.0	12.00	5.00	6.00

TABLE 2

PETROGRAPHIC COMPOSITIONOF SERPENTINIZED ULTRAMAFICS OF KISHORA

	AK-1 Dunite	AK-2 Dunite	AK-3 Dunite	AK-5 Harzburgite	AK-6 Harzburgite	AK-7 Harzburgite	AK-8 Dunite	AK-9 Harzburgite	AK-10 Harzburgite
Antigorite.	40.00	79.00	35.00	30.00	50.00	75.00	71.00	75.00	65.00
Chrysotile.	52.00	10.00	10.00	–	10.00	12.00	5.00	6.00	10.00
Olivine.	–	–	–	–	–	–	–	–	–
Iddingsite.	–	3.00	–	–	–	–	–	–	–
Bastite.	2.00	–	6.00	9.00	20.00	6.00	–	10.00	15.00
CPX.	–	–	–	–	–	–	–	–	1.00
OPX.	–	–	1.5	10.00	2.00	5.00	1.00	1.00	3.00
Talc.	–	5.00	1.00	45.00	16.00	1.00	20.00	4.00	5.00
Carbonates.	1.5	–	–	5.00	–	–	2.00	–	–
Uralite.	1.5	–	45.00	–	–	–	–	3.00	–
Ore Minerals.	3.00	3.00	1.5	1.00	1.5	0.5	1.00	0.5	1.00

TABLE 3

CHEMICAL ANALYSIS OF ALPURAI ULTRAMAFICS

	AA-2	AA-3	AA-15	AA-16	AA-17	AA-18	AA-19	AA-20
SiO_2	40.19	39.48	41.15	39.98	40.30	40.09	41.61	40.28
TiO_2	.01	.01	.01	.01	.02	.03	.03	.01
Al_2O_3	.67	.49	.51	.66	.65	.66	.92	.66
Fe_2O_3	5.39	7.39	6.19	6.36	5.69	8.48	5.90	6.19
MnO	.07	.09	.08	.09	.06	.05	.06	.11
MgO	41.89	43.00	41.24	42.70	41.82	39.82	38.82	42.43
CaO	.65	.53	2.22	1.10	.69	3.42	3.98	1.56
Na_2O	.05	.05	.05	.05	.05	.05	.05	.05
K_2O	.13	.05	.05	.05	.25	.05	.13	.05
P_2O_5	.07	.07	.04	.07	.07	.04	.03	.07
Cr_2O_3	.40	.35	.35	.36	.04	.45	.36	.36
LOI	10.20	8.20	7.90	8.30	9.70	6.70	7.80	8.00
	99.72	99.71	99.79	99.74	99.34	99.84	99.69	99.77
Ba	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm
Cu	64 "	30 "	28 "	32 "	47 "	27 "	39 "	25 "
Zn	19 "	26 "	13 "	18 "	23 "	14 "	10 "	22 "
Ni	1692 "	1878 "	1734 "	1649 "	1915 "	1479 "	1577 "	1864 "
Co	79 "	114 "	88 "	100 "	88 "	103 "	75 "	108 "
Sr	10 "	10 "	10 "	10 "	10 "	10 "	10 "	10 "
Zr	5 "	5 "	5 "	5 "	5 "	5 "	5 "	5 "
Ce	32 "	20 "	20 "	20 "	20 "	20 "	20 "	20 "
Y	5 "	5 "	5 "	5 "	5 "	5 "	5 "	5 "
Nb	20 "	20 "	20 "	20 "	20 "	20 "	20 "	20 "
Ta	20 "	20 "	20 "	20 "	20 "	20 "	20 "	20 "

TABLE 4

CHEMICAL ANALYSIS OF KISHORA ULTRAMAFICS

	AK-5	AK-6	AK-7	AK-8	AK-9	AK-2	AK-2
SiO_2	45.29	42.27	39.67	46.15	40.07	41.48	42.47
TiO_2	.02	.02	.02	.01	.01	.01	.03
Al_2O_3	2.34	1.91	2.50	.50	2.43	.81	.78
Fe_2O_3	6.77	7.06	7.80	5.45	7.20	7.77	6.60
MnO	.06	.07	.08	.06	.08	.07	.08
MgO	35.07	36.62	36.70	36.78	37.33	37.55	37.84
CaO	.32	.28	.44	.22	.11	.25	.20
Na_2O	.05	.05	.05	.05	.05	.05	.05
K_2O	.05	.05	.05	.21	.24	.05	.05
P_2O_5	.03	.03	.03	.04	.03	.04	.04
Cr_2O_3	.33	.36	.54	.29	.31	.52	.37
LOI	9.40	11.00	12.00	10.00	11.90	11.60	11.50
	99.74	99.72	99.88	99.75	99.76	100.20	100.01
Ba	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm	5 ppm
Cu	44 "	53 "	10 "	13 "	13 "	49 "	142 "
Zn	28 "	21 "	26 "	10 "	26 "	12 "	11 "
Ni	1670 "	1723 "	909 "	1487 "	1457 "	1752 "	2182 "
Co	96 "	105 "	76 "	77 "	83 "	85 "	126 "
Sr	10 "	11 "	10 "	10 "	10 "	10 "	10 "
Zr	5 "	5 "	5 "	5 "	5 "	5 "	5 "
Ce	20 "	20 "	20 "	20 "	20 "	20 "	20 "
Y	5 "	5 "	5 "	5 "	5 "	5 "	5 "
Nb	20 "	20 "	20 "	41 "	22 "	20 "	20 "
Ta	20 "	20 "	20 "	20 "	20 "	20 "	20 "

TABLE 4A

CHEMICAL COMPOSITION OF WHOLE ROCK ELEMENTS IN SULFIDES

Samples	Area	Ni ppm	Co ppm	Cu ppm	S%
AA-2	Alpurai	1280	44	64	.03
AA-3		1411	62	24	.02
AA-15	"	1480	53	15	.03
AA-16	"	1440	60	20	.03
AA-17	"	1580	44	13	.04
AA-18	"	1253	59	18	.02
AA-19	"	1417	43	31	.03
AA-20	"	1565	57	22	.04
AK-5	Kishora	1338	56	37	.04
AK-6	"	1559	63	56	.11
AK-7	"	745	43	1	.01
AK-8	"	1026	41	3	.04
AK-9	"	1292	54	5	.04

TABLE 5

ELECTRON MICROPROBE ANALYSIS OF HEAZLEWOODITE

	AA-2/3	AA-2/4	AA-2/4	AA-3C/5	AA-3/4	AA-5	AA-14	AA-15/1	AA-15/2	AA-15/3	AA-16	AA-16/2	AA-17	AA-17/2
S	26.27	26.45	26.11	26.61	26.52	25.40	25.16	26.55	26.72	26.72	26.64	26.67	25.31	26.23
Fe	.04	.05	.07	.25	.15	.14	.05	.08	.08	.05	.08	.43	.16	.10
Ni	72.86	72.10	72.19	71.71	71.29	72.94	72.13	75.43	75.00	74.37	74.33	74.75	71.90	73.71
Co	.06	0.00	.03	.03	.02	.03	.09	.16	.15	.18	.09	.07	1.47	.01
Cu	.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	99.23	98.60	98.40	98.60	97.98	98.51	97.43	102.22	101.96	101.32	101.14	101.92	98.84	100.05

	HEAZIEWOODITE				PENTLANDITE		AWARUITE			
	AA-19/1	AA-19/2	AA-19/3	AA-19/4	AA-2/1	AA-3/1	AA-13/1	AA-13/2	AA-13/3	AA-16
S	26.03	26.93	26.85	26.44	33.77	33.82	.03	.01	.03	.05
Fe	.11	.42	.13	.00	24.28	28.05	22.86	17.62	14.87	21.68
Ni	71.84	73.27	74.59	74.13	34.21	32.90	74.71	80.42	81.78	77.20
Co	.02	.00	.04	.02	7.60	3.42	1.88	.92	.80	.43
Cu	.00	.00	.00	.00	.00	.00	0.62	1.54	2.32	1.07
	98.00	100.62	101.60	100.59	99.86	98.19	100.10	100.51	99.80	100.43

TABLE 6

ELECTRON MICROPROBE ANALYSIS OF

	PENTLANDITE			CHALCOPYRITE			PYRRHOTITE		PYRITE
	AK-3	AK-6/1	AK-6/2	AK-3	AK-5	AK-6	AK-5	AK-5/1	AK-9
S	33.70	32.14	34.69	34.61	34.91	33.19	38.31	38.36	50.46
Fe	27.73	27.14	27.61	30.38	28.01	30.49	55.20	50.34	44.34
Ni	39.12	37.77	33.17	0.16	.00	.17	3.66	9.01	2.77
Co	.21	1.14	2.82	0.3	0.3	0.8	0.25	.36	.88
Cu	.00	.00	0.00	33.35	33.42	34.33	.00	.32	.04
	100.76	98.19	98.29	98.53	97.37	98.26	97.42	98.39	98.67

TABLE 5-A

ELECTRON MICROPROBE ANALYSIS OF MAGNETITE

	AA-2C/1	AA-2C2/2	AA-2C2/3	AA-2C2/4	AA-2C2/5	AA-2C2/6	AA-3C1A/2	AA-3C2A/2	AA9C1A/2	AA-9C2A/3	AA9C/3
Fe_2O_3	66.48	67.33	66.44	68.04	67.14	66.61	64.46	66.68	68.90	68.41	68.30
FeO	29.56	29.89	29.63	29.91	30.01	30.11	30.27	29.81	30.83	30.55	30.58
NiO	1.39	1.01	1.11	1.11	1.02	.99	.83	.91	.40	.43	.22
Cr_2O_3	1.59	.96	1.39	.60	1.44	2.04	4.36	1.56	.39	.32	.08
Al_2O_3	.34	.17	.21	.11	.14	.18	.01	.00	.04	.05	.04
	99.36	99.37	98.78	99.77	99.75	99.93	99.93	98.96	100.56	99.76	99.22

Formulae:-

AA2C/1 = $(Ni_{.043}\ Fe^{+2}_{.957})_{1.00}\ (Fe^{+3}_{1.935}\ Cr_{.049}\ Al_{.016})_{2.00}\ O_{4.00}$

AA2C2/2 = $(Ni_{.031}\ Fe^{+2}_{.969})_{1.00}\ (Fe^{+3}_{1.963}\ Cr_{.043}\ Al_{.010})_{2.00}\ O_{4.00}$

AA2C2/3 = $(Ni_{.035}\ Fe^{+2}_{.965})_{1.00}\ (Fe^{+3}_{1.947}\ Cr_{.043}\ Al_{.010})_{2.00}\ O_{4.00}$

AA2C2/4 = $(Ni_{.035}\ Fe^{+2}_{.966})_{1.00}\ (Fe^{+3}_{1.977}\ Cr_{.018}\ Al_{.008})_{2.00}\ O_{4.00}$

AA2C2/5 = $(Ni_{.032}\ Fe^{+2}_{.968})_{1.00}\ (Fe^{+3}_{1.950}\ Cr_{.044}\ Al_{.016})_{2.00}\ O_{4.00}$

AA2C2/6 = $(Ni_{.031}\ Fe^{+2}_{.969})_{1.00}\ (Fe^{+3}_{1.930}\ Cr_{.062}\ Al_{.008})_{2.00}\ O_{4.00}$

AA3C1A/2 = $(Ni_{.026}\ Fe^{+2}_{.973})_{1.00}\ (Fe^{+3}_{1.867}\ Cr_{.137}\ Al_{.005})_{2.00}\ O_{4.00}$

AA3C2A/2 = $(Ni_{.030}\ Fe^{+2}_{.970})_{1.00}\ (Fe^{+3}_{1.952}\ Cr_{.048}\ Al_{.000})_{2.00}\ O_{4.00}$

AA9C1A/2 = $(Ni_{.012}\ Fe^{+2}_{.988})_{1.00}\ (Fe^{+3}_{1.986}\ Cr_{.012}\ Al_{.002})_{2.00}\ O_{4.00}$

AA9C2A/2 = $(Ni_{.013}\ Fe^{+2}_{.987})_{1.00}\ (Fe^{+3}_{1.988}\ Cr_{.010}\ Al_{.002})_{2.00}\ O_{4.00}$

AA9C3 = $(Ni_{.007}\ Fe^{+2}_{.993})_{1.00}\ (Fe^{+3}_{1.996}\ Cr_{.002}\ Al_{.002})_{2.00}\ O_{4.00}$

by a reaction of the following type, involving molecular components of olivine solid solution:

$$2.\quad 5Ni_2SiO_4 + 26Fe_2SiO_4, + 8SO^{2-}_{4(aq)} + 16H^{++}_{(aq)} + 17H_{2(aq)} = Ni_5Fe_4S_8 + 16Fe_3O_4 + 28.5SiO_{2(aq)} + 25H_2O \quad (3)$$

The agueous silica shown in equations 1-3 is consumed at the reaction site by serpentinization occurring concurrently with the formation of those Fe-Ni sulfides and oxides:

$$3Mg_2SiO_4 + 4H_2O + SiO_{2(aq)} = 2\ Mg_3Si_2O_5\ (OH)_4 \quad (4)$$

Under reducing conditions and a shortage of sulfur nickel has a stornger grasp on sulfur than iron, and the heazlewoodite + awaruite + magnetite assemblage develops in lieu of the pentlandite + pyrrhotite + magnetite assemblage:

$$3Ni_2SiO_4 + 20Fe_2SiO_4 + 2SO^{2-}_{4(aq)} + 4H^+_{(aq)} + 10H_{2(aq)} = Ni_3S_2 + Ni_3Fe + 13Fe_3O_4 + 23SiO_{2(aq)} + 12H_2O \quad (5)$$

In the presence of sufficient aqueous CO_2 to form magnesite, talc forms as a co-product of the alteration of olivine:

$$3Mg_2SiO_4 + 3CO_{2(aq)} + 1.5H_2O = 0.75\ Mg_3\ Si_2O_5\ (OH)_4 + 3MgCO_3 + 0.5\ Mg_3\ Si_4\ O_{10}\ (OH)_2 \quad (6)$$

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TABLE 5-A (Contd.)

	AA-9 C1A/2	AA-9C2A	AA-9C/3
Fe_2O_3	68.90	68.41	68.30
FeO	30.83	30.55	30.58
NiO	.40	.43	.22
Cr_2O_3	.39	.32	.08
Al_2O_3	.04	.05	.04
	100.55	99.76	99.22

Formulae:-

AA9C1A/2 =
$(Ni_{.012}\ Fe^{+2}_{.988})_{1.00}\ (Fe^{+3}_{1.986}\ Cr_{.012}\ Al_{.002})_{2.00}\ O_{4.000}$

AA9C1A/3 =
$(Ni_{.013}\ Fe^{+2}_{.987})_{1.00}\ (Fe^{+3}_{1.988}\ Cr_{.010}\ Al_{.002})_{2.00}\ O_{4.00}$

AA9C/3 =
$(Ni_{.007}\ Fe^{+2}_{.993})_{1.00}\ (Fe^{+3}_{1.996}\ Cr_{.002}\ Al_{.002})_{2.00}\ O_{4.00}$

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OBSERVATIONS ON PRECAMBRIAN OROGENY AND THE AGE OF THE METAMORPHISM IN NORTHWEST HIMALAYA, PAKISTAN

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ABSTRACT:-Presence of Tertiary granites in Himalayas has clouded the earlier metamorphic history of Northwest Himalaya. Evidence from the relationship of various rock units throws fresh light on the chronology and intensity of older metamorphic events which go back to 1840 ma. In particular, a Late Precambrian event rose to amphibolite facies. A Permo-Trais event of much lower intensity is also indicated.

INTRODUCTION

Most of the Middle and higher Himalayas is constituted by medium pressure type metamorphic rocks, with some areas of low pressure regional metamorphism. The age of this metamorphism has remained an unsettled question. Gansser (1964) regarded most of this metamorphism as Precambrian. Others, Frank et al. (1973) Le Fort (1975), Bird (1978) and Bard (1983), however, have tended to regard most metamorphism as Tertiary. In line with the latter Hamet and Allegre (1976) have shown the younger granites of Himalaya as Oligocene or even younger on the basis of Rb-Sr isochron. Metha (1980) has summarised published K-Ar, Rb-Sr and fission track mineral ages of Himalayas in India. According to this study more than 75% of these ages range from Late Cretaceous to Neogene (75-5 Ma BP). However, Rb-Sr whole rock ages range from Precambrian to Early Proterozoic (upto 1840 Ma BP). Ghazanfar and Chaudhry (1987) recognised the higher Himalayan block in NW Himalaya. If this block is compared with Indian block we expect ages of 1800-1900 Ma BP. old orogenic event. (Karelian orogeny). Ages of the alkaline province of Pakistan have been summarised by Kempe (1986). The summary also includes a non-alkaline granite called Malakand granite (Chaudhary et al 1976). The age of Malakanad granite reported by Maluski and Mattee (1984) is 22 ma.

The Cambrian to Precambrian basement rocks of the Indo-Pak plate south of the MMT exhibit polymetamorphism. The evidence for repeated deformation is preserved in these rocks (Chaudhry, 1964, Gansser, 1964, 1981 Krummenacher, 1966, Naha and Ray 1971, Shams, 1983, and Ghazanfar, Baig and Chaudhry, 1983).

The Problem of Metamorphism's Chronology.

However, apart from the general observations listed above, the different ages of various metamorphic episodes remains a debated question. Chaudhry (1964) based on the evidence of the presence of chips of Hazara Slate in Tanakki Conglomerate (regarded as Carboniferous at that time) which is overlain by unmetamorphosed sequence proposed a Palaeozoic

orogeny. Subsequently Baig et al. (1988) relying on the stratigraphic and palaeontological data of Latif (1970, 1972, 1974), Rushton (1973) and Calkins et al. (1975) on Hazara proposed Precambrian metamorphism. Their evidence runs as follows. "The base of Abbotabad Group of Cambrian age is marked by a basal Tanakki conglomerate which has clasts of metamorphics derived from the underlying Precambrian metasedimentary rocks ... Cambrian to Cenozoic rocks above the angular unconformity are unmetamorphosed whereas below the unconformity the Hazara Formation is metamorphosed upto Lower greenschist facies". Not only this evidence is valid but also in line with the previous recognition of Precambrian metamorphism (Gansser, 1964). However, two problems remain, first the intensity of older metamorphism and second the degree of Tertiary reheating.

Below we present direct field and petrographic evidence to show that not only at least one regional metamorphic period and therefore orogeny is older than 500-600 ma but also that in the Mansehra area of Hazara the intensity of this metamorphism reached levels of upper amphibolite facies.

Age and Intensity of Older Metamorphism

The key to the field and petrographic evidence lies in the relationship of the Mansehra pluton and the metamorphosed country rocks in the Mansehra and middle Kaghan area of district Mansehra. The country rocks here comprises what has been called the Tanol Formation, a thick sequence of pelitepsammites. The Tanol Formation is believed to overlie the Infra-Cambrian Hazara Slates and underlies the Infra-Cambrian Tanakki Boulder Bed. Its age, therefore, has been inferred as Late Precambrian. The Tonal Formation in the Mansehra area has been metamorphosed from chlorite to sillimanite grades of regional metamorphism.

In this same area this formation is intruded by a porphyritic granite known as the Mansehra Granite. The Mansehra Granite intrudes all metamorphic zones of the country rocks ranging from chlorite grade to sillimanite grade and shows no relationship to the distribution of temperatures of regional metamorphism. The pluton is in no way confined to the thermal axis of the area. Metamorphic isograds of regional metamorphism are abruptly truncated by the granite body at many places. Not only that but also a thermal metamorphic event associated with the emplacement of Mansehra Granite has been superimposed on the regional metamorphism. Wherever the contact is intact well-developed hornfelses and, at places, contact migmatites have developed. The thermal metamorphism at many places has been clearly superimposed at an angle on the regional metamorphism. Development of contact migmatites and andalusite, silllimanite and cordierite bearing hornfelses is common. Regional metamorphic minerals like almandine, staurolite and kyanite tend to break down leaving recognisable relics or disappear altogether in the thermal aureoles.

The above field and petrographic relationship is enough to suggest that the emplacement of Mansehra Granite is younger than the age of regional metamorphism. Similar arguments of relative age relations for granodiorites and metamorphites of Shiojiri - Takato area, Ryoke Belt, Japan, has been regarded as valid by Miyashiro (1973).

The Mansehra Granite has been dated radiometrically to be 500 to 600 ma old (le Fort et al 1980). The regional metamorphism of the country rocks, the Tanol Formation, which reached upto upper amphibolite facies is, therefore, older than 500-600 ma (Late Precambrian). It can, thus, safely be assumed that at least one phase of the polymetamorphism of Himalayas is Precambrian and in intensity reached at least the amphibolite facies. This also further corroborates a fully developed Precambrian orogeny. An 1800 to 1900 Ma BP old metamorphism and orogeny is proposed on the basis of comparison of the ages of higher Himalayan rocks of India (Metha, 1980) with those in Pakistan. This may be called "Karelian orogeny".

A Permo-Trias Event

An interesting relationship is again exhibited by the Kashmir Sequence (Ghazanfar et al. 1986) of rocks extending into Kaghan Valley. Here the Panjal Formation is metamorphosed to greenschist facies while the overlying Malkandi limestone (Ghazanfar et al. 1986) is unmetamorphosed. The Panjal Formation further eastwards in Kashmir has been dated as Permian to Triassic (Wadia, 1975) on the basis of associated fossiliferous horizons. The Malkandi Formation in Kashmir has been called the Triassic Limestone and dated as Triassic eastward in Kashmir (Wadia, 1975). In Kaghan Valley all rocks older than the Permian Panjal Formation are metamorphosed and the Triassic Malkandi Formation and younger sequence is ummetamorphosed. Obviously, this metamorphism has been affected by Permian or a

Hornfelse zones seen superimposed on regional metamorphism at places. The isograds at places are seen to be cut by granite and hornfelse zones. Unit nomenclatures by Calkins et al (1975) left unchanged.

Base map from Calkins et al (1975) modified

LEGEND

Alluvium	QUATERNARY
Murree Formation	TERTIARY
Kala Chitta Group	TERTIARY
Undifferentiated Sediments	JURASSIC TO CRETACEOUS
Kingriali Formation	CARBONIFEROUS TO TRIASSIC
Panjal Formation	CARBONIFEROUS TO TRIASSIC
Tanawal Formation	PRECAMBRIAN
Hazara Formation	PRECAMBRIAN
Salkhala Formation	PRECAMBRIAN
Mansehra Granite	CRETACEOUS & TERTIARY
Hakle Granite	CRETACEOUS & TERTIARY
Hornfelse	
Strike & dip of bed / foliation	
Metamorphic isograd showing metamorphic index minerals K = kyanite, ST = staurolite, G = garnet, B = biotite and CH = chlorite	
River / stream	
Road / path	

Permo-Trias event which we may say, was associated with Panjal Orogeny. Evidence of a Permo-Trias event from the age of granites has also been provided by Kempe et al. (1986) from elsewhere in the Himalayas. This may be called a Hercynian event.

The Tertiary Metamorphic Event

However, Frank et al. (1973) Le Fort (1975), Bird (1978) and Bard (1980) have regarded most of the metamorphism as Tertiary. Bird (1978) relying on Oxburgh's (1972) concept of flake tectonics proposed as follows: "After India-Eurasia collision in Tertiary, the mantle lithosphere of the northern edge of the Indian plate was split from the overlying crustal layer and plunged deep into the asthenosphere. The crust of Indian Shield came into direct contact with hot asthenosphere and was very strongly heated thus resulting in metamorphism and generation of granite melts."

However, according to Miyashiro et al (1982) small masses of Tertiary granite is not trustworthy evidence for Tertiary age of regional metamorphism of the surrounding areas. He sums up his views on the Himalayan metamorphism as follows. "From the fact that Himalayan metamorphic rocks give radiometric age evidence for Tertiary heating (75-5 ma), we may safely presume that continental collision causes at least low grade regional metamorphism but it is not clear yet whether it can cause medium or high grade regional metamorphism".

By way of negative evidence Gansser (1964, 1981) pointed out that no regional metamorphism has appreciably affected the Palaeozoic and younger sediments in Indian Himalayas. The metamorphism of medium to high grade affects and is restricted to Pre-Cambrian alone.

Ghazanfar and Chaudhry (1986) have delineated the higher Himalayan Block in Kaghan which lies between the Main Central Thrust (MCT) and the Main Mantle Thrust (MMT). They have presented evidence of polymetamorphism (1986, 1987) and clearly related Tertiary leucorgranites with the residual heat of regional metamorphism implying thereby that the Himalayan metamorphism also reached upper amphibolite facies. However, Frank et al. (1973), Le Fort (1975), Bird (1978) and Bard (1980) while correctly pointing out medium to high grade metamorphism as Himalayan in age downplayed the intensity and extent of earlier Precambrian metamorphism.

We, therefore, suggest that a) there is evidence from Mansehra area of a Pre-Cambrian orogeny and metamorphism which reached upto upper amphibolite facies, b) in Pakistan, rocks younger than Cambrian are generally not affected by medium to high grade metamorphism, c) however, in Kaghan and Neelum Valleys there is evidence of a Permian or Permo-Trias metamorphic event of low intesity. d) widespread medium to high grade regional metamorphism of Tertiary age has also been clearly demonstrated, e) late to post-tectonic Tertiary granites in Himalayas, have been clearly related to the residual heat of regional metamorphism of Himalayan age.

On the basis of comparison of higher Himalayan rocks from India and Pakistan and ages from India (Upto 1840 Ma BP, Metha 1980) we suggest an 1800 to 1900 Ma BP metamorphic and orogenic event "Karelian Orogeny".

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WHETHER NEWLY DISCOVERED SHONTARGALI THRUST IS AN ANALOGUE OF MCT* IN THE NORTHWESTERN HIMALAYA IN PAKISTAN!

By

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ABSTRACT:- Shontargali Thrust is a newly discovered megashear in the northwestern domain of Himalaya. A brief introduction to its broad geological aspects is intended in this paper.

Its geographic location is at the base of Nanga Parbat massif = Higher Himalaya. It has been investigated for a stretch of about 50 km in Barai stream, a tributary of Neelam = Kishenganga river in Kashmir and in Mir Malik stream, a tributary of Astor river, in Gilgit Agency. Both of these streams follow the strike of the thrust.

In the Shontargali Thrust, the Salkhala series = Jatog Fm. is thrust over by the Nanga Parbat gneisses = Central crystallines = Vaikritta Group. The thrust has a northeast-southwest strike and dips between 25°-35° towards east. In more tectonized sections, the angle of dip could be more.

The Shontargali Thrust zone, between 3-5 km wide, is highly deformed giving rise to squeezed recumbent or reclined folds. Imbrication in the footwall zone of the thrust is manifest in highly deformed sections which usually give rise to duplex structures. The presence of mylonite and migmitite point to ductile deformation which is frequently noticed in the footwall zone of the thrust.

On the basis of its geographic location and grade of metamorphism of the associated rocks, coupled with its stratigraphic and tectonic settings, the author considers the Shontargali Thrust as an analogue of the Main Central Thrst (MCT) in the northwestern Himalaya in Pakistan.

INTRODUCTION

The Main Central Thrust is one of the major and a well defined megashears of the Himalayan orogenic belt.It is an intra-crustal thrust which has been created as a result of collision between the Indian and Eurasian plates. This thrust was responsible to bring a deep level of basement up over the metasediments of the Lesser Himalayan zone. It has a continuous extension along the Himalayan orogenic belt from Assam Himalaya in the east, to the Punjab Himalaya in the west.

In Kashmir and northwestern Himalaya in Pakistan, the MCT looses its identity. Most of the Himalayan geologists considered the Main Boundary Thrust (MBT) and the Punjal Thrust in Kashmir to be its equivalents.

In the northwestern Himalaya in Pakistan the Panjal Thrust (PT) extend from Pir Panjal in Kashmir to the northern tip of the Hazara-Kashmir syntaxis, and beyond this point its further extension towards northwest is skirmished by the late regional stratigraphic and tectonic turbulence. As a result, three different views pertaining to its extension, west of the syntaxis have emerged. Calkins et al. (1975) consider the extension of PT through Galiat-Abbottabad and after traversing the eastern and southern edge of Gandghar Range terminates in the Attock-Cherat Range, west of the Indus in Peshawar valley.

Lawrence et al. (1988) marked an unrecognised fault which starts from the eastern flank of the brownfo

*Main Central Thrust

syntaxis and passes through Galiat-Galdanian and extends it further east along the southern margin of Mansehra granite pluton.

Seeber et al. (1988) based on seismic data consider a fault to be Panjal Thrust which has east-west extension west of the syntaxis and passes at a depth of 17 km underneath the Indus river.

Keepking in view the lithological characteristics of the rocks associatedd with PT, coupled with its stratigraphic and tectonic setup, the author is not convinced by the idea of these faults being extension of PT. A major and an important lithological component of PT is the association of volcanics which are missing in these fault zones. This detail has been incorporated to specify the location of MCT in the northwestern Himalaya, if Panjal Thrust is considered its equivalent.

SHONTARGALI THRUST

This is a newly discovered megashear located along the boundary of the Lesser Himalaya and Higher Himalayan domains of Kashmir and Nanga Parbat massif. Its southern extent is marked in the Barai stream, a tributary of Neelam river. It continues towards NNE, crosses over Shontargali Pass (14973ft) and enters Astor Valley. Here it follows Mir Malik stream and just short of Mir Malik village the Shontargali Thrust swings towards NNW. Beyond this point the thrust merges with the main mass of Nanga Parbat where it is still to be investigated.

The Shontargali Thrust covers between 3-5 km wide zone and most of its main part which should have exposed thrust slices and other tectonic features, is devoured by the Barai and Mir Malik streams which follow its strike. The rocks involved in the thrust are Salkhala Series of Lesser Himalaya and the Nanga Parbat gneisses of Higher Himalaya; the latter being thrust over the former.

STRATIGRAPHIC SETUP

Salkhala Series involved in the thrust consist of mica schist, garnet schist, talc schist, graphitic schist, yellowish brown medium crystalline limestone to medium to coarse white marble, thin to thick bedded quartzitic sandstone and quartzite, amphibolite, quartzo-felspathic and biotite gneisses along with host of acid and basic intrusions. Their grade of metamorphism in general relates to middle green schist facies but in highly tectonized sections, could elevate to kyanite-sillimanite level.

Salkhala Series has got a quite widespread distribution in Kashmir and northwestern Himalaya and amass a wide range of lithologies which still need proper investigation to establish stratigraphic order. It may be mentioned here that in Astor-Neelam Valleys, two lithologies of Salkhalas are encountered. One is that of a low grade metamorphosed sediments, domainantly schistose with very rare gneiss component.Another is relatively of higher grade and incorporates in substantial part para and ortho-gneisses.

In Astor Valley the former lithology is involved in the Main Mantle Thrust and overlies the Nanga Parbat gneisses with a disturbed contact. This contact is attributed to be a fault but not a thrust. The latter lithology is involved in the Shontargali Thrust which is thrust over by the older Nanga Parbat gneisses.

The Nanga Parbat gneisses are developed in the Nanga Parbat-Haramosh (NP-H) massif which constitutes the northwestern termination of the Higher Himalaya. The dominant rock types are gneissose (biotite and quartzo-feldspathic gneisses) which constitute the bulk of the rock assemblage of this massif. The rest are retrograde schistose rocks which Madin (1986) has grouped under Haramosh schists. Part of these schistose rocks could incorporate Lesser Himalayan facies too.

Amphibolite sills and dykes are very often seen emplaced in the western part of the massif and show gradual decrease towards east. Besides basic intrusives, granitic bodies of pre-and post-alpine orogenies are also present. Recent studies of zircon and amphibole derived from NP gneisses and granites, using U/Pb, AR^{40}/AR^{39} and K-Ar methods, yielded three distinct age groups: C 1800-2700 Ma, C 500-600 Ma and C 10-58 Ma (Zeitler et al., 1986). The oldest age pertains to Naga Parbat gneisses and on the basis of this age these gneisses could comfortably be correlated with the Central Crystallines = Vaikritta Group = Tibetan Slab of rest of the Himalaya.

The age in the middle one corresponds to the Mansehra granite magmatic episode which yielded a 516+ 16 Ma whole rock Rb/Sr isochron (Le Fort et al., 1980). The last age group is related to the magmatic episodes associated with the alpine orogeny. The youngest age of 10 Ma has been obtained from acid magmatism associated with the Raikot Fault which offsets the Main Mantle Thrust on the western margin of the massif (Lawrence et al., 1984). Intricate and complex type of foldings displayed in the rocks have considerably complicated the overall structural pattern of the massif.

TECTONIC SETUP

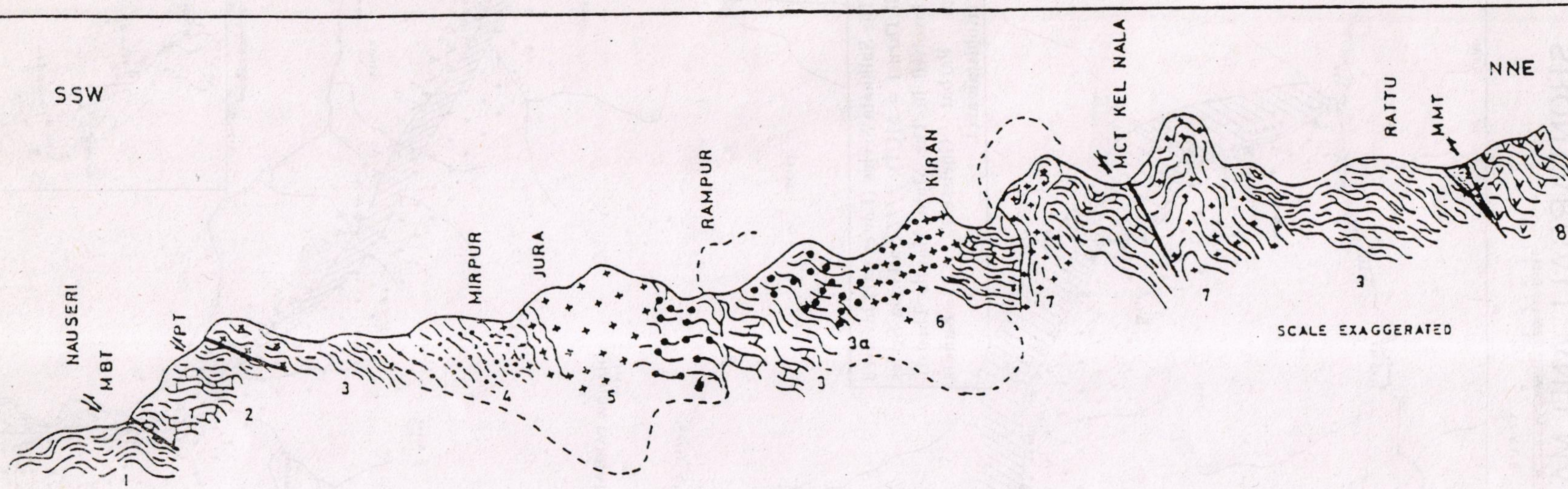

FIG 1 SECTION ALONG NILAM VALLEY, SHOWING POSITION OF MCT WITH RESPECT TO OTHER MEGASHEERS IN NW HIMALAYA IN PAKISTAN

MBT- Main Boundary Thrust, PT - Panjal Thrust, MCT - Main Central Thrust = Shontargali Thrust and MMT - Main Mantle Thrust

FIG-I 1. Murree Fm., 2. Panjal Fm., 3. Dogra Slates, 3a. Quartzitic Sandstone, 4. Quartzites = Tanawal Fm., 5. Jura and Kiran Granites and Granite-Gneisses, 6, Salkhala Series, 7. Nanga Parbat Gneisses, 8. Kamila Amphibolites (Kohistan arc).

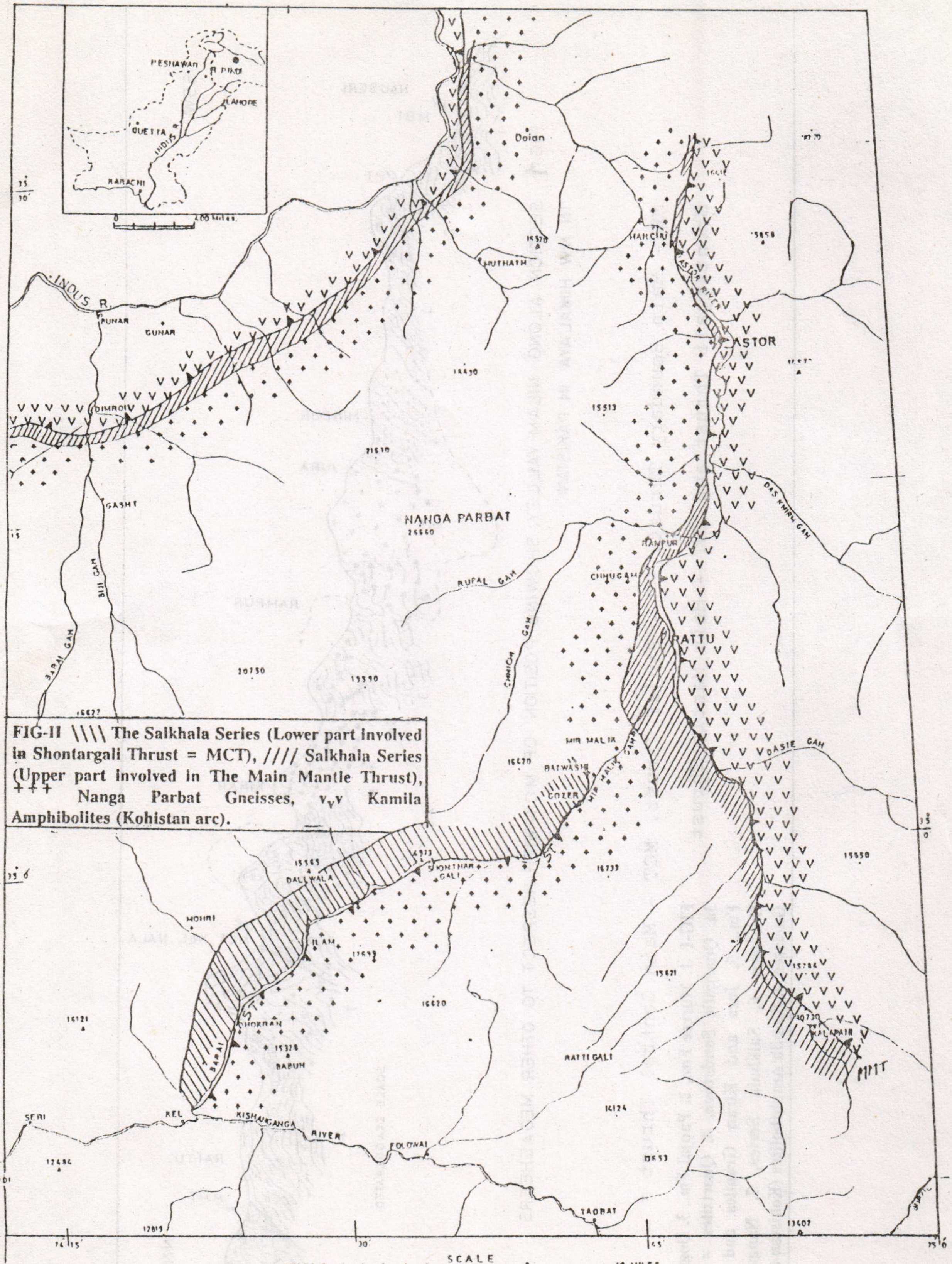

FIG.11:- SHONTARGALI AND MAIN MANTLE THRUSTS IN KASHMIR AND NW HIMALAYA IN PAKISTAN

The Shontargali Thrust has NE-SW strike and the thrust plane dips between 25^{0}-30^{0} towards east. In the more tectonized sections steeper dips are locally observed. It occupies 3-5 km wide zone and as mentioned before, the Barai and Mir Malik streams which follow its strike have eroded the main deformed part of the thrust. Both the hangingwall and footwall zones have developed isoclinal folds which attain tightly squeezed reclined or recumbent styles. Imbrications are conspicious in the footwall zone which in some sections gave rise to duplex structure.

The imbricate structure is suggestive of the fact that the folding movements in the thrust zone were generated both during and after the creation of the thrust. The reworked styles of folds may be regarded due to latter stresses emanating from the Nanga Parbat-Haramosh syntaxial tectonics. According to Zeitler et al (1986), the massif remained active till late Pliocene-Early Pleistocene time.

METAMORPHISM

The Shontargali Thrust zone indicates a higher degree of both surficial and ductile deformations, which are evidenced from the styles of fold pattern and grade of metamorphism of the rocks encountered in the hangingwall and footwall zones. In the highly deformed sections, specially in the close vicinity of the thrust plane, the grade of metamorphsim increases from amphibolite to kyanite-sillimanite. Mylonite, blastomylonite and migmatites are commonly present in the thrust plane, and are associated with the footwall zone which point out to deformation at deeper level. In many sections stretched mylonites have also been noticed indicating higher intensity of later movements which enhanced deformation to this level.

CONCLUSIONS

In this paper, a part of Shontargali Thrust has been described which has an easy access to reach and decipher its well exposed sections. In Mir Malik stream the thrust swings to northwest just short of Mir Malik village, and beyond this point it merges with the main mass of Nanga Parbat. This stretch of ST is expected to be investigated during the next two months with a hope that it will reveal the tectonic behavior of the thrust during its further extension towards northwest.

On the basis of geographic location, stratigraphic and tectonic setup, the author considers the Shontargali Thrust as one of the megashears of the Himalayan domain which is equivalent to the Main Central Thrust in the northwestern Himalaya.

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TIMING OF PRE-HIMALAYAN OROGENIC EVENTS IN THE NORTHWEST HIMALAYA: $^{40}Ar/^{39}Ar$ CONSTRAINTS

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ABSTRACT:- In the Northwest Himalaya, pre-Himalayan metamorphism and deformation is present, which is postdated by early Paleozoic peraluminous granites. The early Paleozoic granites and the Precambrian basement rocks of the Indo-Pakistan plate were metamorphosed and deformed, during the pervasive high-grade Himalayan metamorphism and deformation, which caused uncertainty in the recognition of the timing of the pre-Himalayan metamorphism and deformation.

Field criteria such as intrusive age relationship of metaigneous plutons, relative ages of deformation phases, overprinting of gneissic fabric by weak younger fabric, and an angular unconformity, can provide relative ages for the pre-Himalayan and Himalayan metamorphism and deformation. However, such data do not constrain the absolute timing of metamorphism and deformation, which must be constrained by isotopic dates.

The new $^{40}Ar/^{39}Ar$ dating of the Precambrian basement rocks of the northwest Himalaya of Pakistan, confirms five pre-Himalayan metamorphic events. These metamorphic events occurred at > 2,000 $\pm$ 6 Ma, > 1,950 $\pm$ 3 Ma, 1,865 $\pm$ 3 Ma to 1,887 $\pm$ 5 Ma, 650 $\pm$ 2 Ma, and > 466 $\pm$ 2 Ma. The 600-900 Ma plutonic, volcanic, metamorphic, and deformational events are related to the Hazaran orogeny. The 550-450 Ma peraluminous granites and > 466 $\pm$ 2 Ma metamorphism in the Himalaya, record a separate Cambro-Ordovician orogenic event. This orogenic event correlates with the Pan-African orogeny, which effected most of Gondwana. The Early Proterozoic to Early Paleozoic orogenic events on the Indo-Pakistan plate occurred before the Permo-Triassic breakup of Gondwana.

INTRODUCTION

The Precambrian to Phanerozoic rocks were strongly affected by polyphase metamorphism and deformation in the Himalaya. Earlier workers presented field evidence for the pre-Himalayan orogenesis in the Himalaya (Kumar et al., 1978; Baig & Lawrence 1987; Baig et al., 1988; La Fortune, 1988). The main problem for the recognition of pre-Himalayan metamorphism and deformation is the pervasive Himalayan metamorphic overprint, which has mostly obliterated the evidence of pre-Himalayan metamorphism and deformation in the high-grade basement rocks of the Himalaya. The evidence for the pre-Himalayan metamorphism and deformation from different areas of the Northwest Himalaya will be evaluated on the basis of structural, metamorphic, stratigraphic, paleontologic, and isotopic age criteria. In this paper, we are presenting new initial $^{40}Ar/^{39}Ar$ dating results from the Northwest Himalaya of Pakistan, to show that, at least five pre-Himalayan metamorphic episodes can be dated through the weak Himalayan metamorphic overprint.

EVIDENCE FOR PRE-HIMALAYAN METAMORPHISM AND DEFORMATION IN THE NORTHWEST HIMALAYA

In the Northwest Himalaya, the foreland fold-and-thrust belt constitutes a series of thrust sheets (Figure 1) and duplexes, which were formed following the collision of the Indo-Pakistan and Asian plates. The Precambrian basement rocks were metamorphosed and deformed during the pre-Himalayan orogenesis (Baig & Lawrence, 1987; Baig et al., 1988) and were intruded by early Paleozoic peraluminous granites (Le Fort et al., 1980; 1983; Honegger et al., 1982). During the Himalayan orogeny, the Precambrian to Phanerozoic shelf and platform sediments and the intrusive early Paleozoic granites of the foreland fold-and-thrust belt were metamorphosed from chlorite grade in the south to sillimanite grade in the north. In the north, the pre-Himalayan metamorphic events are mostly obliterated by strong Himalayan metamorphic overprint (Baig & Lawrence, 1987; Baig et al., 1988). However, in the south, where the Himalayan metamorphic overprint is weak or absent in the Precambrian rocks, the pre-Himalayan metamorphism and deformation can be dated (Baig & Lawrence, 1987; Baig et al., 1988; Baig & Snee 1989).

Mansehra area: **In Mansehra area of northern Pakistan (Figure 1, location M), south of the Main Mantle thrust of Tahirkheli (1979), the 516 ± 16 Ma relatively undeformed Mansehra granite (Le Fort et al., 1980) intrudes the low-grade Late Proterozoic Tanawal (Tanol) Formation and its hornfelsic aureole postdates the Late Proterozoic metamorphism and deformation in the Tanawal Formation. Thus, the upper age limit for the pre-Himalayan fabric development in the Mansehra area is > 516 ± 16 Ma and the lower age limit is uncertain. In the north, the Mansehra granite and the Tanawal Formation are multiply deformed and metamorphosed under epidote amphibolite to upper amphibolite facies metamorphism. In this area, the upper amphibolite facies metamorphism has strongly obliterated the evidence for the Late Proterozoic to Early Paleozoic Hazaran deformation and metamorphism. Similarly, in Kaghan Valley, Neelum Valley, and Kashmir, there is no conclusive field, fabric, paleontologic, isotopic, and structural evidence for the pre-Himalayan metamorphism and deformation, due to the strong Himalayan metamorphic overprinting. To document the pre-Himalayan metamorphism and deformation, we need to date the basement rocks of the Kaghan, Neelum, and Kashmir areas of the Northwest Himalaya.**

Swat area: **In Swat area of northern Pakistan (Figure 1, location K), a shelf and platform sequence of the northern margin of Gondwana is exposed. The Precambrian Manglaur formation is unconformably overlain by Carboniferous to Triassic (?) Alpurai group. No basal conglomerate has been reported at the contact. The Manglaur formation is composed of psammitic gneiss and schist, quartzite, meta-pelite, and calc-silicate. However, the Alpurai group is composed of quartzo-feldspathic schist, amphibolite, calc-pelite, schistose-marbles, graphitic schist, graphitic phyllite, and marbles. The Manglaur formation is intruded by Cambrian (?) Swat granite gneiss, which does not intrude the Alpurai group (Kazmi et al., 1984). The Alpurai group, Swat granite gneiss, and the Manglaur formation are metamorphosed to sillimanite grade. Two metamorphic foliations are thought to be present in the Manglaur formation and one in the Alpurai group (Kazmi et al., 1984). The earlier foliation in the Manglaur formation is thought to be pre-Himalayan in age and later foliation is related to the subsequent Himalayan orogeny (Kazmi et al., 1984). Relict garnets in the Manglaur formation have been reported by Kazmi et al., (1984) and this evidence has been used to infer the presence of a pre-Himalayan relict fabric by Kazmi et al., (1984). Detailed $^{40}Ar/^{39}Ar$ dating of the fabric of the Manglaur formation, with compositional analysis on the relict zoning in garnets, may show whether they are due to early prograde Himalayan metamorphism or due to a pre-Himalayan metamorphic event.**

$^{40}Ar/^{39}Ar$ isotopic dates of 25.5 ± 0.3 Ma to 39.9 ± 0.2 Ma were obtained from the metamorphic rocks of Swat (L.W. Snee, in Rosenberg, 1985; Lawrence et al., 1985). These dates show that in this area, isotopic systematics of the earlier Precambrian metamorphism have been reset by subsequent Himalayan metamorphism (Baig & Lawrence, 1987). An $^{40}Ar/^{39}Ar$ date of 515 Ma on biotite has been reported from the Swat granite gneiss (H. Maluski, in Jan et al., 1981), although evaluation of the accuracy of this date is difficult as none of the data has been presented. In the absence of the data, it is unclear, whether this date reflects an inferred Cambrian metamorphic event, or is simply due to presence of excess argon. Thus, due to the strong metamorphic overprinting of earlier fabric and lack of isotopic, paleontologic, and structural criteria, it is suggested that there is yet no clear evidence for the Precambrian metamorphism and deformation in Swat as suggested by Kazmi et al., (1984).

Besham area: **In Besham area of northern Pakistan (Figure 1, location I), in the core of the Indus Syntaxis (Baig & Snee, 1989), the late Archean (?) to Proterozoic Besham basement block of the Indo-Pakistan plate is exposed as a tectonic window south of the Main Mantle thrust. The Main Mantle thrust in an ophiolite-bearing suture between the Kohistan island arc and the Indo-Pakistan plate (Tahirkheli, 1979). The Besham block is bounded on either side by high-angle north-trending normal Thakot and Puran faults. The Thakot and Puran faults offset the Indus suture zone (Figure 1) and has lenses and blocks of suture rocks dragged several Km to the south (Baig & Lawrence, 1987; Baig & Snee, 1989). The stratigraphic, metamorphic, deformational, and magmatic history of the Besham basement complex is different from the Mansehra and Swat blocks along the Thakot and Puran faults. The biotite to sillimanite isograds of the Mansehra and Swat blocks are truncated by Thakot and Puran faults, respectively.**

The Besham block constitutes the late Archean (?) to Middle Proterozoic Besham basement complex and the Middle to Late Proterozoic Karora group. The Besham basement complex is unconformably overlain by the Karora group (Jan & Tahirkheli, 1969; Ashraf et al., 1980; Fletcher et al., 1986; Baig & Lawrence, 1987; La Fortune, 1988). It constitutes the quartzo-feldspathic gneiss and schist, albite gneiss, meta-pelite, calc-pelite, graphitic schist and gneiss, banded quartzite with alternating meta-pyroxenite layers, soapstone tremolite-diopside-bearing marble, magnesite (M. Nawaz Chaudhry & M. Ashraf, 1987; verbal communication), barite, amphibolite, migmatite, Lahor sodic granite gneiss, Shang, Dubair, and Jabrai hornblende-biotite granite gneiss, tourmaline-bearing muscovite sodic granites, and pegmatites. Where the Early Proterozoic to Late Paleozoic granites (> 2,000 Ma to > 272 Ma) intrude the carbonates of the Besham group cause Pb/Zn skarn mineralization. Thus, the skarn mineralization (Ashraf et al., 1980) repeatedly formed during the intrusion of these granites and associated pegmatites between the Early Proterozoic to Late Paleozoic.

The Karora group above the unconformity is composed of a basal Amlo conglomerate, graphitic phyllite, psammitic phyllite, interaformational conglomerate, minor calc-pelite, banded to massive quartzite, and dolomite. The rocks of the Karora group are deformed and metamorphosed to lower greenschist facies. Whereas, the rocks of the Besham basement complex are multiply metamorphosed and deformed under epidote amphibolite to upper amphibolite facies, before the pre-Himalayan deposition of the Karora group.

The evidence of pre-Himalayan deformation, metamorphism, and plutonism in the Besham basement complex is documented by: a) the phyllitic to weakly schistose fabric in the basal Amlo conglomerate of the Karora group truncates the gneissic fabric in the Besham basement complex (Figure 2), and postdates the gneissic fabric in the Besham basement complex to be pre-Himalayan in age (Baig & Lawrence, 1987); b) the phyllitic to weakly schistose matrix of the Amlo conglomerate contains randomly oriented gneissic clasts of the underlying Besham basement complex. This indicates that the gneissic fabrics in these clasts formed before the deposition and metamorphism of the Amlo conglomerate; c) The rocks of the Karora group above the unconformity are metamorphised from chlorite-to low-biotite-grade, in contrast, the rocks of the Besham basement complex below the unconformity are metamorphased from garnet-to sillimanite-grade. Thus, the garnet-to sillimanite-grade metamorphism in the Besham basement complex occurred before the pre-Himalayan deposition of the Karora group; and d) the presence of mafic and felsic clasts of the underlying Besham basement complex in the Amlo conglomerate, shows that, the felsic and mafic magmatism in the Besham basement complex occurred before the pre-Himalayan deposition of the Amlo conglomerate. $^{40}Ar/^{39}Ar$ dating of the Besham amphibolites shows that the pre-Himalayan metamorphic events in the Besham basement complex occurred at > 2,000 $\pm$ 6 Ma, > 1,950 $\pm$ 3 Ma, and 1,865 $\pm$ 3 Ma to 1,887 $\pm$ 5 Ma. These metamorphic and deformational phases were postdated by approximately 1500 Ma graphic tourmaline-bearing muscovite sodic granites (Baig & Snee, 1989). This data confirms that the sedimentation, mafic and felsic magmatism, and polyphase metamorphism and deformation in the Besham basement complex occurred before the Middle to Late Proterozoic unconformable deposition of the Karora group.

Subsequently, the Early to Late Paleozoic sodic leucogranites and pegmatites intrude the Karora group and the Besham basement complex, and show the hornfelsic affects in the country rocks. The actinolite, diopside, cordierite, and tremolite along the hornfelses aureole, overprint early fabrics in the Karora group and the Besham basement complex. These Paleozoic granites postdate the Karora group and the Besham basement complex fabrics to be pre-Paleozoic in age.

Nanga-Parbat area: In Nanga-Parbat Haramosh-Massif (Figure 1), the Shengus and Iskere gneisses yield U/Pb dates of 2.3 Ma to 2,500 Ma (Zeitler et al., 1989). The Iskere gneiss gave an upper intercept with concordia of 1,852 ± 14 Ma and lower intercept of 23 ± 16 Ma. The Shengus gneiss yields an upper intercept with concordia of 2,500 Ma and lower intercept between 400 to 500 Ma. Zeitler et al., (1989) interpreted 400 Ma to 2,500 Ma dates to be the protolith ages for the Nanga-Parbat gneisses and 2.3 Ma to 11 Ma dates to be the age of Himalayan metamorphism. The 1,852 ± 14 Ma upper intercept of Iskere gneiss is within one sigma error of 1,865 ± 3 Ma $^{40}Ar/^{39}Ar$ plateau date of the Besham basement complex. The 1,852 ± 14 Ma U/Pb date may be the age of pre-Himalayan metamorphism similar to 1865 ± 3 Ma to 1887 ± 5 Ma metamorphism and deformation in the Besham basement complex. The upper intercept date of 2,500 Ma of Shengus gneiss is protolith age of the Shengus gneiss (Zeitler et al., 1989) and lower intercept date of 400-500 Ma may relate to > 466 ± 2 Ma metamorphism and deformation in northern Pakistan (Baig, unpublished data). $^{40}Ar/^{39}Ar$ and K/Ar dates from the rocks of the Nanga-Parbat and adjacent Kohistan island arc range from 4-86 Ma (Zeitler 1985; Coward et al., 1986; Zeitler et al., 1989). This data indicate that the most of these rocks have been affected by Himalayan metamorphism and deformation. More $^{40}Ar/^{39}Ar$ geochronologic work is needed in the Nanga-Parbat area to date the pre-Himalayan metamorphism and deformation.

Sherwan area: In the Sherwan area of Tarbela (Figure 1, location A), north of Panjal thrust (Abbottabad thrust), the Cambrian fossil-bearing Sherwan Formation unconformably overlies the Late Proterozoic Tanawal (Tanol) Formation. The unconformity is marked by a basal metaconglomerate (Ali, 1962; Calkins et al., 1975; Baig & Lawrence, 1987), which is equivalent to the Early Cambrian Tanakki conglomerate of Hazara. The Cambrian rocks above and the Late Proterozoic rocks below the unconformity have been weakly metamorphosed. The Late Proterozoic rocks below the unconformity have two sets of folds with associated cleavages. The first cleavage predates Cambrian deposition, whereas the second set is related to the Himalayan orogeny. Stratigraphic, paleontologic, and structural criteria support our interpretation that the Late Proterozoic deformation and metamorphism occurred prior to the deposition of Cambrian strata.

Hazara area: In Hazara area (Figure 1, locations B, C, D, E, F, G, and H), Precambrian to Phanerozoic rocks are exposed south of the Panjal thrust (Latif, 1970, 1974; Calkins et al., 1975). The Late Proterozoic Hazara Formation is unconformably overlain by the Cambrian Abbottabad Group, whereas the Abbottabad Group is disconformably overlain by the Hazira Formation (Figures 3a and 3b). The Hazira Formation contains reworked Early Cambrian fossils, and thus a Cambrian age has been assigned to the underlying Abbottabad Group (Latif, 1974). The unconformity is marked by the basal Tanakki conglomerate between the Abbottabad Group and the Hazara Formation. The Cambrian sedimentary strata truncate the slaty cleavage in the deformed and metamorphosed Late Proterozoic Hazara Formation (Figure 3a). The sedimentary matrix of the Tanakki conglomerate, at the base of Cambrian Abbottabad Group, contains randomly oriented cleaved low-grade metamorphic clasts (Figure 3c), derived from the underlying Late Proterozoic Hazara and Tanawal Formations. This indicates that the cleavage development in these clasts (Figure 3c) occurred before the Cambrian deposition of the Tanakki conglomerate (Baig & Lawrence, 1987; Baig et al., 1988). These field data confirm that the Early Cambrian deposition of the Tanakki conglomerate postdates the Late Proterozoic to Early Cambrian Hazaran deformation and metamorphism (Baig & Lawrence, 1987; Baig et al., 1988). Rb/Sr whole rock model dates of 728 ± 20 Ma to 951 ± 20 Ma have been obtained from the Hazara Formation (recalculated from Crawford and Davies, 1975). These dates suggest that the age of provenance of the Hazara Formation is late Precambrian; alternatively, the provenance dates may have been partially disturbed by later metamorphism (Baig et al., 1988). $^{40}Ar/^{39}Ar$ dating of the pre-Himalayan fabric in the Hazara Formation, below the Tanakki conglomerate, confirms that the Hazaran metamorphism and deformation occurred at 650 ± 2 Ma (Baig, unpublished data) in the Hazara Himalaya of Pakistan.

Kisthwar area: In the Kisthwar area (Figure 1, location L) Jammu and Kashmir State, the Salkhala Formation is unconformably overlain by the Cambro-Silurian Chingam Formation (Gupta & Datta, 1979). The Salkhala Formation is metamorphosed to kyanite grade below the unconformity and the overlying Paleozoic rocks are metamorphosed to low-grade (Gupta & Datta, 1979). A metaconglomerate is present between the Chingam Formation and the Salkhala Formation. The underlying Precambrian rocks have at least two sets of cleavages with respect to the overlying Paleozoic rocks (Gupta & Datta, 1979). The early set of cleavage may be pre-Himalayan in age (Baig & Lawrence, 1987) and later related to the Himalayan

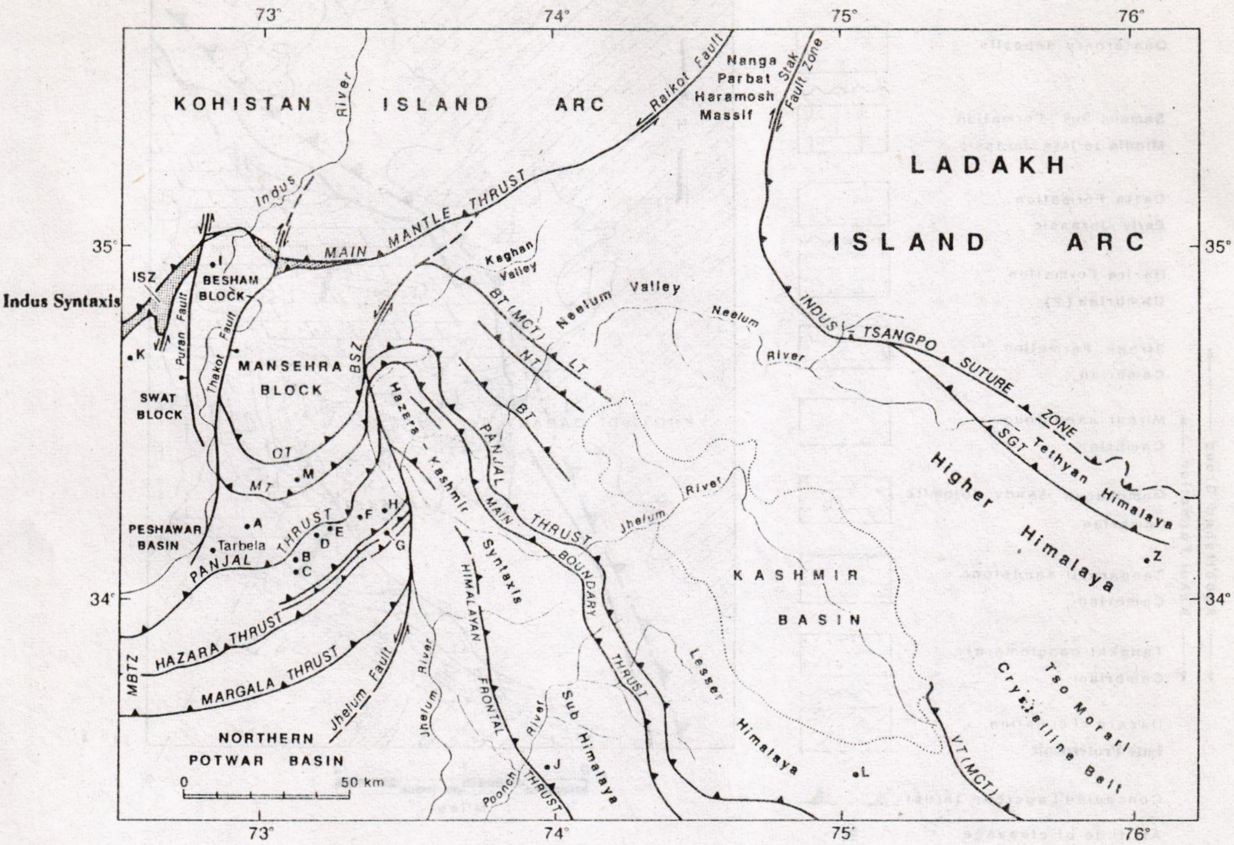

Figure 1. Tectonic map of NW Himalaya of Pakistan, showing locations for the evidence of the pre-Himalayan deformation and metamorphism. A = Sherwan, B = Khoti-Di-Qabar, C = Tanakki, D = Sobrah, E = Public School Mirpur, F = Sangargali, G = Thandiani, H = East of Daultmar, I = Besham, J = Kotli, K = Swat, L = Kisthwar, M = Mansehra, Z = Zanskar. Lt = Laut thrust, BT = (MCT) = Batal thrust, SGT = Shontargali thrust, VT (MCT) = Vaikrita thrust (Main Central thrust), MT = Mansehra thrust, BSZ = Balakot shear zone, NT = Neelum thrust, BT = Barian thrust, OT = Oghi thrust, MT = Mansehra thrust, ISZ = Indus suture zone. Compiled from Baig and Lawrence, 1987; Baig, 1980; Ghazanfar et al., 1983; Bossart et al., 1984; Coward and Buttler, 1985; Ghazanfar and Chaudhry, 1986; Madin, 1986; VerPlanck, 1987; Tahirkheli, 1987; and field observations of M.S. Baig during 1986-1987.

