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CONTENTS

A MICROFACIES RECONNAISSANCE OF THE KINGRIALI FORMATION OF THE NAMMAL GORGE AND GULAKHEL AREAS, PUNJAB

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Abstract : *Microfacies-analysis of 60 thin sections based on* 80 *rock samples from two sections namely Nammal Gorge and Gulakhel belonging to the Kingriali-Formation is presented. Eleven types of microfacies have been differentiated and are described. Most of these are of dolosparitic nature, others are dolomicritic. Furthermore, calcitic onco—, oo— and bio-sparites are also encountered during the present investigation. Based on facies-analysis the rock sequence is subdivided into different facies units. Paleoenvironments are interpreted as shallow marine to interidal.*

INTRODUCTION

A collaborated research programme between the Institute of Geology of the Punjab University and that of the Ruhr-University was initiated in winter 1983-1984 to investigate facies of the Lower Mesozoic (Triassic and Jurassic) and Permian Strata of the Salt Range and Trans-Indus Range of Kohat/Potwar-province. Some of the results of this research have been presented in the First Pakistan Geological Congress by the present authors (MENSINK *et al.*, 1985). The purpose of this paper is to determine the microfacies of the Kingriali Formation exposed in the Nammal Gorge and in Gulakhel area of the Punjab. The Nammal Gorge and the Gulakhel area are located at lat. 32° 40′N, long. 71°48′E and lat. 32° 58′N, long. 71° 12′E respectively on Topo sheet No. 38 P Mianwali, first edition, scale 1 : 250.000.

Kingriali Formation is the youngest of the Musakhel Group which has been divided into three formations, namely, from bottom to top, the Mianwali-, Tredian- and Kingriali-Formation (Shah, 1980). The type locality is at Kingriali Peak (lat. 32° 14′N, long. 71° 02′E). In Khisor Range, District Dera Ismail Khan, N.W.F.P. from which the name Kingriali is derived.

Wynne (1878) was the first geologist to work on this rock unit, he described the Triassic sequence as "Triassic Ceratite Group" and "Pseudomorphic Salt Crystal Zone". Waagen (1892) found at least seven different units within the Triassic : a basal "Ceratite Group" with four distinct parts, a "Bivalve Limestone", a "Dolomatic Group" and a "Topmost Limestone". Gee (1945) made a detailed study of the Triassic and named the topmost cliff-forming rocks as the "Kingriali Dolomite". Finally Fatmi (1973) formalized the name as "Kingriali-Formation". Ashraf (1977) described geology and mineral composition of Kingriali-Formation exposed near Chichali Nala. He made an attempt to subdivide it into seven lithological units of dolomitic and sandy dolomitic nature displaying various colours. Some oolitic structures are also observed. The author expressed the opinion that these dolomites developed in a late diagenetical period.

The age of the Musakhel Group has been described as Triassic. The Kingriali-Formation is doubtfully assigned to a late Triassic age.

The contact with the underlying Tredian Formation is transitional. Its contact with the overlying Datta-Formation of Surghar Group is discontinuous because in particular areas parts of the Kingriali-Formation are not exposed (Fatmi, 1973 ; Shah, 1977, 1980).

DESCRIPTION OF MICROFACIES

The Kingriali-Formation is mainly composed of dolomitic and calcitic rocks interbedded with minor clastic, sandy material. Our measured sections are shown in figure 1. Microfacies-analysis is based on 60 thin sections prepared from 80 rock-samples. The distribution of the analysed samples is also shown in figure 1. Analysis follows the methods of quantitative and qualitative description of ground-mass and components proposed by Flugel (1982). Scale of crystal size is adopted from Folk (1959, in Flugel, 1982). Percentage is estimated with the help of comparison charts from BACELLE & BOSSELINI (1965, in FLUGEL, 1982). Classification of microfacies follows that of FOLK (1959, 1962 in FLUGEL, 1982).

Eleven microfacies-types have been differentiated. In the text NG stands for Nammal Gorge GK indicates Gulakhel.