(a)

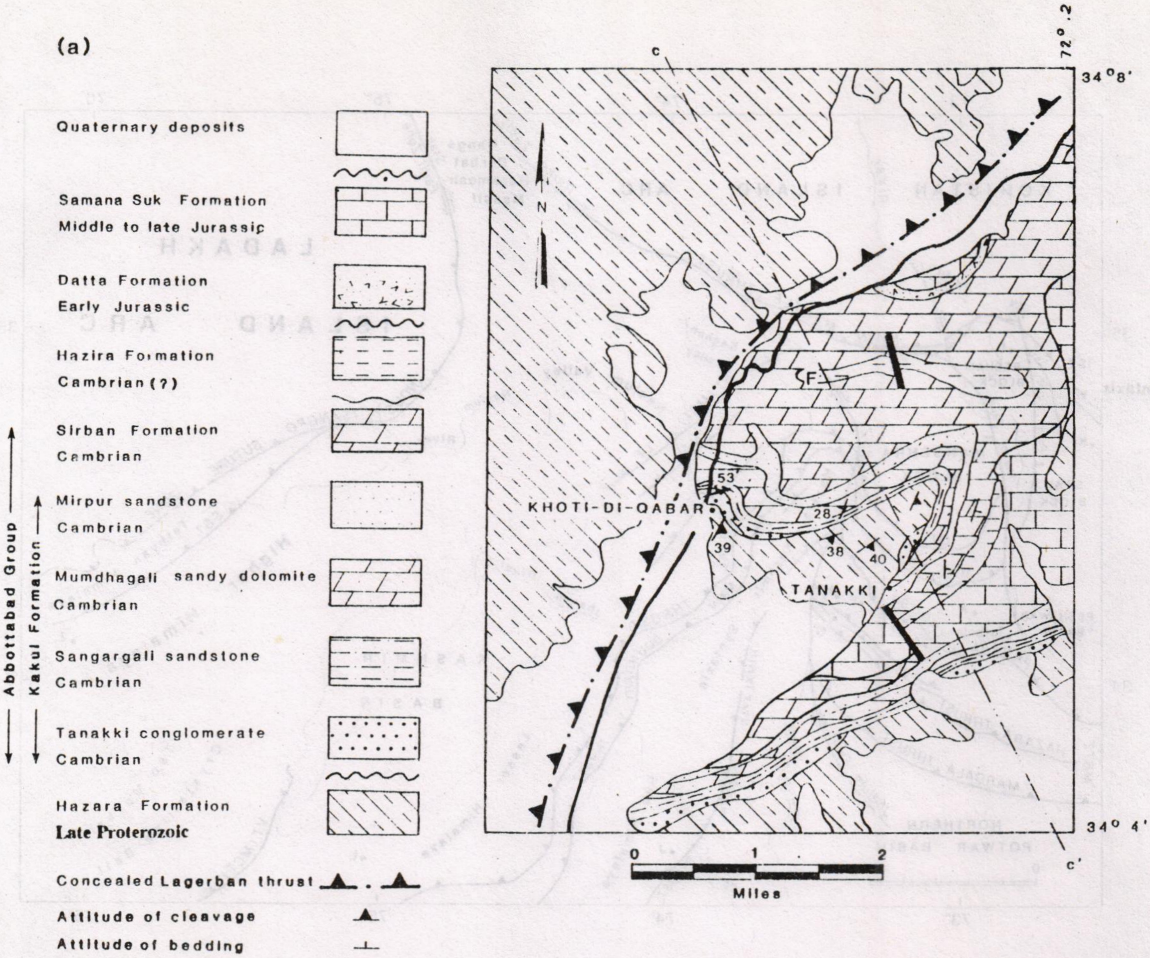

Figure 3. The field relations of the Cambrian Abbottabad Group and the Late Proterozoic Hazara Formation near Tanakki area of Hazara. For location of Tanakki area see Figure 1.

(a) Geological map of the Tanakki area, showing the angular unconformity at the base of the Tanakki conglomerate of the Abbottabad Group (Modifical after Latif, 1970). "F" marks the Cambrian fossil locality. The Tanawal Formation is eroded between the Abbottabad Group and the Hazara Formation. Note the slaty cleavage in the Late Proterozoic Haraza Formation is truncated by the Cambrian sedimentary strata of the the Abbottabad Group.

(b)

(b) Geological cross-section along the line c-c' on Figure (3a) showing the unconformity at the base of the Tanakki conglomerate.

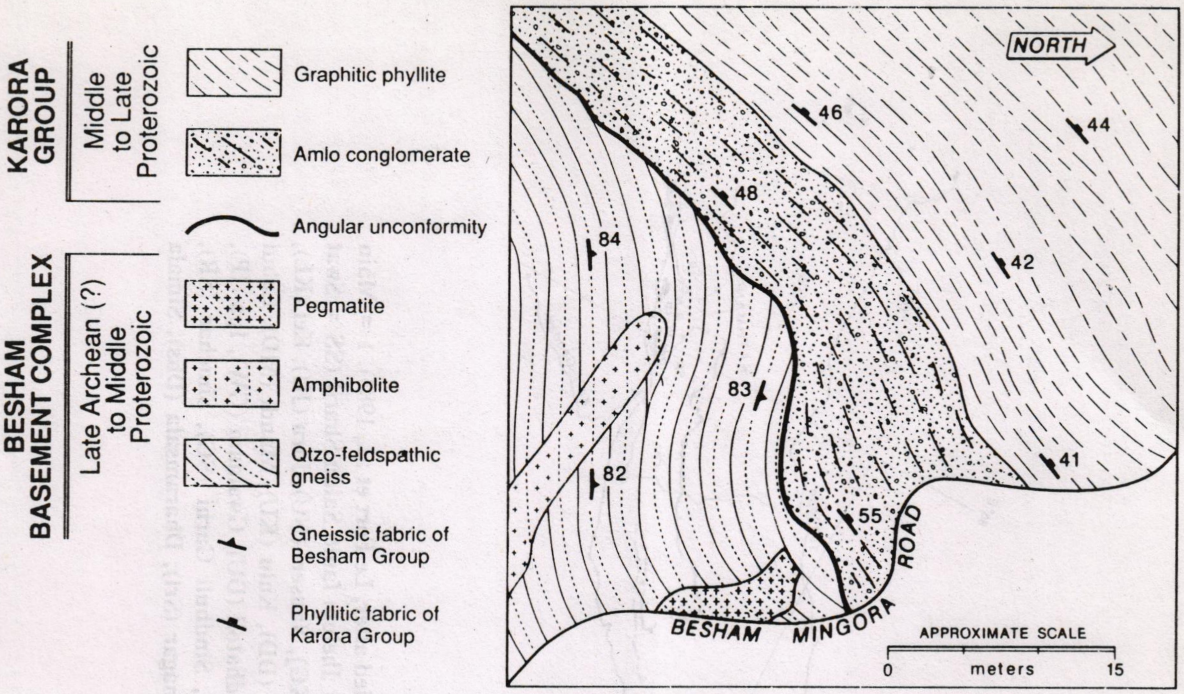

Figure 2. Geological field sketch map showing the field relations of the Karora group and the Besham basement complex, near Dipiar village about 4 Km west of Besham (Figure 1, location I), along the Besham-Mingora road (Modified after Baig and Lawrence, 1987). The contact between the Karora group and the Besham basement complex is marked by an angular unconformity. The gneissic foliation in the Besham basement complex is truncated by the overlying Amlo basal conglomerate of the Karora group.

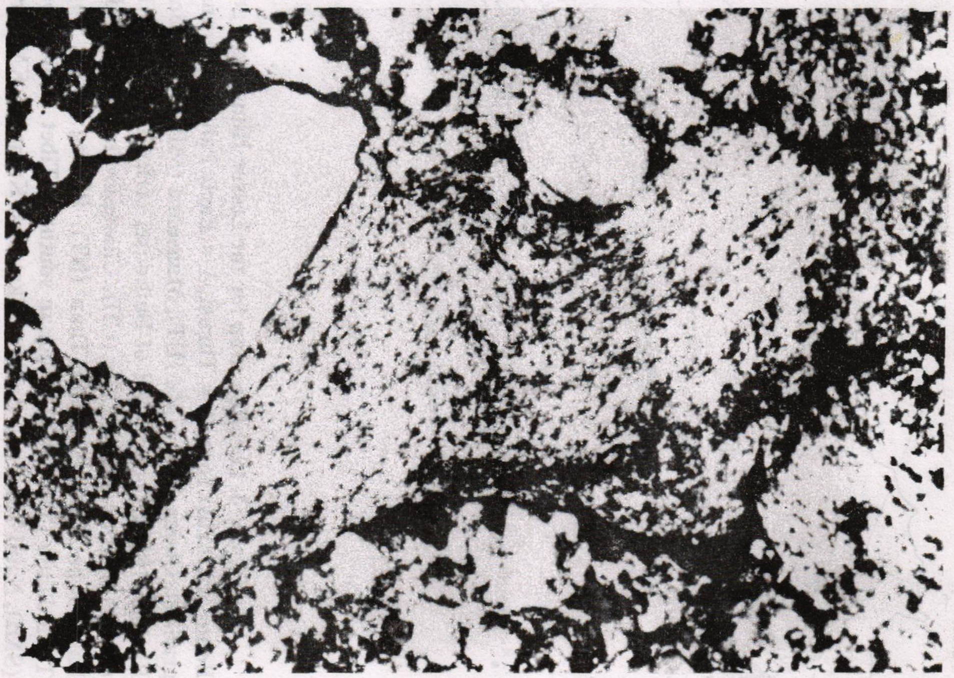

Figure 3(c) Photomicrograph of the Early Cambrian Tanakki conglomerate, showing randomly oriented low-grade metamorphic clasts of the slates of the Hazara Formation. Note that the clasts do not show preferred orientation, and the fabric between clasts has angular relationship. This indicates that the fabric in these clasts formed before the Early Cambrian deposition of the Tanakki conglomerate. Magmification - 2x; crossed nicols; 6.7 mm field of view.

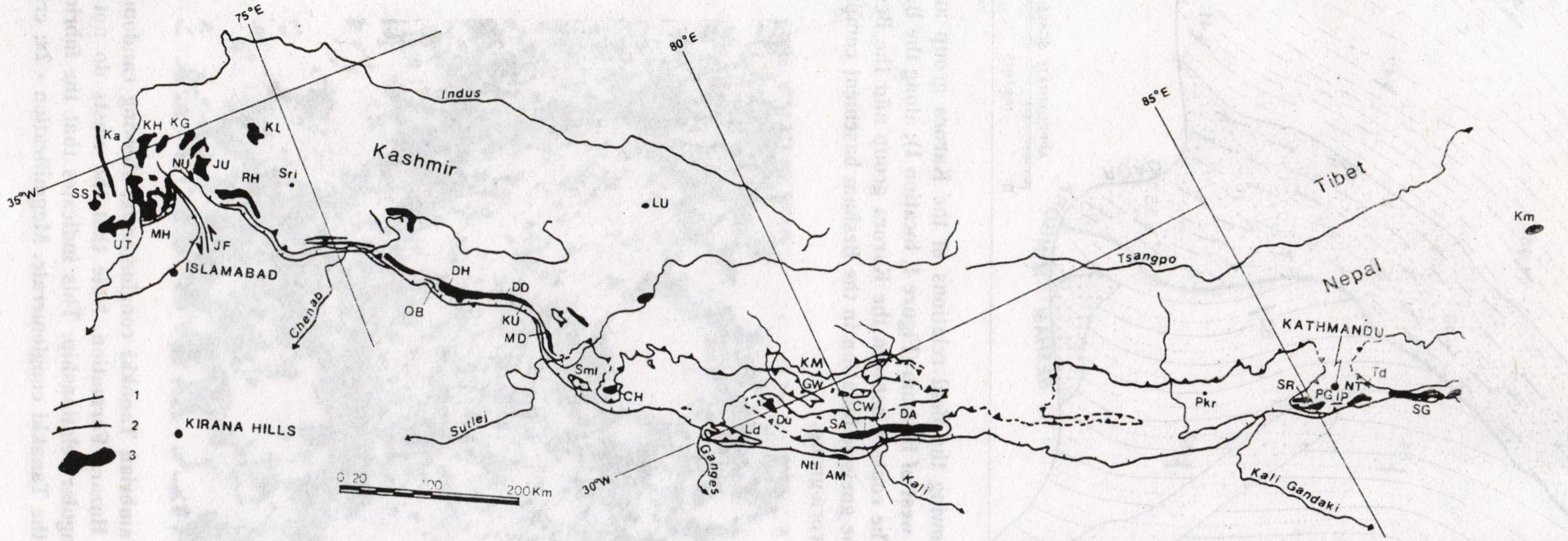

Figure 4. Location map for the Lesser Himalayan granite belt (Modified after, Le Fort et al., 1983). 1 = Main Boundary thrust zone, 2 = Thrust, 3 = Early Paleozoic granitic belt, and JF = Jhelum fault. Saidu Sharif (SS = Swat granite), Choga (KA), Ulta (UT), Mansehra (MH), Kohistan (KH), Kaghan (KG), Nauseri (NU), Jura (JU), Kel (KL), Rashian (RH), Outer band of Dalhousei (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), Simala (SMI), Naini Tal (Ntl), Pokhra (Pkr), and Kumaon (KM) areas of Himalaya.

orogeny. In this area, due to the overprint of possible earlier pre-Himalayan fabric by Himalayan metamorphism and due to lack of isotopic age data, the presence and timing of pre-Himalayan metamorphism is uncertain.

Zanskar area: In the Tethyan Himalaya (Figure 1, location Z), the Precambrian Zanskar crystalline basement is overlain by the Paleozoic to Cenozoic rocks. The rocks of the Tethyan slab in the north are in thrust contact with the Indus-Tsangpo suture zone. The weakly metamorphosed late Precambrian to early Cambrian Phe Formation conformably overlies the high-grade Zanskar crystalline basement (Nanda & Singh, 1976; Shrikantia et al., 1978; and Fuchs, 1981; 1982). In contrast, Baud et al., (1984) and Herren (1987) have considered this contact to be tectonic. The Zanskar crystalline basement of Proterozoic age is composed of gneisses, schists, marbles, and amphibolites (Srikantia et al., 1978), which have been intruded by 500 Ma two-mica porphyritic granite gneisses (Honegger et al., 1982). The basement rocks were metamorphosed from biotite to sillimanite grade and the grade of metamorphism decreases upward in the Zanskar crystalline (Herren, 1987). Pognante & Lombardo (1989) suggest that the Precambrian basement rocks were affected by polyphase metamorphism and deformation in the SE Zanskar. The evidence of polyphase metamorphism is documented by: " a) presence of earlier relic garnets; b) replacement of earlier kyanite and prismatic sillimanite by later muscovite and fibrolite sillimanite; c) and difference in equilibration temperatures ($\Delta T = 150^{\circ}C$) between the cores and the rims of garnet-biotite pairs" Pognante and Lombardo (1989). They suggest that the earlier metamorphic episode is possibly related to the pre-Himalayan metamorphism and that the later event is related to the Himalayan orogeny. However, isotopic dates of Tertiary age and the polyphase metamorphism and deformation in the Higher Himalayan crystalline rocks are mainly related to the Himalayan orogeny (Frank et al., 1977; Honegger et al., 1982; Artia, 1983; Brunel & Kienast, 1986; Searle & Fryer, 1986; Herren, 1987). More petrographic and geochronologic work is needed to conclusively demonstrate the presence of pre-Himalayan metamorphism and deformation in the Zanskar area (Pognante & Lombardo, 1989). Thus, the timing of pre-Himalayan metamorphism and deformation is still uncertain in the Zanskar area.

DISCUSSION

The above data indicate that in the northwest Himalaya, where the Himalayan metamorphism has strongly overprinted the Precambrian basement rocks of the Indo-Pakistan plate, the timing of pre-Himalayan metamorphism and deformation is uncertain.

Near the Besham area of northern Pakistan, an unusual basement block of the Indo-Pakistan plate is exposed in the core of the Indus Syntaxis. The Besham block records the evidence of the earliest pre-Himalayan metamorphic events yet to be found in the Himalaya. The 2,500 Ma to 1,850 Ma U/Pb and Rb/Sr isotopic dates on the granitic rocks of the Himalaya have been interpreted the timing of pre-Himalayan intrusive events (Bhanot et al., 1979; Divakara, 1982; Sharma, 1983; Choudhary et al., 1984; Zeitler et al., 1989). However, no $^{40}Ar/^{39}Ar$ isotopic age data is available from the Himalayan collision zone to document a detail history of pre-Himalayan metamorphism and deformation. The timing of pre-Himalayan events in the Besham block is herein interpreted on the basis of field, fabric, metamorphic, and $^{40}Ar/^{39}Ar$ isotopic age data. The $^{40}Ar/^{39}Ar$ dating of the amphibolites of the Besham basement complex, shows that, the pre-Himalayan metamorphic and deformational events occurred at > 2,000 $\pm$ 6 Ma, > 1,950 $\pm$ 3 Ma (Baig & Snee, 1989), and 1,865 $\pm$ 3 Ma to 1,887 $\pm$ 5 Ma. The absence of Early Proterozoic metamorphism and deformation in the Himalaya made difficult for earlier workers to conclude that the 2,500 Ma to 1,850 Ma granites are orogenic in nature. The evidence for the multiple deformation and metamorphism between > 2,000 Ma to 1,865 Ma and presence of 2,500 Ma to 1,850 Ma granites confirm that the Early Proterozoic orogenic events occurred in the Himalaya. These metamorphic, deformational, and plutonic events were postdated by approximatly 1,500 Ma graphic tourmaline-bearing muscovite sodic granites. The orogenic events of the Besham basement complex predated the Middle to Late Proterozoic unconformable deposition of the Karora group.

After the Besham orogenic events, the Late Proterozoic to Early Cambrian Hazaran orogeny occurred on the Indo-Pakistan plate. The evidence of Hazaran deformation and metamorphism is recorded in the Hazara area. Here, the pre-Himalayan fabric below the Cambrian unconformity has not been completely overprinted by Himalayan metamorphism, combined metamorphic, structural, stratigraphic, paleontologic, and isotopic age criteria, provide the most definite evidence of Late Proterozoic to Early Cambrian metamorphism and deformation, yet to be found anywhere in the Himalaya. During the Hazaran orogeny, 900-600 Ma silicic volcanism and plutonism (Baig & Lawrence, 1987) accompanied the 650 $\pm$ 2 Ma metamorphism and deformation in Indo-Pakistan plate and predated the Early Cambrian deposition.

This study shows that the Late Proterozoic to Early Cambrian Hazaran orogeny is younger than the Early to Middle Proterozoic Besham orogenic events of the Besham area.

Subsequently, the Early Paleozoic granites intruded into the basement rocks of the Himalaya and postdated the Proterozoic deformation, metamorphism, and plutonism. The presence of 550-450 Ma peraluminous granites through out Himalaya (Figure 4), and dating of metamorphism and deformation at > 466 ± 2 Ma in Pakistan (Baig, unpublished data), confirm a Cambro-Ordovician orogenic event in the northwest Himalaya. The Early Paleozoic orogeny of the Indo-Pakistan plate correlates with the Pan-African orogeny, which effected most of Gondwana.

After the Early Paleozoic orogeny, the Late Paleozoic rift-related cimmerian event occurred on the Gondwana of the Indo-Pakistan plate. During the initial rifting phase, the Carboniferous alkaline rocks (315 Ma to 297 Ma, Le Bas et al., 1987) and sodic granites (> 272 Ma) intruded in the northwest Himalaya of Pakistan. This was followed by final rifting phase of the Permian mafic Panjal volcanism. Thus, the Carboniferous alkaline magmatism predated the Permian mafic Panjal volcanism, during the cimmerian event, to form the cimmerian microcontinents. The paleotethys those were formed during the cimmerian event, were closed during the Mesozoic to Cenozoic collision of the Indo-Pakistan and Assian plates. The Besham, Hazaran, and Cambro-Ordovician orogenic events on the Indo-Pakistan plate occurred before the Permo-Triassic breakup of Gondwana.

CONCLUSIONS

In summary, there is no conclusive "direct" evidence for the timing of pre-Himalayan metamorphism and deformation in Swat, Mansehra, Kaghan, Neelum, Kashmir, Nanga-Parbat, Zanskar, and other areas of northwest Himalaya, where the Himalayan metamorphism has strongly overprinted the Precambrian basement rocks of the Indo-Pakistan plate.

In polyphase metamorphosed and deformed rocks, relative ages of deformational phases, intrusive age relationship of metaigneous plutons, overprinting of gneissic fabric by weak younger fabric, and an angular unconformity, provide the relative age constraints, but do not provide the absolute dating of metamorphic fabric. Field criteria must be supplemented by isotopic dates to establish absolute age constraints on the Himalayan and pre-Himalayan deformational and metamorphic events.

For the unambiguous dating of Precambrian metamorphism and deformation in the Himalaya by field criteria outlined above, we should look for areas further south in the Himalayan foreland fold-and-thrust belt, where the fossil-bearing Cambrian sedimentary strata, unconformably overlie deformed and metamorphosed Precambrian basement rocks of the Indo-Pakistan plate (Baig & Lawrence, 1987; Baig et al., 1988).

The $^{40}Ar/^{39}Ar$ dating of the Precambrian basement rocks of the Indo-Pakistan plate in the northwest Himalaya of Pakistan, shows that at least five pre-Himalaya metamorphic events are preserved in the Himalayan collision south of the Indus suture zone.

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GEOLOGY AND GRAVITY INTERPRETATION OF NAGAR PARKAR AREA AND ITS POTENTIAL FOR SURFACIAL URANIUM DEPOSITS

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ABSTRACT:- Geological Mapping of 350 Sq Km of Nagar Parkar Virawah area has been conducted on 1:200,000 scale. The area exposed is a part of the Indian shield in the southern extremity of Tharparkar desert. Published gravity data on the area (Farah & Jafree 1965) has been utalized for gravity modelling presented herein. The granite interpretation of the geology of the area speaks contrary to the apparently gravity dominated exposed geology. Instead, the area is interpreted to be dominated by basic rocks intruded by minor granitic intrusions.

A bed rock geology dominated by granitic rocks is a basic pre-requisite for the formation of surfacial Uranium deposits in the arid environments. Nagar-Parkar area therefore offers little potential for such mineralization.

INTRODUCTION

Nagar Parkar area represents part of the Indian shield exposed in Tharparkar desert. Earlier published accounts of the geology of this area are restricted to description of isolated granite outcrops in the vicinity of Nagar Parkar (Shah 1975). The study of china clay deposits formed by alteration of these granites have also been the subject of some investigations (Kella, 1983).

This study provides a somewhat detailed account of the exposed geology of the area with an attempt to interpret the published gravity data.

Surfacial uranium deposits have been discovered in a number of desert areas in the world. The most important occurrences are those of yellerie in Australia and in the Namib desert (Carlisle et al., 1978). In addition to arid climatic conditions, the availability of deeply weathered source rock of granitic composition has been regarded as essential for the formation of surfacial uranium deposits (Carlisle et. al., 1978).

Since the exposed geology of the area shows a predominance of granitic rock in a desert environment, the area was investigated for its potential for surfacial uranium deposits.

GEOMORPHOLOGY

Isolated hills, dominantly comprising of grey granite on the ridge crests and pink granite on the flanks are the main physiographic features. These hills form a semi-circular enclosure where peneplane exposures of basic rocks are present with laterite and china clay deposits at places. This circular form has a clay cover providing excellent cultivation ground. Topographic expression of various rock units is a reflection of their relative resistance to weathering under the prevailing climatic conditions. Grey granite makes the high ground in the area whereas a pink

granite is next in line making flanks of high ridges or low hills followed by metabasites which weathers rather easily and probably occupy most of the area under a thin soil veneer. Locally however, torrential rains have filled the topographic lows with debris from granitic rocks and associated clays. Lithified dune or stream sandstones are also present in such intramountain areas indicating a long prevailing desert conditions. These sandstones are associated with fossiliferous limestones with fresh water fossils representing palaya lake deposition. Bhitani nadi is a through going stream with a fair amount of surface run off. The area receives heavy rainfall in July/August whereas rest of the year prevail fairly arid conditions.

SURFACIAL GEOLOGY

Surfacial geology of Nagar Parkar and adjoining areas is dominated by stabilized sand dunes and interdunal clay pans. The stabilized dunes have abundant vegetation during the rainy season. The process of pedogenesis (soil formation) has now taken firm roots in the area as is examplified by widespread occurrence of pedogenic calcrete ($CaCo_3$ enrichment in soil through capillary action of ground water). In addition to pedogenic calcrete formation, several thick horizons of non-pedogenic calcretes have also been identified in the close proximity of granite hills of Nagar Parkar area. Non pedogenic calcrete is formed through laterally moving groundwater. As this groundwater comes against an impervious barrier, the groundwater rises closer to the surface where the desert climate causes its evaporation to form non-pedogenic calcrete. It is this non pedogenic calcrete which is the host of large Uranium deposits in Australian and the Namib deserts (Carlisle et al., 1978). If the groundwater responsible for the formation of non-pedogenic calcrete is enriched in Uranium leached from the underlying granitic rocks, the calcretes are likely to host Uranium mineralization.

Non pedogenic calcretes encountered during this study in the area are however, devoid of Uranium mineralization.

BED ROCK GEOLOGY

A geological map of 350 Sq Km area around village of Nagar Parkar is presented in Fig-1. The following units have been mapped:

1. Pink granite.
2. Grey granite.
3. Amphibolites (meta-basites).
4. Acid-Basic complex.

1. Pink Granite

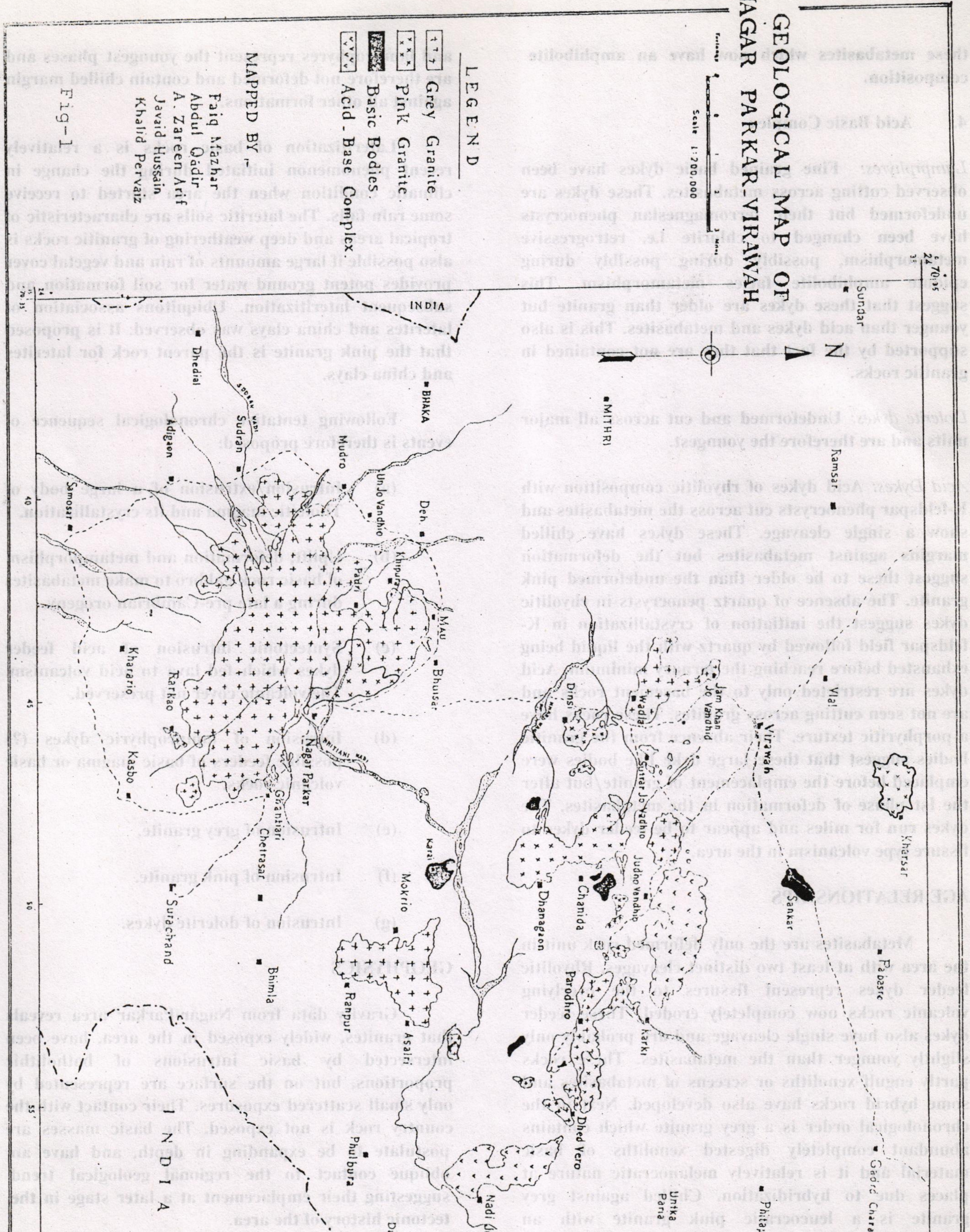
Pink granite is a medium grained equigranular granite composed almost entirely of an alkali feldspar (pink) and quartz with minor ferromagnesians. At places ferromagnesians are relatively more abundant. This is generally in the vicinity of either the country rock metabasites or grey granite. Locally coarser facies are developed as pods and open space fillings lined with euhedral quartz. Pegmatites, quartz vein and other evidences of late stage saturation in water are distinctly lacking. These rocks lack deformation structures.

2. Grey Granite

Coarse grained, hypidiomorphic granular to semiporphyritic textures prevail. Biotite and possibly hornblende with greenish blue colour make up to 10% of the rock and may increase in quantity substantially when in close proximity to the country rock metabasites. Grey granite is generally undeformed but some parts may show slight deformational features. Pink granite has chilled contact against grey granite. Grey granite has xenoliths of mafic country rocks. A variation in grain size from coarse to very coarse is observed but no pegmatitic facies were observed within this granite. However, granitic veins traversing the gneissic metabasites develop coarse pegmatitic textures with abundant development of epidote. This suggest that a relatively dry granitic magma could crystallize coarse facies only when it aquired water from the amphiboles of the enclosing country rock metabasites. No pegmatites or other features of late stage water saturation were observed. The existance of blue amphibole suggests the alkaline affinities of these granites.

3. Metabasites

Medium to coarse grained gneissic metabasites make the oldest rocks in the area with at least two distinct cleavages contained within the gneissosity which itself is folded. Metabasites have undergone epidote - amphibolite facies metamorphism possibly during the acid volcanic/plutonic phases in the area. Graphic granitic patches indicate a tholeitic nature of


GEOLOGICAL MAP OF
NAGAR PARKAR-VIRAWAH
Scale 1:200,000
N
LEGEND
Grey Granite
Pink Granite
Basic Bodies
Acid-Basic Complex
MAPPED BY,
Faiq Mazhar
Abdul Qadir
A. Zareen Aff
Javaid Hussain
Khalid Pervaz
Fig-1
INDIA
Sundar
MITHRI
Ramsar
BHAKA
Virawah
Nagar Parkar
Bhusar
Chanida
Dhanagam
Mokrio
Surachand
Bhimla
Rampur
Asalri
Kasbo
Dudwah
INDIA

these metabasites which now have an amphibolite composition.

4. Acid Basic Complex

Lamprphyres: Fine grained basic dykes have been observed cutting across metabasites. These dykes are undeformed but their ferromagnesian phenocrysts have been changed to chlorite i.e. retrogressive metamorphism, possibly during possibly during epidote amphibolite facies metamorphism. This suggest that these dykes are older than granite but younger than acid dykes and metabasites. This is also supported by the fact that they are not contained in granitic rocks.

Dolerite dykes: Undeformed and cut across all major units and are therefore the youngest.

Acid Dykes: Acid dykes of rhyolitic composition with K-feldspar phenocrysts cut across the metabasites and show a single cleavage. These dykes have chilled margins against metabasites but the deformation suggest these to be older than the undeformed pink granite. The absence of quartz penocrysts in rhyolitic dykes suggest the initiation of crystallization in K-feldspar field followed by quartz with the liquid being exhausted before reaching the ternary minimum. Acid dykes are restricted only to the basement rocks and are not seen cutting across granites. These rocks have a porphyritic texture. Their absence from the granitic bodies suggest that these large dyke like bodies were emplaced before the emplacement of granite/but after the Ist phase of deformation in the metabasites. The dykes run for miles and appear to be feeder dykes to fissure type volcanism in the area.

AGE RELATIONSHIPS

Metabasites are the only deformed rock unit in the area with at least two distinct cleavages. Rhyolitic feeder dykes represent fissures to the overlying volcanic rocks now completely eroded. These feeder dykes also have single cleavage and are probably only slightly younger than the metabasites. These rocks partly engulf xenoliths or screens of metabasites and some hybrid rocks have also developed. Next in the chronological order is a grey granite which contains abundant completely digested xenoliths of basic material and it is relatively melanocratic nature at places due to hybridization. Chilled against grey granite is a leucocratic pink granite with an equigranular texture as opposed to porphyritic to semi porphyritic nature of the grey granite. Dolerite dykes and lamprophyres represent the youngest phases and are therefore not deformed and contain chilled margin against all other formations.

Lateritization of basic rocks is a relatively recent phenomenon initiated during the change in climatic condition when the area started to receive some rain falls. The lateritic soils are characteristic of tropical areas and deep weathering of granitic rocks is also possible if large amounts of rain and vegetal cover provides potent ground water for soil formation and subsequent lateritization. Ubiquitons association of laterites and china clays was observed. It is proposed that the pink granite is the parent rock for laterites and china clays.

Following tentative chronological sequence of events is therefore proposed:

(a) Intrusion/extrusion of a large body of Tholeitic magma and its crystallization.

(b) Uplift, deformation and metamporphism of basic rock gabbro to make metabasites during a late pre-Cambrian orogeny.

(c) Syntectonic intrusion of acid feeder dykes which fed lava to acid volcanism. The volcanic cover not preserved.

(d) Intrusion of lamprophyric dykes (?) possible feeders of basic magma or basic volcanic rocks.

(e) Intrusion of grey granite.

(f) Intrusion of pink granite.

(g) Intrusion of dolerite dykes.

GEOPHYSICS

Gravity data from Nagar-Parkar area reveals that granites, widely exposed in the area, have been intersected by basic intrusions of batholithic proportions, but on the surface are represented by only small scattered exposures. Their contact with the country rock is not exposed. The basic masses are postulate to be expanding in depth, and have an oblique contact to the regional geological trend suggesting their emplacement at a later stage in the tectonic history of the area.

Granitic intrusions are found to have intruded into a sequence of metamorphosed Pre-Cambrian rocks of Indian shield (craton) in Nagar-Parkar Virawah region. Few small exposures of basic rocks are scattered at some places (Fig. 1). Their contact either with granites or the metamorphosed country rock is covered by a blanket of recent alluvium. Conclusions regarding the structure and emplacement of these plutons have so far been based on information grained from surface exposures only. No detailed studies of the deep structure of the area were undertaken as yet.

The area has been covered by regional gravity survey and a Bouguer anomaly map was prepared by Farah & Jafree (1965). We have utilized this for our gravity modelling of the area. The Bouguer anomaly map of the region (Fig. 2) shows a general regional gradient from North and North East to South and Southwest, with localized changes in intensity and direction. The regional dip of the geological formations as depicted from the exposed horizons in generally southwards. The regional gravity rise southwards is attributed in increase in the thinkness of the sedimentary basin overcompensated by thick sequences of carbonate rocks (Farah & Jafree, 1965).

In the study area the Bouguer anomaly contours, except for the extreme northern portion, show a strikingly distinct pattern along a line across and perpendicular to the regional NE-SW trend of the Bouguer contours. Average North-South anomaly gradient of 0.6 m. gal/Km in the Northern part of the map changes to an intense NW-SE gradient of 4 m. gal per Km in central South Western parts giving rise to two positive anomaly peaks, on in the North Eastern part near Chanida village and the second in the South of Nagar Parkar. The northern positive closure is located on the surface over a small exposure of basic rocks, whereas the southern positive peak is found within alluvium cover.

Commulative total of errors associated with the gravity survey, arising mainly due to inaccuracies in elevation determination, location of observation points and choice of density for Bouguer correction has been worked out as 0.6 milligals (Farah & Jafree, 1965).

In order to distinguish between the long wavelength anomalies caused by deep crustal anomalies and the short wavelength anomalies due to the density boundaries in the shallow crust, which are of our immediate interest, a residual gravity map has been prepared after removing the regional effect from the Bouguer anomaly map (Fig. 3). Griffin's (1940) eight point averaging method was employed for this purpose. A grid of values were transferred from the Bouguer anomaly map. The average of eight gravity values read from the periphery of a circle of 1.5 Km radius were substracted from the gravity value at the centre of the circle to give residual gravity was calculated for every grid station. The residual gravity map thus prepared portrays sufficiently the local distribution of anomalies as manifestations of density variations in the shallow subsurface caused by rocks of contrasting lithologies embedded in the metasedimentary rocks of presumbly homogenous density.

The intense positive anomaly closures are distinctly marked in the central and southwestern portions of the area of investigation. These are aligned in NE-SW, which is roughly perpendicular to general trend of Bouguer contours in the region. The peak of the northern anomaly of +9 milligals is closing over a small mafic rock exposures protruding out of the alluvium cover, whereas, the south western positive closure of +8 milligals is located in the alluvial plains having no rock exposure. These two distinct and strong positive anomalies are uniformly aligned and are well contained within the zero value contour. The zero contour enclosing the two positive peaks is flanked by a number of weak negative anomaly closures, maximum of which is - 2 milligals. Most of the negative anomalies are found to occur over or slightly effset of the granite exposures. Another small positive closure of +1 milligal is found in the eastern extremity of the area. Here, too, geological formations are covered by alluvium.

The extension, alignment and steepness of gradients across both of the positive closures is remarkably uniform suggesting that the basic rock units have a sharp and rather shallow contact as well as a symmetrical two dimensional geometry. The shape of the anomalies indicates the elongation of intrusive mass in a direction roughly perpendicular to the general strike of the Bouguer contours considered to represent the general geological strike. Gravity evidence, therefore, indicates that the high density gabbroic rocks are evidently extending below the surface, the few small and scattered exposures on the surface are probably interconnected in deeper depth into a much bigger continous intrusive mass.

As far as negative anomalies are concerned the gentle gradients and low anomalies are indicative of being caused by shallow granitic masses of limited

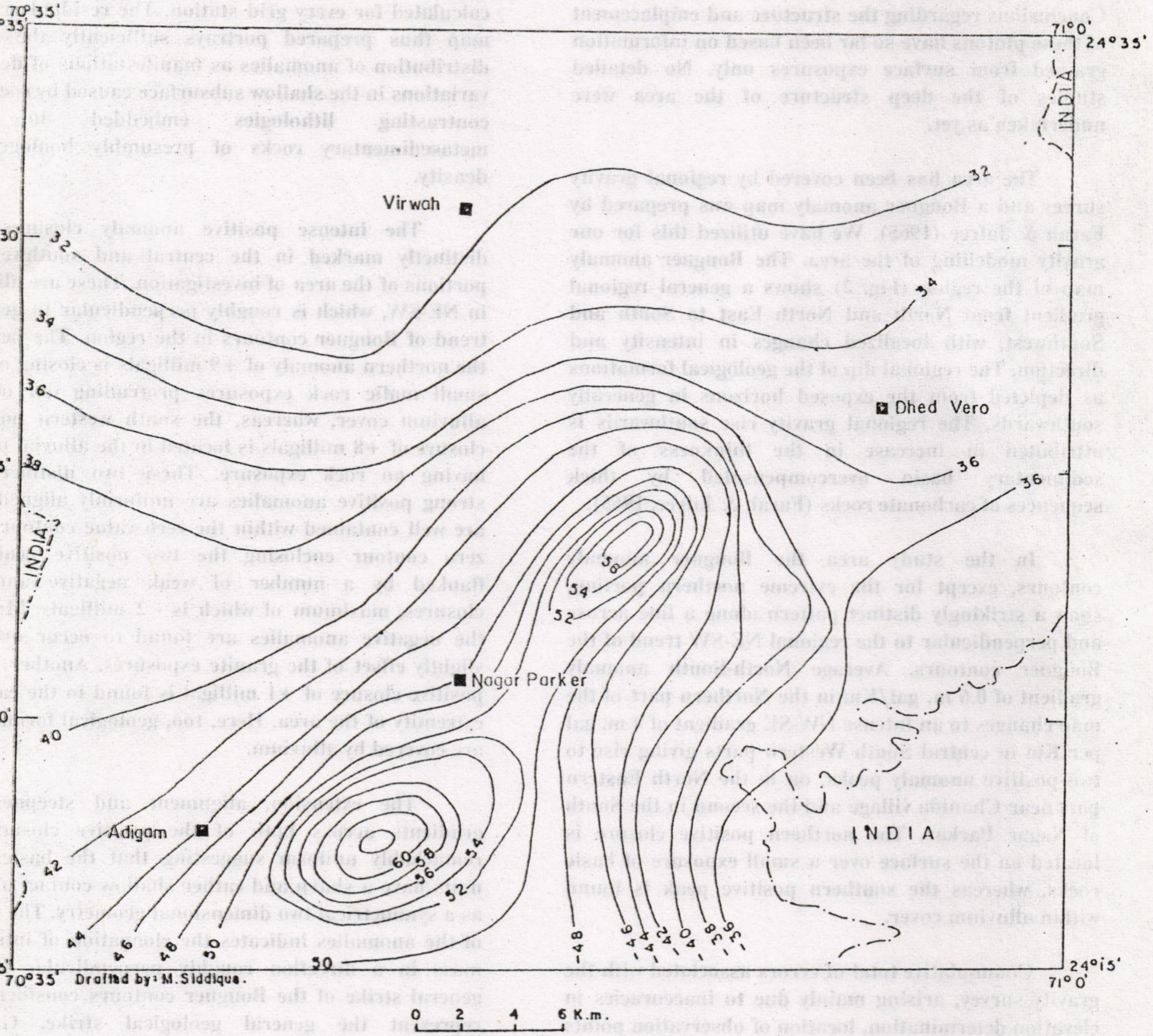


FIG. 2 BOUGUER ANOMALY MAP OF NAGAR PARKER — VIRWAH. (Farah & Jafree 1965)

CONTOUR INTERVAL 2 MILLIGALS

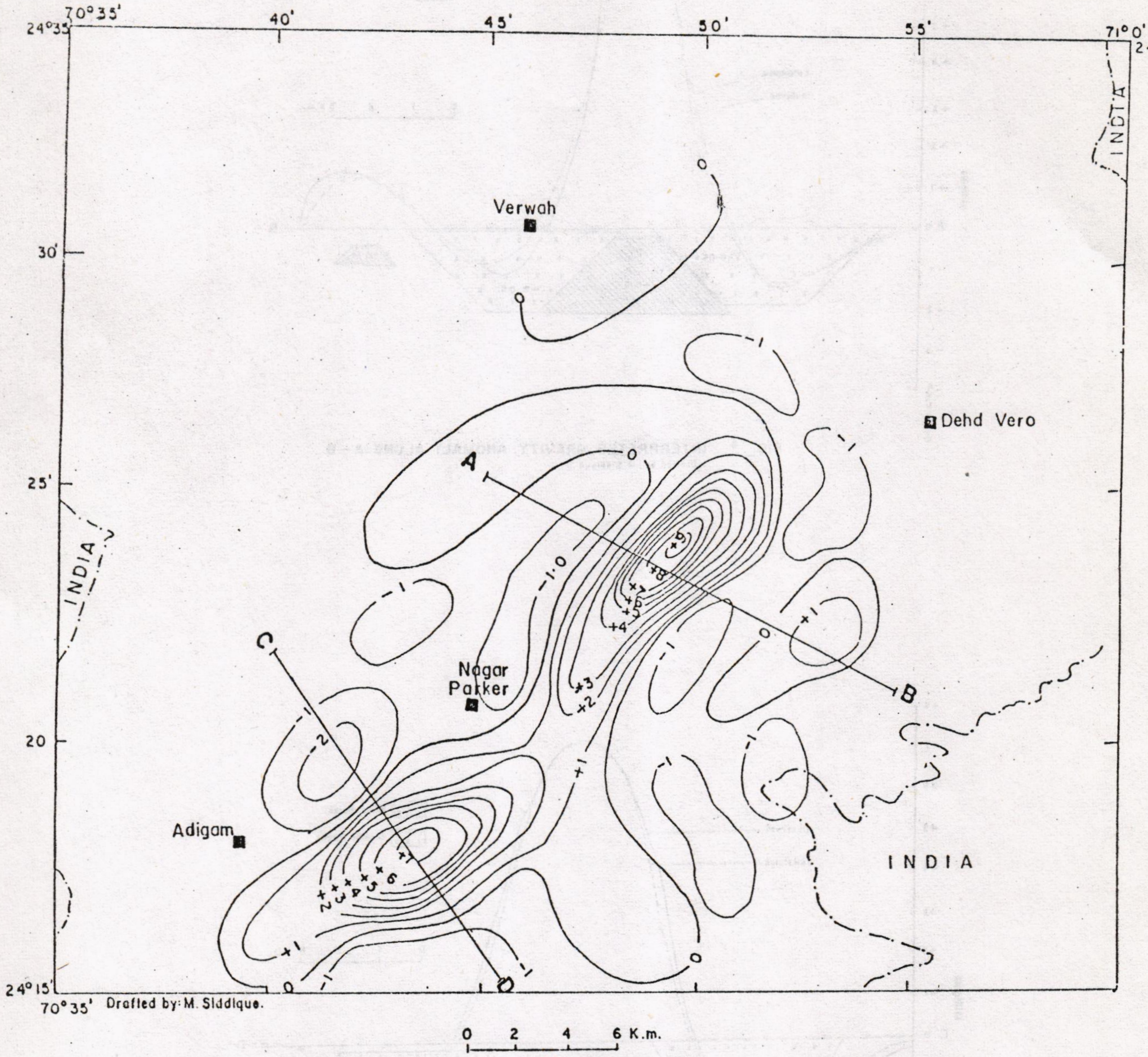


FIG. 3 RESIDUAL GRAVITY ANOMALY MAP OF NAGAR PARKER – VIRWAH

CONTOUR INTERVAL I MILLIGAL

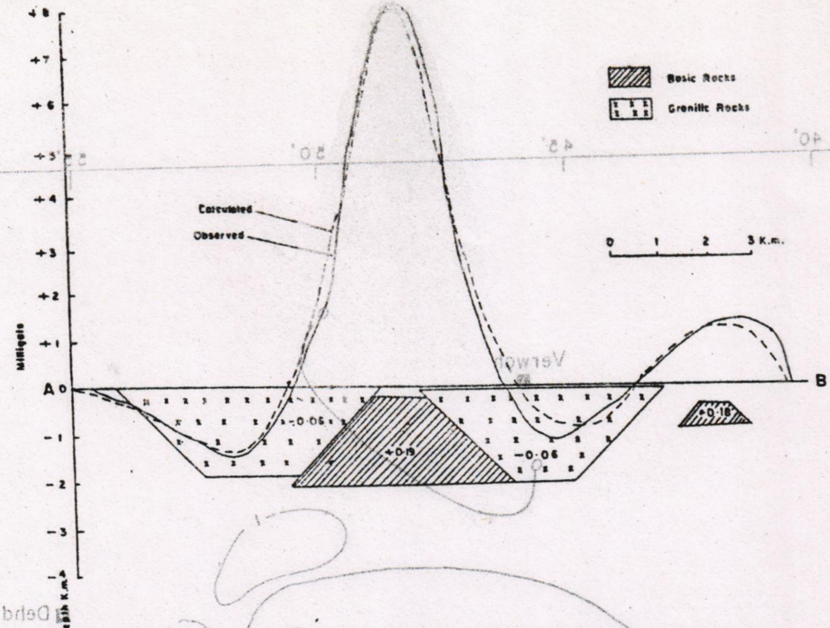


FIG 4 INTERPRETED GRAVITY ANOMALY ALONG A – B
Drafted by: M. Siddique.

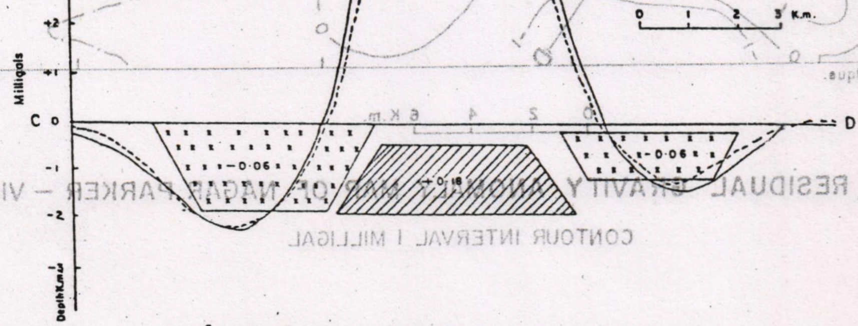


FIG 5 INTERPRETED GRAVITY ANOMALY ALONG C — D
Drafted by: M. Siddique.

depth extent and of relatively lower density than the host metasediments. The smaller anomalies can also be attributed to thinning out of the metasediments giving an effect of undercompensation in the gravity picture, but the anomaly patterns over the exposed granite bodies and their measurably lesser densities than the country rock make them an obvious cause of the negative anomalies.

Density models were calculated along two east west oriented, almost parallel, profiles. The section lines were drawn essentially across the positive anomaly peaks and extended through the flanking negative anomalies. Analysis was carried out by using a formula evolved by Sankram et al. (1977) for the gravity effect of two dimensional trapezoidal prism. A Casio programmable calculator, model No FX 700P was used for the calculations.

Representative densities, for calculating the models, were worked out on the basis of densities measured from the surface samples of the exposed rock units. Metamorphosed country rock constituting the background density is not exposed in the study area. Its value was selected from previous work in the shield rocks of Chiniot area (Nazirullah, et al., 1983). A uniform density of 2.70 g/cm^3 was used as the representative density of the metasediments. Sampling of granites gave an average value of 2.64 (+ 0.01) g/cm^3, giving a density contrast of - (+ 0.01) g/cm^3. Similarly, surface samples of basic rock units gave an average density of 2.91 (+ 0.02) g/cm^3. A mean density of 2.89 g/cm^3 was used as representative of basic rocks, giving a density contrast of + 0.19 (+ 0.02) g/cm^3

Profile A B (Figure-4) passes through the positive gravity closure of + 8 milligal occuring over and slightly offset of the basic rock expsoure near Chanida village. It is indicated that the basic rock broadens in the subsurface in a Trapezoidal form. The body can be as much as 2 Km thick for a density contrast of + 0.19 g/cm^3 whose top is assumed at 0.15 Km. below the surface. The upper and lower edges of this 2 D trapezoidal prism are 1 Km and 4.6 Km wide, respectively, with symmetrical outward sloping edges at an angle of 45^o. Granitic masses of a density contrast of 0.06 g/cm^3 are evidently in sharp discordant contact on both sides of this basic body. The low density granite plutons appear to be thinning out with depth and are slightly uplifted with respect to the intervening basic body suggesting emplacement of the gabbroic intrusion in a later phase. Near the western extremity of the profile a small trapezoidal shaped basic mass having a density contrast of 0.18 g/cm3 is also indicated. Its upper edge having a width of 0.4 Km is placed at 0.4 Km depth. It broadens to 1.4 Km at a depth of 0.8 Km giving a thickness of 0.4 Km. The body seems to have a lesser lateral extension as compared to the main basic intrusion, as is obvious from the residual gravity map (Fig. 3).

Profile CD (Fig. 5). drawn across the southwestern positive peak of +7 milligals is also interpretted in a similar fashion. The denser basic rock body is indicated at a depth of 0.4 Km. The widths of upper and lower edges of this two dimensional trapezoidal prism, having a thickness of 1.45 Km and a uniform density contrast of 0.19 g/cm3, are estimated to be 3 Km and 5 Km respectively. Its edges are sloping outwards at an angle of 45^o and seemingly not in direct contact with the flanking granite masses, but are seperated by thin partition of country rock. Here, too, granite bodies are indicated as tapering in the deeper horizon.

From the modelling and the assumptions made therein, it can be concluded that the basic rocks occurring in small isolated exposures are the peaks of an undulatory top surface of a single continuous body whose lower limit extends at least upto 2 Km depth. The granitic rocks on the other hand have relatively shallow roots. Its sharp sloping contacts with granites clearly indicate that these intrusions occured sometimes after the regional metamorphism and the granite emplacements. Upward narrowing of the basic bodies alongwith the indicated uplifting of adjacent granites seems to suggest that the faulting associated with pluton emplacement was concurrent with its emplacement. However, in the absence of a detailed structural analysis it is difficult to conclude about the form of structural control of emplacement and the elongated configuration of the Pluton in direction which is markedly oblique to pre-existing regional geological trend.

CONCLUSION

Basement metabasites are deformed with at least two cleavages readily observed in the field. The granitic rocks of Nagar Parker area are undeformed and are intrusive into the basement metabasites. similarly, huge felsic dykes which are interpretted to be the feeder dykes of these magmatic reservoirs are also deformed with only one cleavage. This field relationship suggest the post tectonic nature of these granites. Similar undeformed granites are also reported from Rajputana area in India and are known as Jalor granite and Siwana granite (Wadia 1966). These granites are known to be associated with alkaline intrusives. These granites are intrusive into Milani rhyolites which have been dated to be 745 + 10 M.Y. (Crawford 1969, Crawford and Compston, 1970). Undeformed nature of Nagar-Parkar granite and deformed nature of huge rhyolite dykes tentatively interpretted as feeder dykes of Melani rhyolites places these granites into upper Precambrian.

Present day of exposed geology of the area shows a false predominance of granitic rocks. Geophysical data suggests that much of the area is underlian by basic rocks with minor granitic intrusions. This is also reflected in the absence of even minor Uranium mineralization in non-pedogenic calcrete in Nagar-Parkar area. The area is considered unfavourable for the occurrence of surfacial Uranium mineralization due largely to the abundance of basic rocks in its bed rock geology.

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APPLICATION OF OLIVINE SPINEL AND TWO PYROXENE GEOTHERMOMETERS TO THE DARGAI ULTRAMAFIC COMPLEX PAKISTAN

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ABSTRACT:- Seven olivine-spinel and two pyroxene geothermometers were applied to the Dargai Ultramafic Complex, Pakistan. Using olivine - spinel geothermometer, the temeperatures were estimated between 675°C - 825°C whereas the temperatures fall between 900°C - 950°C when pyroxene data were plotted on pyroxene quadrilateral. This discrepency is attributed more likely due to various degree of re-equilibration in two thermomenters.

INTRODUCTION

The olivine spinel geothermometer is based on simple Mg^{+2}-Fe^{+2} exchange reactions. It relies on the preservation of crystallization ratio of the Mg-Fe elements during subsequent thermal events (Medaris, 1974, Clark, 1978 and Wilson, 1982).

Several calibrations of the so called olivine-spinel geothermometer have been done in recent years, such as by Irvine (1965), Jackson (1969), Evans and Frost, (1975), Fuji (1978), Roeder et al. (1979), Fabries (1979), Henery and Medaris et al. (1980) and Sack (1982).

Despite persistent uncertainties in the calibration of the olivine spinel geothermometer, this writer has adopted the Roeder et al. (1979) geothermometer which is derived from that of Evans and Frost, (1975). This geothermometer is very commonly used for temperature estimates.

Several attempts have been made to calibrate the so called OPX-CPX geothermometer by means of experimental studies, Wood and Banno (1973), Wells (1977), Powell (1978), Herzberg and Chapman (1976) and Lindsley (1981).

Wood and Banno (1973) developed a geothermometer for natural pyroxenes. This two pyroxene geothermometer is based on Mg-Fe partition between ortho and clinopyroxene. Later on Wells (1977) revised it on the basis of experimental results on the Diopside-Enstatite join. Both of these thermometers were widely used, but the inherent assumption of ideal mixing of OPX and CPX is not valid (Lindsley, 1981 and Davidson et al. 1982).

Table 1

Olivine-spinel geothermometer variables based on data from the Dargai Ultramafic Complex. (Calculation are according to Evans and Frost, 1975).

No.	Sample No.	K_D	In K_D	Corrected In K_D	Y^{sp}_{cr}
i.	BK-1	8.829	2.17	1.61	0.68
ii.	BK-2	13.16	2.57	2.01	0.71
iii.	BS-2	8.49	2.13	1.52	0.59
iv.	BS-4	8.26	2.11	1.64	0.63
v.	LR-3	9.17	2.21	1.62	0.69
vi.	JG-1	7.71	2.04	1.57	0.62
vii.	DC-82B	6.70	1.90	1.35	0.45

They believed that the temperature obtained with this method is about 100°C too high. Furthermore Wood and Banno (1973), and Wells (1977) did not take into account the nonquadrilateral components of pyroxenes which contribute 6 to 12 % of the total pyroxene composition.

Lindsley and Anderson (1983) proposed a scheme to obtain mole fraction of Wo, En and Fs in natural pyroxenes. This new scheme takes into account nonquadrilateral components of pyroxenes.

Olivine-spinel and ortho-clino pyroxenes are important constituents of the basic and ultramafic rocks of the Dargai complex. Ahmed 1982 estimated temperature of the Dargai complex by using olivine-spinel geothermometer. In order to achieve more meaningful results, comparative study is needed by using two thermometers. for this purpose analyses of co-existing minerals are required. The chemical composition of these minerals when co-existing in equilibrium is a function of the pressure and

temperatures which prevailed at the time of their formation.

APPLICATION OF OLIVINE-SPINEL GEOTHERMOMETER

Plotting of ln K_D and Y_{cr}^{sp} for the olivine-spinel mineral pairs from the Dargai Complex indicate the most of these minerals have equilibrated over a range of temperature of 675^oC to about 825^oC (Fig-1). The calculations are according to Evans and Frost (1975) (Table-1). This range of temperature is substantially lower than the expected temperature for mafic magma which is about 1300^oC and represents reequillibration following magmatic crystalization.

By using this thermometer temperature differeneces have been observed by various workers and probably ae due to some of the following reasons:

i) The thermometer assumes ideal solutins, but there is some degree of non ideal solid solution existing between molecular components of olivine and spinel.

ii) Co-existing olivine and spinel dervied from serpentinized rocks yield lower temperature as compared to unaltered rocks.

iii) Trace elements like Zn^{2+}, Mn^{2+}, V^{3+}, Ni^{2+}, and Co^{2+} have some effect on the Mg-Fe^{2+} exchange.

iv) Uncertainty in analytical values cause descrepancy in temperature estimates.

APPLICATION OF TWO PYROXENE GEOTHERMOMETER

The data derived from the Dargai Complex is presented in Table-2. Following the scheme by Lindsley and Anderson (1983) the composition of co-existing OPX and CPX from the Dargai complex are plotted on the pyroxene quadrilateral (Fig-2). The tempeature for the Dargai Complex falls between 900 and 950^oC when estimated from experimentally dtermined 10Kb isotherms. This pressure corresponds to the upper mantle conditions. The temperature of the Dargai Complex using olivine-spinel geothermometer was estimated between 675^oC and 825^oC (This study). Temperatures estimated by using the olivine-spinel and two pyroxene thermometer show a maximum difference of 225^o C. This discrepancy is probably due to various degrees of reequilibration.

Most of the plutonic pyroxenes exsolve on cooling and it is, therefore, not possible to determine the original crystallization temperature of the rocks in which they occur. The higher temperatures obtained for the Dargai Complex using the two pyroxene thermometer is believed to represent the temperature at which exsolution ceased among these minerals. The product of this exsolution is represented by granular pyroxene in the Dargai Complex. The lower temperature estimated by two pyroxene geothermometer for the Dargai Complex is 900^oC. Thiis supports the Henry and Medaris (1980) idea, which holds that after the granular exsolution of OPX and CPX continued to equilibrate and have produced a second kind of exsolution resulting in the so-called Schiller texture. This type of texture is a very common feature of the rocks of the Dargai Complex.

The temperature estimates obtained from the olivine-spinel and the OPX CPX temperatures for the Dargai complex are typical of ophiolitic environments as mentioned by Loney et al., 1971; Jackson and Thayer, 1972.

CONCLUSION

The Olivine-spinel and two pyroxene geothermometers were used to estimate the subsolidus reequilibration temperature of the Dargai Complex. The estimated temperatures were 675^oC - 950^oC which are quite low as compared to mineral pairs derived from cratonic stratiform Complexes. It seems reasonable to assume in the case of Dargai Ultramafic Complex that the orthopyroxene - clinopyroxene mineral pair reequilibrated to the 900 - 950^oC whereas olivine-spinel continued their equilibration to the 675 to 825^oC temperature range.

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Table-2

Analyses of co-existing OPX and CPX from the Dargai Complex

	1		2		3		4		5		6		7	
	OPX	CPX	OPX	CPX	OPX	CPX	OPX	CPX	OPX	CPX	OPX	CPX	OPX	CPX
			DC								Z			
	16	16	21	21	15	15	30	30	222	222	275	275	277	277
Na_2O	.02	.05	.02	.00	.00	.22	n.d.	n.d.	.11	.17	.28	1.15	.19	.00
MgO	34.79	18.07	36.14	18.51	33.59	18.38	32.55	17.01	33.39	16.98	34.23	16.99	35.30	16.17
Al_2O_3	1.91	1.52	1.46	2.00	2.06	1.68	1.40	1.45	2.11	2.59	.00	.40	1.55	2.28
SiO_2	58.19	54.86	55.95	53.55	58.20	54.06	56.04	53.44	56.01	53.20	57.35	54.52	57.39	53.20
K_2O	.00	.00	.00	.00	.00	.03	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
CaO	.51	25.25	.77	24.78	1.41	24.16	.66	24.24	.89	23.83	.80	22.11	.42	23.57
TiO_2	.04	.04	.00	.04	.00	.00	.07	.06	.04	.07	.04	.00	.08	.36
Cr_2O_3	.54	.79	.60	.76	.59	.71	.34	.63	.63	1.05	.17	1.61	.103	1.77
MnO	.16	.05	.14	.07	.08	.10	.23	.09	.14	.08	.17	.07	.14	.00
FeO	5.56	1.61	5.54	1.96	5.15	1.66	8.44	2.65	6.02	2.24	5.78	2.34	4.20	1.75
NiO	.09	.04	.02	.01	.03	.00	.12	.00	.88	.00	.11	.00	.08	.06
Total	101.82	102.28	100.67	101.68	101.13	101.01	99.85	99.57	99.42	100.21	98.93	99.19	100.38	99.16
Cations on basis of 6 oxygens														
Na	.001	.003	.001	.000	.000	.014	n.d.	n.d.	.004	.008	.016	.039	.012	.000
Mg	1.750	.956	1.850	.988	1.699	.983	1.699	9.29	1.727	.920	1.774	.929	1.793	.905
Al	.075	.63	.058	.086	.082	.070	.054	.061	.083	.109	.000	.013	.61	.099
Si	1.964	1.946	1.921	1.918	1.975	1.942	1.962	1.957	1.944	1.935	1.993	2.000	1.957	1.929
K	.000	.000	.000	.000	.001	.001	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ca	0.18	.960	.028	.950	.050	.930	.023	.951	.031	.927	.029	.869	0.14	.947
Ti	.001	.001	.000	.001	.000	.000	.001	.001	.001	.002	.001	.000	.002	.009
Cr	.014	.021	.016	.021	.015	.020	.008	.017	.016	.039	.004	.044	.024	.049
Mn	.004	.001	.004	.001	.002	.002	.006	.002	.002	.002	.004	.001	.002	.000
Fe	.156	.046	.158	.058	.145	.050	.246	.079	.173	.067	.167	.070	.118	.054
Ni	.002	.001	.000	.000	.000	.000	.003	.000	.022	.000	.002	.000	.002	.018
Total	3.984	3.999	4.037	4.021	3.969	4.012	4.002	3.997	4.002	4.009	3.986	3.966	3.985	4.01
*Ca/Wo	.009	.456	.013	.465	.027	.453	.011	.455	.016	.448	.014	.425	.007	.449
*Mg/En	.948	.534	.908	.505	.919	.529	.863	.504	.894	.515	.900	.543	.931	.520
*Fe/Fs	.041	.009	.077	.029	.053	.017	.125	.041	.089	.036	.084	.040	.061	.030

*Ca, Mg, Fe is derived from OPX analyses whereas Wo, En, Fs is calculated from CPX analyses.