1. **Dolosparite-Facies (Fig. 2.1)**

Samples : NG 1, 11, 12, 15, 17, 19 ;
GK 1, 2, 25, 32, 33, 36, 37, 38, 39, 40

This facies is composed of white to yellow or pinkish dolosparites which are usually thick bedded sediments. They are composed of 90-100% of sub- to euthedral dolomite crystals. These are finely to coarsely crystalline material which are in every case more than 20 *μm* in size. Texture is mostly hypidiotopic to idiotopic with equant dimension crystals. Non equant crysals are rare. Textures of these are porphyrotopic or poikilotopic. Components show maximum percentage of 10% of the total material. Quartzsilt alone is 5% while accessories such as feldspar, pyrite, echinoderms and shells are 5% of the total components. Intraclasts are notable in sample NG 19.

2. **Sandy Dolosparite to Dolomitic Sandstone-Facies (Fig. 2.2)**

Samples : NG 2, 3
GK 4, 6

Characteristic feature of this microfacies is the high percentage of clastic components. Detrital, angular to subangular quartzgrains range in size from 50 to 500 μm and the percentage varies from 15 to 70%, however in most cases more than 35% are observed. Plagioclase are more than 5%. Other accessories which form 5% of the total material are pyrites, micaceous minerals, intraclasts and echinoderms. Groundmass is composed of dolosparite. Crystals are of subhedrals shape which range in size from 35 to 50' μ m. In certain cases crystals bigger than 50 μ m occur and show porphyrotopic textures.

3. **Sandy, Bioclastic Dolosparite-Facies (Fig. 3.1)**

Samples : NG 4, 5
GK 20

In sample GK 20, groundmass is of equant dimension, 30 μm is crystal-size and crystal shape is subhedral. In the samples from Nammal Gorge crystal-size is differentiated into two dimensions, about 100 μm and about 250, μ m, these latter ones are porphyrotopic grown. Detrital quartz is angular to subangular which range in size from 50 to 750 μm, percentage range between to 10 to 20%. Bioclasts are mainly echinoderms, 10 to 20%, and some shells are also present and others are a few grains of feldspar and pyrite.

4. **Bioclastic Dolosparite Facies (Fig. 2.3)**

Samples : NG 7, 8, 18, 14
GK 8, 21, 22, 23, 24, 35

In this facies echinoderms are the only preserved bioclastic components ; percentage range between 10 to 30%. Quartz may be present as detrital grains up to 5%. Groundmass is dolosparite of subhedral crystals about 50 to 250 μm in size.

5. **Peloidal Dolomicrite Facies (Fig. 2.5)**

Samples : NG 23
GK 41, 42

Micritic dolomitic matrix contain well sorted, rounded to oval pellets which are equally distributed up to 30%. Intraclasts of micrite quartz-grains and echinoderms are encountered each up to 1%.

6. **Dolomicrite Facies (Fig. 2.4)**

Samples : NG 9, 21, 22, 24
GK 19, 26, 28, 29, 30, 31, 43, 44, 45, 46, 47.

This dolomicrite is composed of 90 to 100% dolomicritic crystals. Crystal size of finer layers is less than 10 μm those of the coarse layers which are up to 20 μm in size.

Rounded quartzsilt-grains and angular echinoderms up to 1mm in dimension are evenly distributed at the base of the coarse layers.

Sometimes birds-eye structures, mud-cracks, pseudomorphs after gypsum, irregular wavy laminations and laminations of algal origin are observed.

7. **Intrcalastic Dolomicritic Facies (Fig. 2.6)**

Samples : NG 18, 20, 24

The groundmass is finely crystalline and dolomitic. The intraclasts which are the characteristic components of this facies-type are of weathered white colour, rounded or angular, irregularly distributed, up to 2 mm in size and consist of finer material than the surrounding groundmass. There is no sign of coating, even relict structures of bioclasts are not observed. Quartz grains and well-preserved echinoderms are present with each 1% of total components.

8. **Oncolitic Biosparite Facies (Fig. 3.2)**

Samples : GK 9, 11

Oncoids of irregular shape, up to 2cm in size are the most important competent of this facies, which range from 20 to 30% of the total material. Foraminifera and algae are supposed to participate in the formations of the coatings of the oncoids. Accessory bioclasts encountered are echinoderms (10-15%), gastropods (up to 5%), foraminifers (up to 1%) and dasycladaceen algae (up to 1%). Some components are bioclasts surrounded by micritic envelops (10-15%). In between all these components there are some irregular areas of micrite which are probably associated with further algae. Groundmass is a calcisparite of subhedral crystals with maximum sizes about 50 μm.