**Data for analyses 4,5, 6 and 7 are derived from Ahmed and Hall (1984).

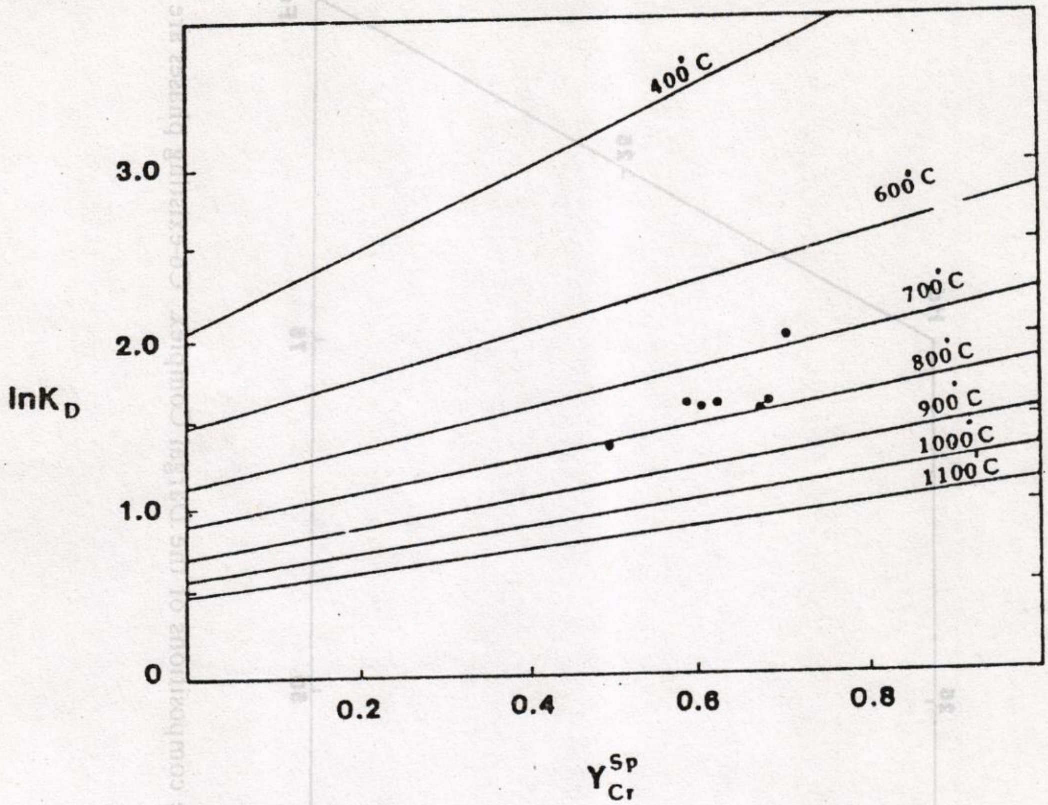

Figure 1 Plot of ln K_D as a function of Y^{sp}_{Cr} for the rocks of the Dargai Complex. This plot is normalized to $Y^{sp}_{Fe^{3+}}$ = 0.050 according to Evans and Frost, 1975. The solid sines are isotherms of Roeder *et al.* (1979). The Dargai data are shown with filled circles.

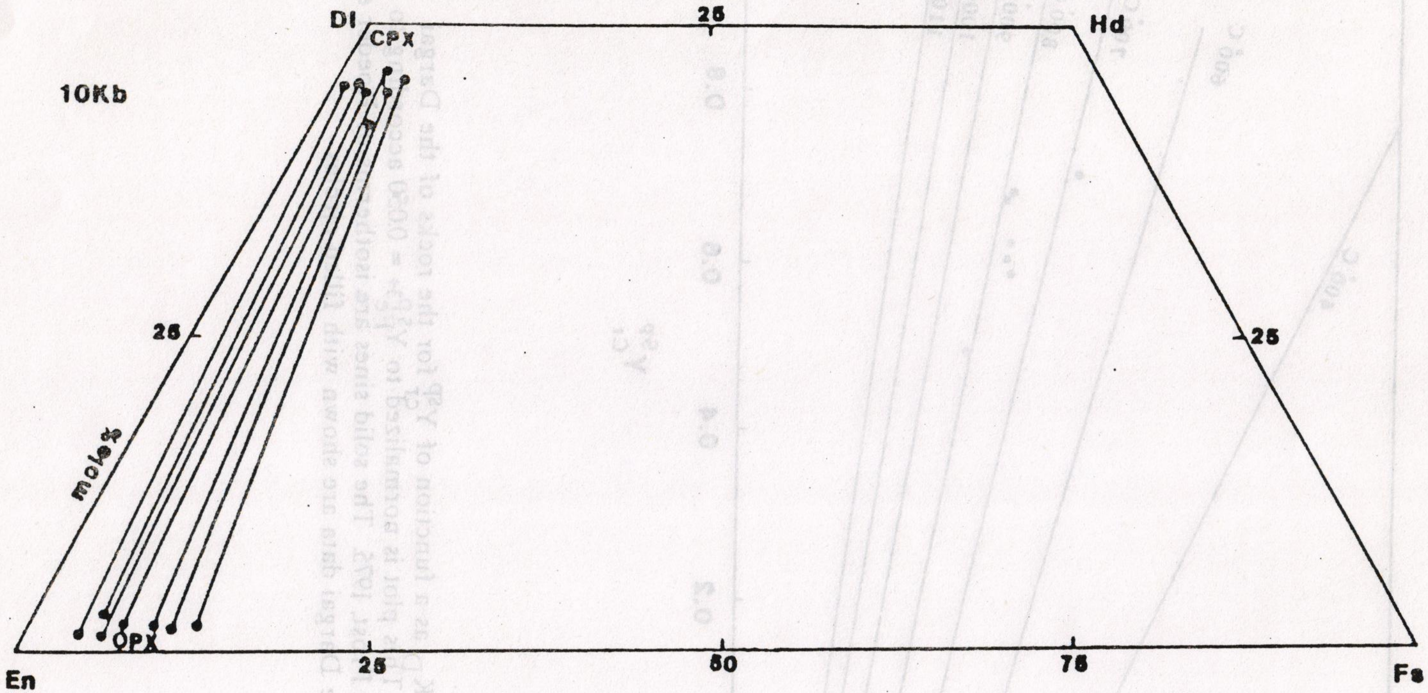

Figure 2 Plot of orthopyroxene and clinopyroxene compositions of the Dargai Complex. Co-existing phases are connected by tie lines.

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METAMORPHISM OF THE OBDUCTED DARGAI OPHIOLITE, PAKISTAN

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ABSTRACT:- The secondary minerals in the rocks of the Dargai Complex resulted through polymentamorphism. Field petrologic, and geochemical studies show that the complex passed through hydrothermal metamorphism at the mid oceanic ridges. A retrograge metamorphic event is discerned from the gabbroic mineral assemblages. The syn tectonic metamorphism involved the obduction of the Dargai Complex which produced the dynamothermal effects in the underlying metasediments. The presence of antigorite and garnet mica schist near the southern (lower) boundary contact is related to dynamothermal metamorphism.

INTRODUCTION

The metamorphism is essentially a series of post magmatic events that has affected the Dargai Complex. Much of the primary mineralogy of the Dargai Complex was obliterated due to pervasive alteration.

The metamorphic phases in the Dargai Complex can be conveniently classified as pretectonic and syntectonic. The pretectonic phase involves oceanic serpentinization and hydrothermal metamorphism whereas the syntectonic phase includes continental serpentinization and dynamothermal metamorphism.

PRE-TECTONIC METAMORPHISM

Serpentinization is a common process which affected the ultramafic rocks to variable degrees. The secondary mineral assemblages in the Dargai complex apparently were formed by hydration and carbonation reactions. All minerals formed by these processes are shown in the diagram of Figure-1.

Alteration of olivine (Mg_2SiO_4) produced mineral assemblages of serpentine + brucite and magnesite, whereas the orthopyroxene changed to olivine and talc. The chemical reactions involved in alteration of forsterite and enstatite are as follows:

i) $$\underset{\text{forsterite}}{4Mg_2SiO_4} + 6H_2O \rightleftharpoons \underset{\text{serpentine}}{Mg_6Si_4O_{10}(OH)_8} + \underset{\text{brucite}}{2Mg(OH)_2}$$

ii) $$\underset{\text{serpentine}}{2Mg_3Si_2O_5(OH)_4} + 3CO_2 \rightleftharpoons \underset{\text{talc}}{Mg_3Si_4O_{10}(OH)_2} + \underset{\text{magnesite}}{3MgCO_3} + 3H_2O$$

iii) $$\underset{\text{enstatite}}{5MgSiO_3} + H_2O \rightleftharpoons \underset{\text{olivine}}{Mg_2SiO_4} + \underset{\text{talc}}{Mg_3Si_4O_{10}(OH)_2}$$

(Deer, Howie and Zussman, 1978)

Metasomatism of varied rock types associated with serpentine is widespread in Phanerozoic orogenic belts (Coleman 1967). Ultramafic and associated mafic rock types are transformed into rodingite during the process of hydrothermal alteration. In metasomatised mafic igneous rocks, the rodingite is composed of idocrase, diopside, wollastonite, chlorite, sphene and tremolite (Coleman, 1977). Dykes of this rock are exposed near the village Herushah in the project area. The Dargai rodingite is a calc-silicate rock which is characterized by enrichment in calcium and undersaturation in the silica relative to the original composition of the gabbroic rocks (Coleman, 1977) observed that the average CaO content of 23 peridotites is 35 wt%, for 19 dunites 0.75 wt%, and for 26 serpentinites. 0.08 wt%. The study shows that Ca is released during hydrothermal alteration. The main sources of calcium in the Dargai ultramafic rocks are pyroxenes. Thus the clacium was released by the breakdown of pyroxene which became available for the metasomatic transformation of mafic rocks into rodingites.

Hydrothermal metamorphism is caused by hot sea water convective currents circulation at the mid oceanic ridge. This is common feature (Andrew and Eyfe, 1986) in an idealized ophiolite section (Fig. 2) The high temperature chemically charged sea water currents are capable of producing metamorphic charges in rocks at spreading centers. The grade of metamorphism increases downward from the top of pillow lavas in a complete ophiolite sequence. The degree of progressive metamorphism varies from zeolite facies to greenschist facies to amphilbolite facies.

The tectonic interpretation of the Dargai Complex implies that it is a dismembered ophiolite sequence pillow lava and sheeted dykes are missing in the sequence of rock units in the Dargai Complex. The zeolite facies which would occur in these units consequently is not present. This study shows that the Dargai gabbroic rocks contain tremolite, chlorite, epidote, albite and sphene which correspond well with mineral phases in the greenschist facies (Miyashira, 1961).

In prograde metamorphism, epidote breaks down and releases calcium to produce Ca-plagioclase while in retrograde metamorphism Ca-plagioclase eliminates to form Na-plagioclase and epidote (Miyashiro, 1961). The common appearance of Na-plagioclase in the Dargai gabbroic rocks is believed to represent retrograde metamorphic facies.

SYNTECTONIC METAMORPHISM

a) Continental Serpentinization started with the obduction of the ultlramafic mass. The water in the underlying sediments played an important role in this serpentinization process. Petrographic study reveals common occurrence of antigorite near the peripheral parts of the Dargai Ultramafic Complex. Antigorite is a characteristic mineral of metamorphic terrane and is rarely found in dredged samples from the ocean floor (Prichard, 1979). The lizardite and chrysotile form at temperature 300^{o}C (Barnes and O, Neil, 1969) whereas antigorite is stable slightly above 500^{o}C at 4000 bars P_{H_2O} or greater. A stable isotope study shows that metamorphic water was involved in the formation of antigorite (Wenner and Taylor, 1973). Therefore presence of antigorite represents the allochthonous nature of the Dargai Complex.

b) Dynamothermal metamorphism beneath ophiolite slabs is described from different parts of the Tethys ophiolite belt in the Dinarides (Karamata, 1968), Newfoundland (Williams and Smith, 1973), and from California and Oregon (Coleman, 1977). It depends on factors such as: (1) heat content of the ultramafic mass, (ii) temperature and water content of the underlying rocks, (iii) thickness of the ophiolitic slice, and (iv) the velocity of ascent of the ultramafic mass (Karamata, 1979).

A number of field and petrographic observations indicate a dynamothermal metamorphic nature of the Dargai Complex.

i) Field study of the Dargai complex shows that the grade of metamorphism decreases (i.e. garnet mica schist to phyllite) southerly at the southern boundary contact. Garnet mica schist is developed at the southern boundary contact near Bahram Dheri and is absent near the nothern boundary contact. This indicate that the Dargai complex was not completely cold at the time of obduction. Garnet mica schist appearance corresponds to lower amphibolite facies. Thus the development of garnet mica schist in the underlying metasediments is related to obduction of the Dargai Complex.

ii) Petrographic studies of rocks from the Dargai Complex show that it has suffered variable degrees of serpentinization. Olivine and orthopyroxene exhibit kink banding and undulatory extinction which indicate that the Dargai complex suffered regional metamorphism. Moreover, some serpentine veins show a crosscutting relationship with olivine and orthopyroxene porphyroblastic crystals. This indicates that the serpentinization episode occurred later than metamorphism.

iii) Two trends of flow layering occur in the Dargai Complex. One is parallel to the foliation of metasediments whereas the other is not comformable. The non conformable foliations represents the igneous layering whereas the conformable more likely is related to Neogene regional metamorphism of the complex. The absolute time of metamorphism is not discernable, but the sequence is clear.

The pre-tectonic and syn-tactonic metamorphic episodes are represented by following mineral assemblages:-

Sequence of Metamorphism		Resulting Mineral Assemblage
1. Pre-tectonic metamorphism hydrothermal metamorphism	⟶	chrysotile + lizardite, tremolite, chlorite, epidote, albite, sphene.
2. Syn-tectonic metamorphism		
a) Continental metamorphism	⟶	antigorite ± ± lizar dite.
b) dynamothermal metamorphism	⟶	garnet appearance in the underlying meta-sediments schist).

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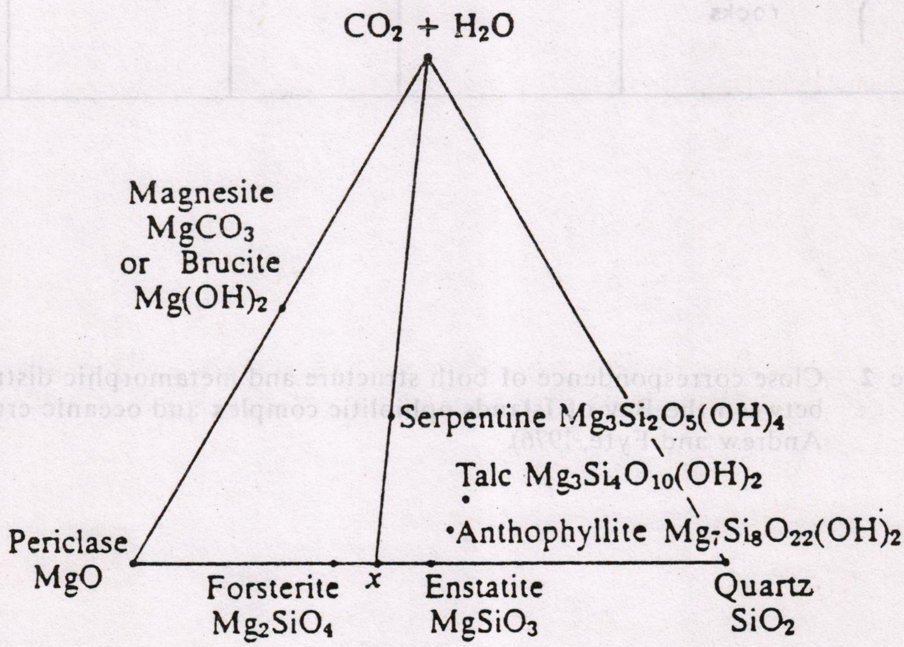

Figure 1 Minerals in the MgO-SiO_2-H_2O + CO_2 system (Ehlers and Blatt, 1980). (x) represents the dehydrated serpentine. The various minerals assemblages in the Dargai Complex are seen in this system. They formed in hydration and carbonation processes.

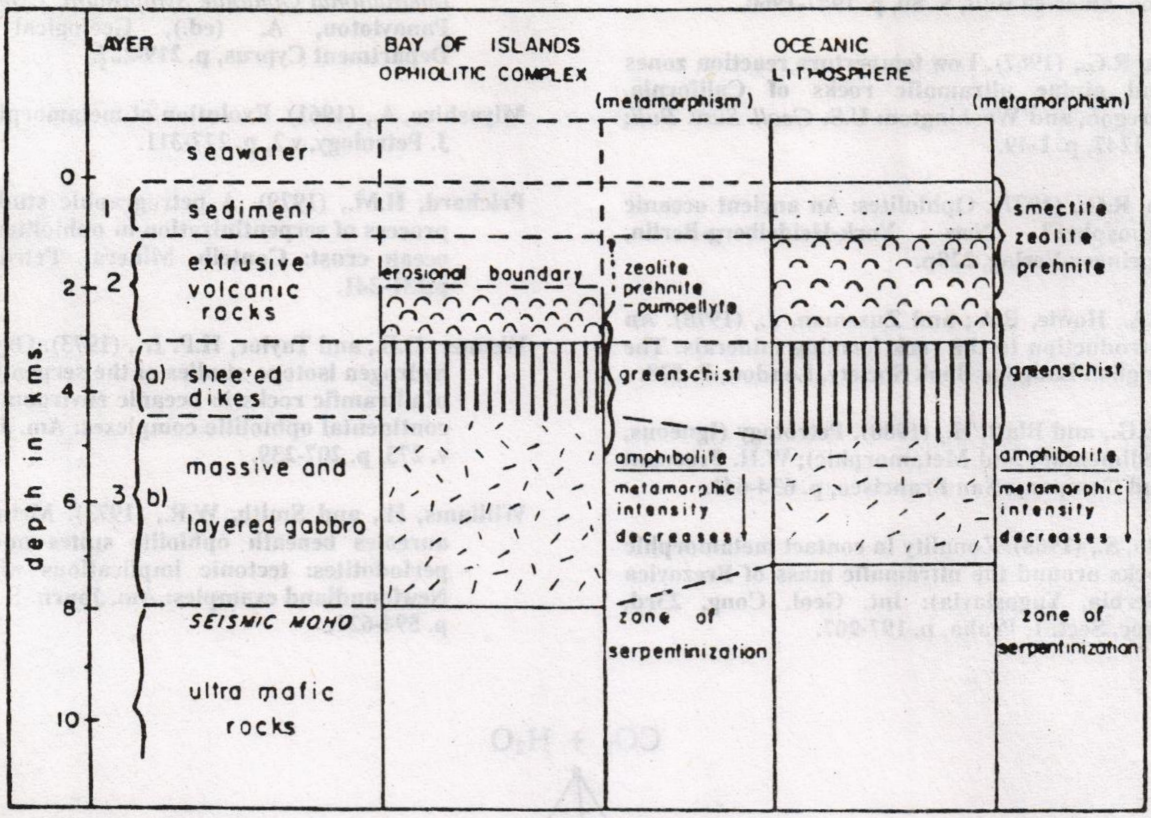

Figure 2 Close correspondence of both structure and metamorphic distribution, between the Bay of Islands ophiolitic complex and oceanic crust (From Andrew and Fyfe, 1976).

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PANJAL VOLCANICS: GEOCHEMISTRY AND TECTONIC SETTING IN AZAD JAMMU & KASHMIR & KAGHAN VALLEY NW HIMALAYA

By

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ABSTRACT: Panjal volcanic rocks, with maximum upto 1400 m thickness, occur within a system of Main Boundary Thrust and Panjal Thrust in the NW Himalayas from Kahuta to Kaghan. The geotectonic evolution of these volcanics have been studied by field investigations, petrography and geochemistry.

Petrographic study of the Panjal rocks show that they are basalts to basaltic andesites and are tholeiitic to slightly alkaline in character. They were formed mostly in submarine environments showing alteration of their minerals to epidote, chlorite and sodic Plagoiclare.

Major element data for the Panjal volcanics are plotted on different tectonomagmatic geochemical discriminant diagrams,, to infer their tectonic environment. The data largely plot in the oceanic fields. The geology of the area, geochemistry and inferred tectonic setting show that Panjal volcanics were erupted in a rift to oceanic, environment.

INTRODUCTION:

The Panjal volcanics form a continuous outcrop and extends for more than 100 km from the Kahuta area in the south east of Muzaffarabad to Kappigali in the northeast where they swing along the Kashmir Hazara syntaxial bend in the lower Kaghan valley (Fig. 1). These volcanics crop out between the Mian Boundary Thrust or Murree Thrust (MBT) and Panjal Thrust. Volcanism in this area appears to have occurred since the Carboniferous to Permian

The Panjal volcanics are basaltic to basaltic andesites. Geology and geochemistry of the Panjal volcanics in the valley of Kashmir have been studied by several authors (Lyddeker, 1876; Middlemiss, 1909, 1910; Nakazwa & Kapoor, 1973; Pareek, 1973; Bhat & Zainuddin 1979, 1981. Their results indicate that rocks have a tholeiitic character. Tholeiitic nature of these rocks is also shown by Butt et al. (1984). Papritz and Rey (1989) showed that Panjal volcanics in syntaxial bend are geochemically similar to those of volcanics in Suru valley of Kashmir.

Basaltic rocks are generated by spreading processes at mid ocean ridges, island arcs, ocean islands and as continental flood basalts. On the basis of basalt geochemistry, distinction between continental flood basalts, island arcs, and mid ocean ridge basalts has been made using discriminative elements which are immobile such as Ti, P, Mn, Zr, Y, Nb, Ta, Hf and rare earth elements (Pearce and Cann, 1971, 1973; Pearce et al. 1975; Mullen, 1983; Wood et al. 1979-1980); Pearce and Norry, 1979; Pearce, 1982).

The Panjal volcanics in Suru valley of Kashmir have been studied by Bhat & Zainuddin (1979). However, no detailed geochemical investigation of the Panjal volcanics in Azad Kashmir and Kaghan area were carried out by anyone.

The purpose of this paper is to carryout a detailed geochemical study of the Panjal volcanics in the Betar valley (Kahuta area), Jhelum and Neelam valleys (Muzaffarabad area, Azad Kashmir on the eastern side of Kashmir Hazara syntaxial bend) and the Kaghan valley Pakistan on the western side of syntaxial bend. Field characters, petrographic and

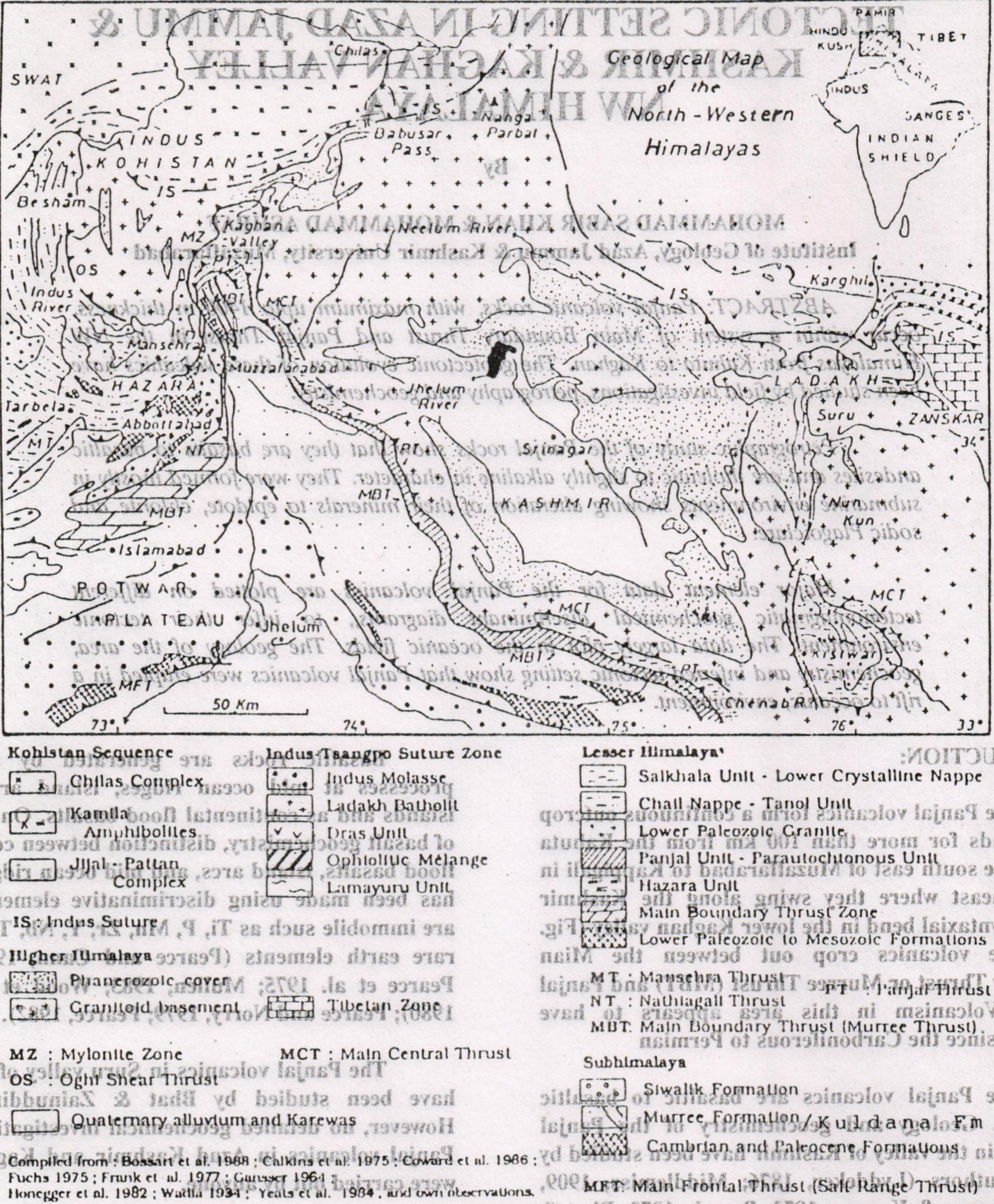

Fig . 1

Geological Map of the North-Western Himalayas.

major element geochemistry data of Panjal volcanics will be used in order to outline their tectonomagmatic environment, and to describe in some detail the metabasalts exposed along Main Boundary Thrust.

GEOLOGICAL SETTING

In the eastern and western Kashmir - Hazara syntaxial area, Sub Himalaya comprises mainly of Murree Formation with subordinate Siwalik sediments. These rocks together form molasse like sediments and extends from Kaghan to Kahuta area. The Murree Formation forms the core of Kashmir Hazara syntaxial bend (Bossart et al. 1988; Chaudhry & Ashraf 1985).

The lesser Himalaya in this region consist of Panjal volcanics and associated rocks lying in autochthonous folded zone in the NW Himalayas (Wadia, 1928, 1931, 1934) and Tonals and Dogra slates (Wadia, 1928, 1934,).

The Tonals, possibly of lower Carboniferous age were developed in Muzaffarabad and Kaghan area. The metasediments of Tonals are comprised mostly quartz micaschist and quartzites intruded by two mica granite. Dogra slates are exposed in Kahuta area.

The dolerite and amphibolite dykes and sills are common in the metasediments of Tonals (Papritz & Rey 1989). At places the contact of Tonals are gradational with agglomeratic slates of the Panjal Volcanics (Ghazanfar and Chaudhry, 1984). But present study does nto confirm their views.

A pile of agglomeratic slates, Panjal lava flows and associated carbonate rocks of upper Carboniferous to Triassic age of variable thickness constitutes a major tectonic geological group within the autochthonous zone (Wadia, 1934). This group follows the Main Boundary Thrust (MBT) over a distance of about 100 km from the Kahuta area to Kaghan valley (Fig. 1). Equivalent of this unit are also reported in the southeast of Kahuta in Indian held Kashmir.

The Panjal volcanic rocks have steep thrust contacts against the molasse like sediments of Murree Formation and metasediments of Tonals and Dogra slates. The metasediments are riding over the Panjal volcanics along the Panjal Thrust. The Panjal volcanics have been thrust over younger sediments of Tertiary age along the Murree Thrust. The volcanics in this region are thrust bounded and at places the volcanics and associated rocks form imbricate slices and are also effected by post eruptive Himalayan orogeny. Agglomeratic slates lie at the base of the Panjal volcanics and are equivalent to Agglomeratic Slates of Bion and Middlemiss (1928) and Wadia (1928), metaconglomerates of Ghazanfar and Chaudhry (1985) and tilloids of Bossart et al. (1988) from Kaghan. These are overlain by the Panjal volcanics and Triassic limestone.

The Panjal volcanics are greenish grey and dark grey in Kaghan, Neelam & Jhelum valleys and Kahuta area. They are very fine grained amygdaloidal, but sometimes very hard, compact and massive. More than two flows can be observed on the basis of colour, vesicular population and intercalated limestone and bedded chert. The size of flows vary from 10-25 meters to more than 50 meters.

The amydgules are filled with chlorite, epidote, quartz, calcite and chalcedony. Epidote, quartz and calcite veins are common in these rocks which show alteration of these rocks.

The volcanics are generally vesicular. The vesicles range in size from few mm to more than 6 cm in longer direction. They are rounded to subrounded and are found abundantly towards the top of the lava flows. Stretched and elongated vesicles are common towards base of the Panjal lava flows.

Pillow lavas (Fig. 2) within the Panjal volcanics also exhibit vesicles ranging in size from few mm to 1 cm in long direction. Pillows are rounded to subspherical in Kahuta area whereas they are more stretched/deformed and elongated in the area around the Kashmir-Hazara syntaxial bend.

PETROGRAPHY

The microscopic examination of 67 samples of the Panjal volcanics show textural and alteration characters. These rocks are plagioclase phyric with minor pyroxene and their alteration products. The groundmass is very fine grained possibly of devitrified glass. Opaque minerals such as magnetite and hematite are also present. These mineral phases appear to be repeated in different flows and do not show systematic change (Table - 1).

Plagioclase forms microphenocrysts and microlites in these rocks. The grain size varies from 0.4 mm to 1 mm. The microphenocrysts are sometimes deformed and fractured which are healed with epidote and chlorite. The composition of plagioclase ranges from labradorite to andesine and even sometimes changes to albite.

Pyroxene grains varies from 0.5 mm to 0.63 mm in size. Pyroxene was observed in few rocks of Kahuta

Fig. 2 Pillow structures shown by Panjal Volcanics in Kahuta Area

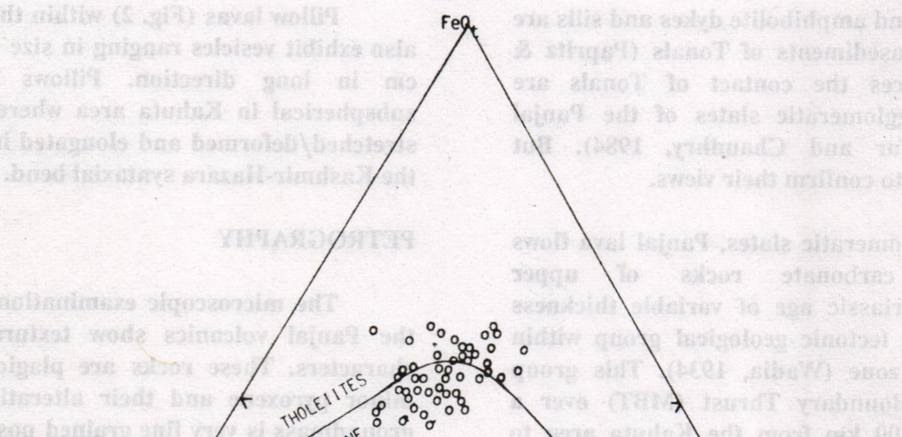

FIG.3 The fields of tholeiites and calc-alkaline shown by the Panjal Volcanics. Diagram after Irvine and Baragar(1971).

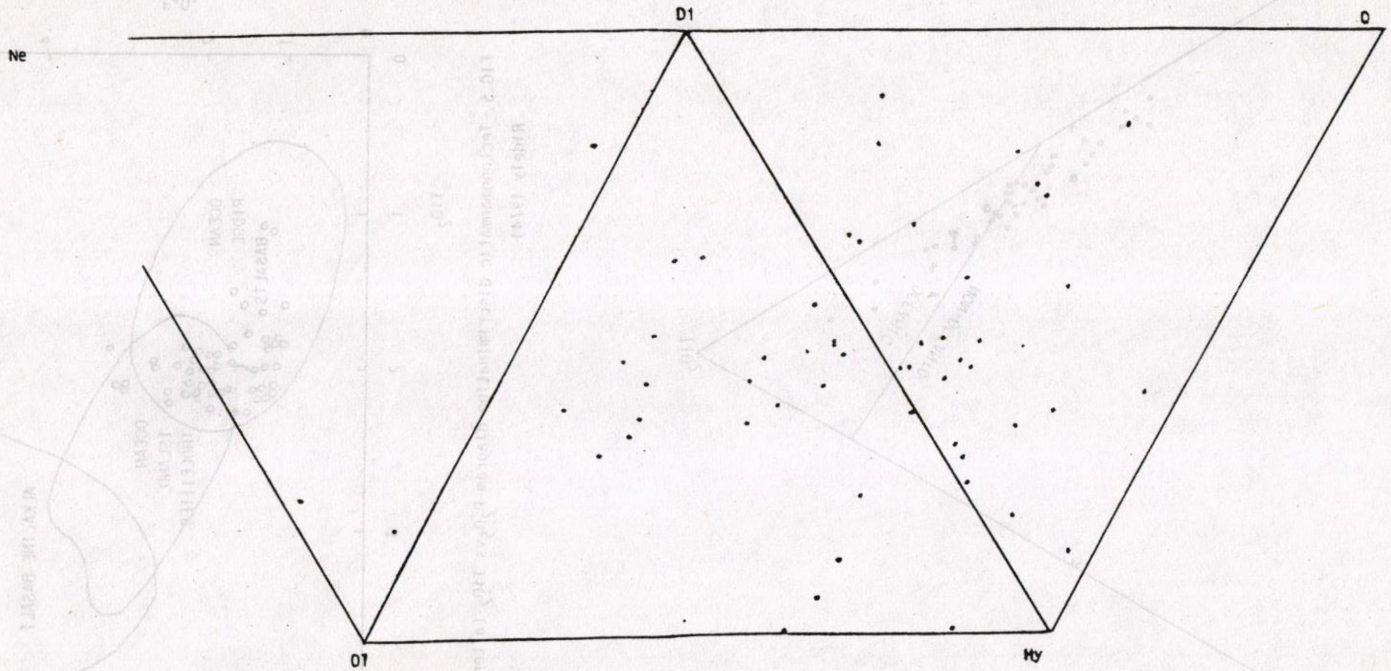

FIG.4 Plots of relative proportions of normative Ne.Ol.Hy.Di & Q inthe Panjal Volcanics.

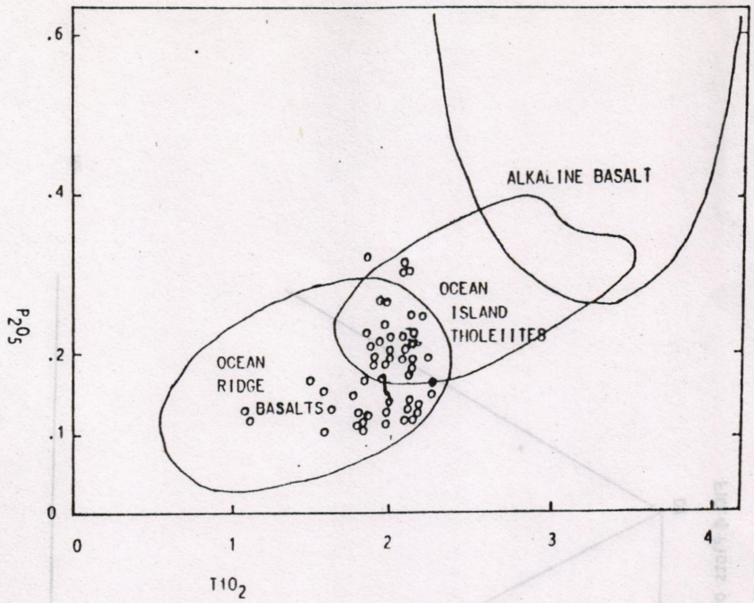

FIG.5 Tectonomagmatic discrimination diagram P_2O_5 vs TiO_2 (after Ridely 1974).

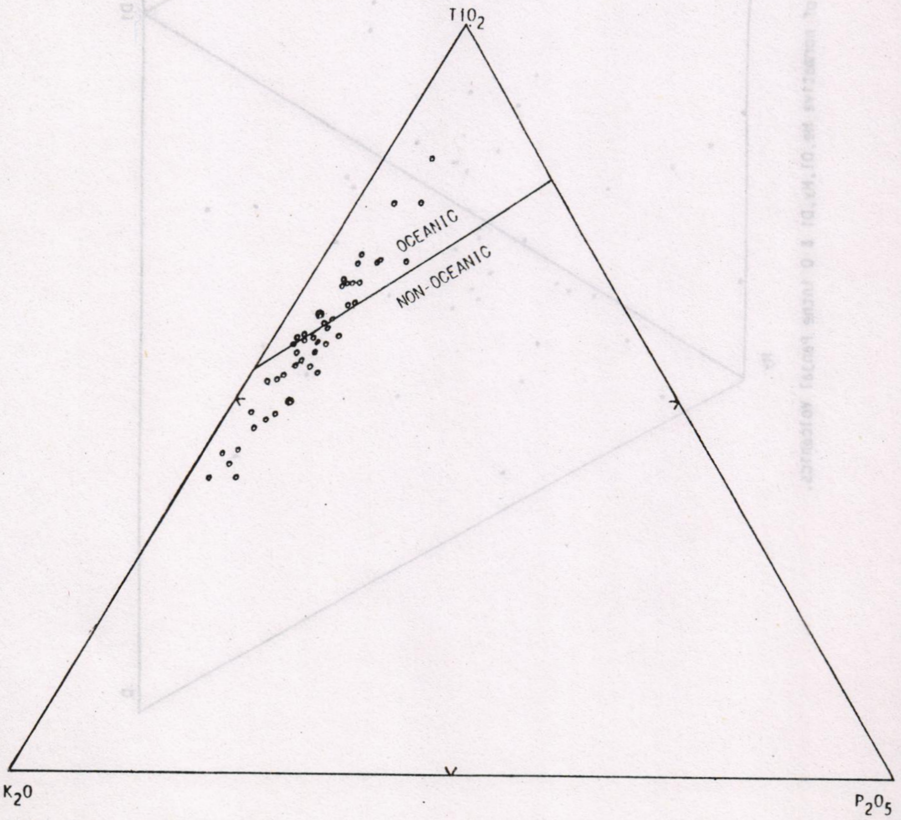

FIG.7 Discrimination diagram showing the plots of the Panjab Volcanics in oceanic to non-oceanic environments(after Pearce,et al. 1975).

FIG.6 Harker diagram for Panjal Volcanics.

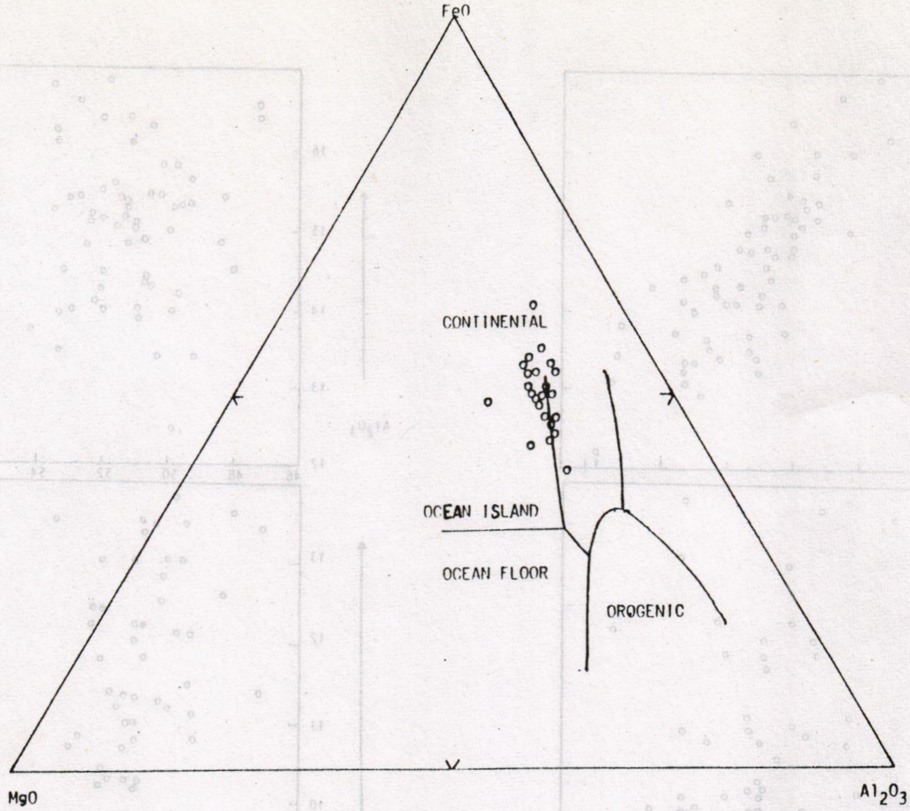

FIG.8 Discrimination diagram for Panjal Volcanics (after Pearce et al.1977).

MORB=MID OCEANIC RIDGE BASALT
OIT =OCEAN ISLAND THOLEIITES
OIA =OCEAN ISLAND ALKALI BASALT
IAT =ISLAND ARC THOLEIITES
CAB =CALC-ALKALI BASALT

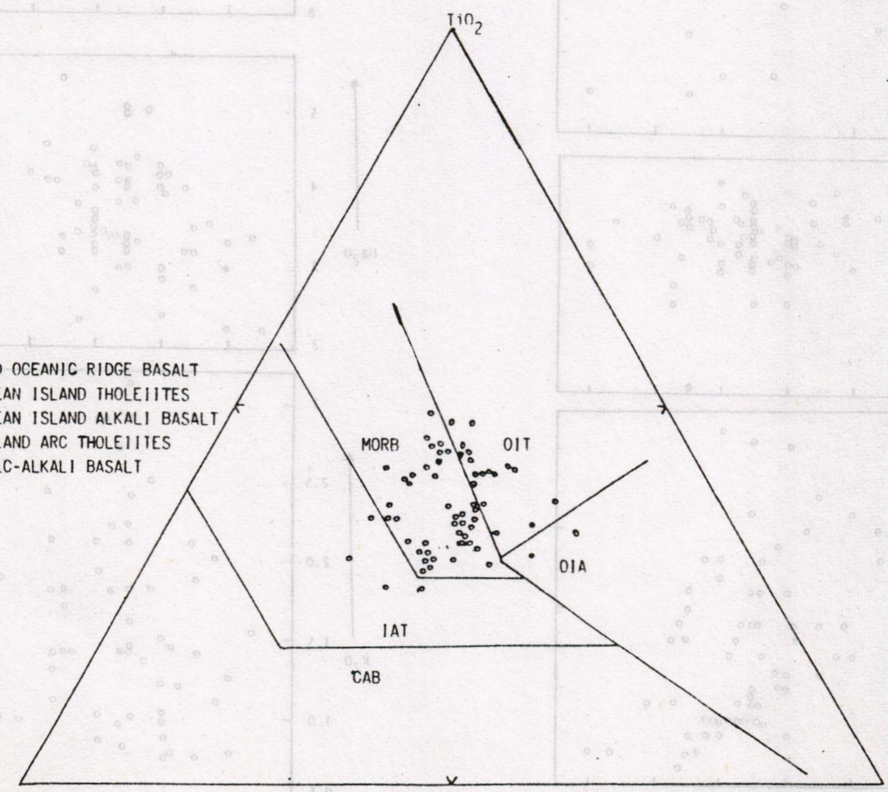

FIG.9 Tectonomagmatic discrimination diagram for the plots of MnOx10-P_2O_5x10-TiO_2 of the Panjal Volcanics.Diagram after Mullen(1983).

area. The presence of pyroxene reveals an earlier crystallization. Compositionally it is augite. It also occurs in groundmass. No pyroxene grains were found except few pyroxene relics which were found in Muzaffarabad area and Kaghan Valley.

Chlorite, epidote and actinolite are common alteration products of plagioclase and pyroxene. Chlorite occurs more abundantly in some flows. Epidote replaces the plagioclase. Albite occurs as replacement of plagioclase. Biotite occurs in few rocks and forms tiny flacks and streaky aggregates. Calcite, chalcedony and quartz are found filling the vesicles and are secondary phases.

Opaque minerals magnetite and hematite form microscopic dust to aggregates and tiny grains.

The abundant fine grained groundmass possibly reveals alteration and devitrification of volcanic glass, however, no remnants of glassy textures were found.

For variation in composition in Panjal Volcanics of Kahuta, Jhelum & Neelam valleys and Kaghan area tables 1 to 4 may be seen.

GEOCHEMISTRY OF THE PANJAL VOLCANICS

The major and trace elements data for the Panjål volcanics are presented in Table 5 to 8 and the variation diagrams for major oxides plotted (Fig. 6).

The Panjal volcanics are classified into basalts and basaltic andesites on the basis of SiO_2 (Middlemost 1975, 1980; Cox et al. 1979). Most of these rocks are hyprsthene, olivine and quartz normative (Fig. 4) only few are nepheline normative. The nepheline normative plots are inferred to be due to secondary alteration which resulted in alkali enrichment.

The AFM diagram (Fig 3, Irvine and Baragar, 1971) indicates that these rocks are tholeiitic to calc-alkaline, but calc alkaline trend is also effected by alkali enrichment and spilitization which causes a shift of data towards alkali rich side. Spilites from Himalaya have also been reported by Taron, 1982.

In view of the secondary alterations in the Panjal Volcanic magma characterization is based on the Ti, P diagram (Fig. 5) because these elements are immobile during secondary alteration and low grade metamorphism upto green schist facies (Cann, 1970, 71). The Panjal volcanics are dominantly of tholeiitic character as revealed by the P_2O_5 - TiO_2 variation diagram.

The major oxide composition of the Panjal lava flows are given in this paper (Tables - 5 to 8). The variation diagrams for major oxides are plotted in Fig. 6. The MgO and FeO show trends of an evolving Panjal magma. The Na_2O and CaO reveal a scattered patterns, which is possibly due to alteration. Na_2O varies from 2.21 to 5.44%. CaO varies from 3.52 to 10.39%.

Tectonomagmatic environment of the Panjal volcanics is based on the results obtained from the use of major elements, such as K, Mn, Ti, and P, which are more resistant to alteration during greenschist facies that these volcanic have undergone (Cann, 1970, 1971, Pearce and Cann, 1973, Floyd & Winchester, 1975, Winchester and Floyd, 1977, Smith and Smith, 1976, Pearce and Norry, 1978, Pearce, 1982, Mullen, 1983). These relatively immobile elements serve to infer the petrologic identity and paleotectonic setting of the metabasalts (Pearce and Cann, 1971, 1973; Bickle and Nesbit, 1972; Ridley et al. 1974; Pearce and Norry 1979; Pearce, 1982; Mullen, 1983).

Compositional data of the Panjal volcanics are plotted on various tectonomagmatic geochemical discriminant diagrams following the procedure and by adopting compositional limits outlined by Pearce et al. (1975, 1977). Geochemical data of Panjal lave flows is also shown on geochemical discriminant diagrams of Mullen (1983) and Ridley et al. (1974).

DISCUSSION

In the broad tectonic sense, there can be no doubt that all of the Panjal lava flows were emplaced in a rift related submarine environment. It is therefore, of considerable interest that most of geochemical data of the Panjal lavas from northwest Himalayas of Kaghan to Kahuta area plot in the fields which have oceanic affinities. Pearce et al. (1975, 1977) proposed two tectonomagmatic discriminant diagrams. These are the ternary diagrams based on TiO_2 - K_2O - P_2O_5 (Fig. 7) and FeO - MgO - Al_2O_3 (Fig. 8). The TiO_2 - K_2O - P_2O_5 variation diagram simply discriminates between oceanic and non oceanic basalts. The geochemical data of the Panjal volcanics from Kaghan, Neelum, and Jhelum valleys and Kahuta area, plot in the fields of non oceanic to oceanic field. This clearly shows a trend from rifting to oceanic conditions. The second of these diagrams (Fig. 8, Pearce et al. 1977) was used to discriminate basalt and basaltic andesties (having SiO_2 from 51-56%) into continental, ocean islands, ocean floor and orogenic setting. Most of the Panjal volcanics geochemical data plot in the ocean islands or in the continental fields (Fig. 8).

TABLE - 1

PETROGRAPHIC COMPOSITION OF PANJAL VOLCANICS, KAHUTA AREA

	85-THLH-4	86-THLH-6	87-THLH-16	88-KV-19	89-KV-20	90-KV-24	91-KV-24	92-GLDV-1	93-GLDV-2	94-GLDV-3	95-GLVD-4
	Tholangar					**Kiran**		**Gali Dhok**			
Plagicolase	46	--	41	35	32	40	30	38	42	27	33
Epidote	14	25	10	18	16	17	25	33	5	20	15
Pyroxene	5	40	18	7	--	--	--	--	17	--	--
Chlorite	10	21	19	16	11	15	20	19	13	8	12
Sericite	6	--	3	13	9	19	--	--	6	40	18
Quartz	3	6	--	4	6	--	--	4	4	--	8
Calcite	--	2	6	2	5	--	7	-	3	--	3
Actinolite	--	--	--	--	--	--	2	--	--	--	--
Sphene	--	--	--	--	1	9	1	--	--	--	--
Chalcedony/Chert	9	2	--	--	--	--	15	--	4	--	6
Hematite	3	4	1	5	1	--	--	3	--	4	5
Sphene	--	--	--	--	--	--	--	--	--	--	--
Amphibole	--	--	--	--	--	--	--	--	--	--	--
Magnetite	4	--	2	--	--	--	--	--	2	1	--
Clay minerals	--	--	--	--	19	--	--	3	4	--	--

TABLE - 2

PETROGRAPHIC COMPOSITION OF PANJAL VOLCANICS, JHELUM VALLEY

	17-CK-10	18-CK-12	19-CK-14	20-CK-16	21-CK-18	22-CK-20	23-CK-22	24-CK-24	25-CK-26
				Chahhama					
Palgioclase	40	27	30	18	18	25	18	35	18
Epidote	28	35	25	35	30	22	30	30	22
Chlorite	30	20	30	45	45	45	45	18	35
Sphene	3	8	4	--	--	--	--	6	5
Sericite	36	--	10	--	1	5	1	8	3
Quartz	--	--	--	--	--	1	--	--	6
Calcite	--	2	--	1	1	--	1	--	1
Actinolite	--	--	--	--	--	--	--	--	1
Magnetite	--	3	--	--	--	--	--	--	2
Chalcedony	2	3	--	--	2	1	2	2	--
Chert	1	--	--	--	3	1	3	1	2
Hematite	--	2	--	1	--	--	--	--	3

TABLE - 2 (Contd)

PETROGRAPHIC COMPOSITION OF PANJAL VOLCANICS, JHELUM VALLEY

51-NLPN-4	52-NLPN-5	53-NLPN-6	54-NLPN-8	55-NLPN-10	56-RSLM-1	57-RSLM-3	58-RSLM-5	59-RSLM-14	60-RSLM-16	61-KL-1	62-KL-2	63-KL-4	64-KL-5	65-KL-8
Nilpash (Lamnian)					Lamnian					Kafarkhan				
30	14	20	30	22	35	30	23	30	10	16	25	24	17	12
25	35	28	23	30	28	20	33	27	40	35	30	40	31	35
23	40	33	35	25	30	33	19	21	35	32	38	28	39	38
11	--	3	--	--	3	5	2	--	--	4	1	--	--	2
1	4	--	2	--	2	3	14	14	1	7	--.	2	--	2
--	3	10	8	7	--	4	--	--	--	--	5	--	4	4
--	1	--	2	3	--	1	--	--	3	--	--	--	1	3
1	1	--	--	--	--	--	4	4	--	3	2	2	2	--
1	--	2	--	5	1	3	--	--	5	--	--	3	--	2
3	1	3	--	2	--	1	3	2	2	2	1	1	2	2
5	1	--	--	--	1	--	2	2	--	1	--	--	--	--
--	--	1	--	5	--	--	--	--	4	--	3	--	4	--

TABLE - 3

PETROGRAPHIC COMPOSITION OF PANJAL VOLCANICS, NEELAM VALLEY

	66-NUS-3	67-NUS-5	68-NUS-8	68-NUS-9	70-NUS-11	71-NUS-12
	Nauseri					
Plagicolase	23	16	20	52	12	39
Epidote	33	30	18	27	35	18
Chlorite	38	35	30	39	36	27
Sphene	1	2	--	--	--	11
Sericite	--	--	16	5	2	3
Quartz	--	8	--	--	2	--
Calcite	--	2	3	1	3	1
Actinolite	2	--	3	2	--	--
Magnetite	--	4	--	--	2	--
Chalcedony	1	1	4	--	2	--
Chert	--	--	2	--	1	--
Hematite	3	2	4	1	5	1

TABLE - 3 (Contd)

PETROGRAPHIC COMPOSITION OF PANJAL VOLCANICS, NEELAM VALLEY

	36-MJ-8	37-MJ-10	38-MJ-12	39-MJ-13	40-MJ-14	41-MJ-18	42-MJ-19	43-MJ-20	44-MJ-21	45-MJ-17
					Manjotar					
Plagioclase	35	18	35	27	25	30	15	20	40	26
Epidote	30	35	10	25	30	32	20	25	32	32
Chlorite	18	40	30	35	35	28	35	35	18	27
Sphene	6	--	10	4	--	7	5	4	3	7
Sericite	8	--	12	3	7	--	6	--	5	1
Quartz	--	5	1	--	--	--	6	8	--	--
Calcite	--	--	1	--	1	--	1	--	--	1
Actinolite	--	1	1	--	1	--	1	1	--	1
Magnetite	--	1	--	1	--	3	4	1	1	--
Chalcedony	2	--	--	3	--	--	--	--	1	--
Chert	1	--	--	--	--	--	2	--	--	--
Hematite	--	--	--	2	1	--	3	4	--	5

TABLE - 4

PETROGRAPHIC COMPOSITION OF PANJAL VOLCANICS, KAGHAN AREA

	BJ-11	BJ-14	BJ-16	BJ-18	BJ-20	BJ-22	BJ-23	BJ-24	BJ-25	BJ-27	BJ-28	BJ-29	BJ-32	BJ-34	BJ-35	BJ-37
Plagioclase	40	55	45	45	35	30	20	55	35	20	20	15	18	15	20	25
Epidote	15	24	20	10	20	30	35	20	30	40	25	40	35	25	30	35
Pyroxene	--	--	--	--	--	--	--	--	5	--	5	--	--	--	--	--
Chlorite	35	15	15	40	40	35	43	20	25	35	45	31	30	40	44	30
Sericite	5	--	12	4	2	2	--	--	--	5	5	4	5	2	--	--
Quartz	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Calcite	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Actinolite	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sphene	5	5	7	--	7	2	--	4	5	--	--	10	12	18	5	10
Chalcedony/Chert	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Hematite	--	1	1	--	--	1	--	--	--	--	--	--	--	--	1	--
Amphibole	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Magnetite	--	--	--	1	1	--	2	1	--	--	--	--	--	--	--	--
Clay minerals	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

TABLE - 5

CHEMICAL ANALYSIS OF PANJAL VOLCANICS, KAHUTA AREA

	85-THLN-4	86-THLN-6	87-THLN-16	88-KV-19	89-KV-20	90-KV-24	91-KV-24	92-GLDV-1	93-GLDV-2	94-GLDV-3	95-GLDV-4
SiO_2	52.32	50.21	49.32	51.34	51.12	50.72	53.2	49.89	50.98	51.37	52.84
TiO_2	2.1	2.12	1.96	2.01	2.12	1.69	2.12	1.9	2.12	1.93	1.86
Al_2O_3	14.12	15.87	13.42	15.39	15.16	14.34	14.52	15.86	13.97	14.84	16.71
Fe_2O_3	12.4	12.52	10.82	11.31	11.31	13.4	8.46	12.13	10.35	10.77	10.85
FeO	--	--	--	--	--	--	--	--	--	--	--
MnO	0.18	0.17	0.12	0.12	0.13	0.11	0.14	0.23	0.17	0.27	0.13
MgO	4.34	4.72	5.32	3.57	3.59	4.72	3.37	5.1	5.23	4.89	2.92
CaO	5.32	4.62	10.21	6.72	6.75	7.11	10.39	6.46	5.12	7.42	6.44
Na_2O	3.42	4.34	3.21	4.32	4.29	3.21	2.78	4.24	3.84	3.21	2.37
K_2O	2.91	1.54	2.12	1.43	1.46	2.12	1.48	1.24	3.12	2.48	1.91
P_2O_5	0.32	0.31	0.06	0.14	0.13	0.13	0.12	0.17	0.14	0.13	0.7
LOI	2.59	3.56	3.5	3.68	3.9	2.45	3.41	2.77	5.1	2.69	3.87
Total	100.02	99.98	100.06	100.00	99.96	100.00	99.99	99.99	100.01	100.00	100.06

CIPW NORM

	85-THLN-4	86-THLN-6	87-THLN-16	88-KV-19	89-KV-20	90-KV-24	91-KV-24	92-GLDV-1	93-GLDV-2	94-GLDV-3	95-GLDV-4
Q	0.62	--	--	--	--	--	7.5	--	--		9.48
Or	17.2	9.1	12.53	8.45	8.45	12.53	8.75	7.33	18.44	14.66	11.29
AB	28.94	36.72	23.38	36.56	36.56	27.16	23.52	35.88	32.49	27.16	29.05
An	14.58	19.28	15.85	18.38	17.75	18.46	22.83	20.58	11.67	18.76	29.32
Ne	--	--	2.05	--	--	--	--	--	--	--	--
Di	8.09	1.34	28.18	11.71	12.22	13.31	22.92	8.57	10.5	14.17	1.6
Hy	19.52	14.39	--	11.82	11.38	14.99	3.6	5.79	5.06	13.02	17.09
Ol	--	7.07	7	1.7	1.7	3.68	--	11.37	8.99	2.07	--
Mt	3.76	3.77	3.52	3.6	3.6	3.9	3.18	3.7	3.45	3.51	3.52
Il	3.99	4.03	3.72	3.82	4.03	3.21	4.03	3.61	4.03	3.67	3.53
Ap	0.74	0.72	0.14	0.32	0.32	0.3	0.28	0.39	0.32	0.3	0.25
Plag Comp.	34	34	41	33	33	40	49	36	26	41	59

TABLE - 6

CHEMICAL ANALYSIS OF PANJAL VOLCANICS, CHACHHAMA (JHELUM VALLEY)

	17- CK-10	18 CK-12	-19 CK-14	20- CK-16	21- CK-18	22- CK-20	23- CK-22	24- CK-24	25 CK-26
SiO_2	52.34	53.45	50.74	49.78	48.46	54.32	51.78	50.52	53.42
TiO_2	2.14	2.21	1.82	2.17	1.94	2.01	2.12	1.87	1.75
Al_2O_3	15.17	15.28	14.37	12.45	14.87	13.72	16.87	15.43	13.49
Fe_2O_3	12.3	8.73	13.43	11.52	12.66	9.66	10.31	13.46	8.74
FeO	--	--	--	--	--	--	--	--	--
MnO	0.11	0.12	0.17	0.13	0.1	0.12	0.14	0.13	0.17
MgO	4.65	3.79	5.78	5.32	6.72	4.32	4.82	5.32	4.47
CaO	6.32	7.41	6.59	7.43	7.32	6.46	5.51	3.72	9.63
Na_2O	3.71	4.52	3.82	4.21	3.52	4.24	3.47	4.43	3.21
K_2O	0.82	1.41	0,39	1.22	1.13	0.93	1.75	1.12	1.14
P_2O_5	0.13	0.19	0.17	0.18	0.17	0.14	0.13	0.23	0.18
LOI	2.38	2.88	3.63	5.6	3.12	4.07	3.1	3.78	3.8
Total	100.0	99.99	100.01	100.0	100.01	99.99	100	100.01	100
				CIPW NORM					
Q	3.69	1.67	1.29	--	--	5.68	2.27	0.72	6.1
Or	4.89	8.33	2.3	7.21	6.68	5.5	10.34	6.62	6.74
AB	31.39	38.25	32.32	35.62	29.79	35.88	29.36	37.49	27.16
An	22.32	17.24	20.91	11.47	21.44	15.66	25.29	16.95	19.03
Ne	--	--	--	--	--	--	--	--	--
Di	6.79	14.96	5.14	19.92	11.3	12.7	0.98	--	22.52
Hy	20.5	8.81	26.66	4.94	7.13	13.01	20.88	22.28	7.68
Ol	--	--	--	7.08	12.69	--	--	4.19	--
Mt	3.73	3.22	3.9	3.62	3.78	3.35	3.45	3.9	3.22
Il.	4.06	4.2	3.46	4.12	3.68	3.82	4.03	3.55	3.32
Ap	0.3	0.44	0.39	0.42	0.39	0.32	0.3	0.58	0.42
An							46	31	41
Plag. Comp.									

TABLE - 6 (Contd)

CHEMICAL ANALYSIS OF PANJAL VOLCANICS, LAMNIAN (JHELUM VALLEY)

	51-NLPN-4	52-NLPN-5	53-NLPN-6	54-NLPN-8	55-RSLM-1	56-RSLM-3	57-RSLM-5	58-RSLM-14	59-RSLM-16	60-KL-1	61-KL-2	62-2KL-4	63-KL-5	64-KL-8
SiO_2	50.92	52.64	55.51	50.93	49.86	47.24	49.42	49.32	50.89	53.12	51.92	50.92	53.42	51.42
TiO_2	1.94	2.19	1.94	2.18	1.98	1.99	2.14	2.1	1.89	2.13	1.99	2.13	1.88	1.97
Al_2O_3	15.36	14.89	15.42	14.91	14.12	16.14	15.32	15.43	14.97	15.49	15.66	14.17	16.11	15.16
Fe_2O_3	9.13	9.34	8.77	10.86	13.86	11.46	11.12	12.48	11.86	10.72	10.43	12.24	9.46	11
FeO	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MnO	0.18	0.12	0.27	0.19	0.27	0.17	0.21	0.23	0.23	0.17	0.27	0.19	0.17	0.23
MgO	4.64	3.58	3.12	4.87	5.44	6.24	5.42	5.02	5.14	3.32	4.1	4.41	3.29	3.7
CaO	8.67	7.35	8.75	6.74	5.49	10.12	8.64	7.64	8.24	6.46	6.32	8.42	6.47	7.66
Na_2O	4.88	3.78	2.89	4.67	3.78	2.24	2.79	3.32	3.1	4.24	3.21	3.36	4.21	3.29
K_2O	0.95	2.93	0.89	0.88	1.32	1.24	1.41	1.24	1.42	1.57	1.43	2.3	1.42	2.92
P_2O_5	0.19	0.23	0.22	0.13	0.19	0.23	0.25	0.19	0.19	0.2	0.23	0.21	0.18	0.19
LOI	3.14	2.92	2.2	3.63	3.68	2.93	3.29	2.04	2.04	2.57	4.42	1.62	3.38	2.71
Total	100	99.97	99.98	99.99	99.99	100	100.0	99.01	99.97	99.99	99.98	99.97	99.99	100.2
CIPW NORM														
Q	--	--	12.45	--	--	--	0.5	--	0.67	2.26	5.46	--	3.55	--
Or	5.61	17.32	5.26	5.2	7.8	7.33	8.33	7.33	8.39	9.29	8.45	13.59	8.39	16.07
AB	37.49	31.99	24.45	39.52	31.99	18.95	23.61	28.09	26.23	35.88	27.16	28.43	35.62	27.84
An	17.2	15.01	26.48	17.12	17.66	30.32	25.12	23.54	22.74	18.6	24.1	16.79	20.87	18.57
Ne	2.06	--	--	--	--	--	--	--	--	--	--	--	--	--
Di	20.08	16.43	12.81	12.72	6.92	15.06	13.23	10.87	10.87	13.97	4.76	19.62	8.33	15.14
Hy	--	7.79	8.93	7.63	18.87	11.72	17.72	12.08	18.24	13.22	17.86	5.91	12.53	10.48
Ol	7.02	0.53	--	6.21	4.92	5.78	--	5.81	--	--	--	5.75	--	1.51
Mt	3.28	3.31	3.22	3.52	3.96	3.61	3.57	3.76	3.67	3.51	3.47	3.73	3.32	3.55
Il	3.68	4.16	3.68	4.14	3.76	3.76	4.06	3.99	3.59	4.06	3.78	4.05	3.59	3.74
Ap	0.44	0.53	0.51	0.3	0.44	0.53	0.58	0.44	0.44	0.44	0.53	0.49	0.42	0.44
Plag Comp.	31	32	52	30	36	62	52	46	46	34	47	37	37	40

TABLE - 7

CHEMICAL ANALYSIS OF PANJAL VOLCANICS, NAUSERI (NEELAM VALLEY)

	66-NUS-3	67-NUS-3	68-NUS-8	69-NUS-9	70-NUS-11	71-NUS-12
SiO_2	52.72	50.43	53.49	51.17	51.21	49.25
TiO_2	2.03	1.88	2.1	2.24	2.29	2.21
Al_2O_3	15.47	16.3	16.89	16.13	16.49	14.34
Fe_2O_3	9.61	11.39	9.23	11.37	10.32	12.24
FeO	--	--	--	--	--	--
MnO	0.27	0.29	0.18	0.26	0.24	0.14
MgO	3.62	3.79	3.12	3.21	4.1	5.12
CaO	6.12	6.11	6.19	6.46	6.27	7.27
Na_2O	4.32	4.01	4.32	4.12	4.1	3.58
K_2O	1.43	2.52	2.14	2.19	1.33	1.89
P_2O_5	0.22	0.24	0.21	2.26	0.15	0.18
LOI	4.17	3	2.13	2.57	3.6	3.78
Total	99.98	99.96	100	101.9	100.1	100

CIPW NORM

Q	2.52	--	1.24	--	0.5	--
Or	8.45	14.89	12.65	12.94	7.74	11.17
AB	36.56	33.93	36.56	34.86	34.86	30.29
An	18.6	19.04	20.38	19.05	22.63	17.48
Ne	--	--	--	--	--	--
Di	8.53	8.09	7.41	9.45	6.18	14.39
Hy	13.44	2.28	11.87	7.85	16.44	5.29
Ol	--	11.01	--	4.81	--	9.26
Mt	3.35	3.6	3.29	3.6	3.45	3.73
Il	3.86	3.57	3.99	4.25	4.35	4.2
Ap	0.51	0.56	0.49	0.6	0.35	0.42
Plag Comp.	34	36	36	35	39	37

TABLE - 7 (Contd)

CHEMICAL ANALYSIS OF PANJAL VOLCANICS, MANJOTAR (NEELAM VALLEY)

	36-MJ-8	37-MJ-10	38-MJ-12	39-MJ-13	40-MU-15	41-MJ-18	42-MJ-19	43-MJ-20	44-MJ-21	45-MU-17
SiO_2	47.31	57.76	52.34	53.42	51.35	49.42	50.24	55.36	52.13	49.32
TiO_2	2.13	2.14	1.97	1.58	2.17	2.11	1.58	2.14	1.82	1.98
Al_2O_3	16.53	13.52	15.18	16.24	15.17	15.32	15.42	14.42	14.23	15.63
Fe_2O_3	13.48	8.38	8.77	9.11	10.31	13.41	12.83	9.42	10.23	12.14
FeO	--	--	--	--	--	--	--	--	--	--
MnO	0.11	0.12	0.24	0.12	0.11	0.19	0.12	0.19	0.14	0.21
MgO	6.98	3.43	4.24	4.12	5.01	6.01	5.12	3.42	4.12	5.78
CaO	4.32	6.2	8.87	6.62	5.32	5.42	9.54	5.64	8.43	8.41
Na_2O	3.42	4.47	3.45	4.14	4.24	4.02	2.44	3.45	4.52	3.25
K_2O	1.54	0.67	0.91	1.32	1.42	0.74	1.05	1.87	0.27	1.72
P_2O_5	0.25	0.31	0.13	0.1	0.13	0.2	0.15	0.11	0.12	0.27
LOI	3.93	2.98	3.87	3.23	4.77	3.14	1.41	3.99	3.98	1.3
Total	100.00	99.98	99.97	100.00	100.00	99.98	99.90	100.00	99.99	100.01

CIPW NORM

	36-MJ-8	37-MJ-10	38-MJ-12	39-MJ-13	40-MU-15	41-MJ-18	42-MJ-19	43-MJ-20	44-MJ-21	45-MU-17
Q	--	11.81	4.76	2.69	0.15	--	2.13	9.54	1.54	--
Or	9.1	3.96	5.38	7.8	8.39	4.37	6.21	11.05	1.6	10.16
AB	28.94	37.82	29.19	35.03	35.88	34.02	20.65	29.19	38.25	27.5
An	19.8	14.85	23.25	21.83	18.17	21.57	28.02	18.34	17.74	22.98
C	1.98	--	--	--	--	--	--	--	--	--
Ne	--	--	--	--	--	--	--	--	--	--
Di	--	13.37	16.28	8.51	6.04	3.31	15.18	7.37	19.24	13.99
Hy	16.92	9.24	9.98	14.4	18.73	18.2	18.77	12.9	10.48	4.62
Ol	10.81	--	--	--	--	7.08	--	--	--	11.36
Mt	3.9	3.16	3.22	3.28	3.45	3.9	4.28	3.32	3.44	3.71
Il	4.05	4.06	3.74	3.00	4.12	3.82	3.00	4.06	3.46	3.76
Ap	0.58	0.72	0.3	3.00	0.3	0.46	0.35	0.25	0.28	0.63
Plag Comp.	41	28	44	38	34	39	58	39	32	46

TABLE - 8

CHEMICAL ANALYSIS OF PANJAL VOLCANICS, KAGHAN AREA

	1- BJ- 11	2- BJ- 14	3- BJ- 16	4- BJ- 18	5- BJ- 20	6- BJ- 21	7- BJ- 22	8- BJ- 24	9- BJ- 25	10- BJ- 27	11- BJ- 30	12- BJ- 32	13- BJ- 34	14- BJ- 35	15- BJ- 36	16- BJ 37
SiO_2	52.73	50.43	48.21	51.41	52.32	50.76	51.52	51.76	49.51	56.12	52.32	53.42	49.98	51.32	50.72	49.87
TiO_2	1.01	2.32	1.87	2.13	2.21	1.83	2.14	1.93	1.88	1.82	2.32	2.13	1.99	1.99	2.13	1.79
Al_2O_3	14.30	13.45	14.56	15.24	14.54	13.78	16.48	15.52	14.61	15.32	14.41	13.71	14.12	15.42	14.46	15.35
Fe_2O_3	12.40	11.25	13.64	11.10	11.86	12.22	11.23	11.45	13.20	12.40	13.20	13.51	13.33	11.78	12.83	13.15
FeO																
MnO	.17	.19	.12	.11	.12	.15	.13	.16	.11	.12	.11	.13	.14	.15	.12	.17
MgO	4.50	4.13	5.90	6.02	5.40	6.37	4.84	4.32	6.44	2.24	3.42	4.12	5.21	4.21	4.87	5.12
CaO	3.49	8.81	6.87	7.34	6.64	6.43	5.34	6.34	6.34	3.50	3.72	4.23	6.31	6.43	6.62	7.56
Na_2O	5.44	4.80	2.82	3.42	3.34	3.46	3.31	3.42	2.93	3.40	3.64	3.42	4.24	3.53	3.31	2.87
K_2O	1.06	1.84	0.78	0.94	0.85	0.89	2.24	1.87	0.47	3.14	2.12	1.82	0.91	0.82	1.32	0.78
P_2O_5	.11	.16	.17	.14	.12	.21	.18	.17	.12	.11	.13	.14	.21	.32	.14	.15
LOI	4.80	2.62	5.05	2.15	3.61	3.90	2.58	3.05	4.39	1.84	4.60	3.36	3.56	4.13	3.49	3.18
Total	100.00	100.00	99.99	100.00	100.01	100.00	99.99	99.99	100.00	100.01	99.99	99.99	100.00	100.00	100.00	99.99
CIPW NORM																
Q	--	--	0.75	1.42	5.28	1.09	1.04	1.84	2.49	7.83	4.37	5.95	--	4.29	2.14	2.33
Or	6.26	10.87	4.41	5.56	5.02	5.26	13.24	11.05	2.78	18.56	12.53	10.76	5.38	4.85	7.80	4.61
Ab	46.03	29.95	23.86	28.94	28.26	29.28	28.01	28.94	24.79	28.77	30.80	28.94	35.88	29.87	28.01	24.29
An	11.47	9.72	24.77	23.46	22.17	19.44	23.50	21.48	25.33	16.65	16.72	16.68	16.81	23.81	20.70	26.70
C	--	--	--	--	--	--	--	--	--	.23	--	--	--	--	--	--
Ne	--	5.78	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Di	4.28	27.28	6.79	9.85	8.18	9.11	1.50	7.35	4.40	--	0.74	2.83	10.89	4.99	9.30	8.16
Hy	14.50	--	26.27	20.69	19.48	24.24	22.07	18.61	28.10	18.67	21.65	23.18	12.15	20.08	19.93	23.11
Ol	6.74	5.41	--	--	--	--	--	--	--	--	--	--	7.18	--	--	--
Mt	3.76	3.60	3.94	3.57	3.52	3.73	3.58	3.61	3.87	3.76	3.87	3.91	3.89	3.65	4.28	3.86
Il	1.92	4.41	3.55	4.05	4.20	3.48	4.06	3.67	3.57	3.46	4.41	4.05	3.78	3.59	4.05	3.40
Ap	0.25	0.37	0.39	0.32	0.28	0.49	0.42	0.39	0.28	0.25	0.30	0.32	0.49	0.74	0.32	0.35
Plag Comp.	20	25	51	45	44	40	46	43	51	37	35	37	32	44	42	52

On the P_2O_5 vs TiO_2 tectonomagmatic discrimination diagram (Fig. 5) Ridley et al. 1974) the Panjal basalts plot almost entirely in the ocean ridge basalts and ocean island tholeiites fields. This discriminatory diagram clearly shows the oceanic character of these volcanics as P and Ti are more reliable and insensitive to alteration (Cann, 1971).

The major element discriminant diagram (Fig. 9) proposed by Mullen (1983) on the basis of TiO_2 MnOx10 - P_2O_5x10 is useful indicator of the tectonomagmatic environment of the Panjal volcanics. The geochemical data form the Panjal volcanics plot in the mid ocean ridge basalts, and ocean island tholeiitic fields. This discriminant diagram is consistent with the previous diagram of Ridley et al. (1974).

Majority of the Panjal volcanics plot in the fields which reveal submarine environment. However, Papritz and Rey (1989) have pointed out Panjal basalts as continental flood basalts in Kaghan and Muzaffarabad area. Honegger et al. (1982), have also indicated Panjal volcanics as continental flood basalts. The field evidences support the submarine origin of these rocks, which include bedded chert (from few cm to 35 cm thick) which extends laterally for more than 3 km within the volcanics. Intertrappean limestones are also common in the Panjal volcanics. Pillow lava is developed in Kahuta, Muzaffarabad and Kaghan areas. The geochemical data further support the field evidences.

The TiO_2 contents of the Panjal volcanics suggest that the degree of partial melting of the source region of the magma was 13-15% (Sun et al. 1979).

The tholeiitic character of the Panjal volcanics represent that Panjal magma was derived by extensive partial melting of the mantle material (Gast, 1965). The plots of MgO values (Fig. 6), absence of olivine crystals, and lower values for Ni, Cr and Co (Tables 5 to 8) in these rocks suggest that during evolution of magma from source to surface olivine was removed, which is further strengthened by low Mg-number (100 MgO/MgO + FeOt) from 33-49.

The plots of the Panjal volcanics on discriminant diagrams for tectonic setting indicates that Panjal lava erupted in a continental rift tectonics to submarine environmental conditions. The eruption of the Panjal lava occurred in two phases. First agglomerates were formed during Carboniferous time. while with the opening of geofracture during Permian to Triassic times on the northern margin of Gondwana land Panjal lava flows were formed. Rifting lead to the development of the Panjal ocean. The depth and width of this ocean is not known but possibly a shallow ocean basin was developed. Pillow lavas in the Panjal volcanics, bedded chert and intertrappean limestones indicate submarine conditions, Pillow lava has also been reported by Nakazawa et al. (1973) in Srinagar area. All these field evidences are consistent with the geochemical data plots on different tectonomagmatic discriminant diagrams.

SUMMARY AND CONCLUSIONS

The Panjal volcanic rocks are dominantly tholeiitic to slightly alkalic basalts. Agglomeratic slates and tuffs are abundant at the lower part of the volcanics, suggesting subaerial or shallow water marine environmental conditions. Agglomeratic slates reveal the initial phase of volcanism.

The lava flows are hydrothermally altered (possibly at sea floor) moderately to spilites formation. The rocks contain local interbedded cherts, Triassic limestones, and pillow lavas. These features show that these rocks are of submarine origin.

The chemical composition of the Panjal volcanics show that the magma had undergone strong fractionation with sepration of olivine and pyroxene. Chemically the rocks are tholeiitic to slightly alkalic.

On the basis of geochemical data the Panjal volcanics on tectonomagmatic discrimination diagrams mainly plots in the fields of oceanic affinity. However, geochemical data points from rift stage to oceanic conditions. Eruption of agglomerates succeeded by lava flows caused initial rifting of the northern margin of Indian continent with opening of the ocean basin in which Panjal volcanics with interbedded chert and pillow lavas were formed.

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PETROCHEMICAL INDICES OF THE SARIR SANDSTONE, SIRTE BASIN, LIBYA, A GUIDE TO ITS PROVENANCE.

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ABSTRACT:- The Lower Cretaceous sequence of the Sirta Basin Libya, includes a spectrum of feldspathic sandstone types varying in petrography and chemistry from subarkose at one extreme to arkosic wacke at the other extreme. On the basis of their chemical characteristics and texture, the sandstones are immature. An accurate assessment of the framework modes reflects similarities of the studied suite with sandstones ascribed to the craton interior type provenances. High Quartz contents and high ratios of K. feldspar to plagiocalse in these rocks suggest intense weathering on the exposed shield area with low relief and prolonged transport.

INTRODUCTION

The sarir sandstone constitutes the lowest stratigraphic unit and overlies the granitic basement in the Sirte Basin, Libya. It consists mostly of sandstone with intercalations of siltstone, shale, lignite and pockets of loose sand. Traces of anhydrite are common in the sandstone unit.

The sandstone is very fine to medium grained, poorly sorted with a clayey and/or calcareous matrix. It is considered equivalent of the wide spread, non-marine Nubian sandstone (Barr and Weeger, 1972) which covers a large area in the south eastern and south western Libya (conant and Goudarzi, 1964).

Based on the plant fossils and pores, the sandstone sequence has been assigned a Lower Cretaceous age (Viterbo, 1969). Lower Sirte Shale and Lidam Dolomite of Upper Cretaceous age unconformably overly the Sarir Sandstone.

Interpretations of the recent seismic survey, carried out in Sirte Basin, reveal several structural closures in the Sarir Sandstone as well as in the several younger stratigraphic units. To evaluate its hydrocarbon potential, the Sarir Sandstone has been penetrated at several shot points where seismic interpretations reflect a good picture on the contoured horizons.

Handspecimens were obtained for detailed petrographic and chemical studies from subsurface sections penetrated by exploration wells in the south Sirte Basin.

PHYSICAL CHARACTERISTICS

In hand specimens, the sandstone exhibits greysih white colour, especially when the matric material is present only in traces. Sandstone, with a clay or calcitic matrix, shows, a greenish grey colour.

PETROGRAPHY

Quartz is the major detrital mineral. Average grains are 0.8 x 0.44 mm across, mostly subangular and irregular in shape. The grains are mostly monocrystalline, occasionally showing an undulatory extinction. Authigenic silica in the optical continuity with the detrital grains is common. In some sections, quartz grains are spotted, etched and show zircon inclusions.

Feldspar is the next abundant detrital constituent. It is comparatively more rounded than quartz. Grains of both kinds of the major feldspars (alkali - and plagioclase feldspar) are identified. Orthoclase and microcline grains are fresher and more abundant than the plagioclase. The later has been, in extreme cases, completely kaolinized.

Being rich in mica, some of the sandstones from the studied suite are classified as micaceous. Muscovite is the major mica and occurs in well-defined plates. Sometime it is present in the form of shreds. In some sections, the muscovite flakes show bending because of the compaction of grains. Biotite is present only in traces.

Calcite, when occurring as distint grains, shows sutured contact with the quartz and feldspar grains. It is also present as an important cementing material is some sections.

Only sample No. 2 (Table 1) contains gluconite up to about 16% but generally it is present only in traces.

Important accessories include epidote, tourmaline, chlorite, ore minerals and sphene.

On the basis of the relative porportions of quartz, feldspar grains and rock fragements in the detrital framework and the volume proportion of the detrital fraction to the matrix, these sandstones are

subarkose to arkosic wackes according to most definitions. (Pettijohn, Potter, and Siever, 1972; Pettijohn1975 etc).

CHEMISTRY

Five representative samples of sandstone from the Sarir group were analysed for major elements by atomic absorption and spectrophotometer. Al_2O_3 was determined by titration against E.D.T.A. solution, and SiO_2 by gravimetric methods. Results are given in Table 2. Oxide ratios corresponding to maturity index, defined in chemical compositional terms are also listed inteh same table. Mean composition of the principal sandstone classes and overall average from the studied suite are compared with equivalent representative compositions in Table 3.

The Average sandstone composition from the Sarir group differs from the average sandstone of Pettijohn, (1975), mostly in terms of the CaO content by virtue of the abundance of calcite. The average subarkose composition (col. 4, Table 3), too, is rich in CaO and is regarded as calcareous. There is a striking similarity in the analyses listed in col. 4 and 5 of table 3. Analysis in col. 5 corresponds to the chemical composition of the representative calcareous subarkose (Keith, 1940).

The low SiO_2/Al_2O_3 ratios listed in Table 2 are attributed mostly to the abundance of feldspar and muscovite, which are the major alumino-silicate present is these sandstones. The content of total alkalis varies from 1.22% to 2.93% with an average value of 1.8%.

The Na_2O/K_2O ratio is slightly more than 1 in most cases except in the anlysis No. 2, which shows more K2O than Na_2O. On a plot of Na_2O vs. K_2O (Fig. 1), the data points, therefore, exhibit a spread along the diagonal line separating the field of feldspathic graywacke from arkose.

However, when the Na_2O/K_2O ratios are considered in a plot of SiO_2/Al_2O_3 vs. Na_2O/K_2O (Fig. 2), the analyses are confined mostly to the subarkose field.

The SiO_2/Al_2O_3 ratios, when employed as maturity index indicator (Pettijohn et. al 1972), signify the immature nature of these sandstones. The high content of the total alkalis further classify these rocks as of alkali metal-rich type.

DISCUSSION

A meaningful provenance assessment of the Sarir Sandstone must be based on broad studies of these rocks, but the present work, which is restricted to the petrographic and chemical evaluation of the selected samples, does permit certain predictions regarding the interpretation strategy.

It has long been recognized that a variation in the dertrital sand framework compositions is a function of the type of the source terrain and in addition, of the relationship of the source to the depositional basin which is governed by plate tectonics. This view, originally defined by Crook (1974) and Schwab (1975) has been more meaningfully applied by Dickinson . and Suczek (1979) in distinguishing the provenance type of a specific sandstone suite from the mutual relationship of different grains or group of grains in the detrital framework.

After an extensive study of modern marine and terrestrial sand framework modes from known tectonic settings, the relationship between the sandstone compositions and the relative tectonic settings has been standardized with the help of various triangular plots, each involving different sets of grain populations.

On the basis of the available data, only one such plot i.e., QFL can be employed for the provenance assessment of the Sarir Sandstones. After plotting the framework modes from Table 1 in Fig. 3, rocks from the studied suite exhibit maximum coherence with sandstones derived from non-orogenic continental blocks. In greater details, these are more identical with the sandstone of the type derived from the craton interior provenance. The high quartz contents and the abundance of K-feldspar over plagioclase in sandstones as observed in the studied suite are ascribed by Dickenson and Suczek (1979) to the intense weathering on cratons with low relief and long-distance transport of the sediments across continental surfaces.

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TABLE 1

Mineral Composition (%) of the representative sandstone specimens.

No.	Name	Quartz	Feld-spar	Musco-vite	Bio-tite	Rock frag-ments	Calcite	Glau-conite	Chlorite	Ore	Tour-maline Mine-rals	Clay Mine-rals	Sphene	Zircon	Epidote
1.	Arkosic Wacke	60	6	18	Tr	1	13	Tr	Tr	1	1	-	Tr	Tr	-
2.	Subarkose	63	5	8	Tr	3	4	16	Tr	Tr	-	-	Tr	Tr	Tr
3.	Subarkose	85	8	3	-	1	Tr	Tr	Tr	1	-	-	-	-	-
4.	Arkosic Wacke	70	8	1	-	1	2	Tr	Tr	Tr	-	16	-	Tr	1

Tr = Traces

Relative proportions of Quartz, Feldspar and Rock Fragments in the detrital framework.

		Quartz %	Feld-spar %	Rock Frag-ments %
1.	Arkosic Wacke	89	9	2
2.	Subarkose	89	7	4
3.	Subarkose	90	9	1
4.	Arkosic Wacks	89	10	1

Table 2

Chemical compositions of sandstones from the Sarir Group

Sample Identity	1	2	3	4	5
Oxides					
SiO_2	72.53	80.21	88.71	87.35	88.12
Al_2O_3	3.85	4.75	2.92	2.10	2.93
$Fe_2O_3^*$	2.23	1.32	1.32	0.95	0.94
MgO	2.95	0.20	0.25	0.20	0.40
CaO	13.25	7.60	0.90	1.66	3.00
Na_2O	1.09	0.68	0.96	1.70	0.69
K_2O	0.76	0.73	0.78	1.23	0.53
TiO_2	0.15	0.00	0.06	0.08	0.00
P_2O_5	0.16	0.12	0.00	0.00	0.10
MnO	0.04	0.00	0.02	0.00	0.51
H_2O	0.16	0.18	0.29	0.33	0.29
Ignition Loss	2.49	4.12	3.32	3.47	3.72
Total:-	99.66	99.82	99.53	99.07	100.03
Oxide Ratios:					
SiO_2/Al_2O_3	18.84	16.89	30.38	41.59	30.10
Total Alkalis	1.84	1.41	1.74	2.93	1.22
Na_2O/K_2O	1.43	0.93	1.23	1.38	1.30

*Total iron expressed as Fe_2O_3

Table 3

Mean composition of Principal sandstone classes from the Sarir Formation compared with representative anlayses of suborkose and average sandstone.

Oxides	1	2	3	4	5
SiO_2	83.38	84.86	82.67	84.46	87.92
Al_2O_3	3.31	5.96	2.96	3.84	2.86
$Fe_2O_3^*$	1.35	1.79	1.37	1.32	0.78
MgO	0.80	0.52	1.18	0.23	0.20
CaO	5.28	1.05	5.97	4.25	3.41
Na_2O	1.03	0.76	1.16	0.82	0.01
K_2O	0.80	1.16	0.84	0.76	1.98
TiO_2	0.06	0.41	0.08	0.03	-
P_2O_5	0.07	0.06	0.09	0.06	-
MnO	0.11	traces	0.18	0.01	-
H_2O	0.25	0.27	0.26	0.24	-
Ignition Loss	3.42	1.01	3.23	3.72	3.35
Total:-	99.15	99.32	99.99	99.74	99.65

Oxide Ratios:

SiO_2/Al_2O_3	25.19	14.24	27.92	21.99	30.42
Total Alkalis	1.84	1.92	2.00	1.58	1.98
Na_2O/K_2O	1.27	0.66	1.34	1.08	0.01

1. **Average Sandstone. Sarir Formation**
2. **Average Sandstone. Composite Analysis of 371 Sandstones (Pettijohn, 1963, P. 15).**
3. **Average Arkosic Wacke. Sarir Formation.**
4. **Average Subarkose. Sarir Formation.**
5. **Calcareous Subarkose (Cambrian or Ordovician), Bastard Township, Ontario, Canada (Keith, 1949) Reported by Pettijoh, 1975 P. 216.**

Source: After Pettijohn, (1975) Table 7-5.

***Total iron expressed as Fe_2O_3.**

Fig. 1. Plot of Na_2O vs. K_2O from the analyses of the Sarir Sandstone. Stipple outlines area of analyses.

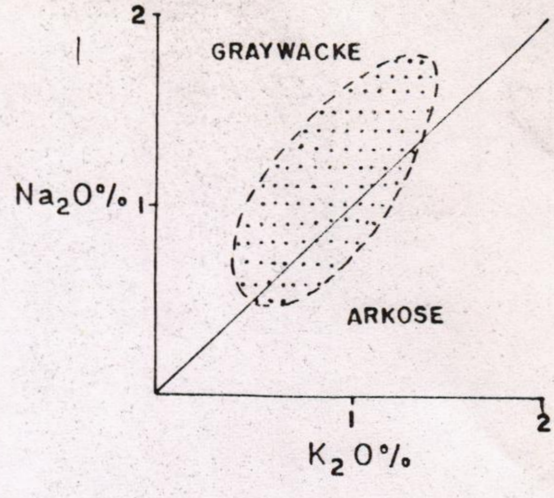


Fig. 2. Plot of the SiO_2/Al_2O_3 vs. Na_2O/K_2O ratios of the Sarir Sandstone. Stipple outlines are of analyses.

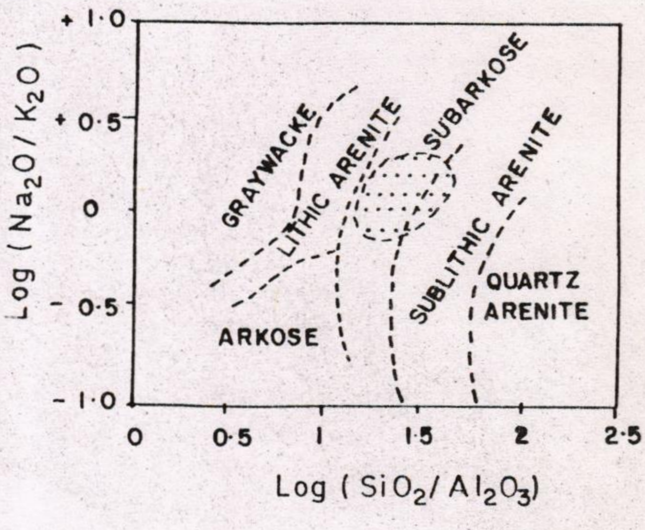
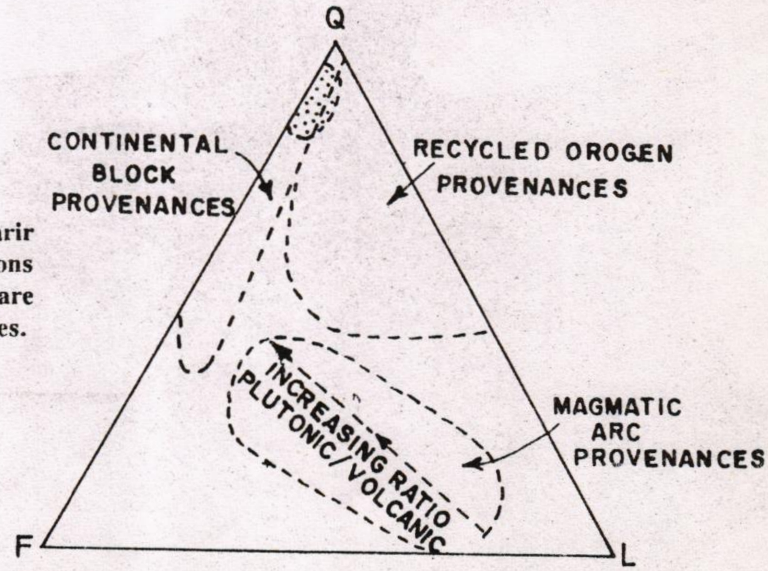


Fig. 3. Ternary QFL plot of samples from the Sarir Sandstone. The tectonic provenance regions of Dickinson and Suczek (1979, Fig. 1) are also shown. Stipple outlines area of analyses.



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GEOLOGY AND EMERALD MINERALIZATION OF BARANG-TURGHAO AREA, BAJAUR AGENCY, PAKISTAN

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ABSTRACT:- Geology and emerald mineralization of Barang-Turghao area have been studied for the first time. Rocks of the area are comprised of (a) granite gneisses, arenaceous, calcareous and argillaceous metasediments (rocks of Indian Plate) and (b) greenschists, greenstones, quartzites, gabbros and talc-carbonates (ophiolitic melange zone). Emerald mineralization is associated with talc-carbonates. Petrographic and field studies reveal that this mineralization is pneumatolytic, post tectonic and structurally controlled. The source of the beryllium bearing fluids, responsible for emerald mineralization could be the non-foliated younger granites in the surroundings. It is also supported by the presence of blue beryl in the area. Other minerals which may have some economic significance are hessonite garnet, green garnet, epidote, graphite and apatite.

INTRODUCTION

The geology and emerald mineralization of Barang-Turghao area have been studied and reported for the first time. The field studies were carried out as a part of gemstone exploration programme in the Bajaur Agency.

Emerald has been mined from Amankot, Barang by the locals for the last 15 years but very little geological information existed about the area.

Barang and Turghao occupy the eastern and southeastern part of the Bajaur Agency. These areas are quite inaccessible and connected with Malakand Agency and Khar (the headquarter of Bajaur Agency), only by muel and foot tracks. Khar is located at a distance of about 200 kms from Peshawar on main metalled road which connects Timurgara with Peshawar. Amankot is the main locality of the Barang area. The mapped area lies between longitude 71^{o} to 30 71^{o} 45' and latitude 34^{o} 31.75' to 34^{o} 45' (Fig 1). Barang and Turghao can also be approached from Selai Patti and Agra of Malakand Agency by foot tracks. Suspension and cradle bridges at places are used to cross Swat River for entering into Bajaur Agency.

The area is drained by the Barang and Turghao Khwars which ultimately fall into River Swat. Altitude of the area is from 750 to 2475 meters above mean sea level.

As stated earlier very little geological information existed about Bajaur Agency. However, Kakar et al. (1971) and Badshah (1979) have described the general geology of a part of the Bajaur Agency.

Badshah (1979) included epidote-chlorite schists, talc carbonate schists and peidmontite schists in meta-sediments of Paleozoic age. He correlated Nawagai limestone group with the Banna Formation of Allai area, placed by Tahirkheli (1979) in the Besham group of Paleozoic age.

GEOLOGY

Geologically the area under study consists of rocks of Indian Plate and Kohistan sequence with a melange zone which has been developed along a major fault running approximately north-south (Fig 2). The geology of the area is similar to the geology of Indian Plate edge and MMT suture zone exposed in Swat, Dir and Malakand and described by Chaudhry et al., (1974, 1976, 1986), Ashraf and Chaudhry (1977), Hamidullah et al., (1986), Hussain et al., (1984) and Kazmi et al., (1984). The rock sequence exposed in the area is as follows:-

Kohistan Sequence	Amphibolite etc.	Cretaceous
	--------------------Main Mantle Thrust------	
Melange Zone	Talc carbonates Ultrabasics Gabbros Green schists/stones Amphibolites Metasediments	Cretaceous to Paleocene.
---------------Thrust---	--	
Indian Plate	Carbonatites Minor Granite bodies	Tertiary
	Graphitic schists Garnetiferous calcareous rocks Quartzite/Quartz mica schists	Middle Paleozoic to Pre-Cambrian
	Granite gneisses	Cambrian/ Pre-Cambrian

INDIAN PLATE ROCKS

1. Granite Gneiss

Three outcrops of granite gneiss are exposed in the area.

(i) KOT GRANITE GNEISS:- The south western extension of Malakand granite gneiss is exposed in the south eastern part of the mapped area. It is medium to coarse grained and well foliated. Quartz, feldspar biotite and muscovite are the main mineral constituents recognizable in hand specimen. Granitised metamorphics are commonly associated with granite gneiss. These screens are of siliceous rocks, garnet mica schists and garnetiferous schists. The amount of mica is higher in the screens than in the gneiss. Blue beryl and fluorite mineralization is observed in quartz lenses and pegmatites in a three hundred to five hundred feet wide zone along the contact in Batoo and Barh areas (not indicated in map no. 2). Pegmatite veins/lenses observed in this granite gneiss can be classified as follows:-

a. Quartz-feldspar pegmatites
b. Quartz-feldspar-mica pegmatites
c. Quartz-feldspar-mica-fluorite pegmatites.

(ii) SELAI PATTI GRANITE GNEISS:- A north east-southwest extending medium to coarse grained leucocratic outcrop of granite gneiss is exposed in the Selai Patti area. Ferromagnesian minerals are relatively more abundant in this gneiss than the one described earlier.

This granite gneiss overlies the siliceous metasediments and is overlain by a thin bed of carbonatite. Both the contacts are sharp and parallel to the foliation of the gneiss. Selai Patti granite qneiss contains a number of pegmatites and patches of surrounding country rocks, i.e. siliceous schists. The pegmatites, on the basis of texture and mineralogy, can be classified as under.

a. Feldspar-quartz-amphibole pegmatites:- Feldspar and amphibole are the main minerals whereas quartz is present in small amount. Besides the large lath shaped crystals of feldspar, dark green to black megacrysts of amphibole 3 x 2 cm in size are quite abundant.

b. Feldspar-amphibole-siderite-garnet pegmatites:- These medium to coarse grained, quartz, feldspar, muscovite, biotite and amphibole bearing pegmatites also contain carbonates (mostly siderite). Brown to reddish brown garnet probably andradite, is found in this type of pegmatites. Individual garnet crystals range from 2 mm to 1.5 cm in size and are translucent to opaque. These garnets are associated with siderite.

c. Feldspar-quartz-amphibole-garnet -pegmatities:- These pegmatites contain megacrysts of feldspar. Amphibole is present in small amounts. Brown to reddish brown garnet, probably andradite, is found in these pegmatites in quartz-o-feldspathic groundmass.

d. Rutile bearing pegmatites and quartz veins:- Rutile crystals ranging in size from 0.5 x 1 cm to 1.5 x 2 cm are found mineralized in a few localized hydrothermal veins and pegmatites which are associated with the granite gneiss and the metasediments.

iii. Agra-Turghao Granite Gneiss:- Another large outcrop of granite gneiss covering an area of about 100 sq. kms in the northern part of the mapped area extends further towards N-NE. Agra-Turghao granite gneiss is overlain by metasediments i.e. quartzite and quartz mica schist. It is composed of quartz, feldspar, muscovite alongwith garnet as accessory mineral. In the southern part greisening has produced more silica and mica in the granite gneiss. It shows good foliation due to alignment of its constituents. Some coarse grained granitic apophyses, probably younger in age, are observed in the gneiss near Bazargai and Narangi Banda villages. Garnet is rarely present in these granitic rocks. Agra-Turghao granite gneiss is cross cut at places by few doleritic dykes of upto 90 metres width and 150 metres length. Screens of metasediments are present in the granite gneiss. Along the contact a mixed zone of granite gneiss, quartzite and quartz mica schist has been developed.

Quartz veins and pegmatites are observed in this granite gneiss. Pegmatites exhibit ptygmatic folding at few places.

2. Metasediments

Metasediments are the part of marginal rocks of the Indian plate. These show marked lithological variations and are metamorphosed upto amphibolite facies. These can be classified into the following rock units:-

(i) Quartzites/Quartz Mica Schists:- Quartz mica schist overlies granite gneiss in Agra, Selai Patti and Turghao areas and occurs as a north-south extending outcrop in the central part of the mapped area.

Massive, compact, thinly to thickly bedded and well jointed quartzites are found within quartz mica schists at Turghao, Katwai Kabar etc. These are fine to medium grained and dirty white, brown and greyish brown. Texturally these rocks are granoblastic to poorly schistosed. Quartzites, with increase in micaceous contents, grade into quartz mica schists. Quartz and biotite are the main minerals whereas chlorite is present locally.

(ii) Garnetiferous Calcareous Rocks:- Garnetiferous calcareous rocks are grey, greyish brown, rusty brown and fine to medium grained, exposed in the south eastern and central part of the mapped area. Extending in northeast-southwest direction, another larger outcrop of garnetiferous schist is also present within melange zone in Takhat Kandao area.

Presence of garnet and intercalations of calcareous schists and marble are prominent features of these schists. The rock exhibits porphyroblastic texture. Garnet is brown, reddish brown and varies in size from 3mm to 1cm. Garnet is opaque, however, locally small translucent crystals are also found. Calcareous beds sometimes contain pyrite and black tourmaline.

(iii) Graphitic Schists/Gneisses:- Graphitic schists are exposed near Katwai Kabar, Turghao and Bagh areas associated with siliceous rocks in the form of thin beds and lenses. These are grey to deep black in colour. Colour depends upon the quantity of graphite and carbonaceous matter. Graphitic contents vary from 2 to 15% approximately and these are maximum in beds near Turghao. Within graphitic beds intercalations of other rocks such as siliceous schists and quartzites are found. Graphitic beds are upto 15 metres wide and may extend upto thousands of metres. Presence of ochre is a significant character which imparts maroon and reddish brown colour to the rock. Microfolding and crenulations are common. Quartz veins upto few centimetres thick can be observed within the graphitic schists.

Graphitic schists make another rock unit extending from Mohmand Agency towards Amankot, Barang Valley. These rocks act as host of the mineralized talc carbonates. Micaceous sheen is shown by the rocks due to the presence of chlorite and micaceous minerals. Some beds are high in chloritic contents. Therse are greenish grey in appearance. Quartz veins of milkv colour upto 15 cm thick are observed in Amankot area. These veins sometimes cross cut the rock foliation.

(iv) Undifferentiated Metasediments:- Rocks of this unit have not been differentiated on the map. It is comprised of graphite chlorite mica schist, graphitic schist and garnetiferous schist. These are extensively developed in south and south western part of the mapped area. These rocks are grey, brownish grey and greenish grey in colour. Chlorite, graphite, mica, quartz and carbonate are the main mineral constituents. Graphitic and chloritic contents of the rock vary at places. Black graphite bands having high graphite are present in the rocks of southern part. Garnets are developed at a few places only. Quartz veins and lenses are present along and across the foliation and sometimes show pinch and swell structure. Graphite-chlorite-mica schists also contain intercalated calcareous schists and marble.

3. Carbonatites

Occurrence of carbonatities in Selai Patti, Malakand was first reported by Ashraf and Chaudhry (1977). Subsequently, some analytical work was carried out by Ashraf, chaudhry and Hussain (1987). Detailed geological mapping and field studies were carried out on Selai Patti carbonatites during the present investigations. Besides those reported by Ashraf & Chaudhry (1977) and Ashraf et al., (1987), a few more carbonatites have been found in Turghao and Barang areas which are associated with arenaceous metasediments. Carbonatites of the area are described below:-

(i) *Selai Patti Carbonatites*:- Northeast-southwest extending tabular sill type carbonatite is exposed in Selai Patti area along the contact of granite gneiss and siliceous metasediments. Carbonatite overlies Selai Patti granite gneiss and is overlain by siliceous metasediments. Both the contacts are sharp and almost parallel to the foliation and the schistosity of the underlying and overlying rocks. Carbonatite is 30cm to 6 metres thick and 3 km long. It is white to dirty white, rusty brown and medium to coarse grained granular rock. Its weathered surface shows sugary texture. Besides carbonate minerals, amphibole, pyroxene and vermiculite flakes are present in the form of small rounded patches. Transparent to translucent grains of apatite and sphene, 1mm in size, are present in the rock. Pyrite is abundantly present in carbonatites and it shows alteration to iron oxides. Euhedral to anhedral green garnet is also commonly present in this rock especially towards its southern end. Individual garnet crystals range is size from 1 to 2 mm. However, largaer crystals are also present locally. Anhedral garnets are generally fractured and occur as aggregates. Towards southwestern end carbonatite is white and shows presence of feldspathic matter. Other minerals like sphene, biotite, amphibole and pyroxene are not visible in hand specimen in this part of the carbonatite.

Besides this linear body of carbonatite, another ring shaped carbonatite, 6 metres in diameter, is also present within granite gneiss. It encircles the siliceous schists. The mineralogy is similar to that of the main carbonatite outcrop. It may be the continuation of the first body which has been exposed at this place in the form of a ring, as a result of folding and subsequent erosion.

(ii) Turghao-Bagh Carbonatites:- Carbonatites, 1.5 metres to 6 metres thick and of variable length, are exposed at five localities within a linear distance of 2 km between Turghao and Bagh villages. The extension of these carbonatites has not been traced. The position of carbonatites varies at different places. They occur within arenaceous schists as well as along the contact of granite gneiss and siliceous schists.

(a) Turghao Carbonatite:- A 1.5 metres wide and almost 15 metres long carbonatite body occurs within siliceous schists. it is brownish, earthy white and medium to coarse grained rock. Carbonatite is massive, jointed and sheared at palces. Along the joints and shear zones, quartz-o-feldspathic material is present. Graphite beds are also present in the surrounding siliceous shists. The mineral contents of carbonatites and their associations are described in Fig. 3

(b) Andarai Carbonatite:- Another carbonatite body occurs at GR 781571 towards west of Andarai village within siliceous schists. Carbonatite is 3 to 4.5 metres thick, medium grained and white to rusty brown in colour. It is massive and jointed. Faulting and shearing is prominent. Along sheared zones and faults clayey and feldspathic matter is present. Calcite, biotite, vermiculite, pyrite and garnet can be identified in hand specimens. Light violet coloured actinolite? is also associated with green garnet in the calc-o-feldspathic mass. Pyrite is generally altered to iron oxides along the margins, however, towards core the alteration is less conspicuous.

(c) *Bagh Carbonatite*:- Another carbonatitie body within siliceous schists at coordinates 663654 of toposheet No. 38 N/10, contains green garnet crystals which are disseminated through out this rock. Size of the garnet crystals varies from specks to about one cm across. At some places garnet in aggregates is also present. Besides calcite, other rock constituents are pyrite, vermiculite, muscovite and violet amphibole?. Quality of the green garnet is generally not good. These are anhedral to subhedral and translucent to opaque.

4. Bagh Granite

A granitic body is exposed within metasediments near village Andari and Bagh. It is roughly 2 x 0.5 km in size. Granite is massive, fine to medium grained and shows poor alignment of minerals. In hand specimen grain size of the constituent minerals varies. Feldspar, quartz, biotite, epidote and amphibole are the recognisable minerals.

ROCKS OF MELANGE ZONE:

A north-south stretching ophiolitic melange zone comprising of lenses and blocks of altered and unaltered ultrabasic, basic, volcanic, and metasedimentary rocks runs through Barang valley via Tar and Amankot. This zone appears to be the continuation of Kot melange zone (Hussain et al. 1984). Towards north, it is truncated by Main Mantle Thrust. Thickness of the melange zone varies at places and it attains a maximum thickness near Titobai. Ophiolitic melanges have been emplaced along a number of faults which are usually marked by talcose rocks.

Rocks of the melange zone have angular relationship with overlying calcareous schists. The rock fragments or blocks in the melange zone vary in size usually from few metres to hundreds of metres in longer dimension. However, larger outcrops of ultrabasics, basics and volcanics may range upto thousands of metres across.

These rocks have been subjected to deformation resulting in the formation of tight folds, fractures and faults. Various rock units of the melange zone are described in the following.

(i) *Talcose Rocks*:- Field and laboratory studies indicate that these rocks are the altered ultrabasics. These occur as lenses, patches and sheets of various sizes. Talcose rocks consist of talc, carbonates (mainly magnesite), quartz, actinolite, iron ore, etc. On the basis of relative quantity of talc and carbonates these can be further subdivided into following three types:-

i. Talc schist
ii. Talc carbonate schist
iii. Carbonate rock

Talc schists are talc rich rocks which are foliated and schistose and exhibit tight drag folding. Other accessory minerals may include quartz and carbonate. Talc carbonate schists contain almost equal quantity of talc and carbonate. Soapstone is also associated with talc carbonate schist. It is fine grained, buff coloured rock with rusty brown weathered surface. Carbonate rocks are carbonate (dominantly magnesite) rich with small quantity of talc. These are massive, well jointed and contain abdundant quartz and calcite veins. Lenses and nodular quartz veins and stockwork are sometimes lined by chlorite and fuchsite.

Talcose rocks especially in Titobai and Amankot areas contain phacoids of green schist. Actinolite is developed in talc carbonates at their contacts with metasediments. At these places talc carbonates appear to be metasomatically altered. This is indicated by the presence of feldspar and whitish clayey matter in abundance. Some of the altered bodies are highly feldspathic with chlorite, actinolite, muscovite and quartz as accessory and minor minerals. These patches are upto a few feet across in size.

Emerald mineralization is found in talcose rocks towards north of Amankot. A number of greenstone blocks are found associated with talcose rocks. Silicification of these rocks is also observed and emerald has been mineralized in the silicified parts. Siliceous schists and quartz-schorl rocks are associated with the talc carbonates in the mine area of Amankot.

(ii) *Ultrabasics*:- Although ultrabasics other than talc-carbonates are not exposed in the mapped area, however, these are a part of the melange in the southern area. Serpentinite is the dominant rock type, whereas, pyroxenite and hornblendite also occur. Serpentinites are fine grained, green, greyish green and grey coloured. These are massive and well jointed rocks. Hornblendites are greenish black in colour. Asbestos is developed along the joints and faults in serpentinites. At some places chromite veinlets are seen. Outside the Barang area, ultrabasics contain chromite lenses.

(iii) Green Stone/Schist:- These are blocks and lenses of metamorphosed volcanic and volcano-sedimentary rocks present within the melange zone. These rocks are more pronounced in Ragsar area. Greenstones usually occur in the form of massive horizons but can also be noted in the form of large blocks enclosed in talcosed rocks. Greenschist is greyish green on fresh and weathered surface. Schistosity is well developed due to the presence of platy minerals of which chlorite is dominant one. Feldspar, epidote, carbonate, quartz, mica and magnetite/pyrite are the other minerals. Chlorite alongwith quartz makes the groundmass but veins and veinlets of quartz are also noteworthy. Pyrite crystals are developed along the micro joints as well as in the groundmass. In comparatively less schistosed green schists, carbonate is the major mineral constituent along with chlorite, quartz and mica. Lithology and texture of the rock favour its sedimentary origin.

Greenstones are the massive rocks showing relic igneous texture. These are fine to medium grained rocks having brown, brownish green and greyish green colour on weathered surface and green with whitish specks at some places on fresh surface. The rock comprises chlorite, epidote, feldspar, quartz, carbonate, mica and opaque mineral. Veins and veinlets of quartz, calcite and epidote are noticable. These rocks can be correlated with the greenstones of Prang Ghar, Shangla and Charbagh. Greenstones have faulted contacts with surrounding rocks.

(iv) Gabbros:- Gabbros are encountered in the melange zone in the form of small blocks. Besides, a huge gabbroic body is present in the area to the west of Takhat Kandao. It has contacts with garnetiferous calcareous rocks and siliceous schists. Fresh rocks are brownish green, light green to whitish green. These are usually medium grained. Pyroxene, amphibole and feldspar are the dominant mineral constituents. In the melange zone gabbroic lenses are observed associated with ultrabasics.

(v) Quartz Mica Schist/Quartzite:- These siliceous rocks, found in the melange zone, are light grey to whitish grey in colour. Mineral constituents are quartz, mica, carbonate and chlorite. Quartz veins upto one metre thick and four metres long are found. Chlorite is conspicuously developed in quartz mica schist near its contacts with other rocks. All the minerals are generally aligned. Crenulations and dragging effects characterised by jagged surfaces are pronounced.

Some quartzites are also observed in the melange zone in association with quartz mica schists. These are dirty white to whitish grey in colour, mostly thinly bedded and showing irregular fractures, joints and tight folding. Compared with schists, these are hard, massive and medium to coarse grained. Platy minerals like chlorite and mica are present in small quantity.

(vi) Amphibolite:- A number of amphibolite blocks have been observed in the melange zone towards south of Titobai area. These are greenish black with white specks and thin layers of light coloured minerals. Amphibole, feldspar, epidote and quartz are recognisable minerals in hand specimens. Amphibolites and associated quartz bands are highly folded and crenulated.

(vii) Calcareous Rocks:- Some calcareous blocks have also been noticed in the melange zone. These are the broken parts of the overlying calcareous rocks and have already been described under the metasedimentary rocks.

PETROGRAPHIC STUDIES

A total of thirteen rock samples from Turghao and Barang areas were selected for petrographic studies. The rock types studied petrographically include talc-carbonates, Selai Patti granite gneiss carbonatites, greenstone, quartz schorl rock associated with S-type granite, graphite schist/gneiss and graphite - talc schist. Their mineral composition is given in Table 1 to 4. Unit wise mineral characteristics are summarised below:-

TALC CARBONATES:- Talc Carbonates exhibit gneissic structure and are porphyroblastic. They are fine grained and comprise talc, magnesite and limonite. Talc constitutes about 60% of the whole rock mass. Magnesite occurs as tiny grains and porphyroblasts. Talc flakes envelope the magnesite porphyroblasts. Limonite occurs as streaks and specks.

GRANITE GNEISS:- Granite gneiss is hypidiomorphic and porphyritic. It is fine to medium grained. Mineral constituents are albite, orthoclase, quartz, muscovite and biotite. Calcite, epidote, amphibole and sphene are present as accessories. Albite and orthoclase show alteration to clay and sericite, which is more pronounced in the case of orthoclase. Muscovite and biotite occur as elongated flakes. Together, they impart gneissic structure to the rock. Some hornblende is also found associated with biotite.

QUARTZ SCHORL ROCK:- It is pneumatolytically formed quartz tourmaline rock. Two samples of this rock were studied and subhedral crystals of emerald were found to be present in one specimen (4.0%). Quartz, tourmaline and sphene are the main mineral constituents. Tourmaline belongs to black variety schorlite and exhibits strong pleochroism from pale yellow to dark pale green. It occurs as subhedral to euhedral crystals and also in the form of aggregates. Quartz inclusions are observed in tourmaline.

CARBONATITE:- Four samples of carbonatite have been studied. Carbonatite consists of carbonate, pyroxene, amphibole and apatite. Biotite/vermiculite, magnetite, pyrite, zircon and sphene are also present but generally as accessories. Carbonate constitutes the major part of the rock mass. Pyroxene is a diopside. Amphibole occurs as green and pleochroic crystals. Uvarovite garnets are present in the rock as highly fractured grains and irregularly distributed aggregates. The garnet generally ranges in size from 0.1 to 1.2 mm. Subhedral magnetite crystals contain pyrite in their cores. Magnetite also shows alteration to haematite.

ACTINOLITE-CARBONATE GNEISS:- Actinolite carbonate gneiss is fine to medium grained. The rock is porphyroblastic and shows gneissic structure. Mineral constituents are actinolite, clinozoisite, calcite, fuchsite, biotite, plagioclase and quartz. Actinolite occurs as elongated, acicular crystals and their band type aggregates, with high relief and anomalous interference colours. Calcite occurs as aggregates forming patches and bands. Fuchsite (Cr - mica) is also present in the rock as flakes along parallel planes.

GREENSTONE:- It is fine grained, hypidioblastic and poikiloblastic rock exhibiting gneissic structure. Epidote, albite, chlorite, and quartz are the mineral constituents. Epidote occurs as small colourless to light green and non-pleochroic grains. Poor twinning is noticed in albite. It contains inclusions of chlorite, epidote and sericite. Chlorite is present as tiny flakes and their aggregates. It is medium green and pleochroic from almost colourless to medium green. One sample also contains amphibole which shows alteration to chlorite.

GRAPHITE-TALC SCHIST:- Graphite-talc schist is fine grained and porphyroblastic schistose rock. It comprises talc, graphite and garnet. Talc is the predominant mineral of the rock. It occurs as tiny flakes forming aggregates. Garnet imparts porphyroblastic texture to the rock. Haematite/limonite and pyrite occur as accessories in the form of stains, specks and grains.

GRAPHITE-SCHIST/GNEISS:- It is fine grained and sub gneissic rock having xenoblastic, poikiloblastic and subporphyroblastic texture. Quartz, graphite and muscovite are the major mineral constitutents whereas pyrite, apatite and limonite occur as flakes as well as aggregates. Quartz shows corrosion and eating up effects where it comes in contact with graphite. Muscovite contains inclusions of graphite and quartz. Alteration of pyrite into limonite and goethite is also common.

MINERAL OCCURRENCES

1. *EMERALD:* Emerald mineralization in Barang has taken place in talc-carbonate rocks emplaced along a fault zone within graphitic schists to the north of Amankot village.

Branag emerald mining area is comprised of 3 different mines; the first two are located close to each other but on opposite sides of a hillock whereas the third mine lies about 500 metres further north of the second mine. Mineralized zone is about 80 metres wide. Following types of mineralization has been noted in the first and second mine (Fig 4 to 6):-

i. Quartz veins present along the joints and fractures in talc-carbonates contain emerald crystals. It is present either in the veins or in the host talc-carbonates close to these veins. The quality of this mode of emerald is the best.

ii. Quartz veins, cross cutting the tourmalinized quartzites which overlie the talc-carbonates are

Table: 1

PETROGRAPHIC COMPOSITION OF CARBONATITES.

ROCK NAME	**Carbonatite**	**Carbonatite**	**Carbonatite**	**Carbonatite**
Sample No.	**TO-84-SI-403**	**TO-84-SI-404**	**BG-84-SI-407**	**TO-84-SI-408**
Locality	**Turghao**	**Turghao**	**Bagh**	**Turghao**
Carbonates	52	65	78	71
Pyroxene	20	10	4	5
Amphibole	-	5	4	10
Apatite	20	8	0.8	8
Sphene	2	3	-	-
Muscovite	0	6	3	-
Biotite	-	-	-	1.5
Chlorite	-	-	-	2
Garnet	-	-	6	-
Epidote	-	-	-	0.5
Zircon	1	-	0.2	-
Magnetite	4	2	-	2
Pyrite	-	1	4	-

Table: 2

PETROGRAPHIC COMPOSITION OF GRAPHITIC AND TALCOSE ROCKS.

Rock Name	**Graphite-quartz mica-gneiss**	**Graphite-garnet talc-schist**	**Talc-carbonate rock**
Sample No.	**TO-84-SI-405**	**TO-84-SI-408**	**AT-84-SI-412**
Locality	**Turghao**	**Targhao**	**Amankot**
Quartz	35	-	-
Muscovite	30	-	-
Graphite	30	10	-
Talc	-	78	60
Magnesite	-	-	38
Garnet	-	10	-
Apatite	1	-	-
Pyrite	2	1	-
Limonite/Haematite	2	1	2

Table: 3

PETROGRAPHIC COMPOSITION OF GREEN SCHIST

Rock Name	Actinolite-epidote carbonate-schist	Chlorite-epidote albite-gneiss	Epidote-chlorite schist
Sample No.	TI-84-SI-410	TK-84-SI-417	TK-84-SI-418
Locality	Totabai	Takhat Kandao	Takhat Kandao
Albite	8	45	3
Quartz	8	3	3
Chlorite	-	21	22
Epidote	22	30	42
Calcite	37	-	-
Actinolite	16	-	-
Amphibole	-	-	8
Biotite	3	-	-
Muscovite	-	1	-
Fuchsite	5	-	-
Limonite	1	-	-

Table: 4

PETROGRAPHIC COMPOSITION OF GRANITE GNEISS AND TOURMALINIZED ROCKS.

Rock Name	Quartz-schorl rock	Quartz-schorl rock	Granite gneiss
Sample No.	AT-84-SI-413	AT-84-SI-414	TO-84-SI-401
Locality	Amankot	Amankot	Turghao
Quartz	60	60	24
Tourmaline	38	36	-
Emerald	-	4	-
Sphene	2	-	1
Albite	-	-	34
Orthoclase	-	-	20
Calcite	-	-	1
Muscovite	-	-	10
Biotite	-	-	8
Epidote	-	-	2

mineralized with emerald. The quality of the emerald found in these veins is not good. Sometimes quartzites close to the pneumatolytic veins also contain emerald.

iii. Silicified zones about 0.7 to 1 m across in talc-carbonates contain sporadically mineralized emerald crystals. These are also not of good quality.

iv. Pneumatolytic veins present in the sheared zones along faults in talc-carbonates have emerald mineralization. Emerald crystals are found in pockets and as disseminations.

Colour of Barang emerald varies at places. It is bluish green, light blue with greenish edges, green, grassy green and deep green. It is opaque, translucent and transparent in nature. Size of the emerald varies from very small to 2.5 cm in longer dimension. Weight of the largest stone seen with a local was about 150 carats. Clear and transparent, high quality emerlad of these mines is usually of bluish green colour. Crystals are generally well developed, hexagonal in form and may have inclusions.

2. *HESSONITE GARNET:* Hessonite garnet has been developed in graphitic schists at three places towards NE of Charogai in Turghao area. The hessonite garnet is usually well developed, light yellow, yellowish brown, black and off white in colour. It is translucent to opaque. The size of the garnet ranges from 1 to 3 mm in diameter. Large garnet crystal are usually euhedral and approximately 1 cm in diameter. Ochre bearing graphitic rocks lack garnet mineralization. Mineralized bodies are from 1 to 3 m wide and 5 to 20 m in length. The hessonite garnet developed in graphite rich bodies is mostly transparent to translucent. It can be used as semi-precious ornamental stone.

3. *EPIDOTE:* It is mineralized in a vein found at the contact of siliceous and calcareous schists. The edpidote crystals are small in size, greyish green in colour, brittle and usually fractured. The crystals are developed in clusters, forming lenses which cross-cut the schistosity. It is also found along the joints. Smaller crystals are transparent and can be used as semi-precious stone.

4. *GRAPHITE:* Graphite beds in north east of Targhao contain small sized crystalline graphite. Petrographically graphite makes about 30% of the rock. Size of this body is 400 x 1000 metres. It is medium to thin bedded, containing ochre and clayey layers. More analytical work is required to find its economic significance.

5. *GREEN GARNET:* Grains and crystals of green garnet are found in carbonatites/calcareous rocks. Garnet is opaque to translucent and usually fractured. Some medium quality garnet can be used as semi precious stone but the nature of the host rock makes its extraction very difficult. Its mode of occurrence in Andarai carbonatite is as follows:-

a. Bands of green garnet are observed in massive calcareous rocks. These bands are one to three cm wide. Garnet crystals vary from specks to 1 cm in size. The other associated minerals are pyrite and mica.

b. Green garnet also occurs in the form of pockets or clusters. These pockets are upto 2 cm wide and 10 to 20 cms long. Garnet is euhedral to subhedral, however, quality of garnet is smaller pockets is comparatively better.

c. Garnet is also present in feldspathic and calc-o-feldspathic material. Garnet of this type is disseminated and smaller in size. Other associated minerals are pyrite and actinolite. Alteration of pyrite into iron oxide along the rims is prominent.

SUMMARY AND ORIGIN OF EMERALD MINERALIZATION.

Carbonatites of Turghao-Barang area have been reported for the first time. Before this, carbonatites were known to occur in Swat and Malakand. In lower Swat, carbonatites are closely associated with nepheline syenite and other alkaline rocks. In Malakand no such relationship was noticed. However, all these carbonatites are part of the alkaline province which extends from Loe Shalman-Warsak to Koga, Swat (Siddiqui 1967, Kempe and Jan 1974, Chaudhry 1974). It's exact extension is still to be determined. Although presence of apatite (upto 15%) has been confirmed petrographically in Turghao carbonatites, these are yet to be analysed chemically to find their economic significance for rare earth elements.

Feldspathic bodies associated with carbonatites appear to be fenites developed metasomatically in the host siliceous metasediments prior to the emplacement of the igneous carbonatite bodies.

Some of the quartzites of the melange zone may be banded metacherts.

The melange zones and other rock units in the area studied lie almost in north-south direction making high angles with Main Mantle Thrust in north where these are truncated by it. It may be concluded, therefore, that Main Mantle Thrust here may not be a fossil benioff zone but appears to be a later high angle fault.

Prior to this presentation no direct evidence was available to relate emerald mineralization to its source. Jan et al., (1981) ruled out the possibility that a granite source may have been responsible for emerald mineralization. They suggested the trench related fluids as a possible source of Be responsible for emerald mineralization in talc-carbonates and related ultrabasic blocks of the Mingora melange. Jan et al., (1981) ruled out a granite source of Be on the ground that while the emerald host of Shangla-Mingora (talc-carbonates and related rocks) are Mesozoic, the associated granites are Palaeozoic.

Butt et al., (1985) contested this view and presented evidence from adjoining Ilum area of Swat to show that post tectonic beryl bearing minor granitic bodies of possible Tertiary age may occur. Though no direct evidence was available They proposed a genetic connection of this possible phase of magmatism and emerald mineralization of Mingora-Shangla area. Butt. et al., (1985) contested the possibility of trench source on theoretical grounds as well.

Tertiary magmatism of alkaline nature on the Indo-Pak plate south of the MMT has been known for some time. The ages of various members of this province of NW Pakistan have been reported by a number of workers.

Le Bas et al., (in press, quoted from Kempe, 1986) have determined K/Ar age of 31± 2 My for the carbonatites of Loe Shilman. From this complex Kempe (1973) reported K/Ar age of 41 My on riebeckite.

Maluski and Matte (1984) reported 40 Ar/39 Ar ages of 40 ± 5 and 43.5 ± 5 My on riebeckites and 42 ± 4 My on biotite from the Loe Shilman alkaline complex.

Le Bas et al. (in press, quoted from Kempe 1986) reports K/Ar ages of 31 ± 2 My from Selai Patti carbonatites. Kempe (1973) determined K/Ar ages of 50 My on Koga syenite. Maluski and Matte (1984) reported 40 Ar/39 Ar age of 45.5 ± 1.5 My on the biotite of Ambella syenite gneiss. However, it may be mentioned that Le Bas et al., (in press, quoted from kempe 1986) report Rb/Sr isochron on nepheline syenite and ijolite between 315 ± 15 and 297 ± 4 My (Carboniferous).

On Malakand granite Maluski and Matte (1984) report 40 Ar/39 Ar ages of 22.8 ± 2.2 My. Zeitler et al. (1982) report fission track age 20 My. This granite, it my be mentioned, is not alkaline in nature (Chaudhry et al. 1974, Chaudhry et al. 1976 and Hamidullah et al. 1986).

Butt et al. (1979) and Chaudhry et al. (1983, 1984) defined a post Cretaceous magmatic phase along tensional zones now marked by the alkaline province. This proposal was based on geotectonic considerations. Chaudhry and Ghazanfar (in press) are of the opinion that this tensional zone south of the MMT is an older tensional zone which was reactivated during Tertiary. It may be mentioned that the Indo-Pak sheild contains other older tensional zones as well (Chaudhry, 1986). The Alkaline province contains both alkali granites/gneisses as well as non alkaline granites/gneisses. This phenomenon has been discussed by Chaudhry et al. (1983).

The alkali granites of the alkaline province are expected to be enriched in Be, Th and R.E.E. Butt et al. (1985) have suggested Be and R.E.E. enrichement in acid minor bodies of Ilum. The participation of such alkaline magma (?) source in emerald mineralization is not ruled out, however, no direct evidence to this effect has yet been furnished in the case of Mingora-Shangla zone.

In the Barang-Turghao area the granites and granite gneisses are of two types i.e. S type, garnet and (at places) tourmaline bearing granite gneisses and amphibole bearing (I-type ?) granite gneisses. In addition there are minor post tectonic granite bodies of S type as well as I (?) type. Kot granite gneiss and Agra-Turghao granite gneiss show many features of S type. Both have younger minor acid bodies including some beryl bearing pegmatites. The Kot granite gneiss is an extension of Malakand granite gneiss, studied by

Chaudhry et al. (1974, 1976) and Hamidullah et al. (1986).