9. **Biomicrite to Pelbiomicrite Facies (Fig. 3.3)**

Samples : GK 12, 18

In this facies following bioclasts have been observed :

echinoderms (5%), gastropods (1%), and shells of ostracods (5 to 10%). Beside these pellets are also found up to 20%. In the sample GK 18 the main faunistic content are shells of pelecypods. Groundmass is a calcitic micrite with scattered dolomite rhomboeders.

10. **Oolitic Biosparite Facies (Fig. 3,4,5)**

Samples : GK 14, 17

The most importants are 10 to 25% well sorted, single, normal ooids with radial structures. Accessory are micritic ooids which are up to 10%. These were formed due to total micritization of the above-mentioned calcareous ooids.

Intraclasts and coated grains are distributed up to 5%, echinoderms up to 10 to 15% and sheels of pelecypods as well as gastropods up to 5% together. Groundmass is a calctic sparite.

11. **Biosparite Facies (Fig. 3.6)**

Samples : GK 13, 15, 16

It is an echinodermal limestone with up to 40% of such bioclasts. These are 1mm to 1cm in size. Shells of pelecypods and gastropods, oncoids, coated grains, ooids and pellets may reach 20% of the total material.

Groundmass is a sparite which build a drusy mosaic between the components. On the other hand the echinoderms are surrounded by a syntaxial rim cement.

CONCLUSION

The different types of microfacies described in the preceding chapter are intercalating each other in both sections. They have been assorted into distinct facies units. In Gulakhel area four major facies units of dolomite and limestone are identified (fig. 1). In Nammal Gorge only three such facies units are observed. It is of interest to note that unlike the Gulakhel in this exposure the "Limestone Interval" can't be recognized. In the following part the different facies units are discussed in order of their superposition.

1. Clastic Dolomite Unit

In the Nammal Gorge and in the Gulakhel area inter-calations of "Dolosparite", "Sandy Dolosparites", "Sandy Bioclastic Dolosparite-" and "Bioclastic Dolosparite Facies" are frequently observed. This unit is the transitional zone in between the Tredian-Formation and the higher part of the carbonaceous Kingriali-Formation. In this part dolomitization happened late diagenetically. Rocks were deposited in shallow marine environment. Clastic influence indicates nearby exposed source areas and, therefore, shore-line was not very far away.

2. Limestone Interval

This facies unit is investigated only in the Gulakhel area. It is composed of four facies units namely the "Oncolitic Biosparite-", "Biomicrite"—"Oolitic Biosparite-" and "Biosparite Facies".

Facies No. 8 is observed at the bottom of this unit indicating a very shallow marine, near shore environment with moderately agitated water. The overlying biomicrite developed in a more restricted bay with calm water conditions. This is strengthened by the presence of ostracods, gastropods and a lot of pellets.

Facies changed to highly agitated water during the time of deposition of the oolitic and bioclastic sediments. But it remained shallow marine and near shore. The "Limestone Interval" ended with the sedimentation of biomicrites again in an restricted bay environment.

3. Dolosparite Unit

The thickest unit of the Kingriali-Formation (fig. 1) consists mainly of dolosparites and bioclastic dolosparites. Recrystallisation took place late diagenetically. Sedimentation happened probably in a shallow marine environment as indicated by the preserved bioclasts. Thin layers of biomicrite are interbedded in this unit (fig. 1). Whether they may be interpreted as intervenent changes to restricted hypersaline conditions and, therefore, even indicate an earlier dolomite-crystallisation is not clear.

4. Dolomicrite Unit

The dolomicrite unit build up the uppermost part of the sequences in both sections and consist of dolomicrites and peloidal dolomicrites. These were deposited in restricted calm waters in an extremely shallow environment for example in bays or ponds of tidal flat areas. In Nammal Gorge the presence of mudcracks, birdseyes, reworked intraclasts, algal laminations support this interpretation. GK 47 contains high amount of clay probably indicating a lacustrine environment.

It can be concluded that most of the sediments were formed in a shallow marine sea on a carbonate platform. Clastic input is only important in the basal meters of the Kingriali-Formation. In the higher parts of the measured sections the environment changes from shallow marine to tidal flat conditions with intervenant drying of the carbonate shore.