The younger magmatic phases may show blue beryl mineralization and some tourmalinization. The Selai Patti amphibole bearing granite gneiss and associated minor acid bodies are as yet not known to contain beryl mineralization or tourmaline of their own. It is therefore not possible to relate emerald mineralization with amphibole bearing granite/granodiorite or equivalent gneisses.

The emerald mineralization in the talc carbonates of the melange zone is characterised by its association with post obduction pneumatolitic activity. This activity is manifested by silicification and development of emerald and tourmaline. It is important to note that blue tinges and blue green colours of emerald are common. But green and grass green emerald also occurs.

It is important to note that blue or blue green beryl is also mineralised in acid minor bodies associated with Kot granite gneiss and Agra Turgho granite gneiss. The emerald mineralization can therefore be related to post obduction Tertiary pneumatolytic phases related to acid magmatism. This acid minor magmatism is associated with the S type granite gneisses.

This magmatism is a product of anatexis related to the thrust stacking in the Indo-Pak sheild. Ghazanfar et al. (1986) have examined anatectic phenomena along MCT as well as in the Sharda sheild block.

They have further noted that MCT and MMT come close to each other in Dheri (Bhimbal Katha, Kaghan) and westward towards Swat, Dir and Bajaur slices/areas of old basement where younger anatectic granites occur south of MMT. It is in these zones that younger Be-B bearing minor acid bodies (mainly pegmetites) are present. Here melange ultrabasics (bearing Cr) and Tertiary anatectites (Be-B) interact to give rise to emerald mineralization.

Emerald mineralization is therefore regarded mainly as a product of the interaction of Be-B-Si pneumatolytic activity associated with the emplacement of nearby post obduction younger granites (Tertiary) described earlier. This mineralization is structurally controlled, post obduction and most probably post tectonic. Chromium has been imparted by the host talc-carbonates which are themselves altered ultrabasics.

A granodiorite source associated with the host for Mingora emerald mineralization was proposed by Gubelin (1982). This mineralization represented quartz calcite-emerald assemblage. However, Butt et al. (1985) observed quartz calcite blue beryl veins in Ilum granite which occurs within Swat-Buner-schistose group. On this basis Butt et al. (1985) refute Gubelin's (1982) claim that a granodiorite source has mineralized emerald in talc carbonate host. Recent petrographic studies (Mariano, personal communication) have also confirmed the presence of Cr-tourmaline in Swat emerald mines as well.

The association of tourmaline with and close to the emerald mineralization is an important factor which must be taken into consideration while working out the origin of emerald mineralization.

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LOCATION MAP

FIG NO.1

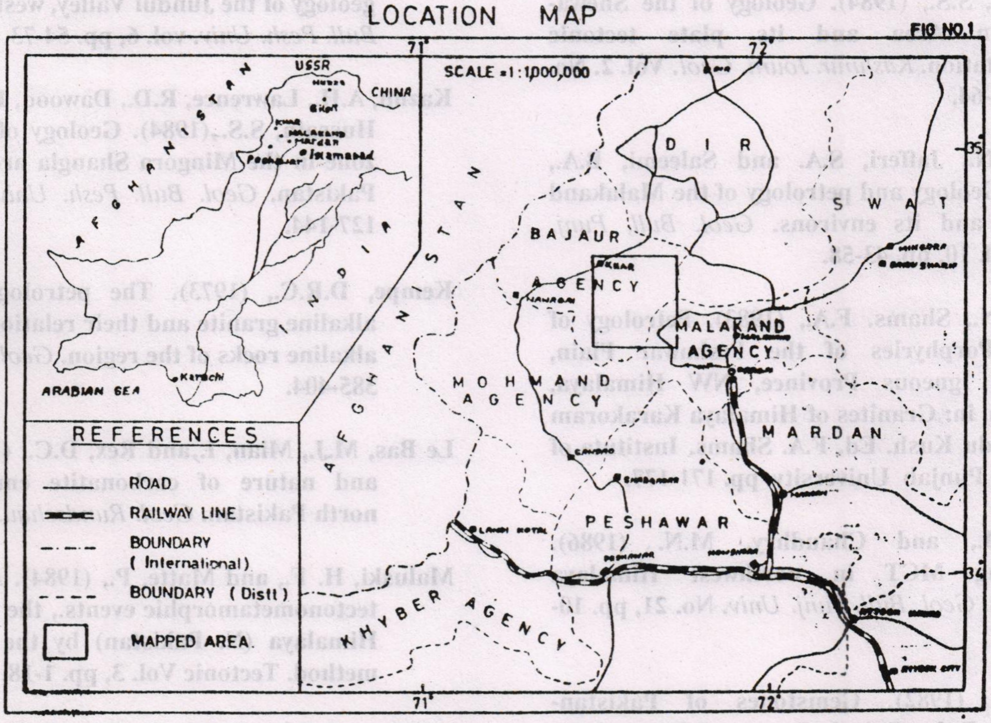
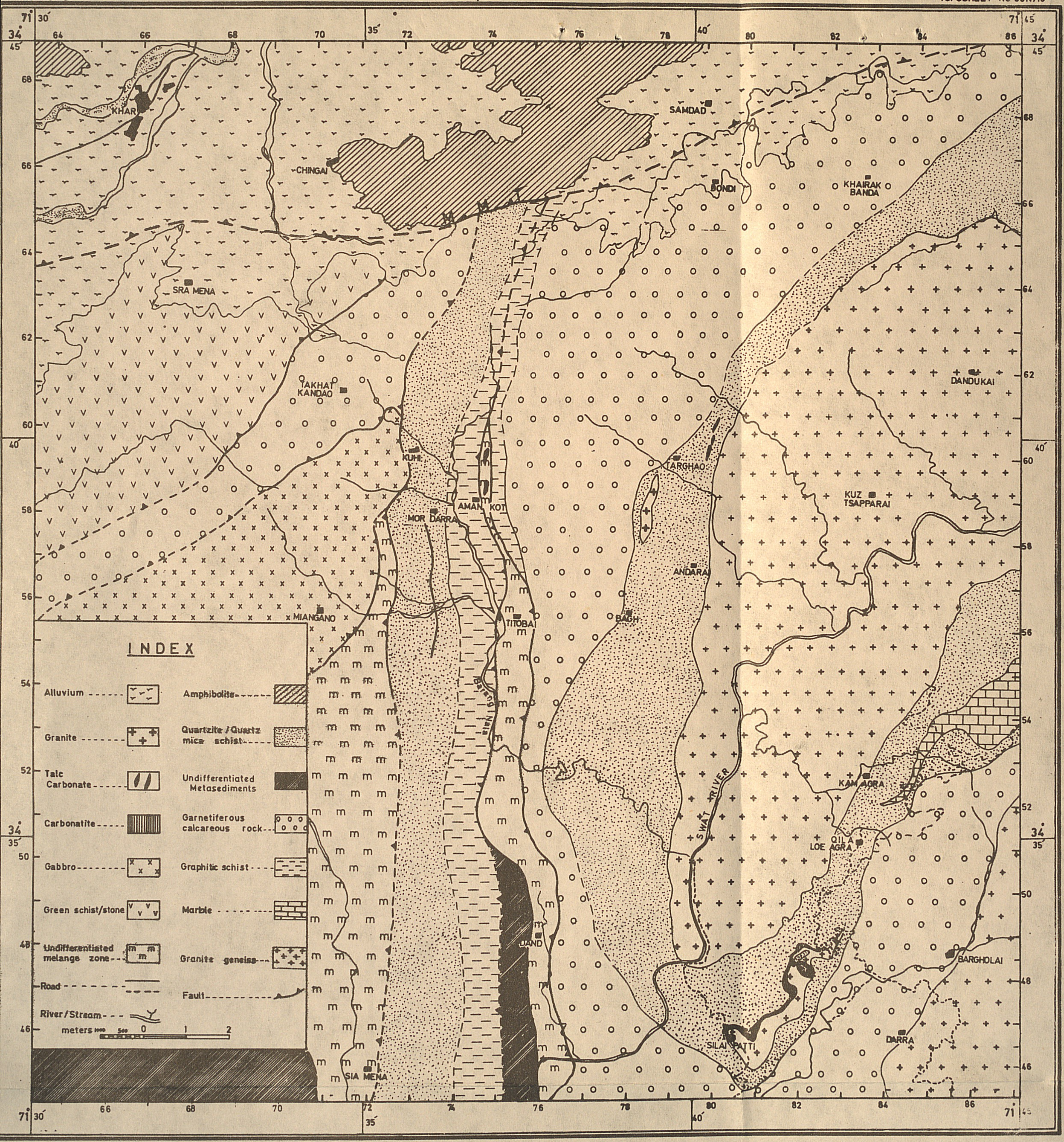


FIG NO:-2

TOPOSHEET NO 38N/10



GEOLOGICAL MAP OF BARANG-TARGHAO AREA
BAJAUR AGENCY, N.W.F.P.

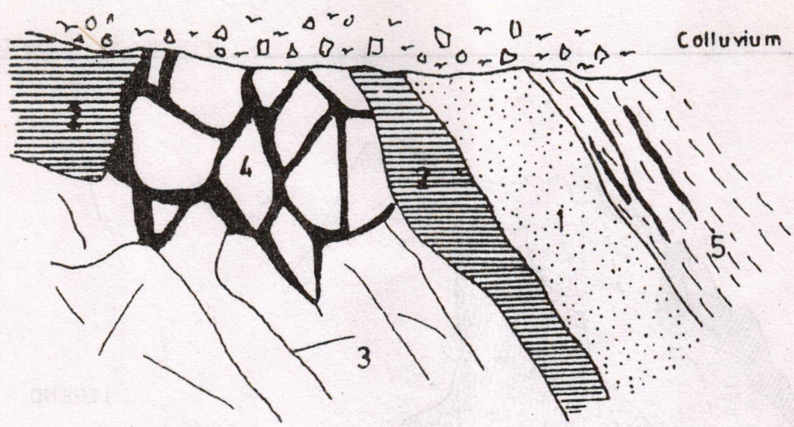


Fig. 3

Sketch showing various zones of Carbonatites and surrounding rocks.

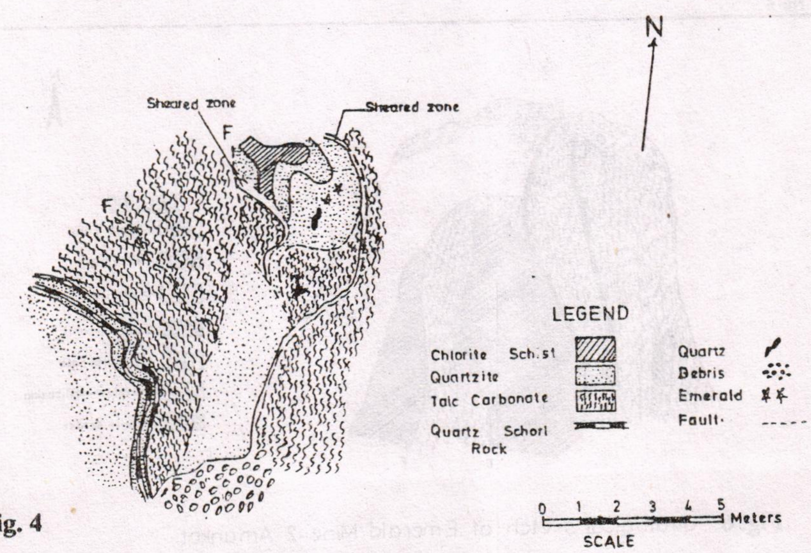


Fig. 4

Geological Sketch Of Amankot Emerald Mine No1 (Top Zone)

FIG.5

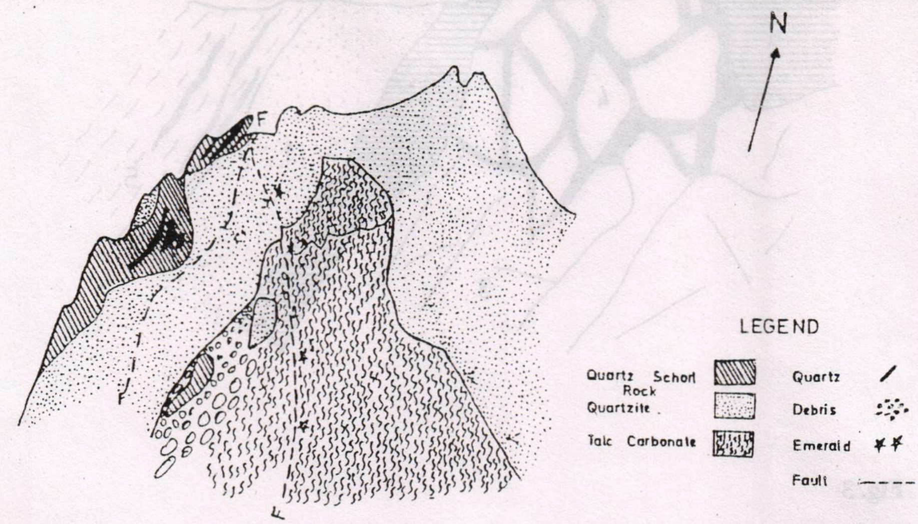


Fig. 5

Geological Sketch Of Amankot Emerald mine-1 (mineralized zone).

FIG No-6

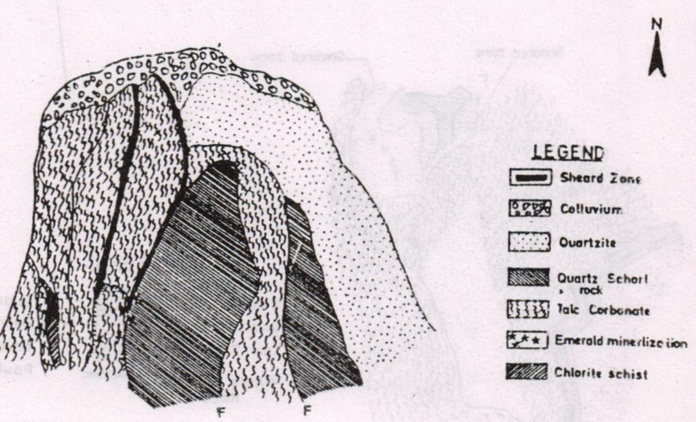


Fig. 6 Geological sketch of Emerald Mine-2 Amankot Barang, Bajaur Agency

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NEW OCCURRENCES OF BLUESCHIST FROM SHIN-KAMER AND MARIN AREAS OF ALLAI-KOHISTAN, NORTHWEST HIMALAYA, PAKISTAN

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ABSTRACT:- In Allai-Kohistan, the Indus Suture Zone is represented by the Allai melanges. The Allai melanges constitute the Baleja ophiolitic melange, Shin-Kamer blueschist melange, and Matai greenschist melange. The Baleja ophiolitic melange, Shin-Kamer blueschist melange, and Matai greenschist melange represent the Neotethys oceanic crust, Neotethys trench, and island arc affinities respectively.

New in situ blueschist occurrences have been found from the Shin-Kamer blueschist melange, near the Shin-Kamer and Marin areas of Allai-Kohistan. The Shin-Kamer blueschist is composed of glaucophane, epidote, chlorite, quartz, white mica, with small amount of calcite and plagioclase. The mineral assemblage suggest blueschist facies P-T conditions of about 380-450°C and pressure of about 7-8 kbar.

In the blueschist melange, the high-pressure blueschist facies metamorphism is overprinted by the low-pressure greenschist facies metamorphism. During the greenschist facies metamorphism, the actinolite (rims around glaucophane), chlorite, and white mica overprinted the blueschist assemblage. Similar change from high-pressure to low-pressure metamorphic conditions also occurred in the Indus Suture Zone of Ladakh and Shangla areas of the Northwest Himalaya. The transition from blueschist to greenschist facies metamorphism in the Indus Suture Zone can be related to tectonic decompression along the Neotethys trench zone or due to a separate tectonic event related to melange emplacement.

INTRODUCTION

In northern Pakistan, the Indus Suture Zone (ISZ; Figure 1) marks the collisional boundary between the Indo-Pakistan plate and the Kohistan island arc terrane. The Indus Suture Zone extends from the west of the Nanga Parbat-Haramosh Massif (Figure 1) to the east as the Indus-Tasangpo Suture Zone (Tahirkheli et al., 1979; Gansser, 1979; Ashraf et al., 1980; Lawrence et al., 1983).

The Indus Suture Zone/Indus-Tasangpo Suture Zone constitutes the Jurassic to Cretaceous oceanic crust and associated metasediments of the passive margin of Neotethys ocean. The rocks of the Neotethys ocean or terrane were tectonically juxtaposed during progressive suture development from Late Cretaceous to Eocene along a series of faults called the Main Mantle thrust zone.

During this study (Figures 1 and 2), various fault-bounded melange units to the east of the Indus Syntaxis have been mapped in Allai-Kohistan, which are herein called the Allai melanges.

Numerous occurrences of blueschists have been previously reported from the suture zones of Shangla (Shams, 1972, 1980), Afghanistan (Tapponnier et al., 1981), Ladakh (Virdi, 1981a, 1981b; Jan, 1985), Burma (Mitchell, 1981), and Nagaland (Ghose and Singh, 1980; Agrawal and Kacher, 1980). In Allai-Kohistan, Majid and Shah (1985) first reported glaucophane-bearing blueschist metagraywacke from a boulder in a stream near Shergarh Sar area (Majid, personal commu., 1987; and Shah, personal commu., 1989). This study shows that the Shergarh Sar area falls within the greenschist melange. This paper reports in situ new blueschist localities near the Shin-Kamer and Marin areas of Allai-Kohistan. The detail structural, metamorphic, petrographic, and microprobe data on Allai melanges will be published elsewhere.

GEOLOGY OF ALLAI MELANGES

The Swat melanges to the west of the Indus Syntaxis (Shams, 1972, 1980; Kazmer et al., 1983; Lawrence et al., 1983; Kazmi et al., 1984; Chaudhry et

al., 1984) reappear as the Allai melanges to the east of the Indus Syntaxis (Figure 1). Various types of fault-bounded melange units are present in Swat; these are the Mingora ophiolitic melange, the Charbagh greenschist melange, and the Shangla blueschist melange (Kazmi et al., 1984). At the apex of the Indus Syntaxis melanges are absent below the ultramafics of the Jijal complex. To the east and west of the Indus Syntaxis, the remanents of the Jijal complex are present above the Main Mantle thrust in Allai and Swat Kohistan.

In Allai-Kohistan, the Allai melanges occur between the Main Mantle thrust (MMT) and the Kishora thurst (KT; Figure 2). A series of newly recognized north-trending faults offset the Allai melanges and has lenses and blocks of mafic and ultramafic rocks dragged several km to the south. The Kishora thrust at the base of the Allai melanges near Ganja Sar is offset about 14 Km to the south by left-lateral Chail Sar thurst (CST; Figure 2). The Chail Sar thrust, along the eastern limb of the Indus Syntaxis, is herein interpreted as a left-lateral ramp fault. A portion of Allai melanges near Shergarh Sar has been mapped by Shah and Majid (1985), which includes blocks of greenschist, epidote-amphibolite, pillow lavas, serpentinite, peridotite, and clinopyroxenite. During this study, Allai melanges between the Kishora thrust and the Main Mantle thrust are separated into the Baleja ophiolitic melange, the Shin-Kamer blueschist melange, and the Matai greenschist melange (Figure 2).

Baleja ophiolitic melange: The Baleja ophiolitic melange (Figure 2) occurs as tectonic blocks and lenses between the Shergarh Sar thrust (SGT) and the Kishora thrust (KT). The Kishora thrust separates the underlying Besham basement complex and the Bana group of rocks from the overlying Shin-Kamer blueschist melange, Baleja ophiolitic melange, and Matai greenschist malange. Whereas, the Shergarh Sar thrust separates the Baleja ophiolitic melange or Shin-Kamer blueschist melange from the Matai greenschist melange. The Shergarh Sar thrust extends to the east of Shergarh Sar and joins the Kishora thrust.

The Baleja ophiolitic melange consists of tectonic blocks and lenses of greenschist metapyroclastic, greenstone metabasalt, metagabbro, metasediment, clinopyroxenite, dunite, peridotite, serpentinized peridotite, serpentinite, pillow lava, minor talc-carbonate, talc, limestone, metachert, and epidote-amphibolite in a sheared matrix of greenschist or serpentinite or minor talc-carbonates. It is tectonically interleaved at the base with graphitic phyllite, carbonate, garnet amphibolite, garnet-bearing schistose marbles, graphitic schist, and garnet-kyanite-bearing calc-pelites of the Bana or Alpurai group. No emeraled mineralization has yet been found from this melange unit. However, there are unconfirmed reports of emeraled mineralization from this melange. It could be the best candidate for the emerald mineralization. It is equivalent to the Mingora ophiolitic melange to the west of the Indus Syntaxis. The ultr mafics of Baleja and Mingora ophiolitic melanges are not the part of the ultramafics of the Jijal complex. These are the part of dismembered ophiolite sequence of Neotethys terrane. Because, the ultramafics of Baleja and Mingora ophiolitic melanges are structurally below the ultramafics of the Jijal complex. Thus, both the ultramafic sequences have different tectonic affinity.

Shin-Kamer blueschist melange: The Shin-Kamer blueschist melange occurs near the Shin-Kamer and Marin areas of Allai-Kohistan (Figure 2). The Shin-Kamer blueschist melange overlies the Besham basement complex along the Kishora thrust and is structurally overlain by the Matai greenschist melange. The Baleja ophiolitic melange occurs as rare tectonic lenses above the Kishora thrust in Marin and Shin-Kamer areas. However, small tectonic blocks/lenses of graphitic phyllite and schist, garnet-calc pelite, and schistose marbles of the Alpurai or Bana group are present at the base of the Shin-Kamer blueschist melange.

It consists of blocks of glaucophane-bearing metagraywacke, greenchist metavolcanics, phyllite, quartz-muscovite-chlorite schist, metagabbro, and minor lenses of talc, marble, serpentinite, serpentinized peridotite, and metachert in sheared matrix of greenschist and phyllite.

The petrography of Shin-Kamer blueschist shows that it is composed of glaucophane, epidote, chlorite, quartz, white mica, with small amount of calcite, albite, and traces of apatite and magnetite. No jadeitic pyroxene, aragonite, paragonite, pumpellyite, prehnite, and lawsonite have been found from the Shin-Kamer blueschist. The glaucophane grains (3mm to 6mm long) are commonly zoned from violet blue core to light blue margin. Along the margins of glaucophane, the actinolite rims are well developed. The probe analyses of blue amphiboles confirm the sodic core of glaucophane and the calcic rim of actionlite (M. Shahid Baig and Alison Till, unpublished data). This data is contraductory to the earlier published Majid and Shah (1985) microprobe data, which indicates glaucophane core and crossite margins of the blue amphibole. The variation of crossite to actinolite rims around glaucophane of Allai-Kohistan may be due to the complex metamorphic history of the Indus Suture Zone.

The Shin-Kamer blueschist blocks show at least two fabrics. The main peneterative fabric is the blueschist fabric, which is marked by the development of glaucophane, epidote, chlorite, quartz, white mica, calcite, and albite. The second lower greenschist facies spaced fabric is axial-planer to generally north-

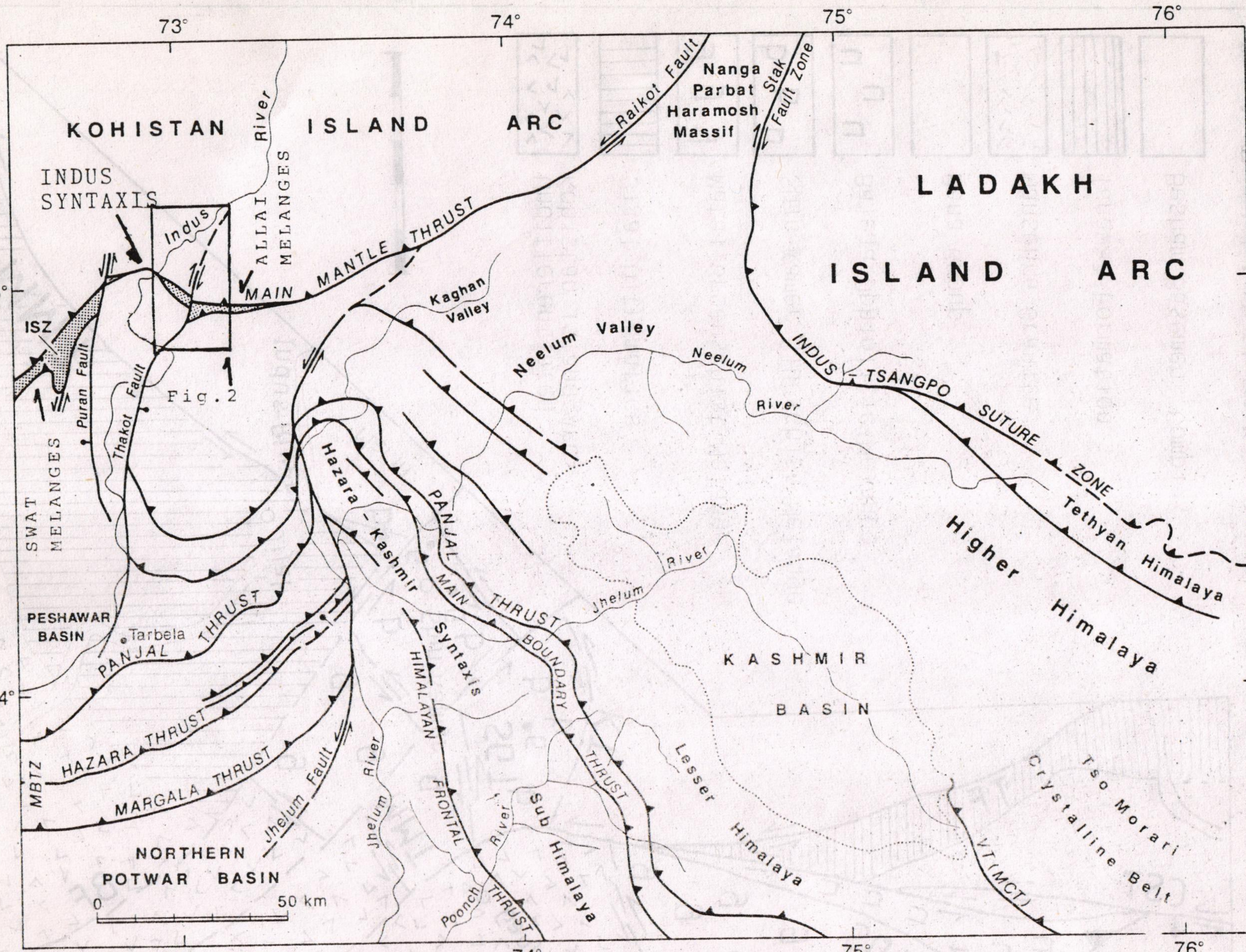

Figure 1. Tectonic map of the Northwest Himalaya. The rectangle along the eastern limb of the Indus Syntaxis, shows the location of Figure 2. Note that the Swat melanges to the west of the Indus Syntaxis reappear as the Allai melanges to the east of the Indus Syntaxis. Melanges are absent at the apex of the Indus Syntaxis. The Puran and Thakot faults offset the Indus Suture zone (ISZ).

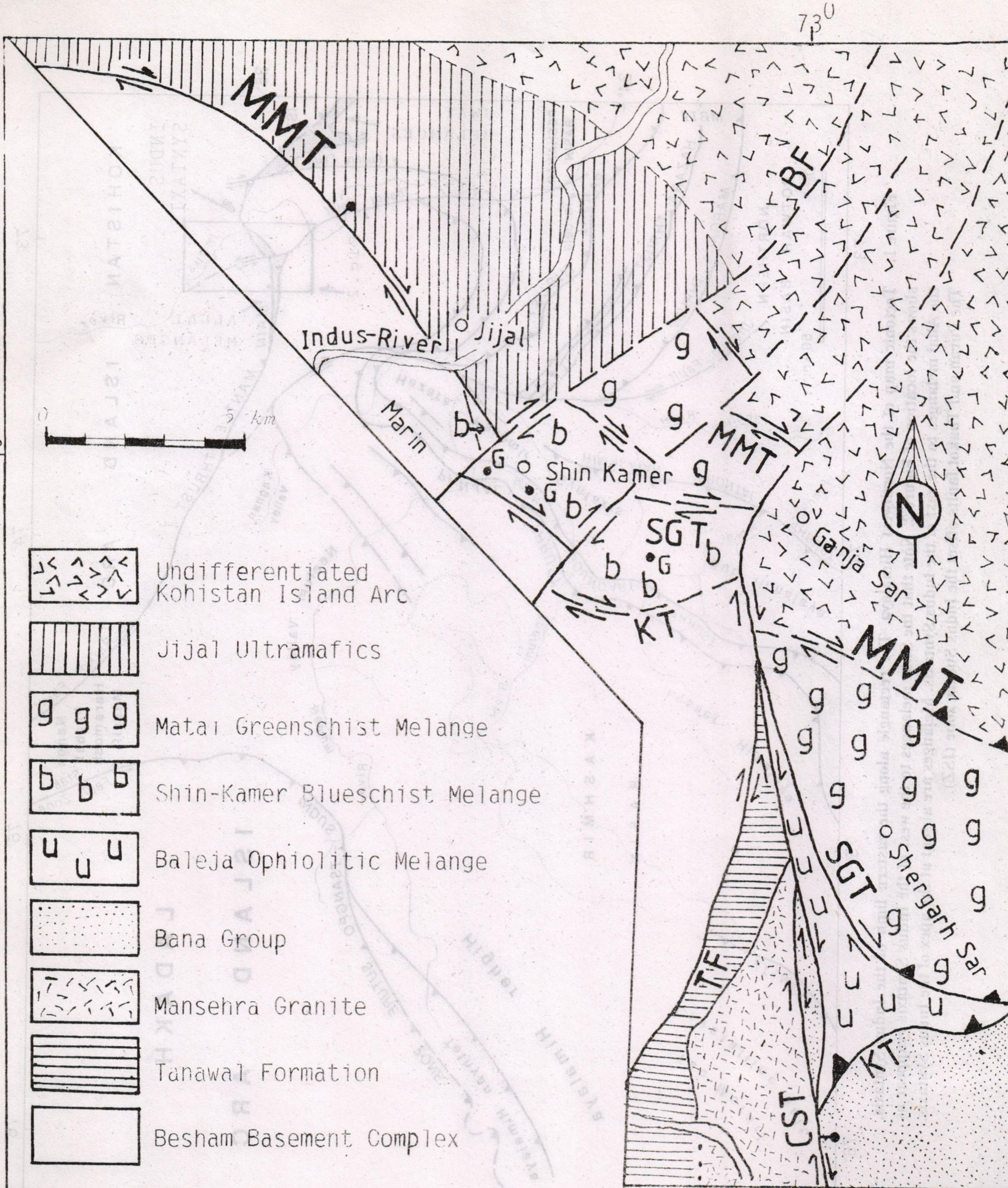

Figure 2. **The geological map of the Shin-Kamer, Ganja Sar, and Shergarh Sar areas of Allai-Kohistan. For location of the Figure 2 see Figure 1. MMT = Main Mantle thrust, SGT = Shergarh Sar thrust, KT = Kishora thrust, TF = Thakot fault, BF = Besham fault, and CST = Chail Sar thrust. Reverse arrows on the faults show oblique-slip motion and teeth show thrust motion. G = glaucophane-bearing blueschist locallities.**

plunging folds. During this lower greenschist facies metamorphic overprint, the actinolite rims were formed around the glaucophanes of Allai-Kohistan. This data indicates the later lower greenschist facies metamorphism of the Indus Suture Zone. The Shin-Kamer blueschist melange is equivalent to the Shangla blueschist melange.

Matai greenschist melange: The Matai greenschist melange (Figure 2) occurs between the Main Mantle thrust and the Shergarh Sar thrust (SGT). To the east of Shergarh Sar, the Matai greenschist melange is in tectonic contact with the underlying Bana group of rocks along the Kishora thrust. Its apparent thickness varies from 2 to 6 Km. It is mainly composed of tectonic blocks of greenstones, metabasalts, greenschists, epidote-amphibolites, and metasediments in sheard greenschist matrix. At the base, the greenschist melange is tectonically interleaved with the graphitic phyllite, slate, and low-grade carbonates of the Bana group. The Matai greenschist melange correlates with the Charbagh greenschist melange to the west of the Indus Syntaxis.

DISCUSSION

The Indus Suture Zone in Allai-Kohistan represents the melanges/terranes of different tectonic affinity. The melanges are the remanents of the Neotethys ocean, Neotethys trench, and island arc. The presence of dominantly ultramafic and mafic rocks in the Baleja and Mingora ophiolitic melanges, shows that these represent a dismembered ophiolite sequence of the Neotethys oceanic crust. The presence of blueschist in Shin-Kamer melange indicates the Neotethys trench affinity. However, the nature of the Matai greenschist melange is not clear, it may have forearc or arc affinity. The melanges of different tectonic affinity were juxtaposed during progressive suture development as a result of the Late Cretaceous to Eocene closure of the Neotethys ocean between the Indo-Pakistan plate and the Kohistan island arc terrane.

The microprobe, petrographic, and fabric data from the Shin-Kamer blueschist melange confirm two metamorphic events in the Indus Suture Zone of Allai-Kohistan. The earlier metamorphic event occurred under high-pressure blueschist facies metamorphism and was overprinted by a later low-pressure greenschist facies metamorphism.

The presence of glaucophane, epidote, quartz, albite, and calcite and absence of jadeite, aragonite, paragonite, pumpellyite, prehnite, and lawsonite from the Shin-Kamer blueschist suggest a temperature range of about 380-450^{0}C and pressure of about 7-8 kbar. The low-pressure greenschist mineral assemblage overprinted the blueschist facies assemblage at about 4-5 kbar and temperature remains more or less the same. During the greenschist facies metamorphic overprint, the calcic amphibole (actinolite rims around glaucophane), chlorite, and white mica have grown. The zoning of glaucophane has been reported from Ladakh (Jan 1985), Shangla (Shams, 1972, 1980; Jan et al., 1981), and Shin-Kamer areas of the Northwest Himalaya.

The presence of actinolite rims in Shin-Kamer, Shangla, and Ladakh blueschists show transition from the high-pressure blueschist to low-pressure greenschist facies metamorphism. This change from high-pressure to low-pressure metamorphic conditions can be contributed to tectonic decompression along the Neotethys trench zone or due to a later tectonic event related to the melange empalcement on the passive marign of the Neotethys ocean.

The white micas from the Shangla blueschist melange which has two mica fabrics yielded K/Ar and $^{40}Ar/^{39}Ar$ dates of 70-84 Ma (Shams, 1980; Maluski and Matte, 1984). These dates have been interpreted by these authors the age of blueschist facies metamorphism. The blueschist melange in Shangla and Shin-Kamer has been overprinted by the lower greenschist facies metamorphism, which is sufficient enough to reset the mica dates related to the blueschist facies metamorphism. Thus 70-84 Ma mica dates do not record the time of blueschist facies metamorphism, in contrast, these dates record the time of melange emplacement which occurred under greenschist facies metamorphism. Thus, the blueschist facies metamorphism must have occurred to the north before 84 Ma along the trench zone of the Neotethys ocean and the Kohistan island arc terrane.

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PHYSICAL CHARACTERISTICS OF SOILS OF MUZAFFARABAD KOHALA AREA AZAD KASHMIR

By

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ABSTRACT: Field and laboratory investigations of physical characteristics related to grades, sediment, water relationship, effect of stress and the amount of strain have been investigated from civil engineering point of view.

The origin of the soils have also been studied to summarize the relationship between the soil types and their response to the varying condition of moisture, stress response in relation to the grades of the soils.

INTRODUCTION

The objective of the paper is to evaluate the important physico-mechanical characteristics of the soils of Muzaffarabad-Kohala area Azad Kashmir (Fig. 1). In the field three factors which were necessary for the soils were evaluated for construction purposes. They are 1). The stratification of the soils, 2). The engineering properties of these materials 3). The prediction of the performance of the structure and the process by which it is constructed. The data is obtained of the three factors during field examination of the soils available at the site. These three components are highly interdependent and all are carried out at the competent level, so that the final product of investigation could be meaningful. Standard penetration test, drilling, plate load test, and density test techniques were used for determining the physical properties in the field to evaluate the bearing capacity of the soils (Foundation & Water Organization 1988).

Careful testing and interpretation are of critical importance and one of the purposes of this paper is to correlate in situ and laboratory results specifically. The material strength investigated is found to be (35.2 to 86.9 PSI). For the assessment of structures (roads retaining walls etc.), the applied forces were related to the displacement of the soil. The testing for strength characteristics is 1 mm per 100 PSI and those are influenced by environmental and historical factors. It would be appreciated that the geotechnical investigations including a broad spectrum of soil mechanics is the first attempt of its kind at least in Azad Kashmir (Table. 2).

Small holes, honeycomb structures and fabric of the soils were studied along the road from Muzaffarabad to Kohala and on the top of the soil bed in Rara, Bagna and Kohala landslide areas. The percolation of rain water to these structures promote mass movement which adversely affect the road construction and other retaining structures. The macroscopic structures like joints, cracks, and other discontinuities were mainly found on the top of the soil bed, which are filled with silty clay, silty sand and clay. Some terraces (Jalalabad, Upper Plate, Chattar Kalas) were also investigated to evaluate the soil characteristics. The beds of soils are 200 to 400 meters thick and are composed of clays, silts, pebbles, and cobbles compacted in a clayey matrix. Lenses of sands, silts and silty clays were marked in the middle of the beds. It is thoroughly examined that the soils present on hill slopes are directly affected by under cutting the toe of the bed and the Murree fault present in the area under investigation. The rocks exposed in the area are mainly of Murree Formation of Miocene age and covers mainly the investigated area. Sandstones are associated with red clays, splintery hard clays, and silts. Cobbles and pebbles mainly mixed with clay, silts and sands are found in terraces, whereas red clays, silty and sandy clays are exposed on hill slopes. Physical and chemical weathering is pronounced where

soils are exposed to open air, the rain water and severe dry and wet climatic conditions.

CLIMATE

The investigated area lies in a humid region in the access of monsoon. In various parts of the area there is small scale variations in humidity and rainfall due to the difference in altitudes. During summer, May to June temperature reaches upto 45^{o}C. (Metrological Department Muzaffarabad). At night temperatures are substantially low but the day is hot. Tops of the mountains are cooler than valleys. In winter the maximum temperature drops to 3^{o}C.

GEOLOGY

The investigated area is a part of Murree Formation and holds an important position with regards to its startigraphic and structural setup. It is associated with the main Murree fault of the Himalaya in Azad Kashmir.

The geological formation exposed in the area are comprised of sedimentary sequence which ranges in age from Cambrian to Miocene. The exposed rock units includes Hazara Formation (Precambrian), Abbottabad Formation (Cambrian), Margala Hill Limestone (Eocene), Murree Formation (Miocene) and surficial deposits of quarternary age. A major unconformity exists between Abbottabad Formation and Margala Hill Limestone which are well exposed in the area under study. The contact between Hazara Formation and Murree Formation is faulted.

The older sequence of rocks from Precambrian to Miocene (Hazara Formation and Murree Formation) is thrusted along the Western foot hills of the Hazara Formation. The broad trend of rocks is generally, in an east-west direction with moderate to high dips towards east. However, their trend is not persistent due to folding and faulting in the area.

A generalized stratigraphic sequence of the investigated area is presented in (Table 1).

Table - 1

Generalized stratigraphic sequence in the investigated area (Muzaffarabad - Kohala).

Formation	Lithology	Age
Surficial Deposits	River deposits, gravel, sands, Silt, and clayey material.	Recent
	Lacustrine deposits, light brown, soft calcareous clays, Quarternary with thin silty intercalations.	Sub-Recent
	Disconformity	
Murree Formation	Purple red greenish Grey sandstone. siltstone, mudstone, and subordinate intraformational conglomerates.	Miocene.
	Disconformity	
Margalla Hill Limestone	Fine to coarse, dark grey, thin to thick bedded, massive, hard and compact limestone with subordinate shales.	Eocene
	Disconformity (Bauxite/Latirite)	
Abbottabad Formation	Fine grained dolomite & cherty dolomite.	Cambrian
Hazara Formation	Fine grained, drak gray, thin to thick bedded, highly fractured and sheared slates.	Precambrian.

STRUCTURE

The structure of the area under investigation can be subdivided into three different regions. Wadia (1931) studied the eastern part and presented a simple structural picture. It was concluded that Pre-cambrian units are present only along the Western foot of the Murree Formation adjacent to Murree fault (Tahirkheli 1980), which is the main part of the Murree thrust. In the eastern slopes of the Formation the rocks are deformed into broad folds. The unstable hills are made up of patches of sandstones, limestones, slates, and clays. These are separated by a North-south trending thrust fault, the strike of which generally follows the valley between the ridges. West of this fault, Muzaffarabad anticline is present. However, the rocks are complexly folded into a broad syncline. These complex structures have produced the conditions favourable to landsliding. The overall structure of the area forms anticlines and synclines. The Murree thrust emerges at the eastern foot of the range where it brings Cambrian rocks over the Murree Formation. It trends to nearly East-West and dips to nearly North-West.

The main structure in Muzaffarabad area is asymmetrical anticline in the east of Muzaffarabad proper. The trend of the axis of the anticline is approximately NW-SE. The asymmetrical anticline is thrusted over the older slate series to the west and south west. The thrusted junction is seen in the Neelum valley and near Lohargali at a distance of about two miles west of Muzaffarabad city.

Folding in Hazara slates and faulting has also af.ected the rocks in the area. Jhelum fault has been traced continuously from the Kunhar river to two miles west of Muzaffarabad city and then to the south along the Jhelum river.

EVALUATION OF PHYSICAL CHARACTERISTICS OF SOILS

A general soil profile was developed by a detailed investigation. However, determination of a continuous relationship of the depths and locations of various types of soils to the design is economically justified. The first phase of the investigation was implemented by plotting logs of soil in excavations, in cut areas, and boreholes, present in the area under study. A relationship was made between geological and engineering characteristics of soils. The depth of exploratory borings (Rocks Well 1988), for roads and bridges were taken for subsurface investigations. Rain water, spring water and frost penetration were considered to study the behaviour of soils to a depth more than its influence.

SAMPLING

Representative soil samples were taken from the boreholes, cut surfaces and channels. During a drilling programme prepared by (FWO in 1987) the soil samples were collected. The size and type of the samples depended on the tests required. It is observed by correlating field and laboratory investigations that the cohesion in the soils of Rara and Kohala landslide is more as compared to Muzaffarabad proper, Chattar, Jalalabad, Upper Plate, Dulai, and Bagna. The results obtained from the consistency limits dry density, and grain size analysis reveal their competency to settlement i.e. 1.20 mm per ten days applying 50 PS1 pressure on 60 x 60 cm blocks of the soils of the area under study (soil testing Laboratory Government of Sind 1988).

Table - 2

Stress and strain relationship of soils of Muzaffarabad - Kohala Area:

Field Description	Total Stress PSI	Strain at failure	Angle of friction
Disturbed	M-1. 35.2	14.5	16^{o}
Samples	M-2. 60.5	14.0	
Samples	K-3. 86.9	14.5	

Table - 2a

Hardness of the soils

		PSI	PSI
Hard Samples	M-1	35	100
	M-2	20	80
	M-3	30	95
Wet Samples	K-1	10	35
	K-2	5	20
	K-3	2	4

M. stands for Muzaffarabad

K. Stands for Kohala

Table - 2b

Bearing capacity of soils of Muzaffarrabad Kohala area:

S.No.	No. of Blows	In situ Condition	Allowable bearing Capacity Tons/ SFT
M-1	2	very loose	0.30
M-2	4	soft	0.30 - 0.60
M-3	8	medium	0.60 - 1.20
K-1	15	stiff	1.20 - 2.40
K-2	30	very stiff	2.40 - 4.80
K-3	730	hard	7.40 - 8.00

OBSERVATIONS

Particle Size Distribution: This test was made to know the quantitative distribution of particle sizes in soils.

Each sample was analysed to determine the percentage of individual grain size in a sample. (Fig. 2).

Correlation has been established in the soils of varying physical characteristics. A general behaviour of the soils of the area is found suitable for the construction of roads, foundations, dam sites, and highway. Bearing capacity of the soils was estimated to be 100 PSI in dry conditions and 10-35 PSI in wet conditions (Table - 2).

The portion of the soil retained in No. 10 sieve (0.02 mm) from a column of series of fractions 3 in (76.2 mm), 2 in (50 mm), $1^1/_2$ in (37.5 mm), 1 in (25 mm), $^3/_4$ in (19 mm), $^3/_8$ in (9.5 mm) were studied quantitatively.

The grain size distribution curve gives the exact idea regarding textural and gradational behaviour. It also makes possible to consider the use of soil as construction raw material. The soils of the area is classified as poorly to well graded (Fig. - 2).

Liquid Limit: The liquid limit of the soil is the water content in percentage that a soil can absorb and with stand at 21°F. The minimum water content at which two halves of a soil pat will flow together for a distance of (12.7 mm) along the bottom of the grove separating the two halves, when brass cup is dropped 25 times from a height of 5 cm at the rate of 2 drops per second.

From Bandian locality nine samples were tested to evaluate the bearing capacity of the soils. The values of the liquid limit ranges from 29.8 to 34%; averages 31.4% (Table - 3). From Channalbong it ranges from (25.2% to 31.8%), and averages 28.5%. At Dulai it increases upto 35.3%. From Banga, the soils have variable textural characteristics. The water content ranges from 26.7% to 34.2% and averages 31.1%. The data available show that the moisture content increases from top to the bottom of the bed, due to increasing clay content in the soils. The Barsala is off the road and the soils are mainly exposed on slopes and valleys. The maximum value of water content observed in this locality is (36.2%) and the minimum value is 29.5%, averaging 32.3%. In this area water content increases moving form top to the bottom of the bed. From Namal the water content increases from 29.2% to 32.3% and the averagae is 26% (Fig. 3).

Kohala is about 35 km from Muzaffarabad. The soils are mainly composed of red clays, silts sands, gravels, pebbles, cobbles and boulders, of Murree Formation of Miocene age. The maximum value of liquid limit was found to be 26.6% whereas the minimum value is 22.6% and average value is 24.8%. From the above data it is inferred that the increase in water content in the soils is more at landslide area 2 km from Kohala and decreases towards Murree due to decrease in clayey material. The moisture content in the soils is more than 40% as the slope angle increase from 10^0 to 75^0 (Figs. 3, 4).

Plastic Limit: The plastic limit of the soil is the water content, present in the soil at which the soil mass do not break under high stress conditions. The presence of water content is expressed in percentage. This state is between liquid and soild states. The water content at this boundary is arbitrarily defined as the lowest water content at which soil was rolled into threads 3.2 mm, in diameter without breaking into pieces.

Plasticity of the soils of the area are due to the inherent variations of structure and composition within the crystal lattice. Generally, the plastic limit for clayey soils decreases in the order montmorillonite, illite and kaolinite. It is inferred from the experimental results that exchangeable ions are Na^+ and Li^+ which increase the plasticity of the soils of the area (Fig. 6).

The soil samples observed form Dulai locality range in value from (15 to 18.2%) and average is 16.6%. It was observed during the laboratory investigation that the plasticity increases in soils collected from the bottom of the bed. The Bagna soil samples show low to high plastic limits (10% to 17.4%) and average is 14.1%. Barsala is off the road showed slightly higher difference in the values. These values range between 14% to 20% and more at places. These changes are due to low content of clay minerals in the soils of this area. Mulia and Kohala show a range in value between 12% to 21% and average is 14.7%. It is evident from the above results that the clay minerals decreases towards Kohala (Figs. 4, 5). In the Kohala landslide area moisture content increases upto 50% due to Sink holes and highly fractured soils on the top of the bed.

Shrinkage And Swelling: One of the most important physical characteristics of the soils of the area from the engineering point of view is their susceptibility to slow volume changes which can occur independently, of loading due to swelling or shrinkage. The imbibe water leads to it swelling, and when it dries out it shrinks. These changes causes appreciable damage to buildings, roads, bridges in Rara and Kohala area. Differences in the period and magnitude of precipitation and evaporation in summer and winter are the major factors influencing the swell-shrink response of the active soil beneath the civil engineering structures. Poor surface drainage and leakage from springs also produce concentrations of moisture in the soils of the area. Small trees with high water demand

TABLE - 3

SHOWING PRESENT AND RECOMMENDED VALUES OF ENGINEERING CHARACTERISTICS OF THE SOILS

Sr. No.	Locality	Liquid limit %		Plasticity Index %		Shrinkage Limit %		Swellability %		Dry Density g/c.c.	
		Recom-mended Values	Present Work	Recom-mended Values	Present Work	Recom-mended Values	Present Work	Recom-mended Values	Present Work	Recom-mended Values	Present Work
		Jumikus (1972)		Jumikus (1972)		Gibbes (1970)		A.A.S.H.O. (1970)		Khanna S.K. & Justo C.E. G. (1980) Highway Material Testing	
1.	Dulai	19 - 43	31.1-35.3	5 - 20	16.1-17.1	7 - 20	9.5	5 - 50	23.8	1.7-1.89	1.67
2.	Bandian	"	29.8-34	"	8.1-14	"	15.5	"	13.4	"	1.76
3.	Barsala	"	29.5-38.2	"	15.2-15.6	"	16.6	"	20	"	1.69
4.	Channalbang	"	25.2-31.8	"	8.5-15.6	"	12.7	"	5.2	"	1.72
5.	Nammal	"	26.0-32.3	"	10.1-10.6	"	16.2	"	12.2	"	1.6
6.	Bagna	"	26.7-34.2	"	14.5-16.8	"	13.4	"	47.5	"	1.78
7.	Mulia	"	29.6-31.6	"	8-13.6	"	13.1	"	52.5	"	1.79
8.	Kohala	"	22.6-26.6	"	9.2-10.9	"	10.3	"	10	"	1.83

TABLE - 4

CLASSIFICATION OF SOILS OF THE PRESENT WORK

LOCALITY	DEGREE OF PLASTICITY	CLASSIFICATION OF SOILS ATTERBERG (1905)	PRESENT WORK	REMARKS
Dulai	Medium Plastic and High Plastic	P.I. - 0 = Sand	> 7 < 17	Soils are sility clay to clay, fine to medium grained, brownish, hard and compact at places.
Bandian	Medium Plastic	P.I. - > 7 = Soil	> 7 < 17	Soils are silty clay, fine to coarse grained, brownish, hard and compact at places.
Barsala	Medium Plastic	P.I. - > 7 < 17 = Silty Clay to clayey Salt	> 7 < 17	Soils are slity clay-clayey silt, fine to coarse grained, brownish to blackish and compact at places.
Channalbang	Medium Plastic	P.I. - > 17 = clay	> 7 < 17	Soils are silty clay-clayey silt, fine to coarse grained, brownish and hard at places.
Bagna	Medium Plastic		> 7 < 17	Soil are silty clay-clayey silt, fine to coarse grained, brownish to yellowish hard and compact at places.
Nammal	Medium Plastic		> 7 < 17	Soils are silty clay-clayey silt, brownish to reddish, hard and compact at places.
Mulia	Medium Plastic		> 7 < 17	Soils are silty clay to clayey silt, fine to coarse grained, brownish to yellowish and compact at places.
Kohala	Medium Plastic		> 7 < 17	Soils are silty clay to clayey silt, fine to coarse grained, brownish and loose to compact at places.

TABLE 5

CLASSIFICATION OF SOILS OF THE AREA UNDER STUDY ON THE BASIS OF PLASTICITY INDEX

S. No.	LOCALITY	L.L.%	P.L.%	P.I.%	LIMIT OF PLASTICITY INDEX	DEGREE OF PLASTICITY	TYPE OF SOIL
M-1	Bandian	34	20	14	> 7 < 17	Medium Plastic	Silty Clay Clayey silt
M-2		30.3	22.2	8.1	> 7 < 17	" "	" " "
M-3		29.8	19	10.8	> 7 < 17	" "	" " "
M-4	Barsala	36.2	20	16.2	> 7 < 17	" "	" " "
M-5		31.3	15.8	15.5	> 7 < 17	" "	" " "
M-6		29.5	14.3	15.2	> 7 < 17	" "	" " "
M-7	Dulai	35.3	18.2	17.1	> 17	High plastic	Clay
M-8		31.1	15	16.1	> 7 < 17	Medium plastic	Silty clay - Clayey silt.
M-9	Channalbung	31.8	16.2	15.6	> 7 < 17	" "	" " "
M-10		28.5	20	8.5	> 7 < 17	" "	" " "
M-11		25.2	13.6	11.6	> 7 < 17	" "	" " "

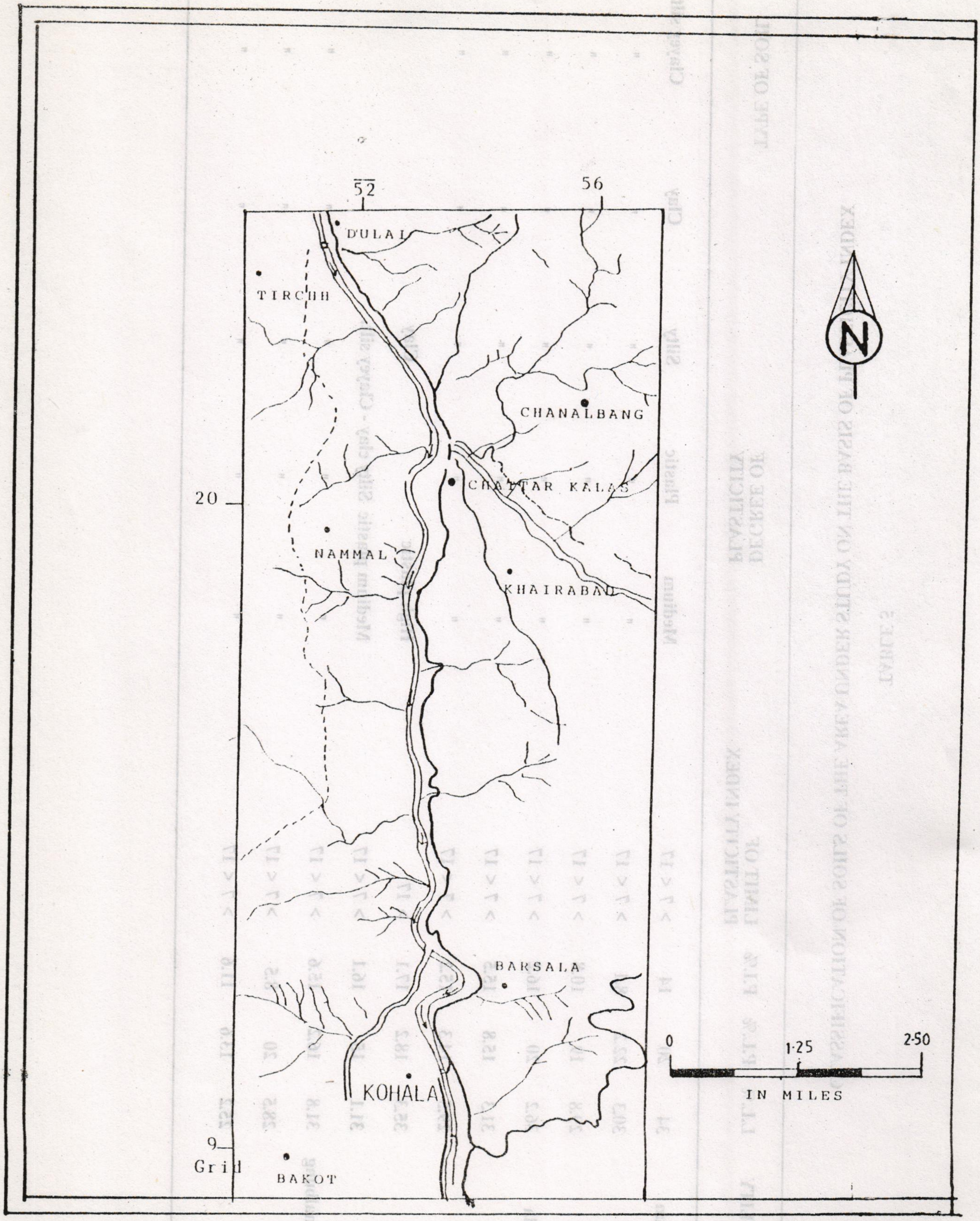


FIG.1 LOCALITY MAP OF DULAI-KOHALA AREA.

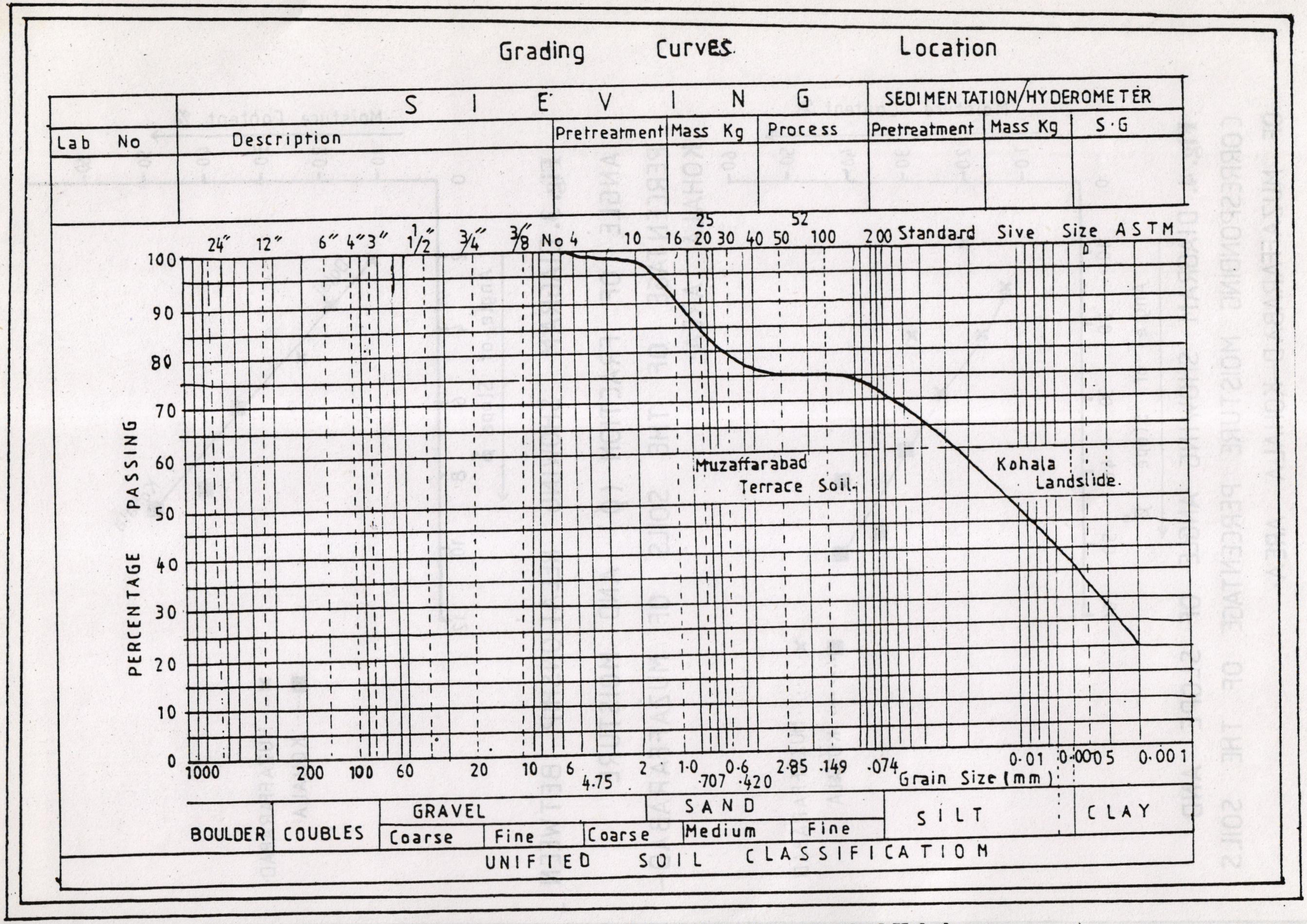


Fig. 2 **Grain size analyses of the soils of Muzaffarabad-Kohala area.**

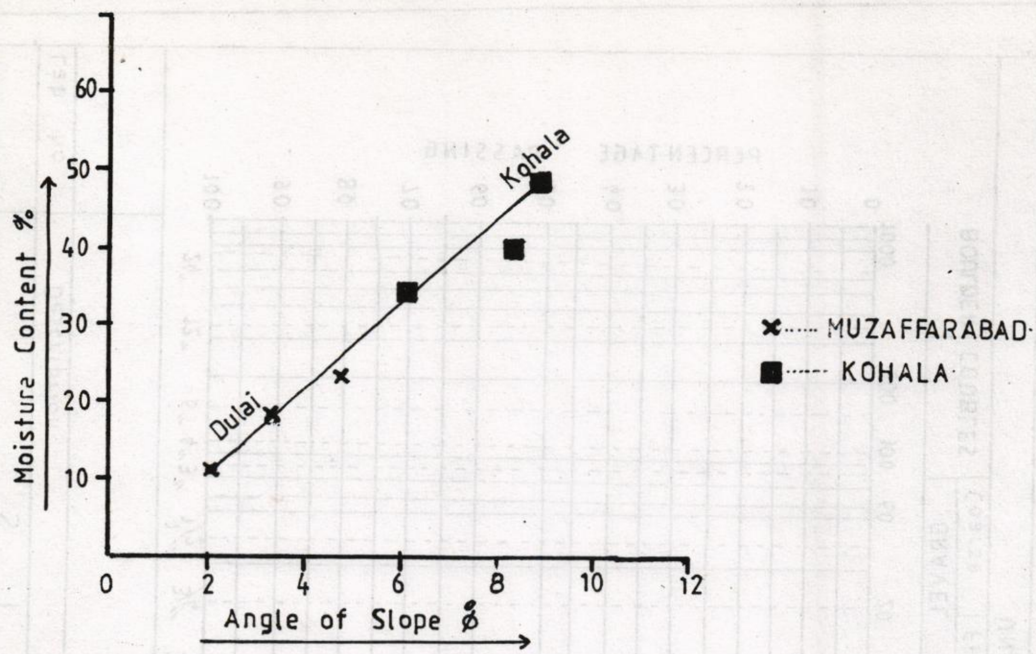


Fig. 3. DIAGRAM SHOWING RELATIONSHIP BETWEEN ANGLE OF FRACTION (∅) AND MOISTURE PERCENTAGE OF THE SOILS OF MUZAFFARABAD–KOHALA AREA.

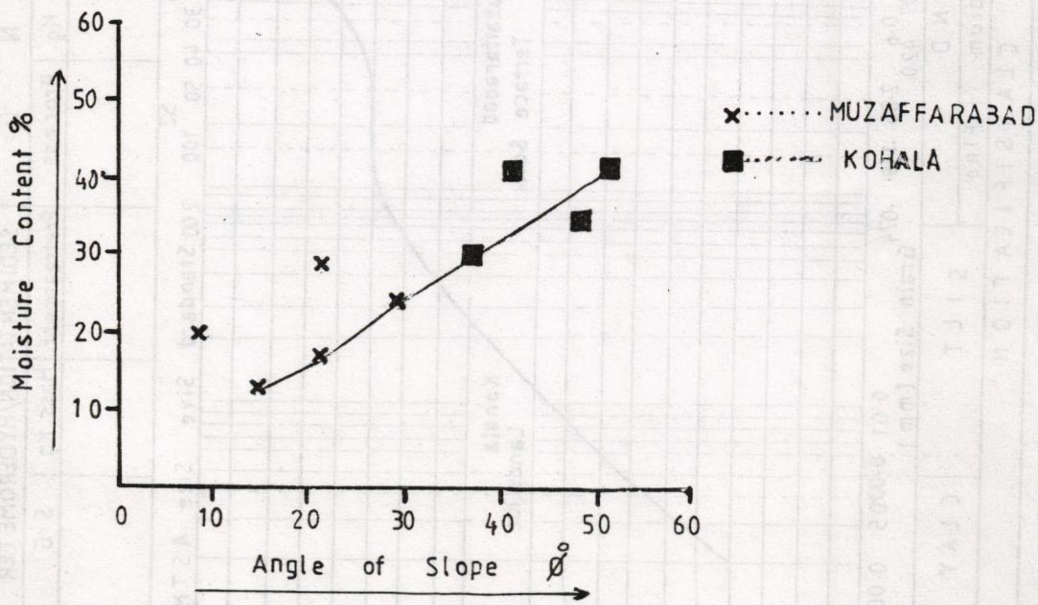


Fig. 4. DIAGRAM SHOWING ANGLE OF SLOPE AND CORRESPONDING MOISTURE PERCENTAGE OF THE SOILS OF MUZAFFARABAD–KOHALA AREA.