ACKNOWLEDGMENTS

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Fig. 1

Measured sections of the Gula Khel and Nammal Gorge, showing Lithostratigraphical sequences, position of samples and concerned microfacies together with proposed microfacies divisions.

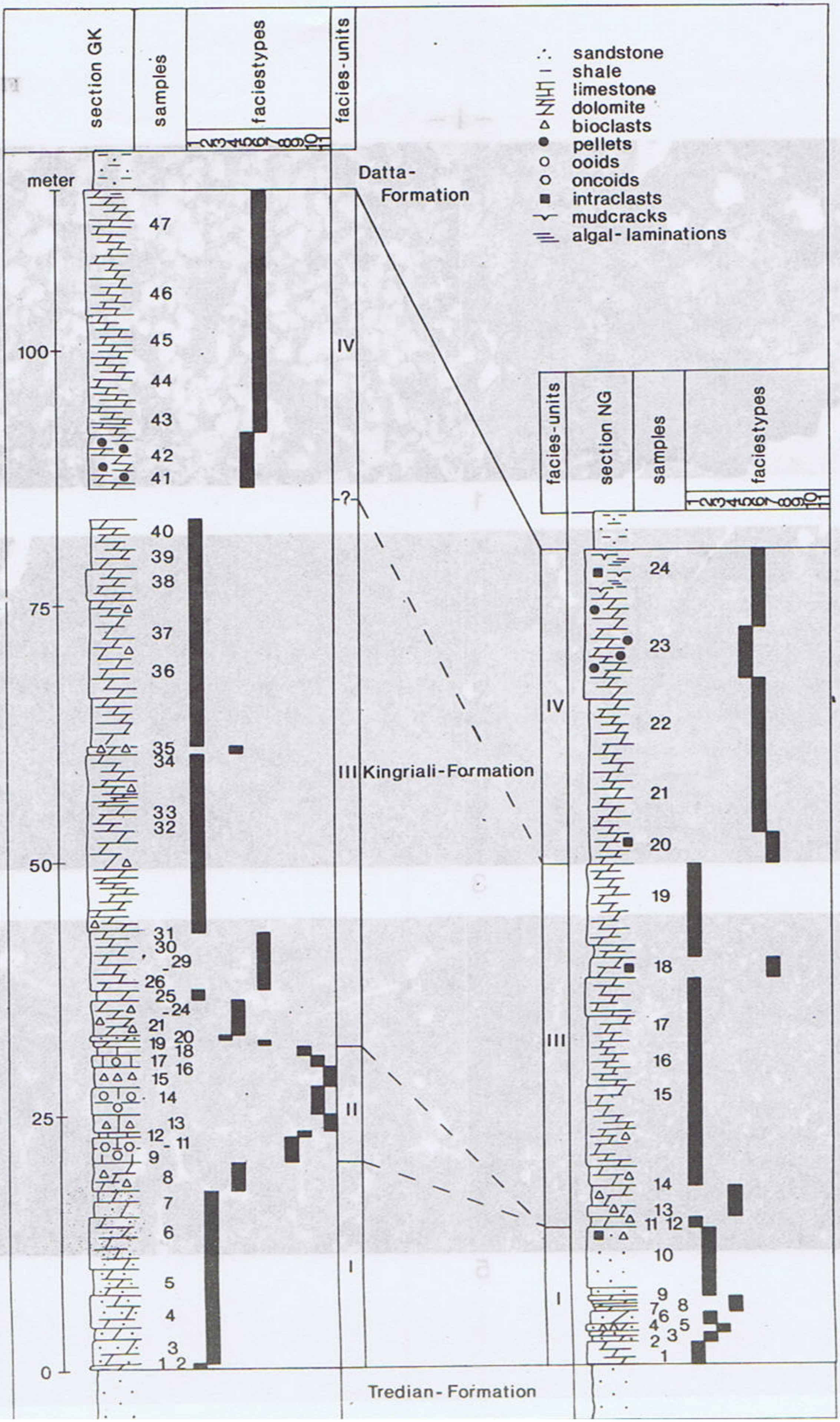
Fig. 2

1. Dolosparite-Facies (Sample NG 12 ; X2, 5).
2. Sandy Dolosparite to Dolomitic Sandstone-Facies Sample GK 4 ; X2, 5).
3. Bioclastic Dolosparite-Facies (Sample NG 7 ; X2, 5).
4. Dolomicrite-Facies (Sample NG 24 ; X10).
5. Peloidal Dolomicrite-Facies (Sample NG 23 ; X10)
6. Intraclastic Dolomicrite-Facies (Sample NG 18 ; X2,5).

Fig. 3

1. Sandy, Bioclastic Dolosparite-Facies (Sample NG 4 ; X2, 5).
2. Oncolitic Biosparite-Facies (Sample GK 11 ; X2, 5).
3. Biomicrite to Pelbiomicrite-Facies (Sample GK 15, X2, 5).
4. Oolitic Biosparite-Facies (Sample GK 17 ; X2, 5).
5. Oolitic Biosparite-Facies (Sample GK 17 ; X10).
6. Biosparite-Facies (Sample GK, 13 ; X2, 5).

FIG 1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samples
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1 2 3 4 5 6 7 8 9 10 11
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Datta-Formation
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sandstone
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FIG 2

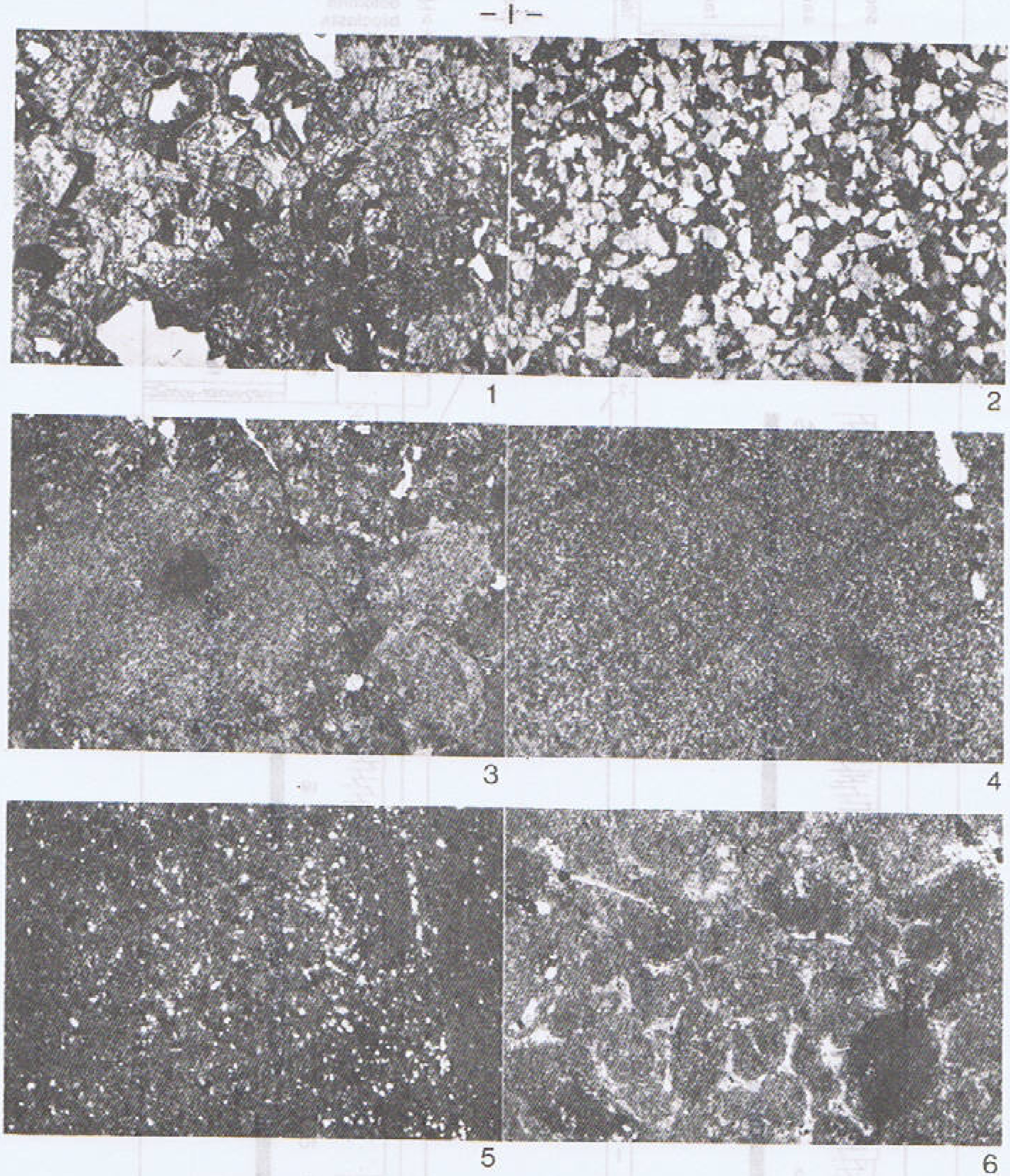
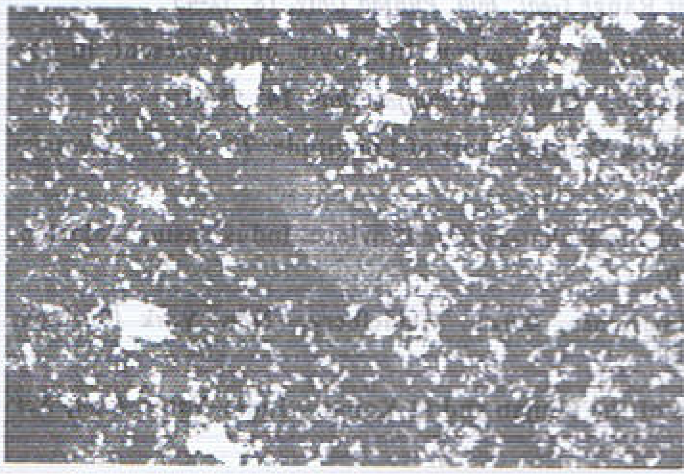