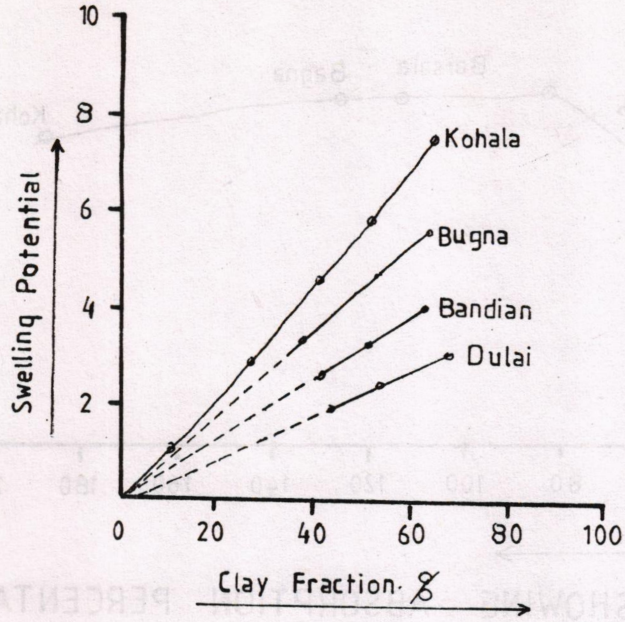


Fig. 5 DIAGRAM SHOWING PLASTICITY INDEX AND CLAY FRACTION OF THE SOILS OF MUZAFFARABAD--KOHALA AREA (TERRACE)

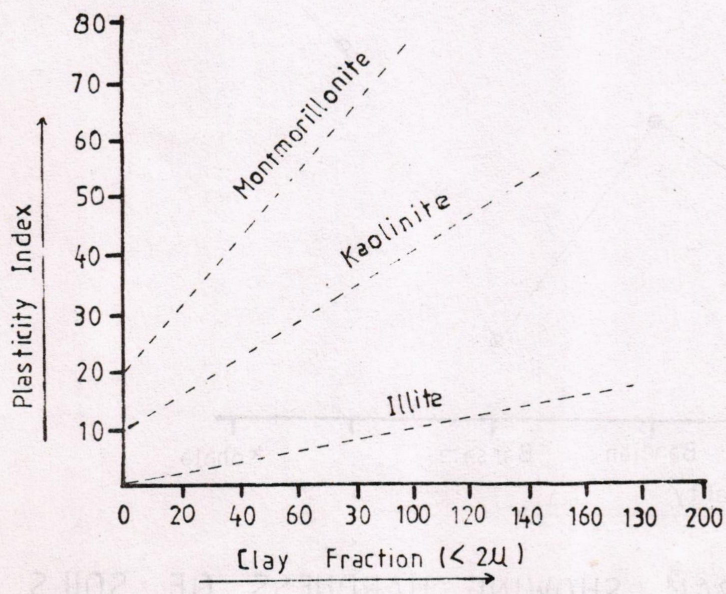


Fig. 6 DIAGRAM SHOWING PLASTICITY INDEX AND CLAY FRACTION OF THE SOILS OF MUZAFFARABAD KOHALA AREA. (TERRACE)

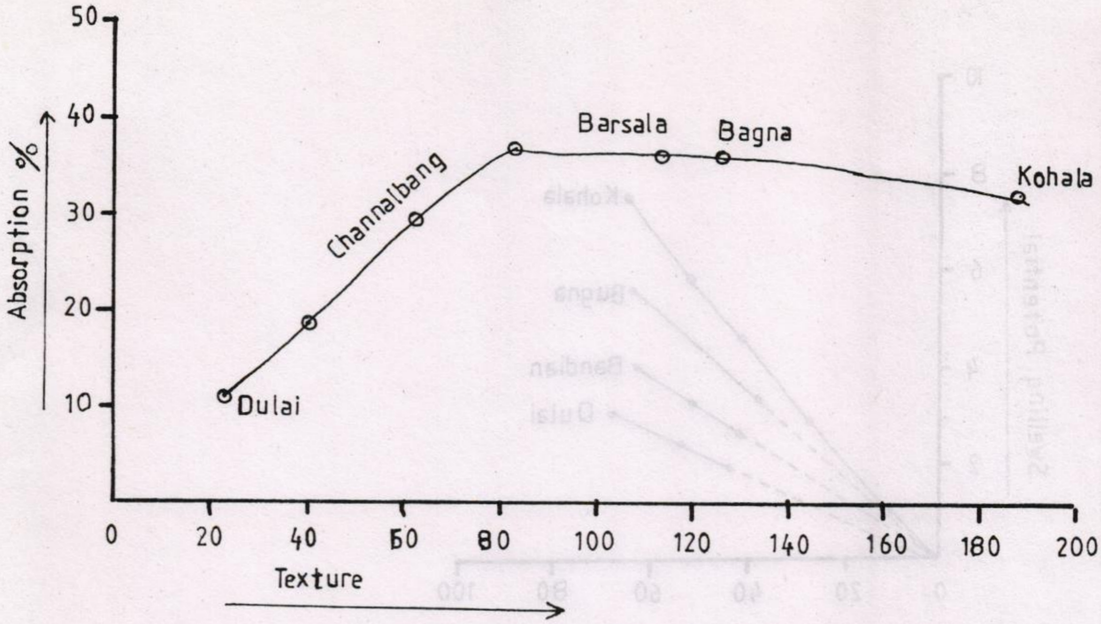


Fig. 7 DIAGRAM SHOWING ABSORPTION PERCENTAGE AND TEXTURAL CHARACTERISTICS OF THE SOILS OF MUZAFFARABAD—KOHALA AREA.

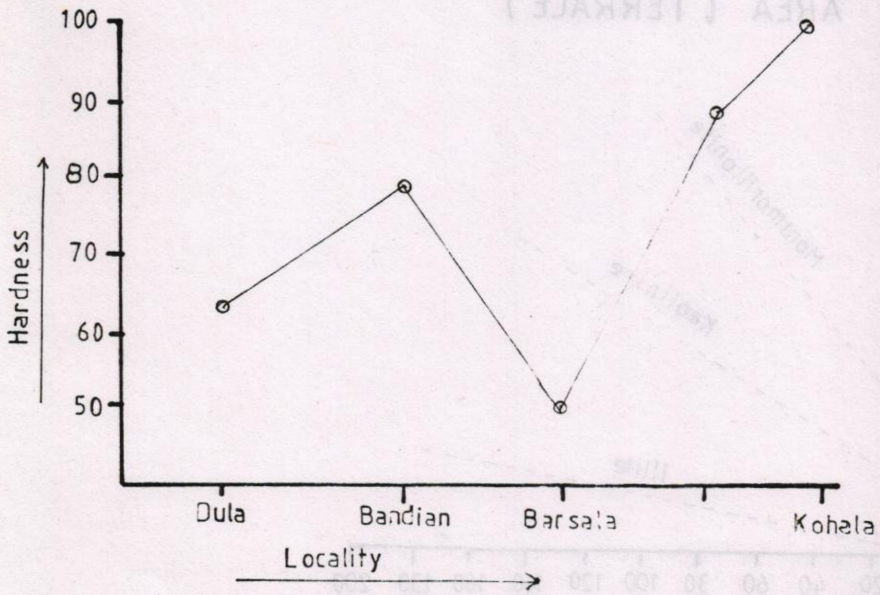


Fig. 8 DIAGRAM SHOWING HARDNESS OF SOILS OF THE LOCALITIES UNDER STUDY.

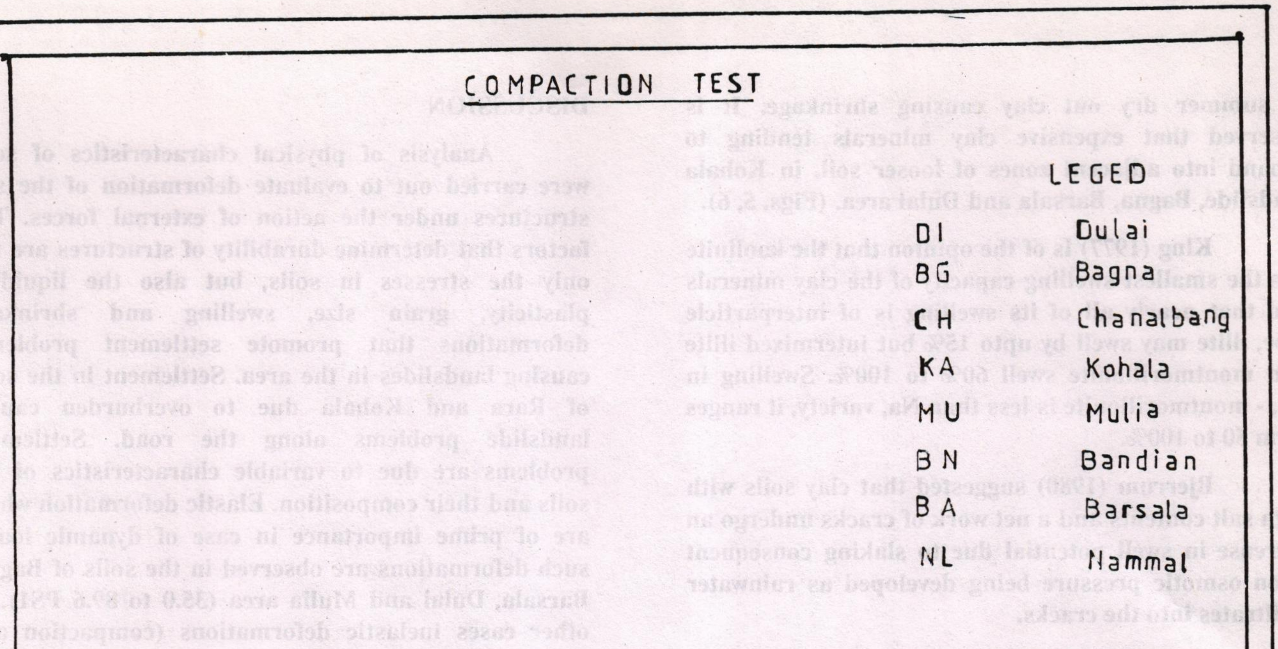
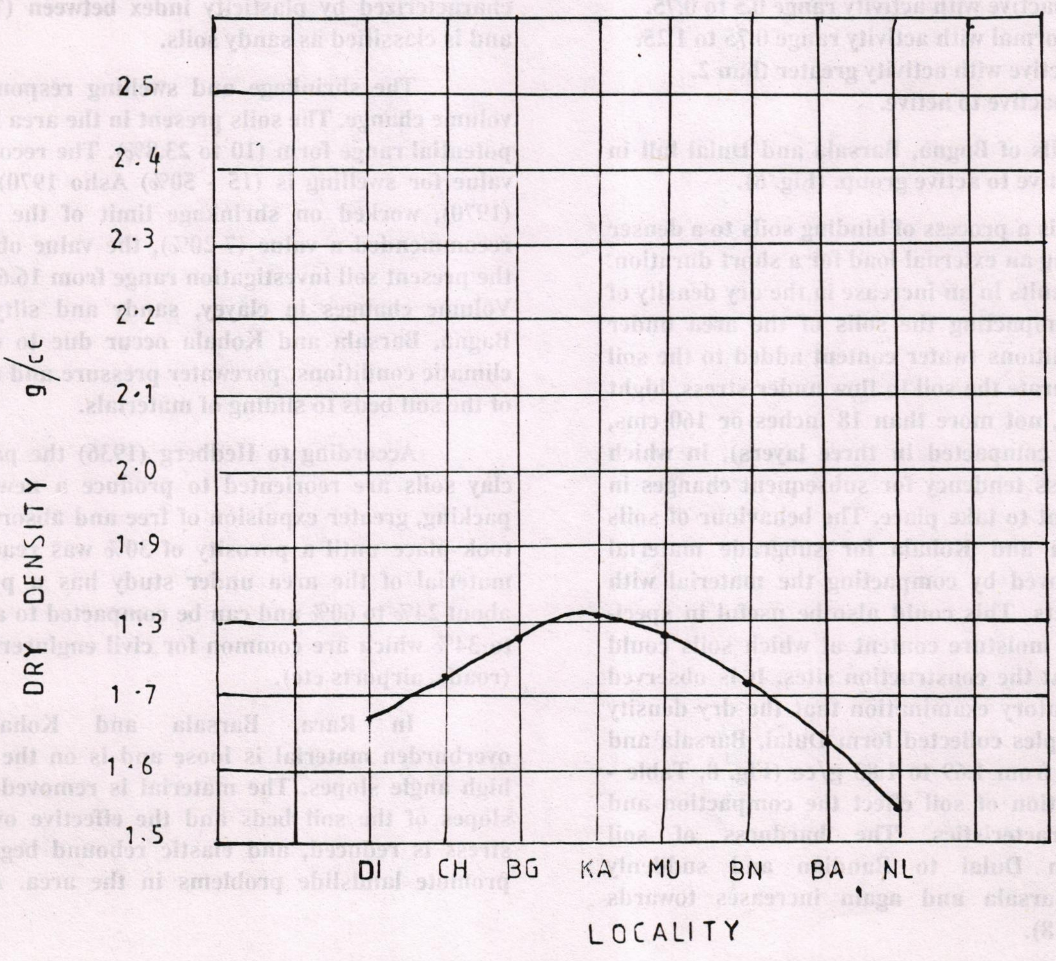


Fig. 9. Showing dry density of the soils of Muzaffarabad-Kohala area.



in summer dry out clay causing shrinkage. It is observed that expensive clay minerals tending to expand into adjacent zones of looser soil, in Kohala landslide, Bagna, Barsala and Dulai area. (Figs. 5, 6).

King (1977) is of the opinion that the kaolinite has the smallest swelling capacity of the clay minerals and that nearly all of its swelling is of interparticle type, illite may swell by upto 15% but intermixed illite and montmorillonite swell 60% to 100%. Swelling in Ca, - montmorillonite is less than Na, variety, it ranges form 50 to 100%.

Bjerrum (1980) suggested that clay soils with high salt contents and a net work of cracks undergo an increase in swell potential due to slaking consequent upon osmotic pressure being developed as rainwater infiltrates into the cracks.

As inferred from the laboratory examinations Rara and Kohala clays increase their swell behaviour when they undergo repeated large shear strains due to mechanical remoulding. They are classified by the swell potential into five groups:

1. Inactive with activity less than 0.50.
2. Inactive with activity range 0.5 to 0.75.
3. Normal with activity range 0.75 to 1.25.
4. Active with activity greater than 2.
5. Inactive to active.

The soils of Bagna, Barsala and Dulai fall in the rage of inactive to active group. (Fig. 6).

Compaction: It is a process of binding soils to a denser state by applying an external load for a short duration. Compaction results in an increase in the dry density of the soil. By compacting the soils of the area under controlled conditions (water content added to the soil should not saturate the soil to flow under stress, hight of the hammer, not more than 18 inches or 160 cms, soil should be compacted in three layers), in which there will be less tendency for subsequent changes in moisture content to take place. The behaviour of soils of Dulai, Rara and Kohala for subgrade material could be improved by compacting the material with repeated impacts. This could also be useful in specifying optimum moisture content at which soils could be compacted at the construction sites. It is observed from the laboratory examination that the dry density of the soil samples collected form Dulai, Barsala and Kohala ranges from 1.69 to 1.83 g/cc (Fig. 8, Table - 3). The absorption of soil effect the compaction and hardness characteristics. The hardness of soil increases form Dulai to Bandian and suddenly decrease to Barsala and again increases towards Kohala (Fig. 7, 8).

DISCUSSION

Analysis of physical characteristics of soils were carried out to evaluate deformation of the soil structures under the action of external forces. The factors that determine durability of structures are not only the stresses in soils, but also the liquidity, plasticity, grain size, swelling and shrinkage deformations that promote settlement problems, causing landslides in the area. Settlement in the soils of Rara and Kohala due to overburden causes landslide problems along the road. Settlement problems are due to variable characteristics of the soils and their composition. Elastic deformation which are of prime importance in case of dynamic loads, such deformations are observed in the soils of Bagna, Barsala, Dulai and Mulia area (35.0 to 89.6 PS1). In other cases inelastic deformations (compaction and swelling) may be critical.

The comparison of the data of present study with the recommended values show that the liquid limit and plastic limit values are slightly higher than the recommended values. The plasticity index was compared with ASTM. The soils of the area are characterized by plasticity index between (7 and 17) and is classified as sandy soils.

The shrinkage and swelling response to the volume change. The soils present in the area have swell potential range form (10 to 23.8%). The recommended value for swelling is (15 - 50%) Asho 1970). Gribbes (1970), worked on shrinkage limit of the soils and recommended a value (7-20%), the value observed in the present soil investigation range from 16.6 to 19.5%. Volume changes in clayey, sandy and silty soils of Bagna, Barsala and Kohala occur due to change in climatic conditions, porewater pressure and unloading of the soil beds to sliding of materials.

According to Hedberg (1936) the particles of clay soils are reoriented to produce a new mode of packing, greater expulsion of free and absorbed water took place until a porosity of 30% was reached. The material of the area under study has a porosity of about 24% to 60% and can be compacted to about 20% to 34% which are common for civil engineering works (roads, airports etc).

In Rara, Barsala and Kohala area, overburden material is loose and is on the flanks of high angle slopes. The material is removed form the slopes of the soil beds and the effective overburden stress is reduced, and elastic rebound begins which promote landslide problems in the area. A part of these landslides resulted due to multiple loading and unloading of the soil deposits on slopes.

It appears from field and laboratory examination that significant time dependent vertical swelling arise, at least in the upper part causing localized tensile and shear failures, are having probably associated with long term deformation of soils of the area having well developed diagenetic effects in clayey soils. Excavations along the road in clayey soils cause immediate dissipation of some stored enegry in the soil which effect the competency of the soils in the area. The soils of the area have been classified according to their physical characteristics i.e. plasticity index, clay fraction and hardness (Figs. 5, 6, 7 - Tables 3, 4, 5).

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ENGINEERING CHARACTERISTCS OF NAUSERI MARBLE, AZAD KASHMIR

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ABSTRACT: White, grey and bluish grey marble and brownish grey to white and dense marble occur in Nauseri area. The deposits were formed at south western margin of Kashmir landmass during Permo-Carboniferous times. They were metamorphosed to varying degrees. White crystalline limestones are calcite marbles of inferior quality comprising a small part of the deposits. Most of these potential sources are not developed so for mainly for lack of technical information. However, on the basis of range of colours, good textures and quality a large and potential quarries could be developed. This paper describes the engineering characteristics of Nauseri Marbles.

A number of mechanical characteristics were determined and most of them are in confirmation to ASTM specifications.

The compressive strength of the marble varies from 3100 PSI to 8100 PSI. Taber Abrasion Index value range from 8.0 to 15.01. The soundness ranges from 0.1 to 5.0%, absorption varies from 0.01 to 8%. Specific gravity ranges from 2.65 to 2.73. The porosity of the marble is 0.5 to 8.3%.

INTRODUCTION

Major deposits of grey, bluish grey and whitish grey coloured marbles are situated on the southern bank of Neelum river, 42kms up-stream of Muzaffarabad along the Muzaffarabad-Neelum valley road. The Nauseri marbles are whitish grey and bluish grey to brown coloured and dense to sheared at places. The marble is rarely used at present as decorative building stone due to non-availability of the physico-mechanical information.

The occurrence of the marble is known in this territory of Azad Kashmir for the last twenty years the deposits of which were not developed and the building industry has to depend on imported stone. The marbles available in the area are fine to coarse grained, white to pink and grey in colour and can take good polish. some quarries are off the road but are approachable by truckable roads. Major problem of the industry is the cutting, sizing and finishing at site. The provision of all the infrastructures at sites will reduce the cost in the development of new quarries. Due to variation in colour and texture, it is also easy to fully utilize all the decorative stones, except the off white marble which is thin bedded on the margins.

As a result of investigation it is expected that the Nauseri marbles may show good results, for proper utilization and their rational exploitation.

The main properties which control performance like porosity, compressive strength, abrasion, resistance to mechanical attack and dimensional stability, have been evaluated. This research provides data which would make the selection and uses of the decorative stones easy.

GEOLOGICAL SETTING

The Nauseri marble deposits occur in the autochthonous zone of the area comprising agglomerates, Panjal volcanics and Triassic limestone. It is bounded on the south-western side by the Main Boundary Thrust (MBT) and on he northeastward by the Panjal thrust. Agglomerates are dark grey to black coloured slates, whereas volcanics in the area exhibit dark green to greenish coloured, fine grained rocks with intercalations of marble and limestone. Wadia

(1934) and Bossart et al. (1984) described these limestones as of Triassic age on the basis of crinoids found in the rocks. Ghazanfar et al. (1983) seprated autochthonous zone by Panjal thrust. It comprises mica schist, quartz mica schist and quartzites in the area. Murree Formation is exposed southwest of MBT. Lithologically, the constituents of Murrees are mainly sandstones, siltstones and shales. Along the thrust plane the rocks are usually sheared. Wadia (1934) recognized the rocks of the autochthonous zone as Carboniferous to Triassic in age.

The Nauseri marble deposits occur in the form of continuous outcrops starting from Nauseri to Manjhoter area (Fig. 1). The rocks are fractured and jointed to massive, from which about 2x2x2m dimension slabs could be made. The outcrop is about 50m thick having a lateral exposure distance of 16 km. The outcrops of marbles are not found beyond coordinates 573439 in the Survey of Pakistan toposheet No. 43F/12.

The individual beds of the deposit ranges in thickness from 10cm to 90cm at places. The stratigraphic succession and the superposition of marbles in Nauseri area is (Table. 1).

Formation	Age	Description
Murree Formation	Miocene	Fine to coarse grained sandstone, clays and shales.
		Murree Thrust
Panjal Volcanics	Traiassic to Permian	
Nauseri marble		Grey Marble White marble Dolomitic marble
Agglomeratic Slates.	Permocarb-oniferous	
		Panjal Thrust
Granites/Gneisses Tanol Formation	Pre-Cambrian	

Mallick (1972) and Shakoor (1976) recognised the carbonate outcrops around Nauseri as Nauseri marbles. Position of marble in the stratigraphic succession is between Panjal volcanics and Agglomeratic Slates. The dolomitic marble overlying the Agglomeratic Slates has been found near Gratnar area.

MINERALOGICAL COMPOSITION

Marbles of various colours were collected for the purpose of petrography and physico-mechanical characteristics. The classification is based exclusively on the physical and mechanical characteristics. It also reflects the mineralogical composition of the marble.

General colour of the rock is grey and whitish grey with subordinate pinkish layers. It shows fine to coarse grained interlocking texture with 10 to 25 per meter joints and fractures in the sheared zones. At places thin quartz veins are present as well.

Nauseri Grey Marbles: The constituent minerals are calcite (94.5-5.96%) as fine to coarse anhedral with strained grains of quartz, white mica, garnet, pyrite and clays as inclusions, Quartz(2%) occurs as fine to coarse subhedral grains with wavy extinction. Muscovite (1%) is seen as small elongated flakes. Garnet occurs as traces, Clay minerals (1.5%), hematite(1%). Pyrite(2%) are present as dust like stuff.

Nauseri White Marbles: Nauseri white marble is mainly exposed in the lower portion of the marble deposit northwest of the river Neelum. Its northwestern contact with Agglomeratic Slates is gradational whereas the southern contact with volcanics is sharp. It is whitish, pinkish and dull in colour. It is a metamorphic rock with coarse crystals, joints, cracks and fractures. Veins of quartz and calcite show boudinage structures.

The constituent minerals are Calcite (95%), as fine to coarse anhedral grains. Quartz (2%) occurs as fine to coarse anhedral strained grains with wavy extinction and sutured margin. Garnet (0.02%), is found as medium to coarse subhedral grains with trigonal fractures and oriented grains surrounded by elongated flakes of muscovite and with inclusions of iron ore (2%), as fine to coarse grains of magnetite, hematite and limonite, with some clay minerals (1.5%) (Table 2).

Nauseri Dolomitic Marbles: Dolomitic marble is exposed in contact with Agglomeratic Slates in the northern part of the area whereas in the southern part its southeastern sharp contact is with Panjal volcanics. In the western side at some places huge patches of Agglomeratic Slates are also found in contact with this unit.

It is greenish grey and pinkish in colour. It is completely metamorphosed rock with lineation, cracks, joints and fractures. The bedding plane is inclined at an angle of 20^0 to 45^0 in NW direction. At places calcite veins were also found.

The constituent minerals are calcite (93%) as fine to coarse anhedral grains with inclusions of quartz along cleavage and at grain margins. It is altered to greyish brown colour. Quartz(2.20%) occurs as fine to coarse grains with sutured margins and wavy extinction. Ore minerals (1.20%) include pyrite. Mica minerals (1%) are of fine to medium flakes of muscovite. The percentage composition is given in (Table. 2).

PHYSICO-MECHANICAL CHARACTERISTICS

The marble is thin to medium bedded fine to medium grained and takes good polish. Lower part of this marble is whitish grey in colour, highly fractured and jointed. The beds dip 20^0 to 58^0 NW direction. Uppermost part is grey in colour and is easily quarriable. Mainly fractures are parallel to main stratification. Cracks are mainly perpendicular to bedding and the aperture is 2 to 15cms. At places fracture planes are dipping at an angle of 30^0 to 50^0 in north-east direction. The joints, fractures and cracks cut the rock into rectangular blocks of 0.5 to 1 meter and at places 1.5 to 2 meters dimensions having small cracks. As the joints are mostly perpendicular to main bedding plane, facilitate in obtaining dimensional blocks. The pure whitish grey marble in the upper part is of architectural variety.

The marble available in the area is not being worked on any appreciable scales due to lack of technical informations. The whitish grey deposits commonly yield dimension stones. However, northeastern portion is highly fractured and can be worked as marble chips. Grey, bluish grey and brownish varieties are exposed in the lower part of the marble deposits in the area and are to be worked as building stones. These varieties are fine to coarse grained, dense very hard and takes good polish. These could be quarried for building stones. After cutting and polishing this variety can be used for interior and exterior decoration. Near the contact of volcanics colour of the marble varies from grey to green.

QUALITY ASSESSMENT AND GRADING

The marbles which are available in the area differ greatly in performance and durability, so the choice of the stone for buildings of national importance cannot be made on the basis of colour and texture alone. The most important physico-mechanical properties in the following pages for quality assessment and grading of Nauseri marbles have been described.

Compressive Strength: Compressive strength range from 22400 PSI to 1500 PSI (ASTM 1986). The strength is rather low for Nauseri marbles because of high intensity of fractures and the presence of microcracks. The rocks are inhomogeneous but at places, strong and few are weak (Table 3).

In addition the marble is anisotropic with the strength range in value from 3100 PSI to 8200 PSI. The stress strain curve (fig. 2) show steps due to internal slips along fractures. This may make the rock weak when used for construction purposes.

Abrasion Resistance: Abrasion resistance was measured by the Taber method which gives an abrasion index. A value of 18 has been obtained. The marble is of high abrasion resistance and is suitable for paving in areas with moderate to heavy traffic (Table 3).

Soundness: Soundness test was carried out by using sodium sulphate saturated solution for five cycles by immersion of 1000g and 100g crushed sample for sixteen eighteen and twenty four hours. Salt crystallization has loosened grain boundaries in fine grained regions, possible slight bleaching and loosening of cleavage in larger calcite crystals. The most noticeable effect is the formation of deep cylindrical pits (about 0.2mm across and 0.5mm deep) where soft clayey material has been removed (Table 3).

Absorption: Nauseri marble is dense, hard and compact, however, tectonic activities in the area made lithological differences which seem to have resulted improvement in compatness of the rocks. The value of absorption ranges from 0.01% to 8.0% and average is 4.01% (Table 3). The most durable marble has values between 0.01% to 0.8%. The values between 2% to 8% or greater have no satisfactory performance. The upper limit for water absorption of external marble in ASTM C 503-79, is 0.75%.

Porosity: The porosity of the rocks exposed in Nauseri area is considered most important physical property for the selection of rocks during designing civil engineering projects, because the rocks of the area are highly sheared due to Panjal Fault. This

TABLE 2

TABLE SHOWING PERCENTAGE COMPSOTION OF NAUSERI MARBLES AZAD KASHMIR

	WHITE MARBLE (NWM-1)	GREY MARBLE (NGM-3)	DOLOMITIC MARBLE (NDM-5	NB-6	NB-8)
Calcite	95	96	93	93	73
Quartz	2	0.2	3	2	20
Muscovite	-	1	-	-	1
Garnet	-	-	1	1	2
Ore minerals	2	1	1	2	2
Pyrite	1	1	1	1	-
Clay	1	1	1	1	2

TABLE 3

PHYSICAL PROPERTIES OF NAUSERI MARBLES AZAD KASHMIR.

S.No.		Compressive-Sgrength (PSI)	Taber Abrasion-%	Soundness %	Absorption %	Specific Gravity	Porosity %	Molulus of Rupture (PSI)
Nauseri	(NWM-1)	7800	14	0.5	0.01	2.56	8.3	3800
white Marble	(NWM-2)	8100	14.5	2.0	2.3	2.71	0.5	1900
	(NWM-3)	8100	15.5	0.81	8.0	2.73	8.0	1500
Grey Marble	(NGM-4)	4100	8.0	2.54	0.5	2.71	2.5	1400
	(NGM-5)	4100	9.02	0.1	0.8	2.65	2.68	1200
	(NGM-6)	3500	13.5	0.55	0.7	2.73	4.63	1100
Dolomitic	(NDM-7)	3100	14.1	5.00	5	2.71	7.2	900
Marble	(NDM-8)	4700	8.2	0.48	2.36	2.65	6.28	900
	(NB- 9)	4000	10.7	0.1	5.23	2.72	7.8	1200
	(NB-10)	3400	8.0	2.50	4.68	2.71	8.0	1300

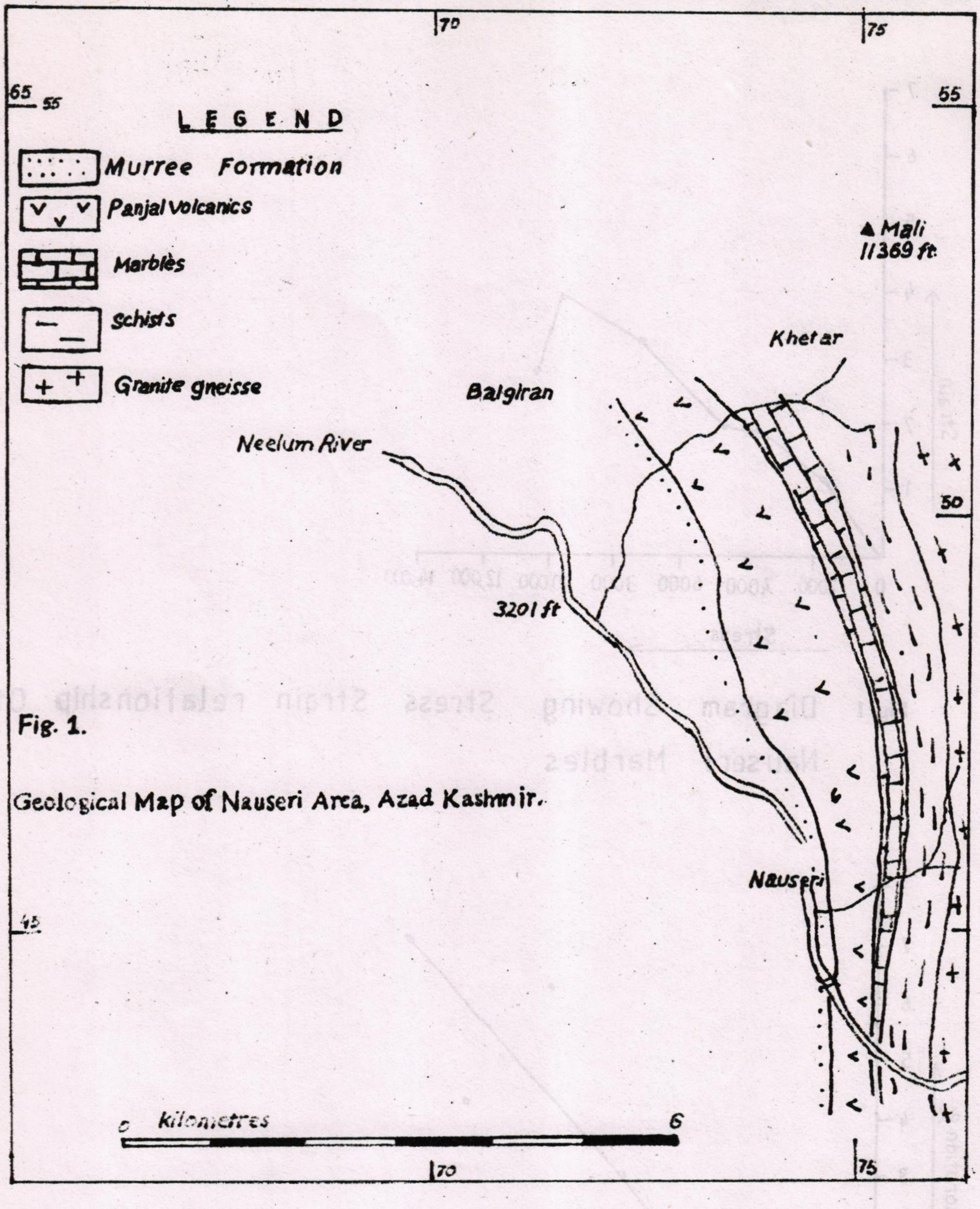

Fig. 1.

Geological Map of Nauseri Area, Azad Kashmir.

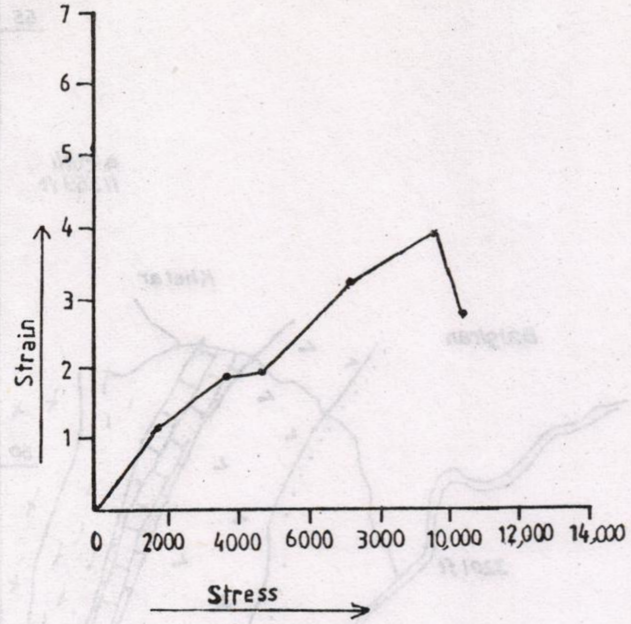

Fig. 1 Diagram Showing Stress Strain relationship Of Nauseri Marbles

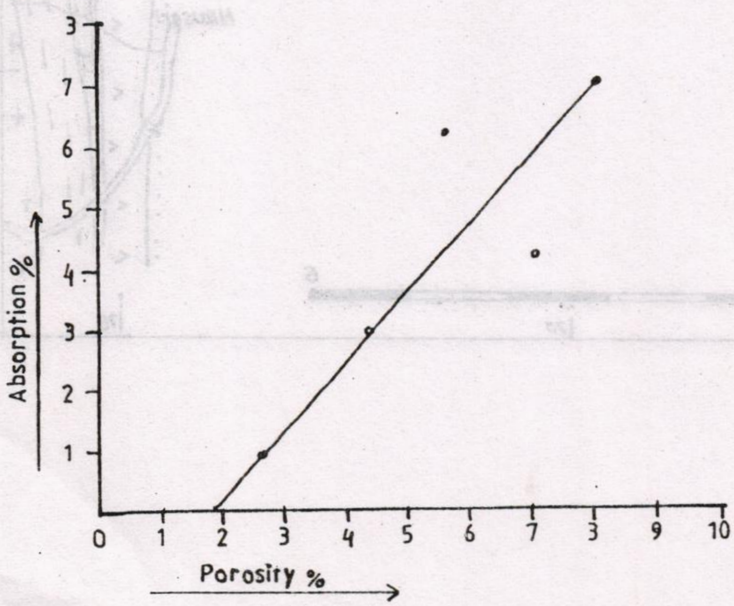

Fig. 2 Diagram Showing Correspondence between Porosity and absorption percentage of Nauseri Marbles.

property was evaluated by using porometer method. The porosity of the Nauseri marbles range from 0.5% to 8.0% and average is 4.8%. It is observed during the microscopic examination that the porosity lies mainly along grain boundaries. The higher values of porosity is due to incoherent boundaries. Dimensional instability (permanent change of dimensions with wetting and drying or heating and cooling) can be correlated with porosity (Table 3). The specific gravity of the marbles is between 2.65 to 2.73. The specific gravity decrease with increase in porosity due to weathering.

Modulus Of Rupture: The modulus of rupture (flexural strength) was measured by the Draft methods of the Standards Association of Australia, and ASTM C 99-52(1981). The failure of the specimen which are taken under the loading of 200x100x60mm. The values range between 500PSI to 3000 PSI of eight samples analysed.

DISCUSSION

The physical properties like soundness, compressive strength, modulus of rupture, absorption, specific gravity, and porosity are determined to evaluate to be used as building stones. Nauseri marble is available in blocks large enough to obtain panels of a useful size, that is over 0.5 meter across and at places 1 meter. The lower two meters is highly sheared and are closely jointed and are therefore, suitable for small floor or wall tiles.

The colours varies from white, cream, pink, green and grey and are mainly demanded in the market. Pure white marble with satisfactory physical properties is available in northwestern part of the deposit. It is possible to produce a product which is consistent in colour and quality for supply to building industry. Texturally, the marble is fine to coarse grained. The water absorption ranges from 0.01 to 0.8% and is dimensionally stable to changes in temperature and moisture regime (ASTM 1986), at places 5 to 8% is objectionable, but such beds are few.

Porosity has been determined for Nauseri marble (Table-3). The marble is rather dense and allow very little water to pass through the pores. The porosity values are 0.5% and 0.7% well below the 0.75% (ASTM 1986).

The compressive strength (unconfined) was measured by ASTM method D2993-79 on specimens 20x20x20 cms. The compressive strength range from 3100 PSI to 8200 PSI. The strength is rather low because of the presence of microfractures and weak grain boundries. The material is inhomogeneous with regards to these defects, but this is not true for all samples, such beds are few and can be identified in the field. Southern and northwestren part of the deposits are fairly good for quarrying. The stress strain relationship show steps due to internal slips on fractures (Fig 2).

Abrasion resistance give an abrasion index value of 18 for this marble. This marble has a comparatively high abrasion resistance and is suitable for paving in areas with moderate to heavy traffic.

The stone is slightly affected by soluble salts crystallization which has loosened grain boundaries in fine grained regions and slight loosening of cleavage in larger calcite crystals has been examined. The most noticeable effect is the formation of deep cylindrical pits (about 0.2mm to 0.5mm deep) where soft clays have been removed. Such stones could be used in crushed aggregates. The modulus of rupture was determined by using ASTM C-99-52 (1981) method.

The rocks seems to be elastic and strong in bending with values 900 to 3800 PSI. ASTM (1986) suggests that the marbles with values around 2000 PSI are elastic whereas, fine grained rocks are of higher modulus of rupture (3000 PSI) and are classed as strong rocks.

It is inferred from the physical properties and mineralogical composition that marbles are dimensionally stable, if not exposed to the weather over long periods, because they can change shape or size with repeated dry and wet cycles. This may result in the opening up of fractures and can cause failure due to shearing.

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GEOTECHNICAL CHARACTERISTICS OF SOILS OF KUNDAL SHAHI ATTHMUQAM AREA, AZAD KASHMIR

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ABSTRACT: The paper deals with the physical characteristics of the soils to evaluate the behaviour with respect to bearing capacity and competency to install hydelpower project and other civil engineering works in Kundal Shahi Atthmuqam area of Azad Kashmir.

Other physical characteristics of the soils which decide the relative merits and demerits have also been investigated in addition to the field characteristics. The observed parameters shows variations in the samples but a limited range are well within the ASTM specifications. It appears feasible to utilize the localities for civil engineering works.

INTRODUCTION

The Kundal Shahi occupies a large portion of Muzaffarabad district and has an area of approximately 40 km square which extends upto Atthmuqam, a Tehsil headquarter of the area of investigation. The soil deposits of the area are mainly composed of fragments of rocks, river sands, silts, and clays.

About 90 disturbed and undisturbed soil samples were collected during 1988, for surface and subsurface geotechnical investigations. The purpose of the soil investigation was to evaluate the safe bearing capacity of soils for proper selection of the site for design of water way, from the slided portion and the competency of the soils.

A drilling programme was prepared by Water and Power Development Corporation of Pakistan and consulting agencies i.e. (the Crescent Group of Engineers), National Engineers (NESPAK) and Foundation and Water Organization of Pakistan. Forty Five borehole and Forty Five trench samples of different lithological units (clay, silt, sand, pebble etc.) were selected for geotechnical investigation. Soil samples were collected on the basis of physical characteristics (colour, texture, lithology) and the weathering of soils in response to varying climatic conditions. The soils seems to be mountainous in nature because the rocks are deformed on the top first and lastly at the base in a cyclic manner.

The sediment accumulated in the foot hill of Nagdar area are by river action, wind action, glacial erosion and gravitation. Rain and glacial water feed the soil beds. The rate of weathering seems to be dependent on 1) grain size of the parent material, 2) mineral composition, 3) temperature during weathering and 4) the presence of water in the soil. Larger fragments in the soil promote sliding problems, and it is more rapid when the lower soils are composed of mica schists, which are high absorbent and slippery when in contact with water and the material is less stable. The process is faster at upper portion of the material. The presence of water enhances certain forms of chemical weathering and increases weathering by removing soluble weathering products. Changing soil masses to move downslope generally, pose problems for hydel power works. Soil characteristics important to design and operation (consistency limits, toughness, compaction, porosity, grain size) were evaluated to ensure the competency.

Garnet mica schist are well exposed in the hills of Kundal-Shahi and Atthmuqam. This rock unit appears in the form of two separate outcrops, separated by Atthmuqam biotite schist, phyllite and the Keran outcrop of the Neelum granite (Ghazanfar et al. (1983).

The Kundal-Shahi Nagdar garnet mica schist are fine grained, light to silvery grey on fresh surfaces and grey to bluish grey on weathered surfaces. An interesting feature of the Kundal-Shahi Nagdar mica-schist is the presence of patches of chlorite-schist within garnet grade. These indicate retrogressive metamorphism (Master 1958, Wadia 1928, 1931, Ghazanfar et al. 1983, and Shakoor 1976). The beds of mica-schist are in the form of alternate bands of pelites and psammites with an inclination of about 75^{0} NW.

The soils of the area are formed by the cyclic deformation of the mica-schist, granites, phyllites etc. which are well exposed on steep slopes. The lower portion is about 200 meters thick with pebbles cobbles, boulders, sands and silts of the same rocks. Upper portion consists of pieces of schists, phyllites, boulders of granites, silts, clays and sandy clays. The toe of the slide in Kundal-Shahi is cut by Jagran Nullah. Some springs are also present in this slide.

The area under investigation lies about 80 km. NE of Muzaffarabad city and linked by 2 km. truckable metalled road from the main road.

Previous Works: The earliest reference to the geology of this region is that of Middlemiss (1896). A brief account is found in the geological reports of Wynne (1879), Lydekker (1881), and Wadia (1928). Pascoe (1959) has also described the geology of the region. Ghazanafar et al. (1983) described the geology of the area and prepared a revised geological map.

No work has been done so far on the characteristics of soils of the project area or the in region of Azad Kashmir.

Geological Setting: Igneous and metamorphic rocks are well exposed in the upper Neelum valley, but in lower part sedimentary, metamorphic and igneous rocks are recognized. The rocks exposed in the Kundal-Shahi-Atthmuqam area are granites and schists (Fig. 1).

The igneous rocks consisting of granites and granite gneisses occur in the NE and eastern part of the area under consideration.

From Nauseri to Atthmuqam four different rock units are exposed 1) Tithwal garnetiferous chlorite schist 2) Kundal-Shahi Nagdar garnet mica-schists 3) Atthmuqam biotite chlorite-schist and phyllites (Ghazanfar et al. (1983).

1) Tithwal Garnetiferous Chlorite-Schist:

This rock unit is exposed on road-side in Nullah cutting from Barian to Tithwal. It is greenish grey to silvery grey on the fresh surface weathers to greenish grey to grey colours with some rusty stains and at places dark to brown colours. The rock is fine grained but schistosity is well developed in these rocks.

The unit is intruded by a number of dolerite sills and quartz veins in which joints and cracks are well developed. Shakoor (1976) first described this unit between Tithwal and Jargi. The contact of the rocks with granite is sheared.

2) The Kundal-Shahi Nagdar Garnet mica-schists:-

Nagdar garnet mica-schist appear to be highly metamorphosed. The outcrops are separated on the road side by outcrop of the Neelum granite. The Kundal-Shahi outcrop appears on the road side between Bata in the North to Rampura in the South. A thick bed of quartzite was found in Nagdar Nullah. The quartzite has a faulted contact with garnet mica schist and gneisses.

Nagdar granet mica-schists are fine grained light to silvery grey on fresh surfaces and grey to bluish grey on weathered surface. This rock unit disintegrated into quartz, muscovite, biotite, chlorite, garnet, iron oxide, tourmaline, sphene, epidote etc. and form the soils in the area.

3) The Atthmuqam biotite chlorite, phyllites contain a few bands of greenish grey quartzites and few metaconglomerates. The whole sequence is marked by an absence of calcareous material and is intruded by quartzo-felspathic dykes and minor aplite veins from the dykes and sills. Quartz veins are also found. The rocks are feldspar, chlorite, quartz, magnetite, muscovite, etc. and form most of the soils of the area. These soils are highly absorbant to water which

promote landslides in the Atthmuqam proper, Kundal-Shahi, and Nadgar Nullah areas.

OBSERVATIONS

Unit Weight: The unit weight of Kundal-Shahi-Atthmuqam soils were determined in wet and dry conditions to evaluate the pore spaces and water content in the soils. The unit weight of the soil was obtained by using the formula:

$$r = \frac{\text{Weight of Specimen}}{\text{Volume of Specimen}}$$

For the calculation of the unit weight, soil specimen were completely dried in an oven. This yields a dry unit weight subjected to the specimen for reduction of its volume. The value is found to be 1.4 $lb/ft.^3$ This characteristic is most important for embankments and other engineering works during construction.

The porosity was evaluated to calculate settlement and consolidation problems and landslides. The porosity of Kundal-Shahi soils range in value from 24 to 72% in the upper 50 meters, which changes the volume of the soils during rainy season. In the lower portion it reduces from 13 to 40% (Table 1).

Atterberg Limits: The behaviour of the soil when wet and dry under stress conditions was under examination to evaluate soil consistency. The soil responded to stress in slightly plastic state with a high range of water content. It was noted during examination that noncohesive soil under high water content, deforms as a viscous fluid, with changing water content, the response of the soil also changes, from bottom to the top of the bed (Fig. 2). In this paper pure sand is designated as slightly plastic. It was observed that the plasticity index of the soil is 6 in lower and upper clayey material. The liquid limit values are from 31.53% to 34.81% and the average value is 33%.

Dry Strength: After removing particles larger than No. 40 sieve, a pat of soil was moulded to the consistency of putty. Pat was dried in an oven overnight. After removing from oven, it was cooled to room temperature in a desicator. The specimens were tested for dry strength in a testing machine (Hydraulic Compressor and the reading on the dial was noted. It was found that the dry strength of the Kundal-Shahi-Atthmuqam soils ranges from 2 PS1 (Kundal Shahi) to 40 PS1 at Attmuqam. (Fig. 3).

Dilatency: Taking into consideration the particles lesser than No. 40 sieve, a pat was prepared with a volume of about one - half cubic inch. Adding enough water, to make the soil soft but not sticky, a pat was prepared. Prepared pat was placed in a machine having a smooth surface, upper and lower stages. The pat was shaked horizontally striking vigorously against upper stage several times. A positive reaction consists of the appearence of water on the surface of the pat, and becomes glassy. After this the specimen was squeezed between the upper and lower stages, the water and glass disappear from the surface, and the pat stiffens, and then it cracks. The rapidity of appearance of water during shaking and its disappearance during squeezing assist in identifying the character of the fineness in the soils under study. It was noted that Kundal - Shahi - Atthmuqam soils gave the quickest to no reaction and was classed as sandy to clayey soil (Table. 2).

Toughness: Ten specimen of soil about one-half inch cubic in size was moulded to the consistency of putty, in dry specimen water was added and the moist specimens were speard out in a thin layer and were allowed to loose some water by evaporation. Then the specimen was rolled out by hand on a glass plate into a thread about one third inch in diameter. The thread was then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles after reaching plastic limit. After the thread crumbles, the pieces lumped together and a slight kneading action continued until the lump crumbles.

The toughness of the thread was experienced near plastic limit. The weakness of the thread at the plastic limit and quick loss of coherence lower the plastic limit indicating sand to clayey soils (Table. 2). The loss of water in the soil changes the volume of the soil which creates settlement problems in the area under study.

Compaction: Compaction of Kundal-Shahi-Atthmuqam soil was achieved by using compaction apparatus. The techniques and equipment were used to compact soil for various civil engineering projects. Soil was placed in layers in a mould in three layers of equal thickness. The soil was repeatedly loaded by a hammer about 12 lbs at 18 inches lift to achieve the desired compaction.

To achieve desired compaction, required control of the soil material, its water content and energy applied to soil. Frictional resistance was not considered during reorientation of the soil grains and reduction of voids. Water present in the soil increases resistance to reorientation of particles by the squeezing out of water from the pores. Increasing water content in the soil reduces this frictional resistance and facilitates compaction. Using proctor compaction test, densities were obtained for different water contents, optimum water content was determined 12% to 30% (Table. 3).

Laboratory results serve as a standard for field measurements. The soils of the area were found to be satisfactory for the construction purposes at lower level.

Table - 1

Showing porosity values of Kundal Shahi and Atthmuqam soils of Azad Kashmir:

S.No.	Maximum Porosity%	Minimum Porosity%
KU-1	46.2	28
KU-2	42.1	25
KU-3	48.8	29
KU-4	50.1	30
KU-5	24.8	13
KU-6	38.1	22
KU-7	40.2	28
KU-8	42.8	27
ATQ-1	62.1	34
ATQ-2	60.5	30
ATQ-3	41.0	22.2
ATQ-4	71.2	40.1
ATQ-5	43.2	23.2
ATQ-6	90.1	46.1
ATQ-7	45.1	23.8
ATQ-8	48.2	25.6
ATQ-9	50.23	28.2
ATQ-10	55.8	30

Table - 3

Showing swellability of soils of Kundal Shahi and Atthmuqam area Azad Kashmir:

S.No.	Dry density lbs/cft	Optimum Moisture Content%	Swell% (4 days Soaking) %
KU-1	100.5	5.0	3.78
KU-2	119.3	10.0	0.0
KU-3	125.5	15.5	0.2
ATQ-4	130.8	25.0	0.0
ATQ-5	140.0	30.0	3.0

Table - 4

Showing natural moisture content of soils of Kundal Shahi and Attmuqam area Azad Kashmir:

S.No.	Natural Moisture Content%	Specific gravity of silt
KU-1	11.29	2.44
KU-2	16.58	2.54
KU-3	16.55	2.44
ATQ-4	5.38	2.44
ATQ-5	11.33	2.47
ATQ-6	13.46	2.38

KU = Stands for Kundal Shahi

ATQ = Stands for Atthmuqam

TABLE - 2

SHOWING CLASSIFICATION OF SOILS ON THE BASIS OF SIEVE ANALYSIS ATTHMUQAM AREA AZAD KASHMIR.

Fine grained soils 50% passing No. 200 sieve.			Coarse-grained more than 50% retained on No. 200 sieve.	
Organic soils	Silt and clays 50%	Silt and clays 50%	Sands more then 30% Passing No. 4	Gravels 50% retained on sieve No. 4

Major Divisions	Description
Gravels	Well graded gravels and gravel sand mixtures on fines.
Gravels with Fines	Silty gravels, gravel sand silt mixtures
	Clayey gravels, gravel sand mixture
Clean Sands	Well graded sands and gravelly sands, no fines.
Sand with Fines	Silty sands, sand silt mixtures.
	Silts very fines sands, rock flour, clayey fine sands.
	Gravelly clays, sandy clays, silty clays with medium plasticity.
	Silty clays with low plasticity
	Micaceous fine sands and silts
	Clays of high plasticity
	Organic clays with medium plasticity
	Organic soils.

Table - 5

Showing assessment of fine grained soils of Kundal Shahi area Azad Kashmir

	Dry Strength	Dilatancy	Toughness
Silt and clays 50%	Slight	Slow	None
	Medium	Very Slow	Medium
	Medium to High	Slow	Slight
Slit and clays 75%	Medium	Slow	Medium
	High	Slow	High
	Medium	Very slow	Medium
Urganic soils	Black Colour	Spongy feel	Fibrous Texture

Dry Density: **The dry density of Kundal Shahi - Atthmuqam soil samples has been determined from the base to the top of the Jagran Nallah ridge. The upper 50 meters of soil offer the dry density values ranging between 100 to 140 lbs/cft. The lower 50 meters also has the same range of value (Fig. 4).**

Swellability: **From the engineering point of view the swellability of the soils is most important characteristic, for the construction of buildings, dams, retaining walls, highways and airports. The soils of Kundal-Shahi-Atthmuqam area lies in tropical region. Rain water, glacial water and spring water feed the soil for a longer period. The soils independently swell during rainy season and shrink during dry season. Poor surface drainage and leakage produce concentrations of moisture in the soils, tending to expand adjacent zones of loose soils. The densely packed soils were observed in the lower part. In the opinion of the authors interparticle swelling takes place. Cyclic wetting and drying bring about changes in the swell potential and results in the break down of the soil structure. Also the net work of cracks in the surface of the soil undergo an increase in swell potential. Laboratory analysis shows a swell potential range between 0.0 to 4 percent (Fig. 5).**

Grain Size: **In this classification system the percentages of material passing 200 mesh and 40 mesh sieves have been considered for grain size analyses. The Kundal-Shahi-Atthmuqam soils have been classified on the basis of grain size analyses and plasticity index of the soils. The grain size distribution of soils finer than 200 sieve size are classified as silt and clay, (Figs. 6, 7). The grain distribution curve gives the exact idea regarding the gradation of the soils.**

RELATIONSHIP BETWEEN LIMITS AND GRAIN SIZE

Consistency limits are useful in predicting maximum density in compaction studies. The value of limits indicate the percentage of clay and the potential swelling of soil (Fig. 4). The liquid limit was used to measure the shear strength of the soil at some water content. An inverse correspondence was found between grain size and liquid limit of the soils of Kundal Shahi Area.

The plastic limit, besides being the lower boundary range of plastic behaviour of soil, tends to increase in numerical value for decreasing grain size. For equal grain size the plastic limit tends to increase for the soil of the area under study.

DISCUSSION

The soils of Kundal-Shahi-Atthmuqam area displays considerable variability in its characteristics due to variable geologic factors. Grain size and consistency limits are the basis of classification of the soil. The characteristics like unit weight, porosity density, water content help defining relationships of various grades of soils, and their engineering properties. Dilatency, toughness and dry strength permit classification for rapid identification and suitability of soils for civil engineering works; such as foundations for buildings, retaining walls, road construction, etc.

Liquid limit, plastic limit and grain size facilitate the response of the soil at different conditions for foundation, and the suitability. The

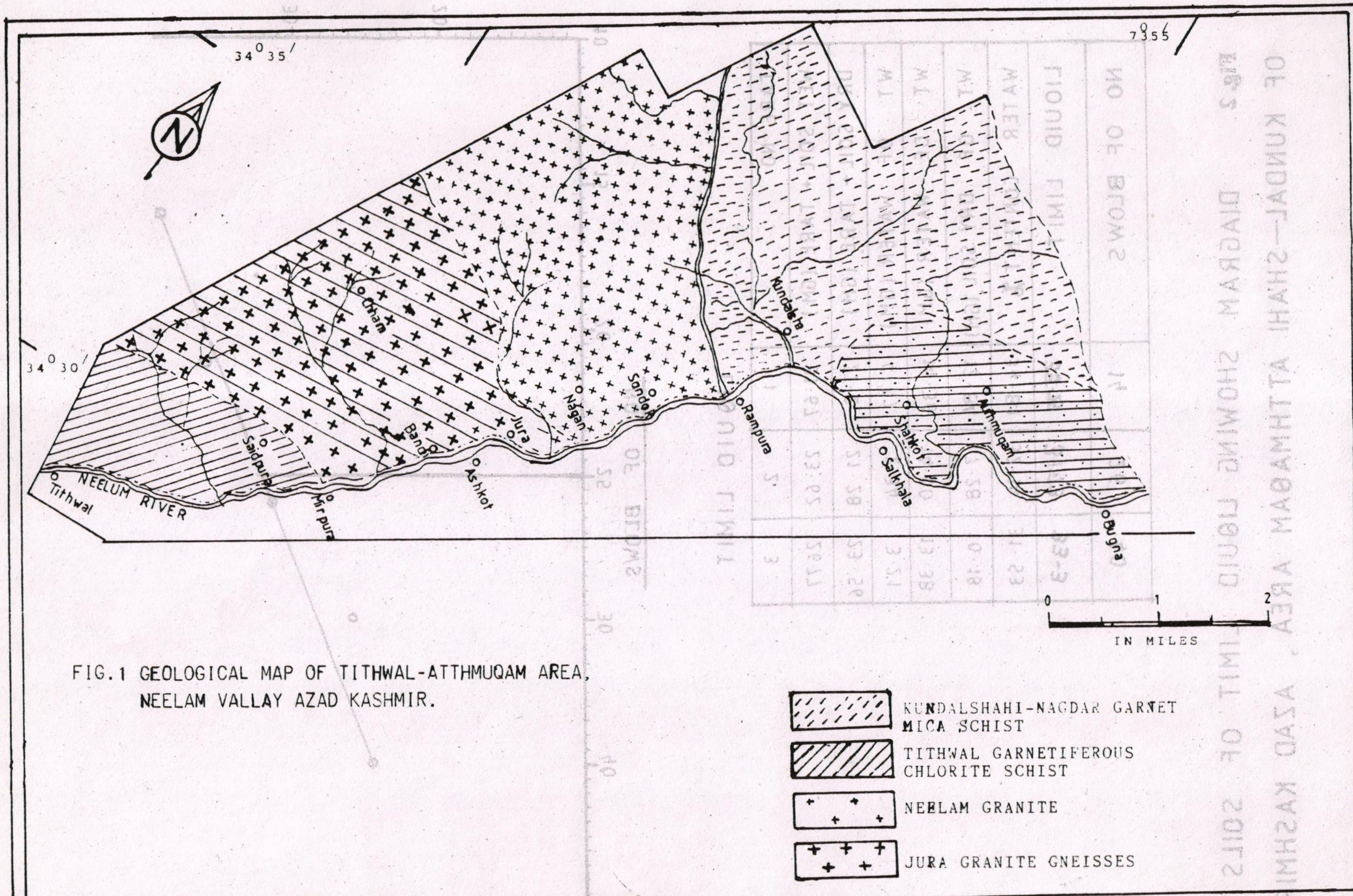
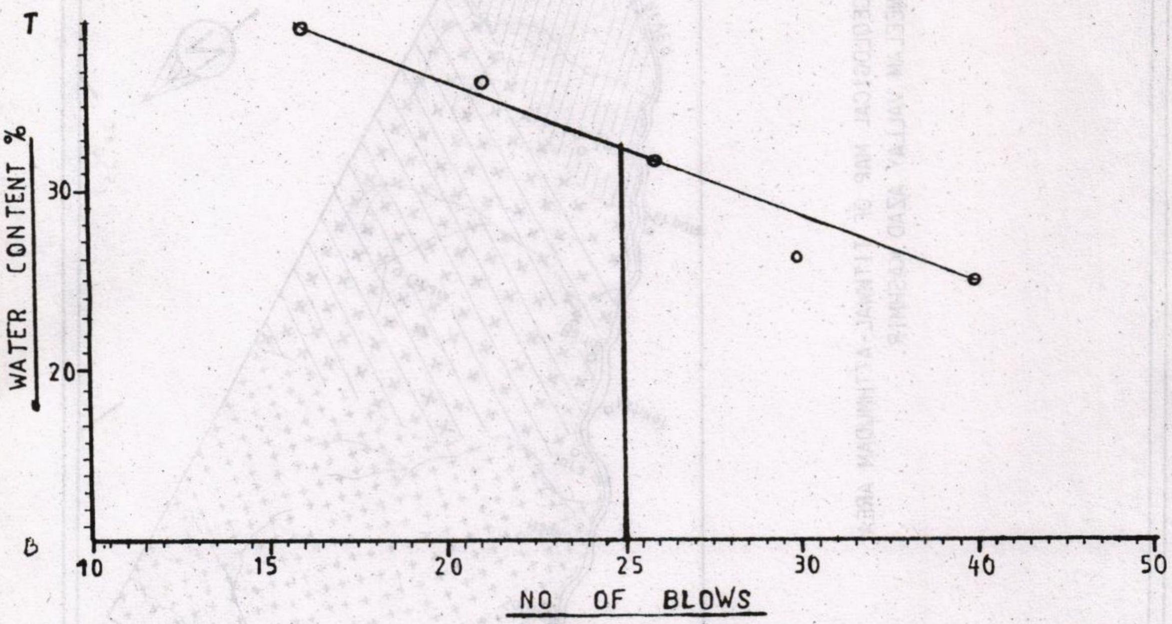


FIG.1 GEOLOGICAL MAP OF TITHWAL-ATTHMUQAM AREA, NEELAM VALLAY AZAD KASHMIR.



LIQUID LIMIT

TARE NO	1	2	3
WET SOIL + TARE (GM)	31·67	23·62	26·77
DRY SOIL + TARE (GM)	27·2	21·28	23·56
WT OF WATER (GM)	4·47	2·34	3·21
WT OF WATER (GM)	14·36	14·00	13·38
WT OF DRY SOIL (GM)	12·84	7·28	10·18
WATER CONTENT %	34·81	32·14	31·53
LIOUID LIMIT	35·73	31·73	33·3
NO OF BLOWS	14	26	40

Fig. 2 DIAGRAM SHOWING LIQUID LIMIT OF SOILS OF KUNDAL—SH'AHI ATTHMAQAM AREA, AZAD KASHMIR·

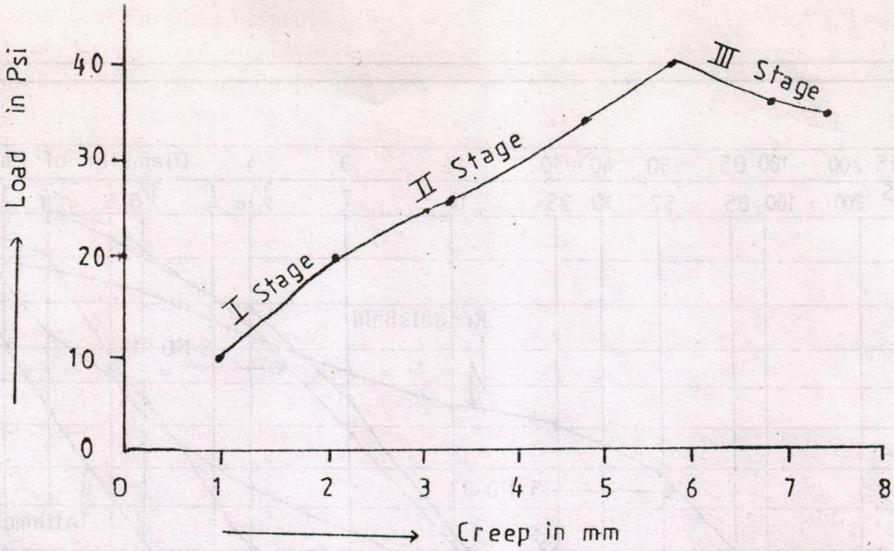


Fig. 3 Diagram showing creep in soils of Kundal-Shahi Atthmuqam Area Azad Kashmir

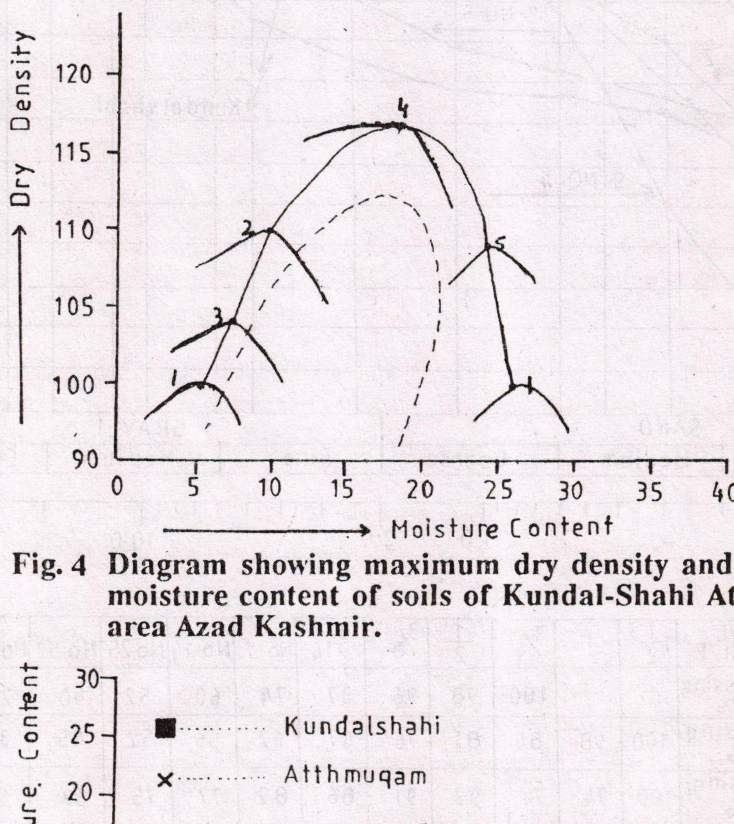


Fig. 4 Diagram showing maximum dry density and optimum moisture content of soils of Kundal-Shahi Atthmuqam area Azad Kashmir.

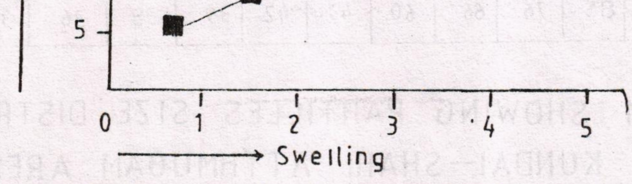
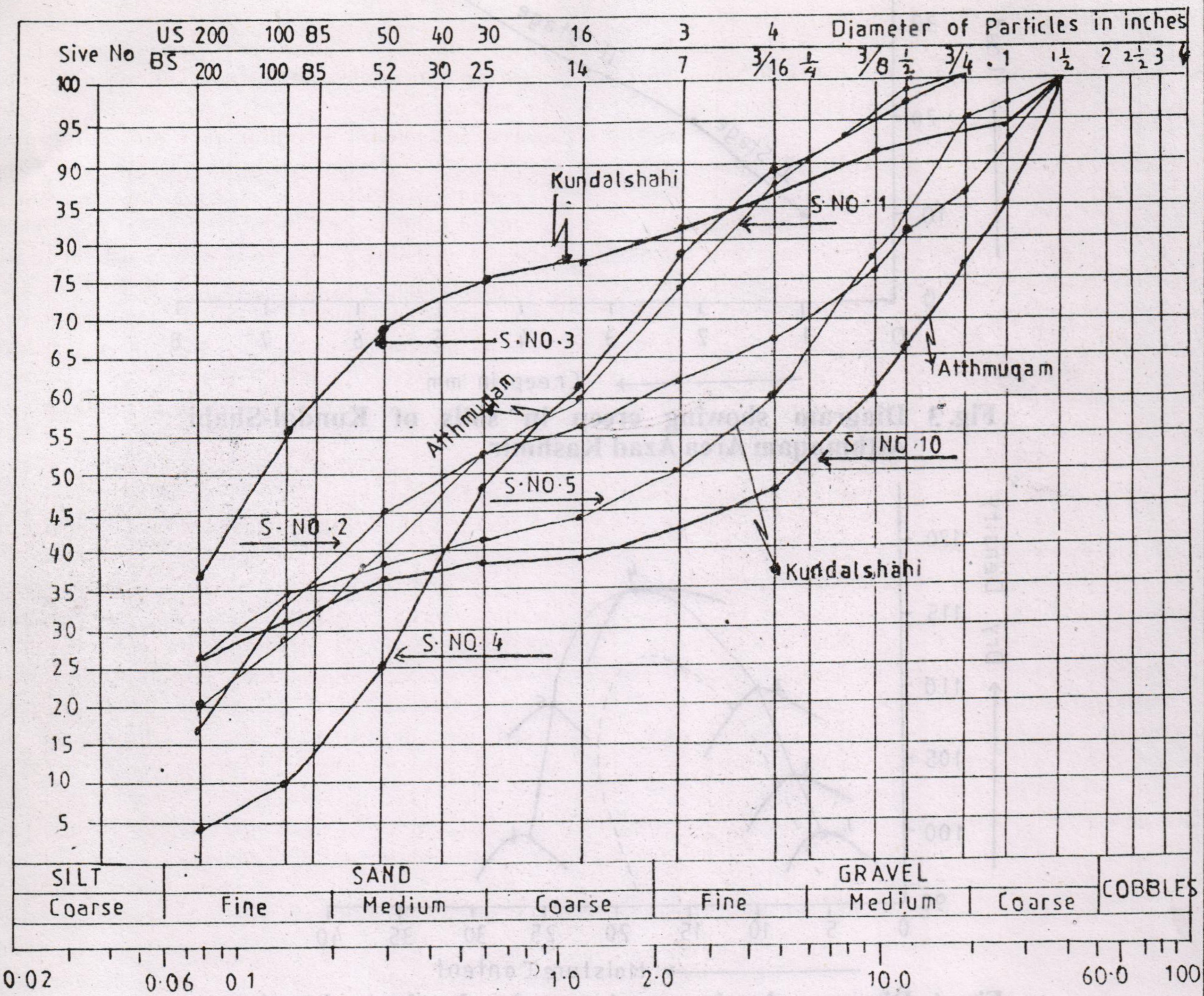
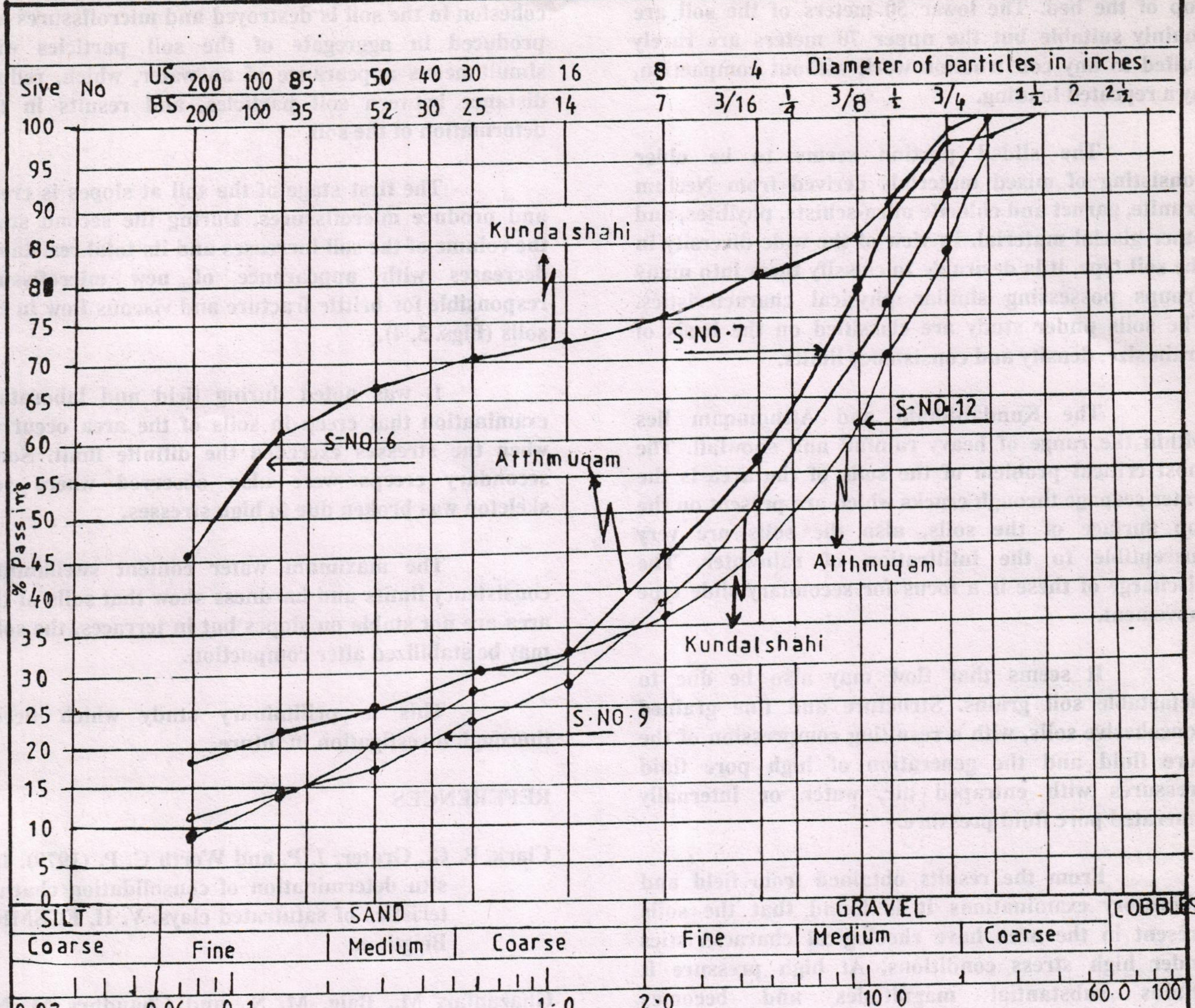


Fig. 5 Diagram showing relationship between swelling and moisture content of the soils of Kundal-Shahi Atthmuqam area Azad Kashmir.



	SIVE SIZE	1 1/2"	1"	3/4"	1/2"	3/8"	3/16"	No-7	No-14	No-25	No-52	No-100	No-200
Sample No: 1–	Passing %	—	—	100	98	96	37	74	60	52	40	29	19
Sample No: 2–	Passing %	100	98	86	81	76	67	62	56	52	45	33	17
Sample No: 3 –	Passing %	100	94	94	92	91	86	82	77	75	69	56	36
Sample No: 4 –	Passing %	—	—	100	97	95	89	78	61	48	25	10	4
Sample No: 5 –	Passing %	100	97	95	83	77	60	50	44	41	38	34	26
Sample No: 10 –	Passing %	100	85	76	66	60	47	42	39	38	36	31	26

Fig. 6 DIAGRAM SHOWING PARTICLES SIZE DISTRIBUTION OF SOILS OF KUNDAL–SHAHI ATTHMUQAM AREA (A·K)



Sive Size		1 1/2"	1"	3/4"	1/2"	3/8"	3/16"	No-7	No-14	No-25	No-52	No-100	No-200
Sample No · 6	Passing %	—	100	98	89	85	80	75	72	70	66	61	45
Sample No 7	Passing %	100	97	97	88	78	57	44	31	27	20	14	9
Sample No · 9	Passing %	100	100	90	76	70	51	38	28	23	17	14	11
Sample No · 12	Passing %	100	97	83	70	61	44	36	31	29	25	22	18

Fig. 7 DIAGRAM SHOWING PARTICLES SIZE DISTRIBUTION OF SOILS OF KUNDAL—SHAHI ATTHMUQAM AREA (A.K)

compressibility of the soil varies from bottom to the top of the bed. The lower 50 meters of the soil are mainly suitable but the upper 70 meters are rarely suited to any construction work without compaction, by a repeated loading.

The slided portion seems to be older consisting of mixed materials derived from Neelum granite, garnet and chlorite mica-schists, phyllites, and other glacial material. In view of the wide diversity in the soil type, it is desirable to classify them into many groups possessing similar physical characteristics. The soils under study are classified on the basis of grain size, density and consistency limits.

The Kundal-Shahi and Atthmuqam lies within the range of heavy rainfall and snowfall. The most critical problem of the soils of the area is the water seepage through cracks which are present on the top surface of the soils, also the soils are very susceptible to the infiltration of rainwater. The discharge of these is a focus for secondary slide type movement.

It seems that flow may also be due to metastable soil grains. Structure and fine grained noncohesive soils, with a resulting compression of the pore fluid and the generation of high pore fluid pressures with entraped air, water or internally generated pore fluid pressure.

From the results obtained from field and laboratory examinations it is found that the soils present in the area have rheological characteristics under high stress conditions. At high pressure it attains substantial magnitudes and becomes dangerous for structures.

Calculation are needed to estimate the creep of clayey soils for stability and strength of retaining structures in this region.

The results of density determination consistency limits and grain size analyses show that the resistance of cohesive clayey soils to external loads depends on the time of load action which with a rapid increase of the load will be at the maximum, whereas with a slow increase and a long action of the load it diminishes, but deformation increase with time even with an invariable physical state of the soil.

The non uniformity of the internal structure in the soil present variation in the strength characteris-tics.

With the prolonged action of colloidal water, cohesion in the soil is destroyed and microfissures are produced in aggregate of the soil particles with simultaneous appearance of no water, which, reduce distance between soil particles, and results in the deformation of the soil.

The first stage of the soil at slopes is creep and produce microfissures. During the second stage the volume of the soil increases and its total resistance decreases with appearance of new microfissure responsible for brittle fracture and viscous flow in the soils (Figs. 3, 4).

It was noted during field and laboratory examination that creep in soils of the area occurred when the stresses exceeded the difinite limit. Some secondary creeps were also observed where soil skeleton was broken due to high stresses.

The maximum water content swellability, consistency limits and hardness show that soils of the area are not stable on slopes but in terraces, the soils may be stabilized after compaction.

This is priliminary study which needs thorough investigation in future.

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A NEW PARACERATHERINE GENUS FROM CHAKWAL, PUNJAB PAKISTAN

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ABSTRACT:– A new genus with the name of Nilatherium has been added to the family Rhinocerotidae. It is the only member of the subfamily Paraceratheriinae recorded from the Siwaliks.

INTRODUCTION

First scientific mention of the Siwalik rhinocerotids was made by Falconer and Cautley (1847) in their publication, 'Fauna Antiqua Sivalensis'. They described four new species pertaining to two genera i.e. *Rhinoceros* and *Aceratherium*. Later on some more forms were discovered by Lydekker (1876, 1881, 1884). During the first decade of 20th century, Pilgrim (1910) made addition in the existing list by erecting a new species. In 1924, Ringstrom pointed out the occurrence of the genus *Chilotherium* in the Siwaliks. Colbert (1934) described a new genus i.e. *Gaindatherium* from Chinji beds of the Lower Siwaliks. The two molar teeth described here are quite different from the Siwalik forms. They show paraceratherine characters and are hence comparable to the forms reported by Cooper (1913, 19 23, 1934) from Bugti Beds of Baluchistan. A close observation has proved the material to belong to a new genus, here named as *Nilatherium*.

SYSTEMATIC ACCOUNT

Order	**PERISSODACTYLA**
Suborder	**CERATOMORPHA**
Superfamily	**PHINOCEROTOIDEA**
Family	**PHINOCEROTIDAE**
Subfamily	**PARACERATHERIINAE**
	***NILATHERIUM* new genus**

Genotype: *NILATHERIUM BALUCHITHERIOIDES* new sp.

DIAGNOSIS

Molar much longer anteroposteriorly than broader. M^3 with much differentiated ecto-and metaloph with postfossette. Protocone well constricted even in M^3

NILATHERIUM BALUCHITHERIOIDES, n. Sp.

TYPE

P.U.P.C*. 69/680, M^2 and M^3 of the left side.

TYPE LOCALITY

Nila, district Chakwal, Punjab Pakistan.

HORIZON

Middle Siwaliks (Dhokpathanian).

HYPODIGM

Type only.

DIAGNOSIS

As for the genus.

DISTRIBUTION

Nila, District Chakwal, Punjab, Pakistan.

DESCRIPTION (Figs. 1-2)

UPPER DENTITION

SECOND MOLAR (P.U.P.C. 69/680):

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

The tooth is of gigantic size. It is damaged at the outer side. The overall general morphology of the tooth confirms it to be the second upper molar of the left side. It is longer than wider (Table I). A well-marked pressure-mark can be seen both at the anterior and posterior sides of the tooth. Its crown is of considerable height. It is in the middle stage of wear. The transverse valley is wide open with the transverse lophs placed far apart. It is quite deep vertically and is not blocked at the base towards the lingual side. Cingulum is fairly developed at the inner face of the hypocone. At the anterior side it elevates to contact with the anterior margin of the protoloph. Posteriorly, it is well-marked and encloses a post-fossette, which is absolutely wide and fairly deep. The enamel layer is thick at the inner and outer sides of the tooth but is comparatively thin at the anterior and posterior borders. Enamel is somewhat rugose at all sides of the tooth.

The protoloph is transversely longer than the metaloph but almost equal to the ectoloph. The protocone is with well-developed antecrochet. The worn surface of the hypocone seems to be somewhat rounded. A vertical groove can be seen at the anterior face of the protocone. Looking from the outer side, the ectoloph appears to be concave as is usual for the second upper molar. The top of the ectoloph is damaged. It is fairly sloping. Crochet is present. A well-developed crista is given by the ectoloph which is blunt towards the transverse valley. The contour of the ectoloph suggests the presence of the parastyle.

TABLE – I

Measurements (in Mm) of 1.M^2 (P.U.P.C. 69/680) in *Nilatherium baluchiterioides*, new species

Length	100
Width	63
Height (preserved)	34
Height (reconstructed)	74
Width/Length index	63
Height/Width index	117
Enemel thickness	2.3

THIRD MOLAR (P.U.P.C. 69/680)

The tooth is of enormous size. It is as large as the M^2. It is damaged at the inner face of the metaloph. Its antero-posterior length is more than the width (Table-II). At the posterior side of the tooth, there is no indication of any pressure-mark proving it to be the last upper molar. It is a high-crowned tooth and is in the early stage of wear. The transverse valley is widely open and is fairly deep vartically. The inner outlet of the transverse valley is quite wide. At the lingual side cingulum is present near the base. Anteriorly, it is very well-marked. Posteriorly, it encloses a very small, rather rundimentary post-fossette. At the antero-exterior and postero-exterior sides, two cingular ridges can be seen running at the crown base. Enamel layer is quite thick at the outer margin of the ectoloph, at the anterior border of the protoloph and at the posterior border of the metaloph. It is comparatively thin at the remaining borders of the tooth. Enamel is lamost smooth at the outer side of the tooth. It is smooth at the anterior, posterior and inner sides of the tooth upto the cingular level but shows some rugosity below the cingulum.

In transverse dimensions, the protoloph is larger than the metaloph but is much smaller than the ectoloph. A vertical groove is present at the posterior edge of the protocone. A similar groove is present at the anterior face of the protocone. Antercrochet is considerably developed. A moderately developed crochet is present. Crista is also present. The worn surface of the ectoloph is quite sloping. A small ectoloph wing extends posterior which is quite unusual for the last upper molar. Parastyl fold is very well-marked.

TABLE – II

Measurements (im Mm.) of last molar (P.U.P.C. 69/680) in *Nilatherium baluchithericides*, new genus and new species.

Length (preserved)	83
Length (reconstructed)	86
Width	62
Height (preserved)	47
Height (reconstructed)	71

Width/Length index	72
Height/Width index	115
Enamel thickness	2.5

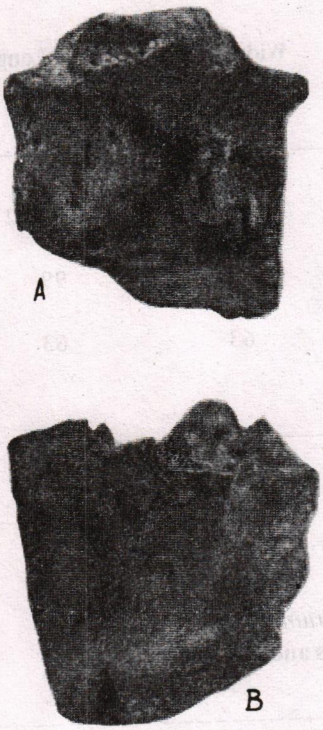

Fig. 1. Type specimen of *Nilatherium baluchitherioides* n.g. et. n.sp.
A. Crown view of l m^2;
B. Buccal view of l M^2.

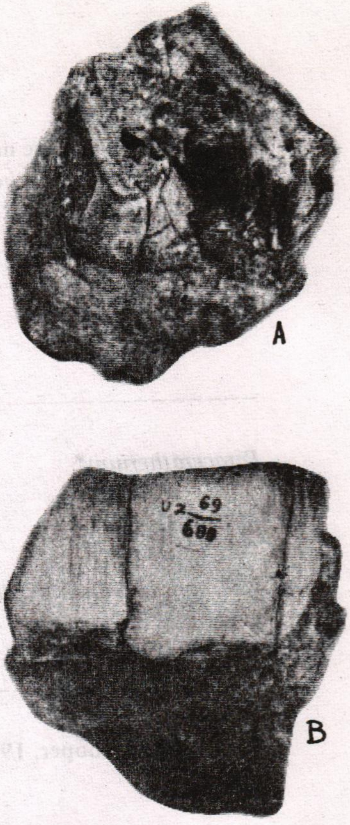

Fig. 2. Type specimen of *Nilatherium baluchitherioides* n.g. et. n.sp.
A. Crown view of lM^3;
B. Buccal view of lM^3.

DISCUSSION

The second molar, P.U.P.C. 69/680, is almost quadrangular with constricted protocone, large crochet, antecrochet and large posteriorly projecting etoloph wing. These favour its inclusion in the genus *Chilotherium.* However, the tooth morphology of the last molar goes against this inclusion. In the last molar, there is a well-defined ectoloph as well as metaloph with a small, shallow post-fossette. A small, posteriorly projecting ectoloph wing can also be observed. In these features, the last molar can only be compared with the last molars of the jiant rhinoceroses of Baluchistan. However, it differs from the later in having a strong crochet, antecrochet and crista. The molars in *Baluchiterium, Indricotherium* and *Paraceratherium* lack these features (Cooper, 1923). Both the teeth are larger anteroposteriorly than the transverse measurements. Regarding molar morphology, the molars under study differ clearly from the Siwalik forms discussed or described by Colbert (1935), Sarwar (1971), Heissig (1972); from the North Asian forms described by Ringstorm (1927), Beliajeva (1971) and from European forms described by Ginsburg (1974), Heissig (1976), Sarac (1978) and Ginsbrug and Antunes (1979). Different indices and molar morphology of the specimens do not allow their inclusion in any of the known genera (Table III-IV). All these warrant the erection of a new genus. This new genus is named as *Nilatherium.* Since its last molar resembles that of *Baluchitherium* in differentiated electoloph and metaloph, the species is labelled as *Nilatherium baluchitherioides* new species.

TABLE – III

Comparative measurements of M^2 in *Paraceratherium, Indricotherium,* and *Nilatherium baluckitherioides,* new genus and new species.

	Length	Width	Width/Length Index
*Paraceratherium**	74-96	75-98	101-102
*Indricotherium**	94	93	99
Nilatherium baluchitheriodies, new genus, new species.	100	63	63

*** From Cooper, 1923**

TABLE – IV

Comparative measurements of M^3 in *Paraceratherium, Indricotherium,* and *Nilatherium baluchitherioides,* new genus and new species.

	Length	Width	Weidth/Length Index
*Paraceratherium**	74-97	70-92	95
*Indricotherium**	96	88	92
Nilatherium baluchitherioides new genus, new species.	86	62	72

***From Cooper, 1923.**

new genus, new species.

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A TRANSITIONAL GOMPHOTHERIID FROM DHOKPATHAN TYPE LOCALITY

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ABSTRACT:– A right lower last molar from Dhokpattan type locality is described. It shows Tetralophodon/Stegotetrabelodon characters of the crown.

INTRODUCTION

The Siwalik tetralophodonts are known since the publication of 'Fauna Antiqua Sivalensis' by Falconer and Cautley (1947). Uptil now, three species of the genus *Tetralophodon* have been recorded formthe area (Sarwar, 1980). Among the known genera of the family Gomphotheriidae, the members of the genus *Tetralophodon* are very close to the members of the genus *Stegotetrabelodon* and probably have been ancestral to the later (Maglio, 1970). The presence of the genus *Stegotetrabelodon* in the Siwaliks was recorded by Sarwar (1977). The known related material is either on the tetralophodont or on the *Stegotetrabelodon* lineage. The molar under discussion (P.U.P.C.* 87/9) can neither be included in the genus *Tetralophodon* nor can be referred to the genus *Stegotetrabelodon* and is placed at the transition of the two genera. It was recovered from near the village Dhokpathan, district Chakwal, Punjab, Pakistan.

DESCRIPTION (Figs. 1-2).

The specimen P.U.P.C. 87/9 is in a good state of preservation, being damaged only at the third ridge-plate. In general contour, it is an elongated and transversely narrow tooth. In general, the tooth is brachyodont with round and blunt tubercles. The gradual tapering of the corwn indicates that it was the last of the molar series. Cement is fairly developed and in unworn condition, it partly covered the buccal side of the plates. It is more confined to the outer base of the crown than towards the inner side. Enamel layer is fairly thick and moderately rugose all around the crown. The rugosity is due to the presence of minute transverse grooves and ridges. Cingulum is very weakly developed. Median sulcus is quite deeper in the anterior three ridge-plates. It can also be seen in the fourth and fifth ridge-plate. However, it is absent in the last ridge-plate.

The tooth is six ridge-plated with a fore- and an aft-talon. It was in very early stage of wear and, therefore, only the first ridge-plate was engaged in the process. The second ridge-plate was just touched by wear. The anterior face of the tooth is slightly damaged at the crown base. The anterior talon is trituberculated. The inner most of these is very small and insignificant. The other two are almost of equal diameter but differ in height. The tiny buccal one is comparatively high and is, hence, more worn. As a result of wear, it has produced a rounded dentinal islet.

First ridge-plate like the others is tetratuberculated i.e. two tubercles in each half. Of these, the outer and the inner most are larger in size than the central two. Posttrite is vertically higher than the pretrites. Pretrite is more worn and the dentinal islets of its two conelets have become contiguous. A very large accessory tubercle may be seen posterior to the inner tubercule of the first pretrite. It almost approaches the tubercle of the first pretrite. Being fairly large in diameter, it has completely blocked the first transverse valley. Base of this valley is covered with a layer of cement.

The first and the second ridge-plates are transversely linear. The second accessory tubercle, which is posterior to the second pretrite is comparatively smaller, low in vertical height and is somewhat outwardly tilted.

The third ridge-plate is slightly arcuate with median conelets somewhat forwardly projecting. The accessory tubercle, posterior to it and that, present in the second transverse valley, were almost underneath the layer of cement.

*Fossil collection stored in the Zoology Department, Punjab University, Lahore, Pakistan.

TABLE-I

Measurements (in mm.) of P.U.P.C. 87/9

Number of ridge-plates	6½
Anteroposterior crown length.	198
Crown width.	83
Width/length index.	42
Crown height.	63
Height/width index.	76
Enamel thickness.	6
Lamellar Frequency.	3.2

Rest of the ridge-plates are comparatively more arcuate. Their outer most and inner most conelets are highly converged towards the median longitudinal axis of the tooth. Accessory tubercles are altogether lacking in the fourth and fifth transverse valleys. The ultimate ridge-plate is trituberculated, wihtout any median longitudinal division.

Hind-talon is also trituberculated but is very low in vertical highet. Of the three tubercles, the outermost is the largest, both in diameter as well as in crown height. The valley between the last ridge-plate and the hind-talon is completely covered by cement.

Anterior root fang nourished the fore-talon and the first ridge-plate, whereas the rest of the tooth was nourished by the posterior root fang.

DISCUSSION

The tooth is referable to the subfamily Anancinae because of the following:

1. **Tooth is multi-ridged and the plates are simple.**
2. **The ridge-plates are rounded in anterior as well as posterior view.**
3. **The ridge-plates are with few but definite rounded tubercles.**
4. **Only one accessory conule present behind each of the first three ridge-plates.**
5. **Cement covering the sides as well as the valleys.**
6. **Ridge-plates are moderately high.**

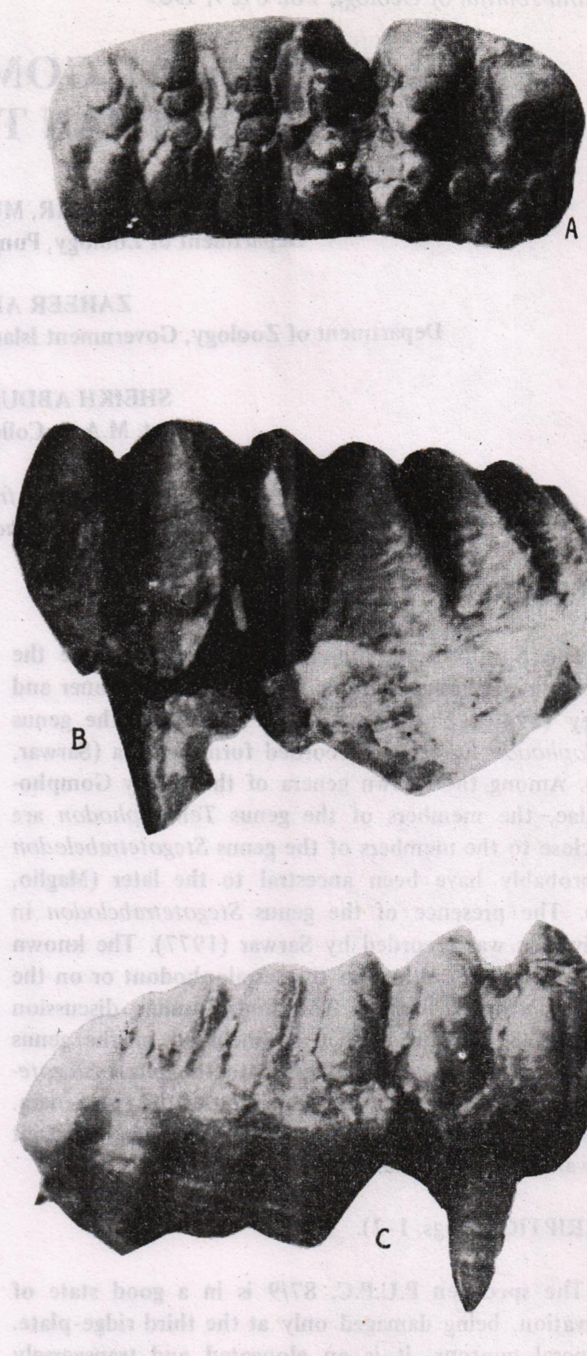

Fig. 1 *Tetralophodon/Stegotetrabelodon.*

A. Crown view; B. Lingual view; C. Buccal view.

All these are the characteristic features of the subfamily anancinae. Two genera are recognsied in this subfamily i.e. *Tetralophodon* and *Anancus* (Sarwar, 1977). In the later genus, the outer and inner halves of the ridge-plates are much displaced (Osborn, 1936). It is, therefore, justified to regard the specimen under study as congeneric with the genus *Tetralophodon*. Genus *Tetralophodon* is

TABLE II

Comparative measurements (in mm) of P.U.P.C. 87/9 and *Tetralophodon punjabiensis.*

	P.U.P.C. 87/9	Ind. Mus.* A 46	*T. punjabiensis* P.U.P.C. 69/752**	Amer. Mus. 19686***
Number of ridge-plates.	6½	5½	5½	5¾
Crown length.	198	242	230	209
Crown width.	83	93	99	96
Width/Length index.	42	38	43	46
Height.	63	52	65	56
Height/Width index.	76	56	66	58
Lamellar Frequency.	3.2	2.3	2.8	2.7

* Taken from Lydekker, 1880;
** Taken from Sarwar, 1977;
*** Taken from Osborn, 1936.

is known by thirteen species of which only three are known from the Siwalik formations (Sarwar, 1977). These are *Tetralophodon falconeri. T. punjabiensis* and *T buzdarensis.* The specimen under study can be differentiated from the species *T. falconeri,* on the basis of the number of ridge-plates. In the last lower molars of the latter, it is not more than 5½ (Lydekker, 1988).

In the molars of *T. punjabiensis,* there is a double trefoil structure (Lydekker, 1886, Maarel, 1932), which is lacking in the specimen under study. Regarding size, the latter is smaller than the *T. punjabiensis* (Table-II). In the molars of *T. buzdarensis* the accessory conule is only present behind the first ridge-plate (Sarwar, 1977).

In fact, in relative crown height, the abundance of cement, the transverse and regular nature of the ridge-plate, the molar under study surpasses all the known Asiatic tetralophodonts recorded by Koken (1885), Lydekker (1886), Maarel (1932), Sarwar (1977); all the European forms recorded by Schlesinger (1917), Zbyszewski (1951), Badillo (1952), Bergounioux and Crouzel (1956) and all the American forms recorded by Cope (1977) and cope and Matthew (1915).

Comparison with the known members of the subfamily Stegotetrabelodontinae shows that the specimen under study may be placed at the base of the group. The ridge-plates are divided into conclets by shallow vertical grooves. Enamel border of the ridge-plates is simple and fairly thicks. Ridge-plates are relatively widely spaced than those of the tetralophodonts (table II) but less than those of the stegotetrabelodonts. The number of ridge-plates is low than those of the species, *Stegotetrabelodon syrticus* and *S. orbus* of Africa described by Petrocchi (1941) and Maglio (1970) respectively.

Keeping in view, the above mentioned characters of the molar under study, it is concluded that the specimen can neither be referred to the genus *Tetralophodon* nor to the genus *Stegotetrabelodon.* It was a transitional stage stepping towards the stegotetrabelodonts. During Pliocene, the mammalian migration between Asia and North Africa was frequent as has also been indicated by many workers e.g. Geraads (1982). Since most of the members of the genus *Stegotetrabelodon* are known from Africa, the individual under study, like the members of the species *Stegotetrabelodon maluvalensis* was an immigrant from Africa.

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SAMANASUK FORMATION, DEPOSITIONAL AND DIAGENETIC HISTORY

By

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Abstract:- Samana Suk Formation exibits an excellent example of what is called as oolite shoal in the literature. Many such examples exist in the geological record and their studies carried out. In this study we tried to interpret the depositional and diagnetic environments of the Jurassic Samana Suk Formation from Hazara, Pakistan.

Several lithofacies are differentiated on the basis of the presence of oolites, fossils and terrigenous content. They include pure micrite to a sandy facies which is classified in the sandstone category.

The diagenetic environments include cementation of the grains with coarse crystalline, bladed calcite which represent an early cement, and equigranular calcite cement representing a later phase. Dolomitization in the phratic zone has replaced all the textures including intraclasts and cements. Replacement of the oolites by the dolomite crystals is another phenomenon observed in the Samana Suk Formation which happened inthe later stage of the diagenetic history.

INTRODUCTION

Samana Suk Formation has been deposited as an upward shoaling lithologic sequences, most of the deposition having occurred during periods of marine transgressions and regressions. The microfacies observed indicate that these sequences end up on a terminal phase where deposition slowed down and subareal exposure is evident by the presence of hardgrounds that corresponds to the terminal phase of Wilson (75). Samana Suk from Hazara shows well developed ooids while Samana Suk from Kalachitta seem to lack ooids, thus indicating relatively deeper environments.

Methods: Samples of Samana, from different sections of Hazara were collected during the summer field season in 1988. 75 Thin sections were prepared for the petrographic study and stained for identification of different types of calcite and dolomite. The standard staining procedure of Evamy (1963) and Friedman (1959) was followed. For this purpose, alizirine red S and potassium ferricyanide were used in a very weak acid medium. This stain helps identify calcite from dolomite and also helps distinguish between ferron calcite from iron free calcite and ferron dolomite from iron free dolomite.

MICROFACIES IDENTIFICATION

Several microfacies have been identified by microscopic studies and theirtheir environmental interpretation done. The work of Wilson (1975) and Feugal (1982) is the most recent in microfacies identification and has been followed in this study. Classification of Dunham and Folk have been used in general categories. The types do not employ faunal and floral identification to the specific level. Most facies fall into two categories.

1- Shelf facies- open circulation
2- Shoal environments in agitated water.

MF1-(SMF 10) Coated or worn bioclasts in micrite packstone-wackestone. Sediment formed in swales and proximity of shoals. Dominant particles are of high energy environment and have moved down local slopes to be deposited in quiet water. (Fig. 1).

MF2(SMF 11) Shoal environments in agitated water. Coated bioclasts in sparite grains. Sediment


Fig. 1: Coated or worn bioclasts in micrite packstone-wackestone.

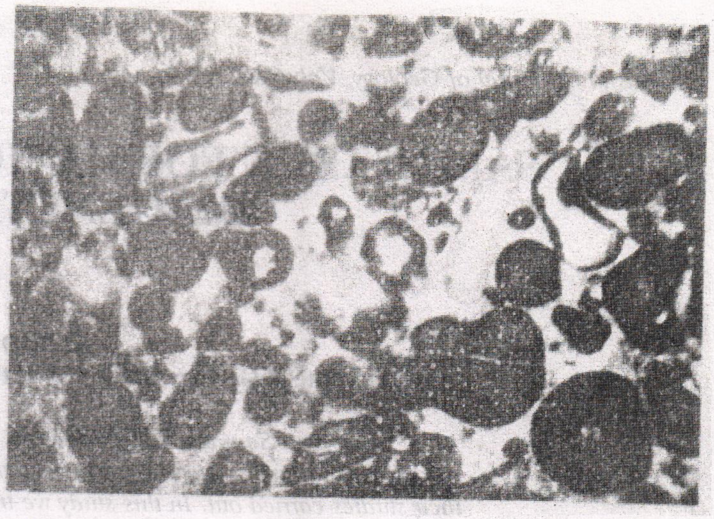
Fig. 2: Coated bioclasts in sparite.

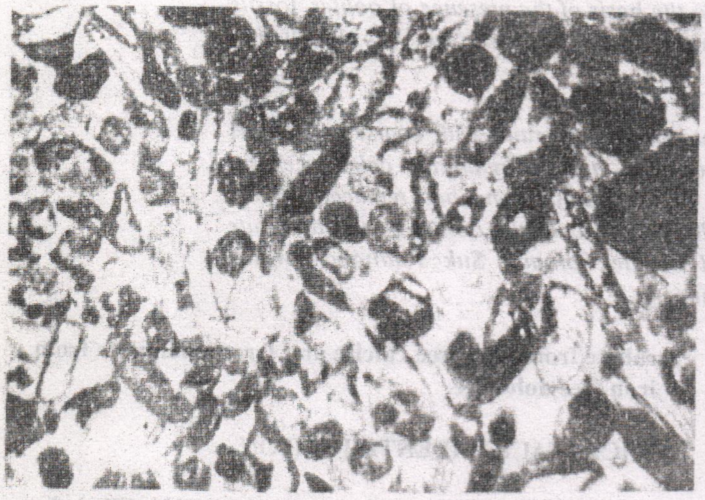
Fig. 3: Coquina bioclastic grainstone or mudstone, shell hash.

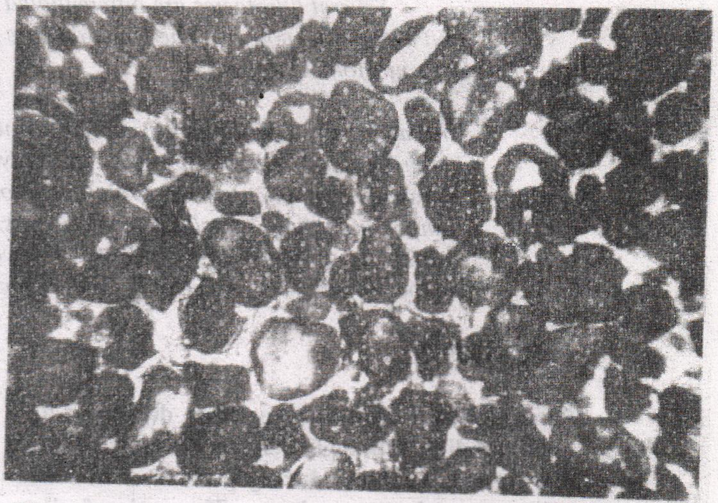
Fig. 4: Lag deposits of coated and worn particles.

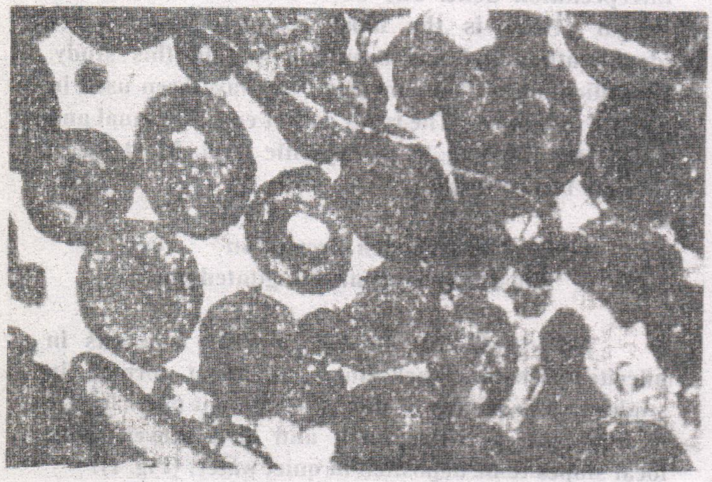
Fig. 5: Ooid grainstone.

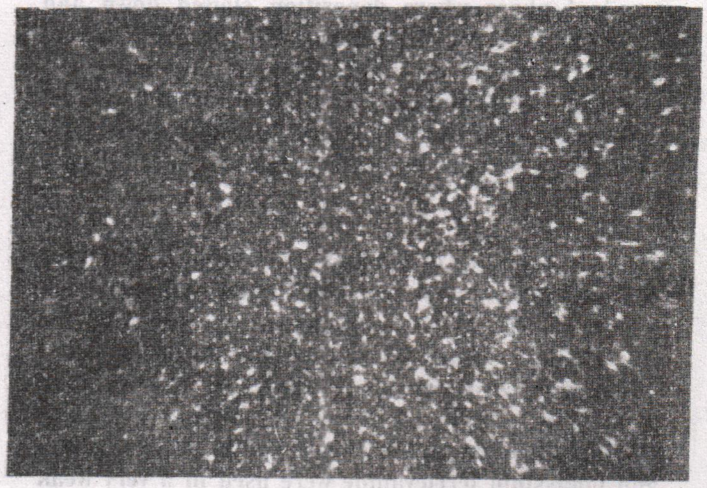
Fig. 6: Pelaparite or pelloidal grainstone.

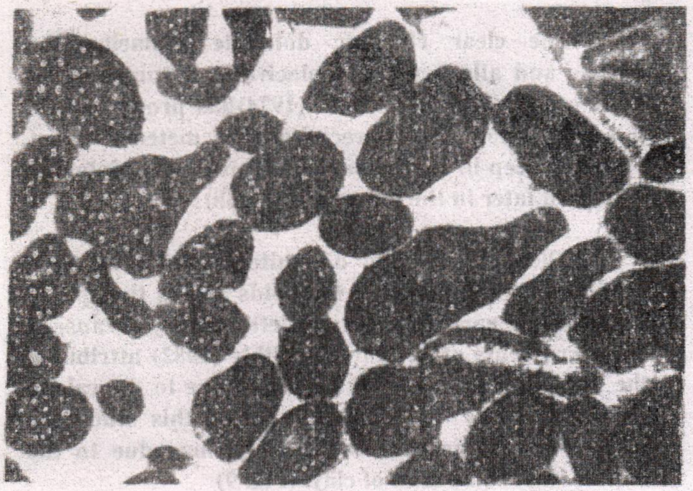

Fig. 7: Coarse lithoclasts rudstone or floatstone.

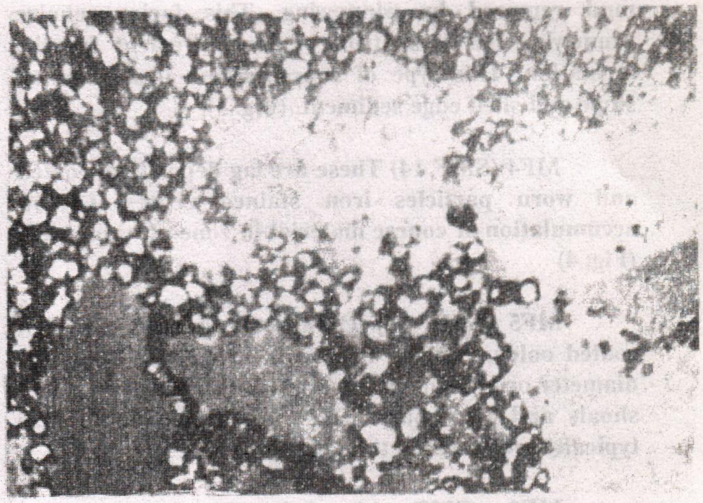

Fig. 8: Dolomite rhombs replacing all the textures.

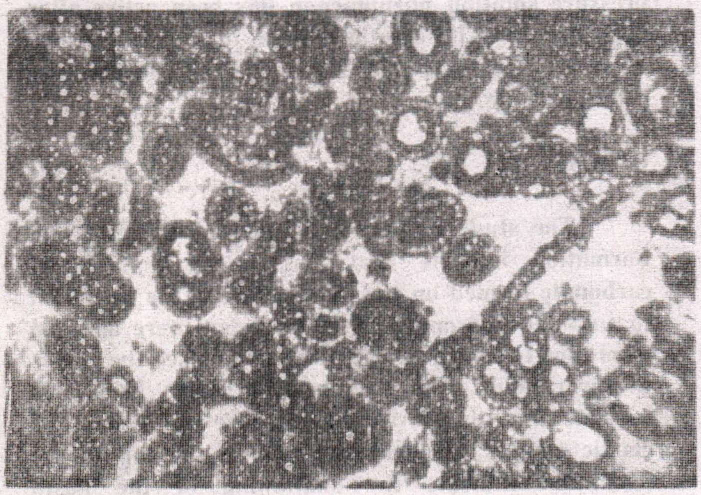

Fig. 9: Dolomite rhombs replacing internal structures of of ooids.

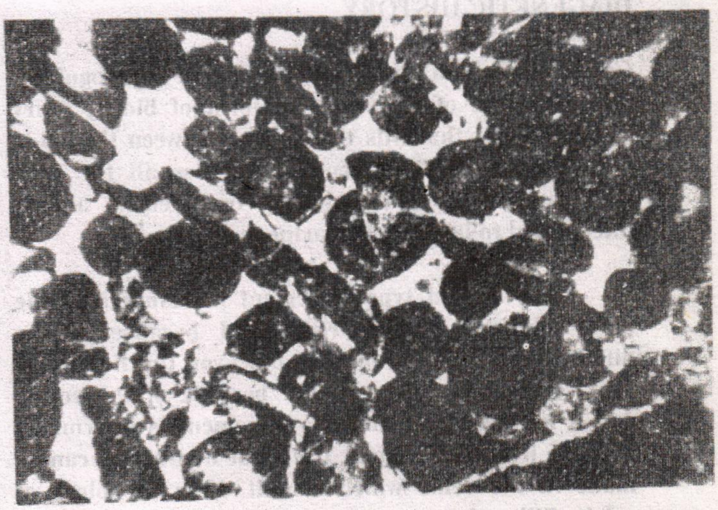

Fig. 10: Stylolitization causing the ooids to break apart.

formed in areas of constant wave action at or above wave base so that the lime mud is removed. (Fig. 2)

MF3(SMF 12) Coquina, bioclastic grainstone or mudstone, shell hash. Sediment formed in an environment of constant wave or current action with mud removed by winnowing. This facies require winnowing but less strong water movement for the formation. This type of concentration is a common slope and shelf edge sediment. (Fig. 3)

MF4 (SMF 14) These are lag deposits of coated and worn particles iron stained represent slow accumulation of course material in zone of winnowing. (Fig. 4)

MF5 (SMF 15) Oolit, ooid grainstone. Well coated ooids, ranging in size from 0.5 to 1.5 mm in diameter originated through water movement on oolite shoals and tidal bars. The best formed oolites are typically produced on tidal bars. (Fig. 5)

MF6 (SMF 16) Pelsparite or pelloidal grainstone. Hardned fcal pellets mixed with some other foraminiferal tests. They are derived by organic pelleting of mud and represent slight water movement. These are common in tidal flats and natural levees. (Fig. 6)

MF7 (SMF 24) Coarse lithoclasts rudstone or floatstone. Unfossiliferous micrite grains in sparite matrix. These may be termed interaformational limestone pebbly conglomerates. It is formed as lag deposits in tidal channels. (Fig. 7)

DIAGENETIC HISTORY

Cementation: Two type of calcite cement is recognized. The first type of cement is in form of blocky srary calcite cement that fills the cavities between the ooids or other grains. This cement occupies all the pore space and is thought to be the first cement and is interpreted to be of early marine origin.

The second type of cement is resulted by the pore solutions and is recognized because of the different stain and is not as blockyas the first type. Two cement are differentiated because of the colors and it is interesting that ferron cement is intermixed with the iron free cement. The same distinction can be made in the veins which exhibit different colors of calcite filling them.

Dolomitization: Two types of dolomite is common in the oolites- one type is found as crystals replacing the whole rock and the second type is seen in the ooids replacing their internal lamellea. The two types of cement suggest two typès of diagenetic processes acting at different times.

The clear rhombic dolomite replacing the micrite and allochems is replacive in nature since it cross cruts all features. Folk (1974)has proposed that this type of dolomite is precipitated by meteoric water, probably deep in the subsurface. This type of dolomite is formed later in the digenesis. (Fig. 8)

The dirty looking dolomite crystals replacing the innermost lamellae of the ooids and is thought to have formed early in the diagenetic history because it never crosscuts other features. Sibly (1982) attributed the dirty appearance of the crystals due to the calcite inclusions while it is thought that in this study the yellowin appearance of the rhombs may due to the includion of some kind of clay. (Fig. 9)

Compaction: No physical compaction processes seem to be evident in the oolite. However, the chemical processes of compaction leading to various categories of pressure solution and stylolitization are evident. Due to this some ooids show eroded boundaries and part leaching of the grins. Stylolites can be recognized due to their irregular boundaries which are highlighted due to the iron staining or presence of the organic matter in the sutures.

Stylolitization: Well developed stylolites have been observed in some section that indicate that the pressure solution phenomenon has been active after deposition and lithification. Some of the oolites also show their edges corroded away due to the pressure solutions. (Fig. 10)

DICUSSION

The study of the microfacies in Samana Suk Formation indicate that this is an example of carbonate formed on the upper shelf in the intertidal to subtidal environments where waters were agitated from time to time and algal material caused the grains to form ooids. The presence of oyster beds also indicate that the environments were not deep. The clastic content, particularly towards the top of the formation indicate the shallowing of the basin conditions. The presence of hard grounds indicate that the deposition was slow at times causing the sea floor to harden, prior to the deposition of the next bed. This is also indicated by the sessile organisms like oysters tht can be observed sticking on the bedding plane surfaces and unevenness of the bedding planes at other places. Paleosols are also developed at some intervals between the bedding plaes which are fine clays of calcareous nature derived from the older strata from the same basin.

CONCLUSIONS

On the basis of the standard microfacies it may be concluded that the Samana Suk Formation is an example of the shoal type of environments. Most of the thin sections indicate that the constituents grains were winnowed away in the basin before they were deposited. The presence of ooids is indicate the action of shoaling waves and currents. Most microfacies also represent the open shelf environments with shoaling waves and currents. There are however differences in the wave energy, water depth or water temperature.

The diagenetic changes in the Samana Suk Formation are the precipitation of sparite that fills the interparticle spaces, dolomite replacement, and pressure solution. The precipitation of sparite has caused the vugs to be filled causing the porosity to decrease. The pressure solution has deformed the ooids and also at places the internal structure of the oolite has been obliterated. Basically, it is an example of the shelf facies with open circulation and shoaling waves and currents, water depth of few tens to hundred of meters. The waters are well exygenated with normal salinity and good current circulation.

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DISTRIBUTION OF CLAY MINERALS IN PATALA SHALES EXPOSED AT NAMMAL GORGE

By

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ABSTRACT:- The Patala formation exposed at Nammal Gorge contains mainly kaolinite and mixed layer clay mineral (illite-montmorillonite) with minor amounts of illite and montmorillonite. Other minerals associated with clay minerals are mainly calcite, dolomite, quartz, feldspars and pyrite. The mineral kaolinite is partly authigenic and partly detrital in origin. The mineral montmorillonite is a detrital mineral and probably represents regional trends of sedimentation. The mixed layer clay mineral and illite were formed due to alteration of montmorillonite in the presence of potassium ions.

INTRODUCTION

The present investigations were carried out to understand the distribution of clay minerals in the Patala Formation, exposed at Nammal Gorge (Figure-1). About 40 samples were collected representing detailed lithology (Figure-2) and 20 samples were selected for clay mineral analyses. The Patala Formation at Nammal Gorge includes mainly shales with sub-ordinate marls, argillaceous limestones and limestone (calcarenite to calcirudite). The marls and limestones are fossiliferous. The base of the Patala Formation is conformable with the underlying Lockhart Limestone. The formation is also conformably overlain by the Nammal Formation. The formation is widely distributed in the Salt Range, Surghar Range, Kala Chitta Hills, Margalla Hills etc. The clay minerals of Patala Shales may be used to understand the regional conditions of sedimentation and diagenetic processes.

METHODS OF INVESTIGATIONS

The samples were finely crushed until they felt soapy. Some of the crushed powder was used for the random powder diffraction data of the samples in range $2^{0}2\Theta$ to $65^{0}2\Theta$. About 3 grams of the finely ground powder was used for the preparation of oriented slides. The oriented slides were prepared by suspending the sample in water and sedimenting it for 35 minutes. Three oriented glass slides were prepared by obtaining the suspension from a depth of 5cms. The oriented slides thus represented the grain size of less than 5 u fraction. Two oriented slides were glycolated and heated for one hour at 60^{0}C and 550^{0}C, respectively. Diffraction patterns of three oriented slides were compared for confirmation of various clay minerals. When kaolinite and chlorite occur together, it gets difficult to recognize and differentiate them, as some of their reflections occur close to each other, specially the 001 reflection of kaolinite and 002 reflection of chlorite may overlap, depending on the chemical composition of chlorite. The acid digestion of the samples, generally removes the chlorites while the kaolinite is not effected. About 3 gms of the crushed powder was boiled in dilute hydrochloric acid for about 15 minutes. The sample was then sedimented and an acid digested oriented sample was prepared, as stated above. Diffraction pattern of the acid digested samples was also compared to confirm the presence of kaolinite. Brown (1964), has given the details for the distinction between chlorite and kaolinite. He has also provided diffraction patterns for the recognisation of these minerals.

RESULTS

The Patala Formation contains mainly kaolinite, mixed layer clay mineral (illite-montmorillonite), illite and montmorillonite as the fine grained clay minerals. In other minerals, reflections of quartz, calcite, dolomite, pyrite, gypsum, siderite, apatite, marcasite and feldspar were observed. Occasionally, week reflections of goethite were also observed. Table: 1 gives the semiquantitative analyses of clay minerals in Patala Shales and Figure: 2 displays their distribution from the base to the top of the Patala Formation.

The mineral kaolinite occurs in poorly crystallized and well crystallized forms in Patala Shales. It was observed in all the samples due to its major reflections at 7.13 and 3.57 A^{0}, $2^{0}2\Theta$ to $65^{0}2\Theta$ in the random powder diffractograms. The reflections of kaolinite did not show any change on glycolation but disappeared after heating at 55^{0}C for one hour. It is the dominant clay mineral and varies from 100% (maximum) to 43% (minimum). Its average distribution is about 66%. it shows sudden increase in its amount at about 19 and 26m intervels from the top of the formation, respectively. Figure: 3 gives the

major reflections of kaolinite in the oriented samples and the effects of glycolation, acid digestion and heating.

The mixed layer clay mineral is a random mixture of illite and montmorillonite. It gives its reflections as the long tail of 10A^{0} illite reflections towards low angle 2Θ degrees. Weaver (1956, 1958) recognized the mixed layer clay mineral as a mixture of illite-montmorillonite which was observed as a long tail of 10A^{0} illite reflection towards low angle 2Θ degrees. Therefore the mixed layer clay mineral has been recognized as the mixture of illite montmorillonite. The reflections generally occured between 10 and 14 A^{0}. The mixed layer clay mineral reflections showed some expansion on glycolation at 60^{0}C for one hour and displayed contraction on heating at 550^{0}. It is the second dominant clay mineral in Patala Formation and occurs in most of the samples (Table 1 and Figure 2). It is absent in some samples but in other samples it is as high as 50% (Table 1). Its average distribution in Patala Formation is about 22%. The mixed layer clay mineral shows a sudden increase at 9 and 12m points from its top, respectively (Figure 2).

The mineral illite occurs in most of the samples and was recognized due to its 10A reflection. The illite reflections did not show any change on glycolation but increased in intensity on heating. This increase in intensity due to heating may be the result of the contraction of mixed layer clay mineral and montmorillonite. The mineral illite is absent in several samples but in other samples it occurs in appreciable amounts (maximum 39%). Its average distribution is about 7%.

The mineral montmorillonite was identified due to its reflections between 12 and 14A^{0} on glycolation at 60^{0}C for one hour and contracted on heating at 550^{0}C. The montmorillonite mineral is the least dominant mineral and was not identified in several samples. It shows its dominant distribution towards top and base of the formation where limestone and marl bands also increase in intensity. It is likely that the mineral montmorillonite has a positive relation with the mineral calcite. The average distribution of montmorillonite in the Patala Formation is about 5%.

DISCUSSION

The mixed layer clay mineral illite and montmorillonite display approximately similar trends in their distribution as compared to the distribution of koalinite which gives the opposite trends (Figure 2). It is likely that kaolinite was formed in comparatively different conditions as compared to illite, montmorillonite and mixed layer clay mineral. The mineral montmorillonite was probably formed in less humid climates where soil solutions were slightly alkaline and cations were removed less rapidly. The nature of mixed layer clay mineral (iilite-montmorillonite) reflections indicate that the montmorillonite of less humid climate was gradually converted to illite and mixed layer clay mineral due to its association with potassium ions, present in marine waters and in early diagenetic solutions. The montmorillonite observed in the Patala Formation probably includes potassium ions as the exchangeable cation as it expands between 12 to 14A^{0} on its treatment with ethylene glycol. Brown (1961) provided a table on page 202, according to which the Tidinit montmorillonite expanded to 13.2A^{0} after treating with ethylene glycol and with potassium ions as the exchangeable cations. It is likely that the montmorillonite of the Patala Formation includes mixed layers due to potassium ions. Weaver (1956) argued that mixed layer clay minerals are usually derived from the degradation or aggredation of pre-existing clay minerals. Muffler and White (1969) studied the clay mineralogy of Salton basin, California, and discovered a gradual change of montmorillonite to illite, passing through a stage of disordered mixed layer clay mineral. It is more likely that the mineral montmorillonite represents the regional sedimentation trends, being the part of detritus material suspended in regionally flowing ancient rivers. It is also probable that the mineral montmorillonite indicates the seasonal fluctuations during the deposition of Patala Shales. Dunoyer de. Segonza (1970) described the five zones of diagenesis on the basis of illite crystallinity and chemistry. He called these zones of diagenesis on the basis of illite crystallinity and chemistry. He called the zones as the zones of sedimentation, early diagenesis, late diagenesis, the anchizone and the epizone. The illite and the random mixed layer clay mineral in Patala Shales may be placed in the zone of early diagenesis.

According to Millot (1964) the minerals of smectite group may originate during the ideological cycle and diagenetic processes. He proposed the following four different environments for the genesis of smectite minerals.

1. Soil profiles: Illite and chlorite minerals are degraded to smectite mineral by steps to total hydrolysis. The smectite minerals may represent intermediate stages of alteration.
2. Basic chemical sedimentation: The smectite minerals may form during the chemical sedimentation of basic rocks. The environment is alkaline and can be marine or lacustrine.
3. Erosion of bentonites: Minerals of smectite group are mostly formed due to erosion of bentonitic deposits. The term bentonite includes deposits with smectite group minerals.

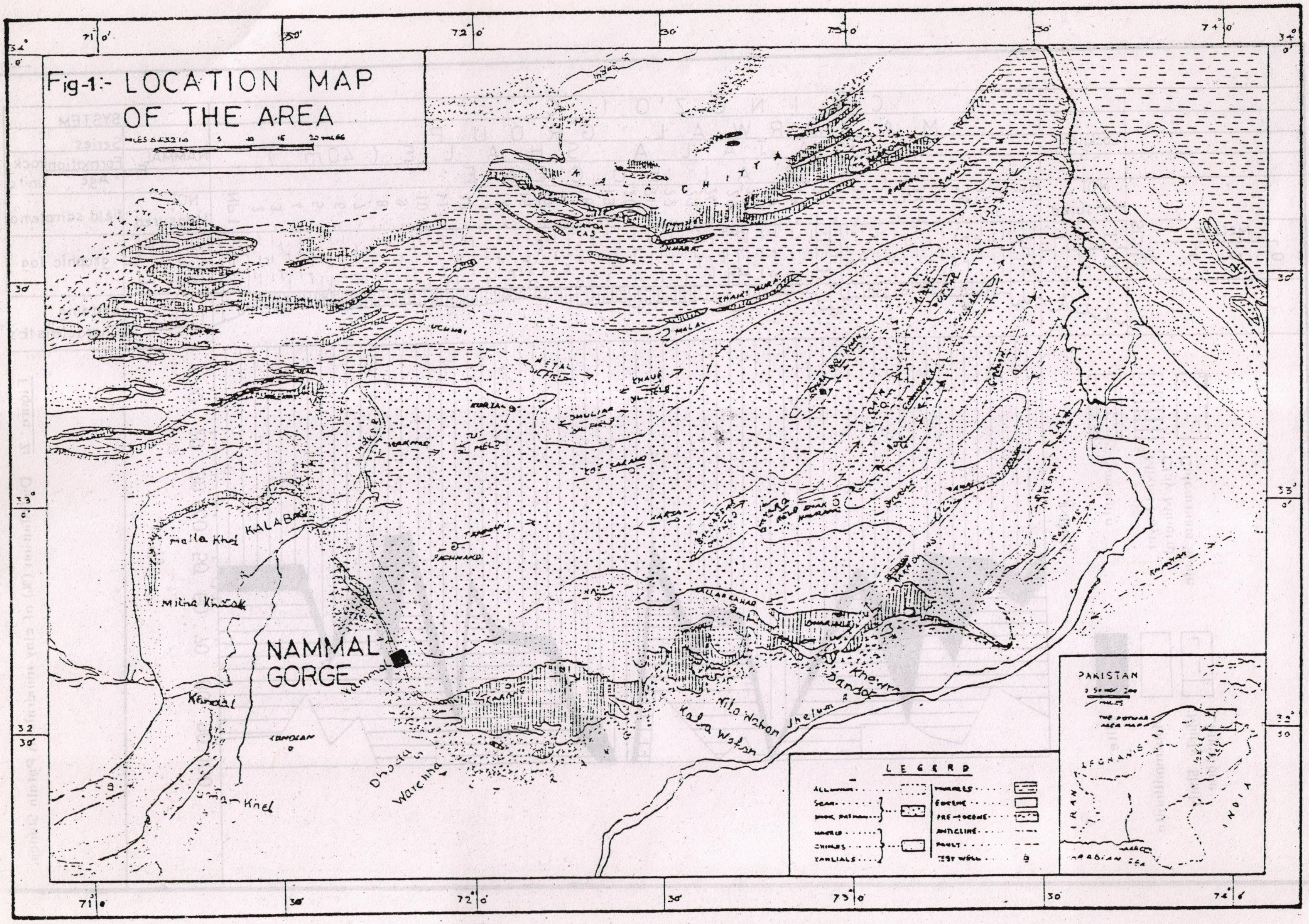
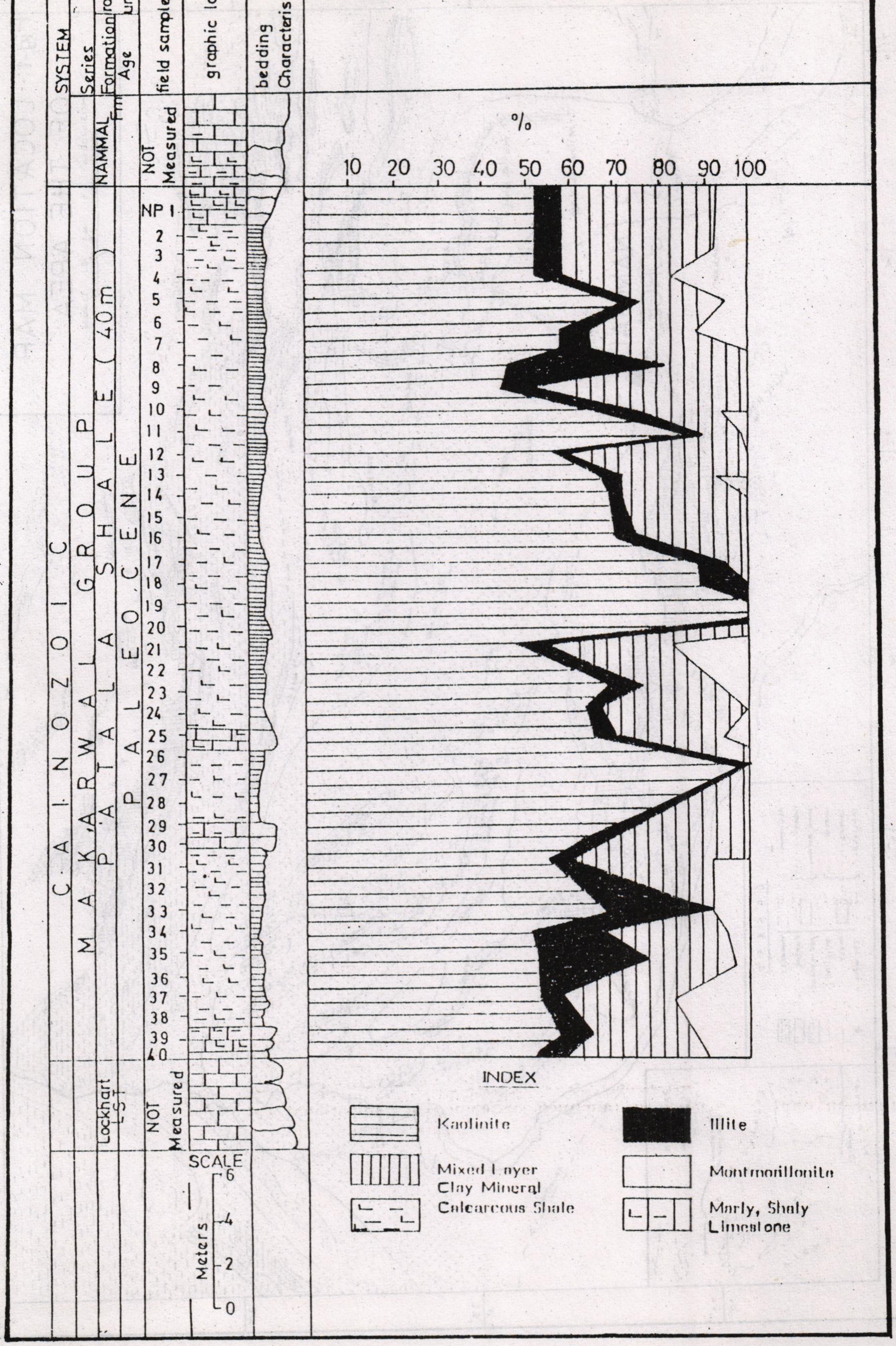


Fig-1:- LOCATION MAP OF THE AREA

(After Abid 1980)

Figure 2: Distribution (%) of clay minerals in Patala Shales.



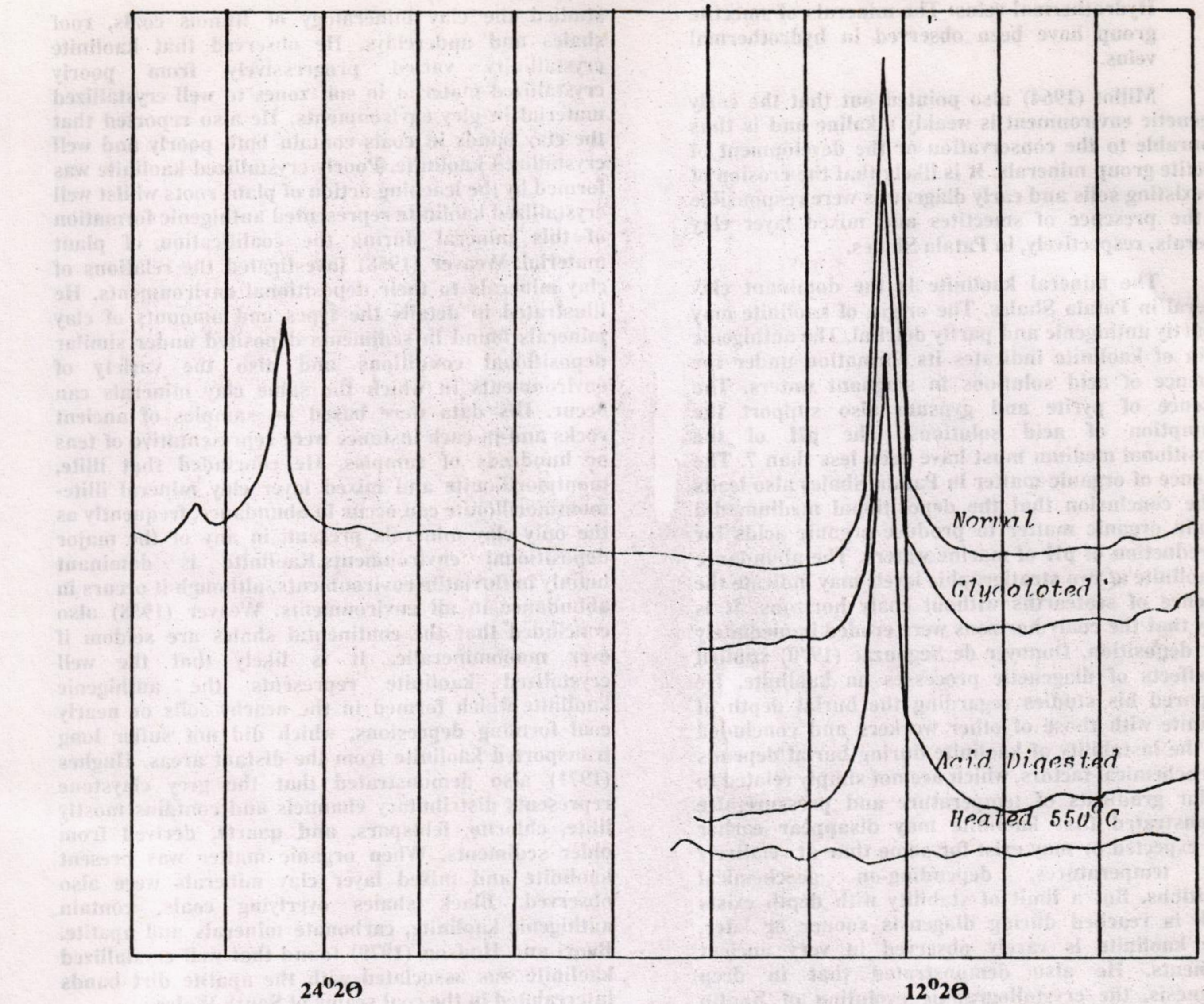


Figure 3: Reflections given by a representative kaolinite (NP-2Θ) sample and the effects of glycolation, acid digestion and heating.

The Patala Shales exposed at the Nammal Gorge contain mainly kaolinite and mixed layer clay mineral (illite-montmorillonite) with minor quantities of illite and montmorillonite. Other non clay minerals are mainly calcite, dolomite, quartz, feldspars and pyrite.

The mineral kaolinite is partly authigenic and partly detrital in origin. The authigenic kaolinite was formed in acidic environments while and detrital kaolinite originated in soils of humid temperate climates on well drained slopes and with abundant vegetation. The mineral montmorillonite was formed in comparatively less humid climates where soil solutions were slightly alkaline. Montmorillonite is probably a detrital content of Patala Formation. The mixed layer clay mineral (illite-montmorillonite) and illite were formed due to alteration of montmorillonite in the presence of potassium ions.

INDUSTRIAL USES

The Patala Formation exposed at Nammal Gorge contains dominantly kaolinite with some mixed layer clay mineral, illite and montmorillonite. The mineral kaolinite shows 100% distribution at 19 and 27m points below the top of Patala Formation and these shales may be used as refractoiry materials. The minor quantities of illite, and mixed layer clay minerals will provide enough plasticity to create bond and strenght.

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We are grateful to Mr. Waheed-ud-Din, Director General, Geological Survey of Pakistan, and Mr. Mohmood-ud-Din, Director, Mineralogical-Petrological Laboratories, Geological Survey of Pakistan for providing laboratory facilities. We are also thankful to Dr. Syed Taseer Hussain for

4. Hydrothermal veins: The minerals of smectite group have been observed in hydrothermal veins.

Millot (1964) also pointed out that the early diagenetic environment is weakly alkaline and is thus favourable to the conservation or the development of smectite group minerals. It is likely that the erosion of pre-existing soils and early diagenesis were responsible for the presence of smectites and mixed layer clay minerals, respectively, in Patala Shales.

The mineral kaolinite is the dominant clay mineral in Patala Shales. The origin of kaolinite may be partly authigenic and partly detrital. The authigenic origin of kaolinite indicates its formation under the influence of acid solutions in stagnant waters. The presence of pyrite and gypsum also support the assumption of acid solutions. The pH of the depositional medium must have been less than 7. The presence of organic matter in Patala Shales also leads to the conclusion that the depositional medium did contain organic matter to produce organic acids for the reduction of pH of marine waters. The abundance of kaolinite at two stratigraphic levels may indicate the presence of seatearths without coaly horizons. It is likely that the coaly horizons were eroded immediately after deposition. Dunoyer de Segonzac (1970) studied the effects of diagenetic processes on kaolinite. He compared his studies regarding the burial depth of kaolinite with those of other workers and concluded that the instability of kaolinite during burial depends on geochemical factors, which are not simply related to regular gradients of temperature and pressure. He demonstrated that kaolinite may disappear earlier than expected or may exist for some time at relatively high temperatures, depending-on geochemical conditions. But a limit of stability with depth exists which is reached during diagensis sooner or later, since kaolinite is rarely observed in very ancient sediments. He also demonstrated that in deep diagenesis, the crystallographic evolution of Kaolin minerals may take place in the order, kaolinite-kaolinite/dickite, dickite-dickite/nacrite and nacrite. The present situation of kaolinite is most likely the first situation of kaolinite as the burial temperatures and pressures did not effect the original structure of the kaolinite. It is more probable that the geochemical conditions controlled the stability of kaolinite.

Grim and Allen (1938) studied the seatearths of Illinois coals and found that they contain abundant kaolinite. Webb (1961) investigated the clay mineralogy of several Pennsylvanian sections in East Central United States. he observed that in the Pennsylvanian roof shales of the Illinois Basin, Illite and Chlorite were the dominant minerals but the kaolinite was common in black shale and was abundant near coals. Baqri (1978) found that kaolinite was the dominant clay mineral in the roof shales of the lakhra and Jhampeer coalfields. Hughes (1971) studied the clay mineralogy of Illinois coals, roof shales and underclays. He observed that kaolinite crystallinity varied progressively from poorly crystallized material in soil zones to well crystallized material in gley environments. He also reported that the clay bands in coals contain both poorly and well crystallized kaolinite. Poorly crystallized kaolinite was formed by the leaching action of plant roots whilst well crystallized kaolinite represented authigenic formation of this mineral during the coalification of plant material. Weaver (1958) investigated the relations of clay minerals to their depositional environments. He illustrated in details the types and amounts of clay minerals found in sediments deposited under similar depositional conditions and also the variety of environments in which the same clay minerals can occur. His data were based on samples of ancient rocks and in each instance were representative of tens or hundreds of samples. He concluded that illite, montmorillonite and mixed layer clay mineral illite-montmorillonite can occur in abundance, frequently as the only clay minerals present, in any of the major depositional environments.Kaolinite is dominant mainly in fluviatile environments, although it occurs in abundance in all environments. Weaver (1958) also concluded that the continental shales are seldom if ever monomineralic. It is likely that the well crystalized kaolinite represents the authigenic kaolinite which formed in the nearby soils or nearly coal forming depresions, which did not suffer long transported kaolinite from the distant areas. Hughes (1971) also demonstrated that the grey claystone represents distributary channels and contains mostly illite, chlorite, feldspars, and quartz, derived from older sediments. When organic matter was present kaolinite and mixed layer clay minerals were also observed. Black shales overlying coals, contain authigenic kaolinite, carbonate minerals and apatite. Baqri and Hodson (1979) found that well crystallized kaolinite was associated with the apatite dirt bands intercalated in the coal seams of South Wales.

It is likely that the kaolinite of the Patala Formation was partly formed in soils of humid temperate climates on well drained slopes with abundant vegetation. These soils (with vegetation matter) were transported into the nearby depositional basins. Most of the vegetative matter was deposited into the nearest parts of the basin while clayey soils were transported comparatively into the farther parts of the depositional basin. The clay particles absorbed ions from the depositional waters and were flocculated by electrolytes. The small colloidal range of clay particles remained suspended in depositional waters for long periods were partly authigenic and well crystallized kaolinite was formed under the influence of acidic environments.

SUMMARY AND CONCLUSIONS

Table:1.
SEMIQUANTITATIVE (Percentage) ANALYSIS OF CLAY MINERALS FROM PATALA FORMATION.

S.No.	K	I	Mont	ML
NP-3	51	6	7	36
NP-4	50	5	21	24
NP-5	71	5	5	19
NP-6	56	7	11	25
NP-7	57	7	-	37
NP-8	46	34	-	20
NP-9	43	7	-	50
NP-10	78	3	3	16
NP-11	78	3	3	16
NP-12	58	2	-	40
NP-13	67	6	7	20
NP-14	70	3	-	27
NP-16	72	5	-	23
NP-17	90	6	-	4
NP-18	90	10	-	-
NP-19	100	-	-	-
NP-20	100	-	-	-
NP-21	49	6	15	30
NP-23	70	7	6	17
NP-24	64	3	-	33
NP-25	67	5	5	23
NP-26	100	-	-	-
NP-30	63	5	-	32
NP-31	56	5	7	32
NP-33	69	23	8	-
NP-34	52	17	5	26
NP-35	54	24	3	19
NP-37	53	5	18	24
NP-39	59	6	12	23
NP-40	53	7	10	30

Index:
K = Kaolinite
I = Illite
Mont = Montmorillonite
ML = Mixed Layer clay Mineral (Illite-montmorillonite).

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Figure:3 Reflections given by a representative kaolinite (NP-20) sample and the effects of glycolation, acid digestion and heating.

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LITHOSTRATIGRAPHY OF THE PART OF TEGUMENT OF THE MASSIF OF AGRENTERA-MERCANTOUR, FRANCE

By

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ABSTRACT:- Carboniferous and Permo-Triassic continental rocks resting unconformably over the basement of the massif of Argentera-Mercantour, and which is from the time of orogenic movements continuously attached to this massif. These continental rocks define tegument in which the Carboniferous period shows cyclic sedimentation of variable intensity, characterized by grey-blackish shale, sandstone, gritstone and conglomerate with arkosic matrix. It has assumed metamorphic aspects because they are tightly folded, intensely faulted during Hercynian and Alpine deformations of the basement, and therefore, may be called metamorphic tegument.

The Permo-Triassic part of tegument shows again a vast continental transgression represented by red gristone, sandstone, and shale of Permian age and variegated quartzite and reddish pelite of Triassic. This Permo-Triassic part produces an angular unconformity either with the basement or with the Carboniferous rocks and which is simultaneously deformed with the basement during alpine orogeny.

INTRODUCTION

Over already folded, faulted and fractured gneisses, migmatites and granites belonging to the massif of Argentera-Mercantour, come unconformably in succession the deposition of Carboniferous and Permo-Triassic continental rocks which define tegument of the massif of Argentera-Mercantour (Abdul Haque, 1986). The lithostratigraphic descriptions of these rocks are given below;

CARBONIFEROUS ROCKS

Carboniferous detrital rocks enveloped by the basement series and are situated in the north-east of figure 1b. These Carboniferous rocks are represented by grey to black schist, fine sandstone and variegated conglomerate which have been intensely folded and faulted alongwith the basement rocks during Hercynian and Alpine orogeneses. Thus, their exact stratigraphic column is not possible to draw. The lithostratigraphy of these rocks is, however, summarized from my field study in the following paragraphs.

Over figure 1b if we follow the line of succession (Fig. 2a) from south-east towards north-west, over the basement, firstly comes grey to black schist and fine micaceous sandstone which are probably schist and arkose already mentioned at the base of Carboniferous sequence (Haudour et al., 1958). Then comes alternatively deposition of grey, beige to reddish conglomerate and arkose with some passage of blackish grey schist. Most of the pebbles, are rounded to subrounded, having been derived from the preexisting basement rocks, namely: amphibolite, aplitic and quartizitic veins, gneisses, migmatites, and granites. The matrix of this conglomerate is arkose containing quartz, felspars and chlorite. These Carboniferous beds shows cyclic sedimentation where the intensity of transportation and the velocity of deposition vary from one bed to the other.

These Carboniferous rocks show the first minor continental transgression over the basement and are locally called *Molieresite* and also dated radiometrically 290+10 Ma (Debelmass, 1967). These are situated at the base of tegument and have been independently deformed into tight synclines and anticlines alongwith the basement rocks by Post-Carboniferous phase of Hercynian orogenesis before the deposition of Permian rocks.

PERMO-TRIASSIC ROCKS

After the deformation of Carboniferous rocks into tight synclines and anticlines alongwith the basement rocks comes the deposition of Permo-Triassic formations. These Permo-Triassic continental rocks have been unconformably deposited either

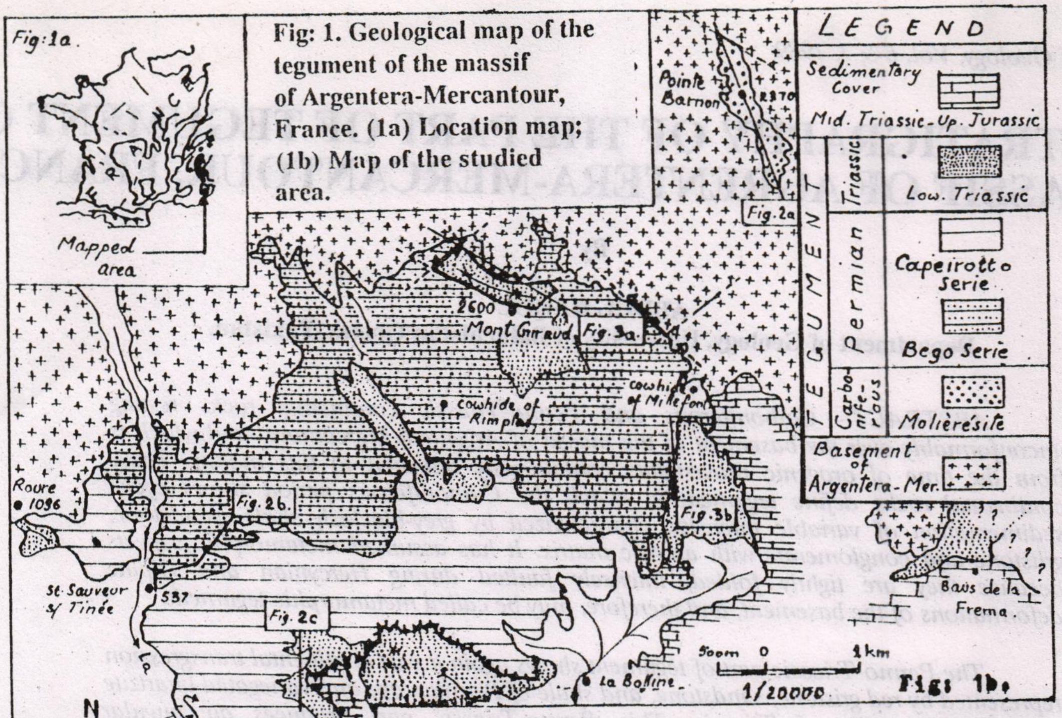

Fig: 1. Geological map of the tegument of the massif of Argentera-Mercantour, France. (1a) Location map; (1b) Map of the studied area.

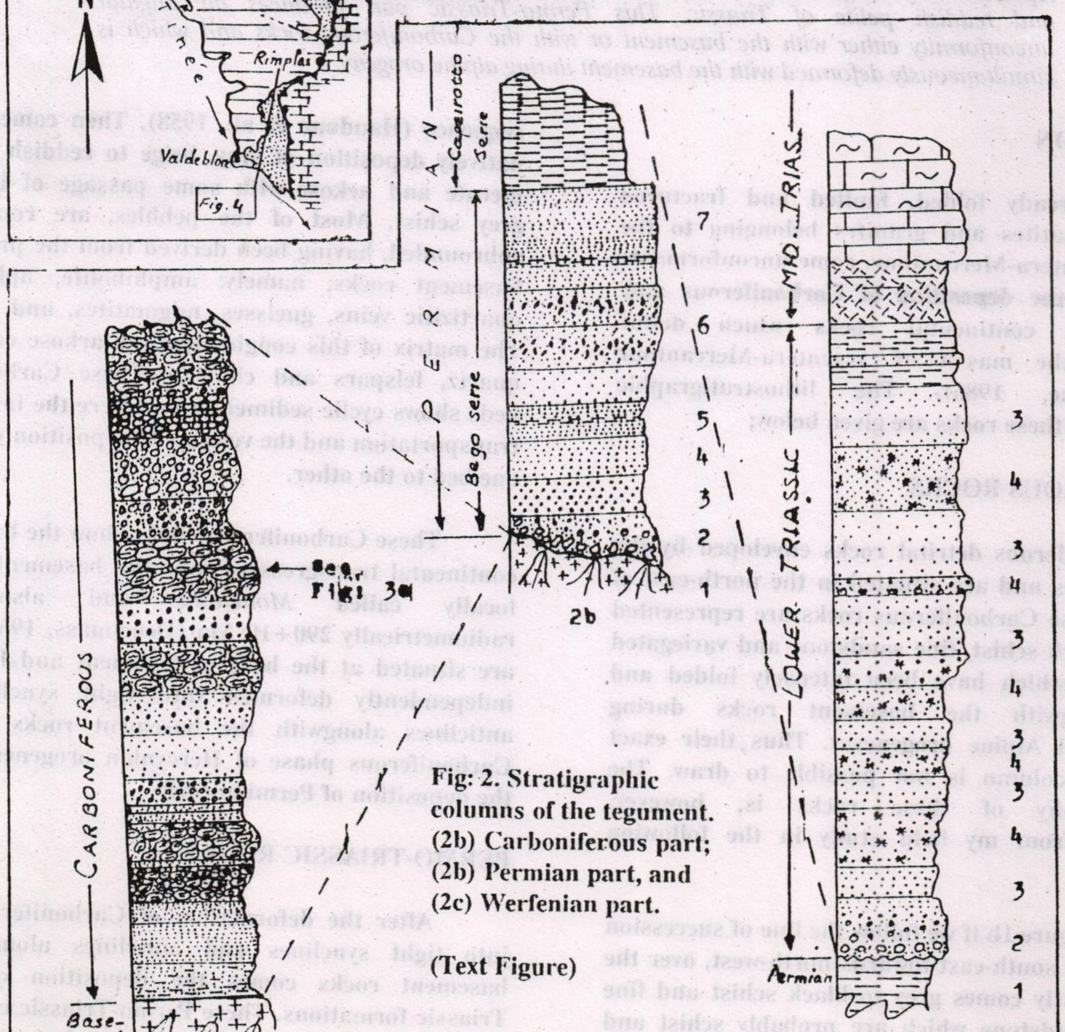

Fig: 2. Stratigraphic columns of the tegument. (2b) Carboniferous part; (2b) Permian part, and (2c) Werfenian part.

(Text Figure)

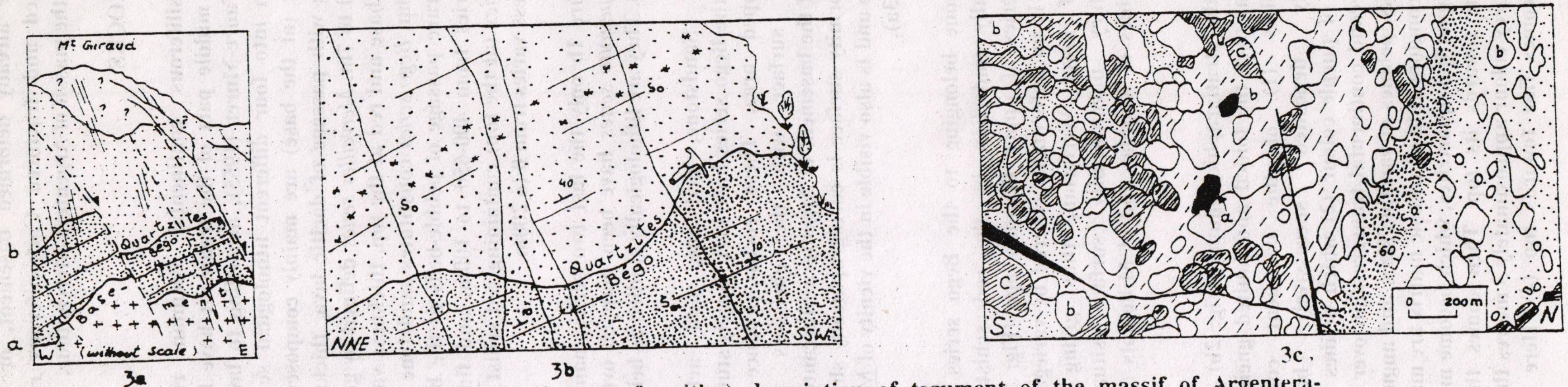

Fig: 3. Lithological and startigraphical (unconformities) description of tegument of the massif of Argentera-Mercantour, France.

(3a): Showing two unconformity surfaces, a. infra-tegumentary and b. intra-tegumentary. (3b): intra-tegumentary. (3c): Detailed lithological description of one of the Car boniferous bed. (Hammer=28cm.).

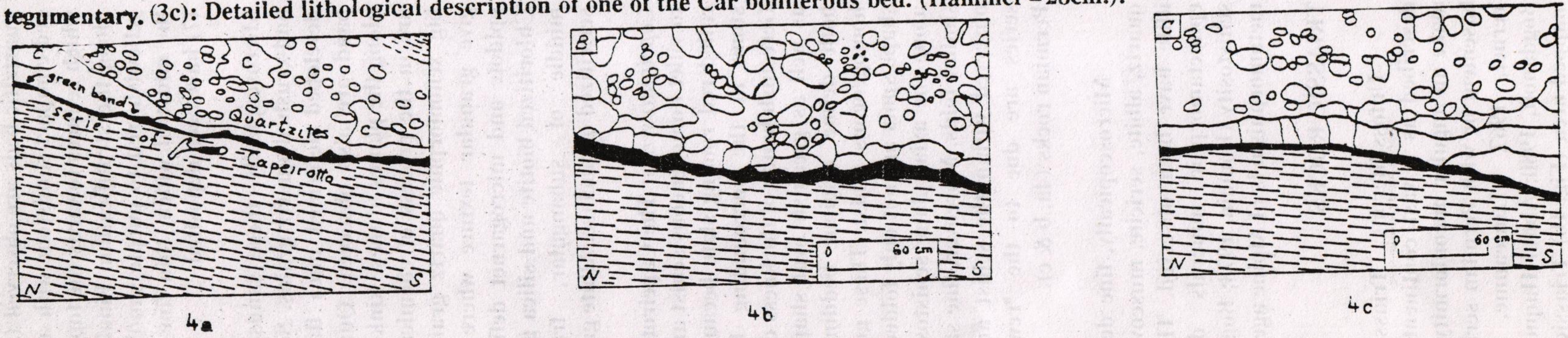

Fig: 4. Charactristics of the Permo-Triassic boundary of tegument of the massif of Argentera-mercantour, France. (4a): Green & quartzitic bands are less prominant in the north. (4b): Green band becomes prominant and quartzitic band is in developing stage. (4c): Quartzitic band is well developed towards south. (Hm=28 cm).

(both are text figures)

directly over already deformed basement, or over folded, faulted and fractured Carboniferous rocks belonging to the massif of Argentera-Mercantour.

PERMIAN ROCKS

Unfossiliferous continental Permian rocks defining the middle part of the tegument have been divided by Faure-Muret (1955), according to law of superposition into four different lithological series. *Inferno series* (at the base) are mainly composed of conglomerate with passage of dacitic lava, thickness varies from 0 to 7m. *Merveilles series* defined by green schist at the base and red at the top, thickness varies from 0 to 500m. *Bego series* constitutes sandstone and arkose with rare passage of pebble-beds at the base, thickness varies from 400-650 to 100m, and finally *Capeirotto series* (at the top) containing red schist and pelite, thickness varies from 0 to 200m.

In figure 1b only the last two series, namely: *Bego and Capeirotto series* have been mapped over a scale 1:20,000. They are lithologically studied as below:

Bego series: Sandstone, gritstone, and arkose belonging to the Bego series have been largely studied in the mapped area. These rocks produce an unconformity surface with the gneissess and migmatites of the basement of Argentera-Marcantour. Such unconformity surface is cartographically shown over figure 1b and is also visible in the vicinity of Mont Giraud, (Fig. 3a).

Sandstone belonging to the Bego series are stratigraphically underlian by the red schist of Capeirotto series of upper Permian age (Fig: 2a). Sometimes it is unconformably covered by variegated quartzites of lower Werferian, thus giving an intrategumentary unconformity surface situated between cowhides of Rimplas and of Millefonts (Fig. 3a).

From the stratigraphic column (Fig: 2b) one ascertains that over the folded and faulted gneisses and migmatites (1) of the basement comes unconformably deposited successively basal conglomerate of purple colour (2) which defines the base of the second continental transgression over the basement rocks. pebbles of variable sizes and angular forms of this conglomerate of arkosic matrix are made of gneisses migmatites, quartzites, which become more and more fine towards its top. Then comes thick sandstone of grey colour approximately 3 metres thick (3) which becomes fine towards top (4). Here the colour is violet to reddish and in the midst of which millimetric to centimetric argillaceous or sometimes quartzitic beds are observed (5). Again we observe fine red-compact sandstone with abundant green snots (6) which reduces towards the top, where they are oriented along the stratification. Finally fine grained massive, yellowish, red to purple sandstone, and sometimes in the midst of which, thin fine argillo-arenaceous beds (7) have been deposited.

Microscopically, these sandstone contain tectonized and crushed quartz grains. Sericite, chlorite and well developed deformed mica flakes giving micro-kink-band are also observed. Quartz grains are aligned along the planes of these kink-bands. Rare plagioclase are in the process of chemical alteration. Moreover, big xenomorphic quartz grains sometimes rounded, give granular texture where micrograin of calcite, epidote and microgarnet define its phyllitic cement. Chloritized biotite and silica grains are present in the middle of subangular, fractured, illitized and sericitized orthoclase. Albite grains are neoformed.

Capeirotto series: The Capeirotto series constitutes red to villet homogeneous schist and pelite which is locally called red roofing slate because of its use as roofing stone in the surrounding buildings of the area. Gereenish bands of thickness centimetric to decimetric as well as greenish oval shape spots (marker beds) both define original bedding planes within such homogeneous schist. These greenish bands and oval shape spots are not only folded but are also displaced along the axial plane schistosity, thus, giving micro-similar folds. Moreover, fine sandstone bands are also observed within the schist and pelite of Copeirotto series are due to the "reworking" of underlying Permian rocks (4a, b & c).

Microscopically, fine detrital minerals such as quartz, albite, sericite, muscovite, zircon, epidote and illite have been observed. The orientation of these epimetamorphic minerals defines the plane of schistosity (Romain, 1978; Bogdanoff, 1980), and such metamorphism is of Alpine age (Baucakrut, 1967).

TRIASSIC ROCKS

Unfossiliferous Triassic rocks are often described as a vast continental transgression which make an angular unconformity surface either with the basement or with Permian series (Faure-Muret, 1955, Vernet, 1967, Lanteaume, 1968; Prunac, 1976, Bogdanoff, 1980; Abdul Haque, 1987). In the present mapped area (Fig. 1b) Triassic rocks are underlained uncoformably either by basement or by the Bego series and have been geologically divided into two units: variegated quartzites of Lower Werfenian, violet pelite of Upper Werfenian.

Variegate Quartzites

Lower Werfenian is generally composed of metric bands of variegated quartzites and minor gritstone both having bright yellow, violet, red and green colours. Figure 2c shows a stratigraphic column taken from the area north of Rimplas, which is limited at the base by red Capeirotto schist of Permian age while at the top by violet pelite of Upper Werfenian age. Within such column we observe an alternation of variegated quartzites, the whole thickness of which is more or less 70m, in that beds (2) and (4) seem to be lithologically important and are described in detail as below.

Bed (2) represents basal conglomerate which contains angular to subangular pebbles with arenaceous matrix and its lower contact with schist and pelite of Permian age is elaborated in figure 4. Over such Permo-Werfenian contact a green undaulatory band of 1 to 4cm thickness is also observed. Over this undulatory band we have.

(a) Heterogenous greyish pebbles of quartz being placed side by side (Fig. 4a) passing towards south into white to greenish quartzitic bands (Fig: 4b) which marks the pinching of sedimentation; (b) rounded quartzitic pebbles of all sizes, all are fractured (Fig: 4a & B, c) very fine grey-yellowish sandy pockets play the role of matrix (Fig: 4b, c); (d) sandy matrix, in which the grains are larger in size than in c, and finally (e) microconglomeratic matrix.

The heterogenous quartzitic band at the base of Lower Werfenian shows the phenomenon of channeling over Permian and has already been mentioned by different authors (Bertrand, 1898; Guillaume & Toussaint, 1965a; Aicard et al. 1968), and which has materialized for the first time by the author of this paper (Fig: 4a, b, c). This conglomeratic bed disappears in the north of Rimplas, where only the green band (supra) over the contact of red Permian schist and the quartzites of Lower Werfenian is observed.

Bed (4) in figure 2c is made of grey buttoned quartzite which is also observed in the SE of cowhide of Millefonts (Fig: 3b). These snady and porous buttons may be due to oxidation of pyrite, magnetite or oligist crystals (Faure-Muret, 1955), and which made these quartzitic beds very fragile.

In thin sections, two facies are distinguished in these variegated quartzites: felspathic sandstone with phyllateous cement is dominant, and sandstone of phyllitic cement. The first one gives compact oriented texture defining argillaceous bedding which contains minerals like sericite, muscovite, biotite, illite and rounded to subrounded quartz grains, thus, giving subiso-granular structure. The second facies is defined by subrounded quartz grains which are surrounded by irreguiar and corroded aureoles of neoformed quartz crystals, thus, showing heterogranular sturcture. James (1976) described accessory tourmaline in this second facies.

Violet Pelite

Variegated quartzites of Lower Werfenian is overlain normally by red and violet pelite of Upper Werfenian with transitional contact of variable thicknesses (3 to 10m). The Upper Werfenian is represented by two facies (Lanteaume, 1968): at the base, the violet pelite; at the top, dolomitic pelite. This author also mentions in it, primary sedimentary structures, like, charge figure, lamination, graded bedding which justify fluviatile origin to these Upper Werfenian rocks. In the studied area, only unmapable violet pelite out-crops have been observed.

CONCLUSION

The deposition of Carboniferous conglomerate over already folded and faulted metamorphic rocks of the basement of Argentera-Mercantour show the first minor continental transgression. The pebbles within these continental rocks have been derived from the pre-existing basement rocks, and their deposition shows cyclic sedimentation in which the intensity of their transport and the velocity of their sedimentation vary from one cycle to the other.

Perior to the deposition of Permain rocks Carboniferous rocks are intensely deofrmed simultaneously with the basement rocks during Hercynian orogeneses.

Permian is also continental and is represented by the deposition of sandstone, arkose, schist and pelite producing unconformity surfaces either with the basement rocks or with Carboniferous. This vast trangression of Permian age also produced intra-

Permain unconformities which show fluctuation of sedimentation by subsidence during this age.

The Werfenian continental transgression is characterized by the deposition of variegated quartzites and violet pelite. Such transgression produces intrategumentary unconformities, as well as the discordance between basement and Triassic rocks. The constant theikness of these variegated quartzites of Lower Werfenian shows that the subsidence which has been prevailed during Permaian ceases during Werfenian age.

The transitional contact between Lower and Upper Werfenian complicates mapping work during the field. Red to violet pelite of Upper Werfenian recall the return of hot rubefiant humid to semi-arid climate which has been existing during Permian age.

The whole Permo-Triassic continental rocks have been adherent to the absement inspite of intensive foldings and faultings during alpine tectonics.

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GRAIN SIZE PARAMETERS OF THE CONGLOMERATE FRACTION OF SOAN FORMATION, ZARGHUN GHAR, BALUCHISTAN

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ABSTRACT:- Grain size analyses of the conglomerate fraction in six separate horizons of the conglomerate of the Soan Formation were carried out and size parameters determined. The analyses show that their modal size range between -5.5 and -6.5 and mean varies between -5.9 and -6.55 on phi scale. The conglomerate is moderately to poorly sorted with phi deviation measure ranging between 0.6 and 1.6, and are positively skewed with values of phi skewness measure between 0.0 and 0.6. These parameters correspond to deposits of rivers of high energy conditions.

INTRODUCTION

The name Soan Formation, proposed by Kravtchenko (1964) for the upper part of the Siwaliks, was adopted as such by the Stratigraphic Committee of Pakistan (1974). In Baluchistan it represents the upper part of the Sibi Group and Urak Group of the Hunting Survey Corporation (1961) and the Urak Formation of Kazmi & Raza (1970). The formation is well exposed in the Zarghun Ghar about 20 km east of Quetta (Fig. 1). It is characterised by the fining-upwards cyclic sequences of alternatly conglomerate, sandstone and slitstone/mudstone members respectively from bottom to top. The conglomerate members are characterised by moderatly to poorly sorted, well rounded and clast-supported pebbles and cobbles which may sometimes show marked imbrication (Fig. 2). The intermediate sandstone members are light brownish grey to light grey, medium to coarse grained, in places pebbly, subrounded to subangular, mostly cross-laminated and in places bioturbated. It may be categorised as lithic arenite and calclithite according to Dott's (1964) and Folk's (1968) classifications (Kassi et al. 1987). The siltstone/mudstone members of the formation are mostly reddish and brownish grey showing micro-cross-lamination, bioturbation and are mottled in places.

Various types of sedimentary structures such as cross-lamination, sole marks and bioturbation are present. The overall cyclic nature of the Soan Formation have been considered to represent the fining-upwards sequences typical of the meandering river deposits (Allen 1965; Kassi 1987). The age of the formation is late Pliocene to early Pliestocene (Kravtchenko 1964).

The present paper provides an idea of the grain size parameters of the conglomerate fraction of some of the lowermost conglomeratic members of the Soan Formation.

GRAIN SIZE ANALYSES

Methodology: Grain size analyses were carried out in a nicely exposed stream section, smoothed by the stream water of the Spintangai Nala (Fig. 1). Cross-section areas were selected and maximum intercepts of cobbles, pebbles and granules were measured and sand fraction of the matrix were ignored. Square areas of about 75 x 75 cm were selected for each analysis whithin which straight lines were drawn parallel to each other about 6 cm apart in order to avoid multiple measurements. Maximum intercepts were measured by ordinary steel made measuring tape successively along the drawn lines within the selected cross-sectional areas. At least 100 measurements were taken in each area and extra care was taken to avoid multiple measurements. The data obtained was classified and histograms (Fig. 3), cumulative curves (Fig. 4) and other size parameters like median, mode, sorting and skewness were determined according to the Inman's (1952) methods. Parameters like phi skewness measures ($\sigma_2 \Theta$) and phi standard deviations ($\sigma \Theta$) were plotted on a diagram after Friedman (1961) which shows position of plots within the field of river sands.

It may be noted that the conglomerates and sandstones mostly consists of limestones fragments with only subordinate amounts of other mineral and rock constituents. Grains which are unsoluble in HCl are rare, therefore, disaggregation of sandstone by acid may lead us to errors in the analyses. However,

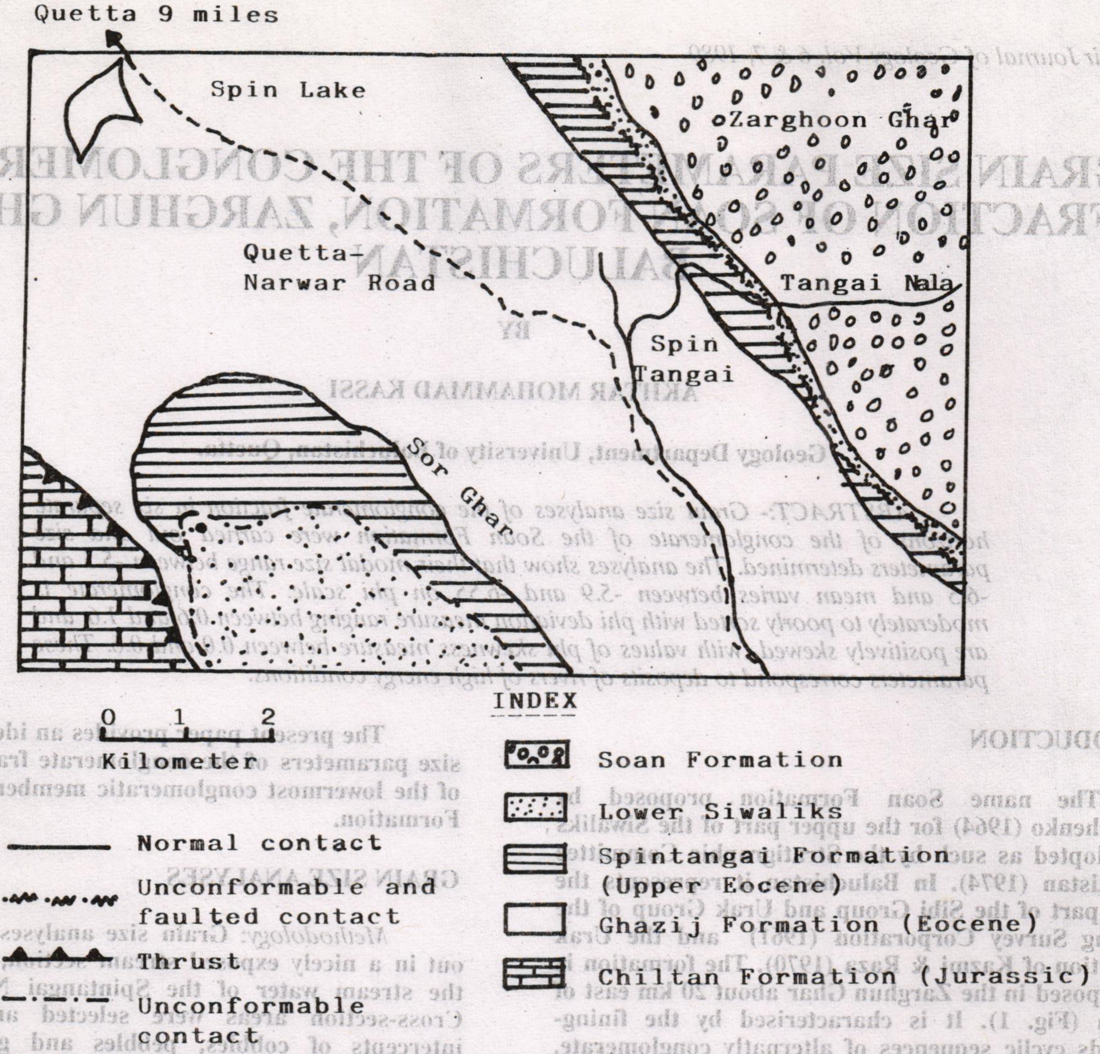

Fig. 1. Geological Map of the Sor Range area showing studied locality

Fig. 2. Photograph of a conglomerate member of the Soan Formation in Spintangi Nala, Zarghoon Ghar, Balochistan.

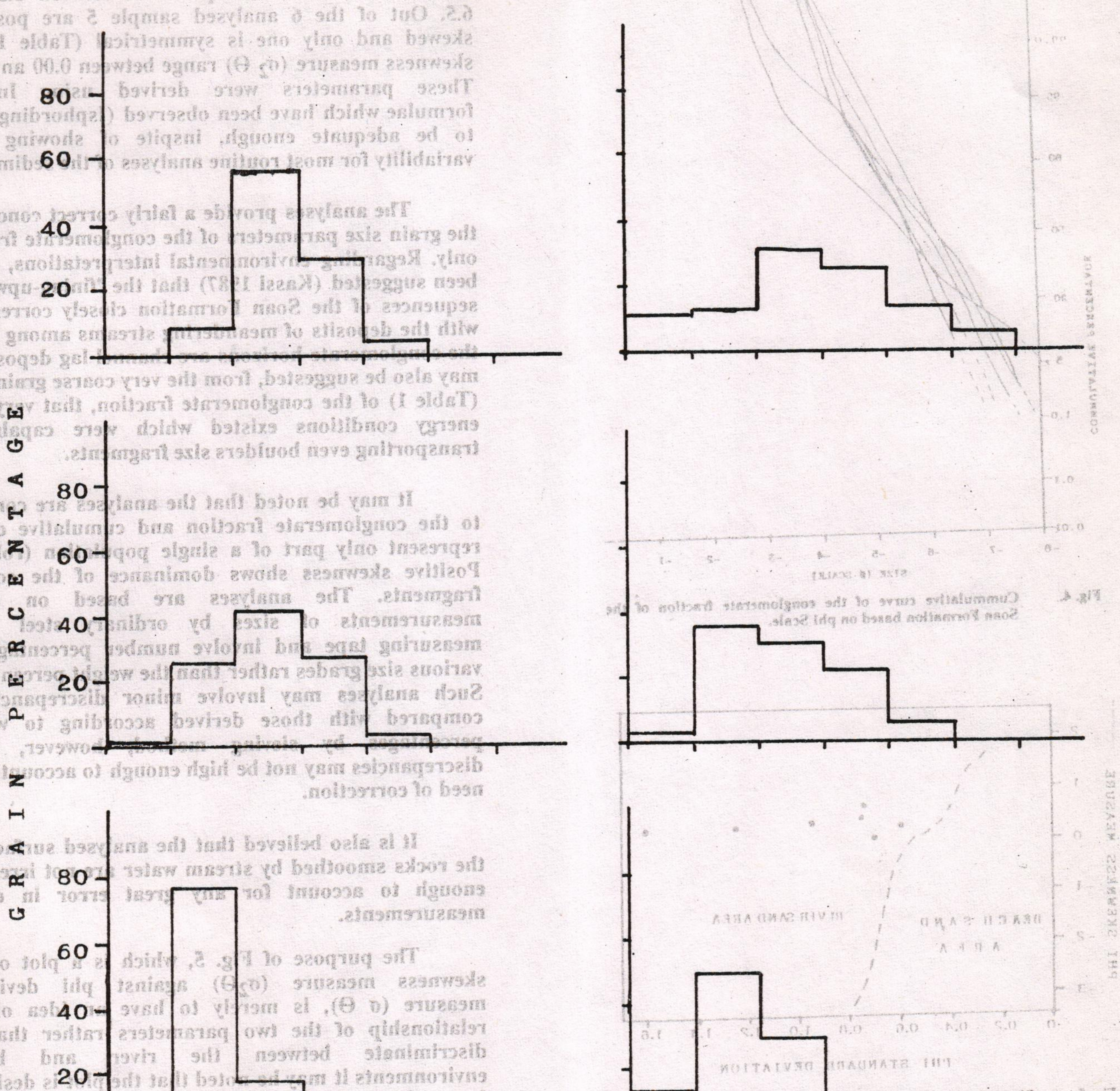

Fig. 3. Histograms of the Conglomerate fraction of the Soan Formation based on phi Scale.

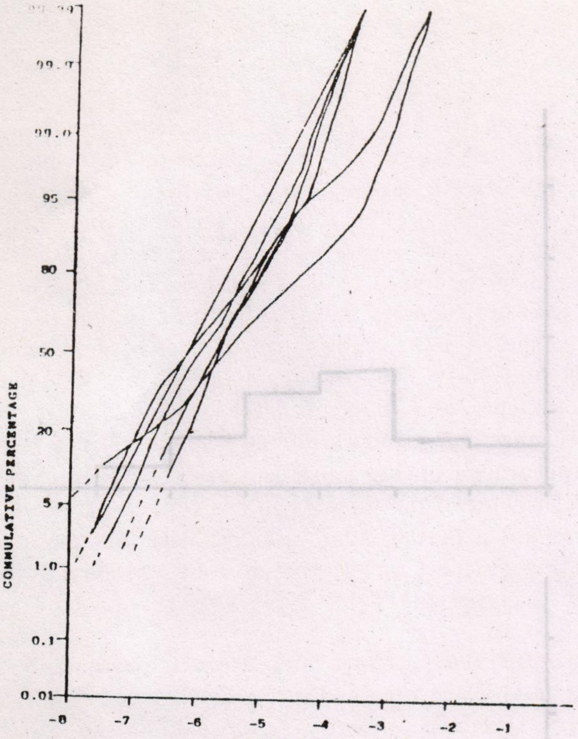

Fig. 4. Cummulative curve of the conglomerate fraction of the Soan Formation based on phi Scale.

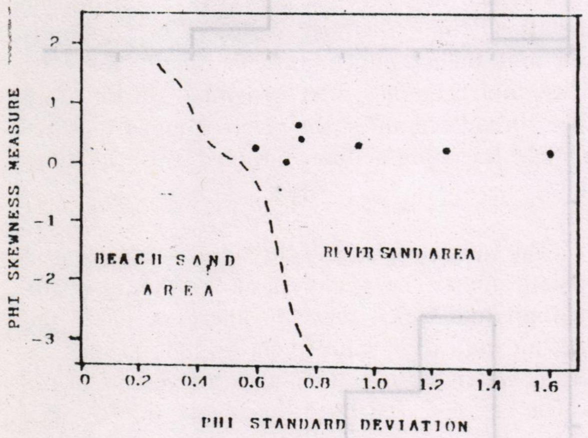

Fig. 5. Plot of the third moment (Skewness) and Standard Deviation of the conglomerate fraction of the Soan Formation (After Friedman 1961).

grain size analyses of the sand fraction of the conglomerate matrix in thin section may be adopted and such attempts will be made later on.

RESULTS AND DISCUSSION

Results of the analyses (Table 1; Figs. 3-5) show that the conglomerate fraction of the Soan Formation is moderately sorted to moderatly well sorted (Friedman 1962) with phi deviation measure (σ Θ) ranging between 0.6 and 1.6, phi median (Θ Md) between -5.6 and -6.2 and phi mode between -5.5 and -6.5. Out of the 6 analysed sample 5 are positively skewed and only one is symmetrical (Table 1). Phi skewness measure (σ_2 Θ) range between 0.00 and 0.60. These parameters were derived using Inman's formulae which have been observed (Isphording 1972) to be adequate enough, inspite of showing great variability for most routine analyses of the sediments.

The analyses provide a fairly correct concept of the grain size parameters of the conglomerate fraction only. Regarding environmental interpretations, it has been suggested (Kassi 1987) that the "fining-upwards" sequences of the Soan Formation closely correspond with the deposits of meandering streams among which the conglomerate horizons are channel lag deposits. It may also be suggested, from the very coarse grains size (Table 1) of the conglomerate fraction, that very high energy conditions existed which were capable of transporting even boulders size fragments.

It may be noted that the analyses are confined to the conglomerate fraction and cumulative curves represent only part of a single population (rolling). Positive skewness shows dominance of the coarser fragments. The analyses are based on direct measurements of sizes by ordinary steel made measuring tape and involve number percentages of various size grades rather than the weight percentages. Such analyses may involve minor discrepancies if compared with those derived according to weight percentages by sieving method, however, these discrepancies may not be high enough to account for a need of correction.

It is also believed that the analysed surfaces of the rocks smoothed by stream water are not irregular enough to account for any great error in direct measurements.

The purpose of Fig. 5, which is a plot of phi skewness measure (σ_2Θ) against phi deviation measure (σ Θ), is merely to have an idea of the relationship of the two parameters rather than to discriminate between the river and beach environments it may be noted that the plot is designed for sand and not for conglomerates.

A drawback of the present work was our unability, at that time, to extend the study to sandy matrix between cobbles and pobbles. A close look at the sandy matrix in thin section reveals that most of the grains, just like in conglomerate fraction, are derived from carbonate rocks of various types. Therefore disaggregation of the sandy matrix by acid may lead us to serious errors because of the desolution of calcite cement and also carbonate fragments. Disaggregation of such a rock by dilute acid may cause the impure type of limestone fragments to desolve partially or uncompletly, consequently, causing reduction in sizes. On the other hand, the use of

Table 1
Grain size parameters of the conglomerate fraction of the Soan Formation. Parameters determined using Inman's (1952) methods.

Parameters	An.1	An.2	An.3	An.4	An.5	An.6
Θ5	-6.6	-8.1	-7.1	-7.4	-7.4	-6.9
Θ16	-6.2	-7.0	-6.7	-7.0	-6.9	-6.5
Θ54	-5.6	-5.5	-5.9	-6.1	-6.1	-5.6
Θ84	-5.0	-4.2	-5.2	-5.1	-5.5	-5.0
Θ95	-4.5	-2.5	-4.7	-4.4	-5.0	-4.3
Θ50- (ΘMd)	-5.7	-5.6	-6.0	-6.2	-6.2	-5.8
Mean (MΘ)	-5.9	-6.2	-6.3	-6.5	-6.5	-6.5
Mode (Θ)	-5.5	-5.5	-5.5	-6.5	-6.5	-6.5
Phi deviaton ($\sigma\Theta$)	0.6	1.6	0.75	0.95	0.7	0.75
Phi skewness ($\alpha_2\Theta$)	0.25	0.19	0.60	0.25	0.00	0.39

concentrated acid may cause partial or complete desolution of other type of rock fragments such as the calclithite type of sandstone fragments derived from the Ghazij Formation (Kassi 1986; Kassi et al. 1987) which will cause mixing of constituents of the sandstsone fragments with the analysed sample. The only appropriate method for analysing the size of such a sandy matrix may be by thin section, which is based on similar principles as have been adopted in the present work and such attempts shall be considered later on.

ACKNOWLEDGEMENTS

Thanks to Mr. Hassan Khan Kharoti and Mr. Mohammad Ahmad Farooqui for their encouring comments.

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Kashmir Journal of Geology, Vol. 6 & 7, 1989

A CASE OF EXTREME FORWARD INCLINATION IN THE MOLAR PLATES OF THE GENUS *ANANCUS* AYMARD

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and

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ABSTRACT: A Molar fragment of the genus Anancus is described. It shows an extreme forward inclination of the molar ridge-plates.

INTRODUCTION

In January, 1991, a posterior molar fragment (P.U.P.C*. No. 91/10 of an anancoid proboscidean was collected by one of the authors near the village Dhokpathan, district Chakwal. After a careful study, it was found that the type of forward inclination found in its ridge-plates, is so strong that it exceeds that of any of the known anancoid molar. Pre- and posttrites are unituberculated. Thus the tooth shows a mixture of advanced and primitive characters.

DESCRIPTION

The tooth fragment is a posterior portion of the last upper molar. It consists of two ridge-plates and a strong heel. The cement is poorly developed. Enamel is thick and roughly corrugated all around the crown. The tooth is low crowned and transversely narrow. The two halves of the penultimate ridge-plate are highly alternating. Pre- as well as the posttrites are unituberculated. Ultimate ridge-plate has also two prominent pre- and posttrite halves. They strongly alternate or displaced. The pretrite is much forward in position. Both the halves are unituberculated. The pretrite tubercle is comparatively much larger than the posttrite one. The transverse valley between the penultimate and ultimate ridge-plate is like an inverted 'V' and is fairly open. A small amount of cement may be seen at the base of the valley. The hind talon is unituberculated. The tubercle is very large and rounded. The valley between the talon and the last ridge-plate is partially filled with cement. The posterior border of the tooth is bounded by a weak cingular fold of enamel.

MEASUREMENTS (in mm)

Anteroposterior length of the last two ridge-plates and hind talon, 88; transverse width of the penultimate ridge-plate, 62; transverse width of the ultimate ridge-plate, 60; Crown height at penultimate ridge-plate, 58; Crown height at ultimate ridge-plate, 56 and the crown height at the hind talon, 28.

DISCUSSION

Forward inclination of the molar ridge-plates is known in all the species of the genus *Anancus* Aymard (Osborn 1936). This forward inclination and alternation of the pre- and posttrites progressively increases in the chronological order of the species (Sarwar, 1977). Thus, the primitive forms show a low degree of forward inclination whereas the advanced forms such as *Anancus osborni* Sarwar, *A. Perimensis* (Falconer et Cautley), and *A. gigantarvernensis* Klahn show comparatively a high degree of forward inclination. The forward inclination found in the anancoid molars described by Osborn (1926), Hopwood (1935), Arambourg (1945), Chang (1964), Sarwar (1977) and Tassy (1983) Show a degree of forward inclination much lower than that found in the specimen under study. The degree of forward inclination permits its inclusion neither in the species, *A. properimensis* nor in *A. perimensis*. It is therefore labelled as *Anancus* sp.

*Fossil collection stored in the Department of Zoology, Punjab University, Lahore, Pakistan.

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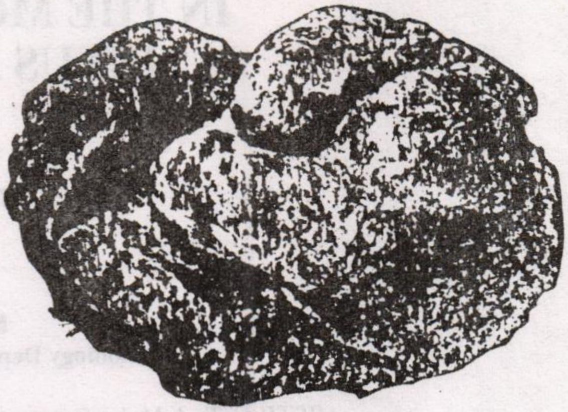

Fig. 1. Crown view of an upper molar fragment of *Anancus* sp.

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HARDGROUND SURFACES IN SAMANASUK LIMESTONE

By

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ABSTRACT:- Hardgrounds are the surfaces of the beds which show evidence of hardening or lithification on the sea floor indicating syn-sedimentary cementation. Such hardgrounds have been recognized in Samana Suk Formation in different parts of Hazara where some work is being carried out on the depositional and diagnetic processes in this formation. The study of hardgrounds reveals that the formation have been deposited in intertidal environments with possible transgressions of the sea and slow sedimentation where the sea floor was lithified before the overlying beds were deposited.

INTRODUCTION

Samana Suk Formation is a Jurassic carbonate sequence which is exposed in different parts of Hazara, Kala Chitta and Samana Range which is the type locality of this formation. While working on the formation, the author observed the bedding plane surfaces and noted that they are uneven, give an evidence of corrosion and erosion, are encrusted by sessile organisms like oysters which are attached to the bedding plane surfaces. There are pebbles of the underlying bed which exist on the bedding plane surfaces and were observed in this formation. Garrison and Fischer, 1969, recognized the hardgounds in the Lower Jurassic Adnet Beds in Northern Calcareous Alp by the following criteria: (a) unevenness of the bedding planes associated with ferruginous crusts and truncated fossils, (b) angularity of fragments in what was identified as solution rubble of limestone crusts, and (c) evidence of brittle fracture of beds during subaqueous slumping. We recognized the hardgounds in Samana Suk Formation with the following criteria: (a) uneven bedding plane surfaces which show evidence of solutioning, (b) fossils, like oysters are seen cemented on the surfaces which also show vertical borings on some beds, (c) clasts of different sizes which are derived from the overlying bed are seen solution rubble cemented on the bedding plane surfaces, (d) polygonal suraces which resulted by the synsedimentary cementation of the carbonate sediment where the layers expand and crack into these polygonal surfaces.

Hardgrounds can be observed in the Changla Gali section, Kundla section, on Lora Maqsood road near jabbri and several other localities. The organically encrusted surfaces have oysters encrusted on the bored surfaces, pebbles and small boulders derived from the underlying strata are encrusted on the surfaces, and polygonal at few localities can be observed which indicate the expansion and cracking of the substrate. Other than that, irregular bedding plane surfaces showing reddish staining due to iron can also be observed.

DISCUSSION

Syn-sedimentary lithification in carbonate sediments is believed to have taken place within permanentaly submerged environments. Hard ground are formed in a wide variety of water depths, majority under few tens of meter, other have formed in deeper water up to 3000 m. Paleogeographic setting indicate that hard grounds are usually a regressive phenomenon, typically formed on seamounts or submerged rises in pelagic environments or on (posterior) shelf areas (Bromley 1978, Davies, 1979). Study of Paris Basin in Burgundy by Purser, B.H. 1969, is an important one regarding the phenomena of syn-sedimentary lithification, which can be observed in the form of "hard grounds". Purser believed that submarine lithification and formation of hard ground may be associated with sedimentary transgression in case of Holocene sediments of Persian Gulf. He further concluded in his study that the process has taken place both in sub-and intertidal environments to produce structure and diagnetic fabric comparable with those produced by similar processes in the holocene sediments of Persian Gulf. Both Holocene and Jurassic submarine lithification seems to coincide with phase of slow sedimentation. Flugel (1982) regards hard ground as long intervals of interrupted sedimentation, intervals of between 2500 and 12500 years have been postulated as the range of hard ground formed for order of Sweden. (Lindstrom 1979).

Bathurst (1975) have dealt with the problem of hardgounds giving examples from different parts of the word. He defines a hardground as "a bed to limestone with upper surface bored, corroded or eroded, if enbcrusting or other sessile organisms are attached to the surface, or if pebbles derived from the bed occur in the overlying sediment." These signs of the one-time existence of a hard floor are accompanied by other features which, though not strictly diagnostic, are characteristic: among these are crusts of or

impregnation by glauconite, calcium phosphate, iron and manganese salts. Commonly the upper surface of the hardground coincides with the paleontological non-sequence. All these qualities show that the hardground was lithified before depsotion of the overlying sediment.

Other studies on the this subject are by Lindstrom (1963) from Sweden and Chalk hardgrounds of northern Europe by, Voigt (1959) and Bromley (1965, 1967, 1968). Bromley's work forms a good basis of the discussion of the interpretation of hardgrounds, especially the Turonian Chalk Rock of England.

CONCLUSIONS

Samana Suk Formation is a regressive carbonate sequence deposited in the intertidal environments with shoaling waves and currents. The hardgrounds have been formed as a result of subaqueous syn-sedimentary lithification except at a few places where an evidence of subaerial exposure can be observed in the form of polygons. The presence of hardgrounds also reveal slow sedimentation so that the sea floor lithified prior to the onset of overlying cycle of carbonate or argillaceous sediments.

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