FIG 3



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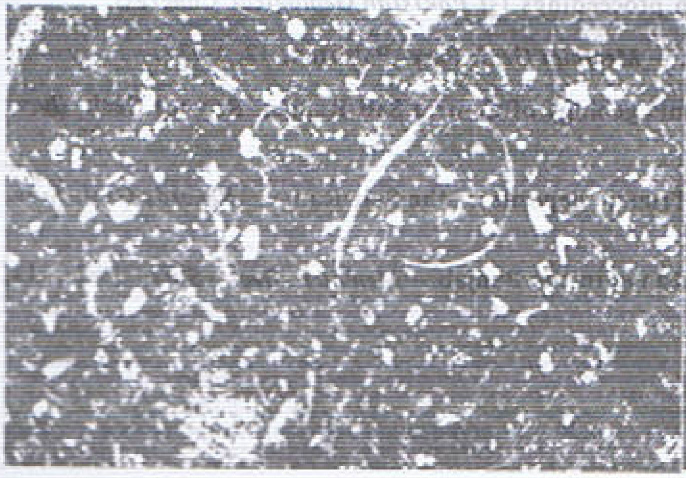

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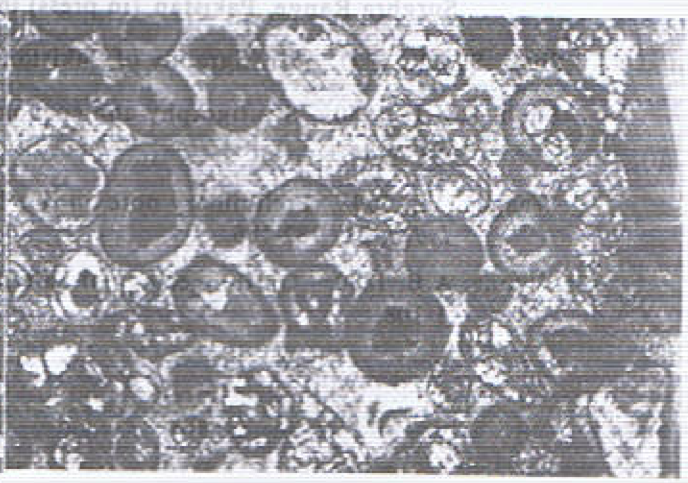

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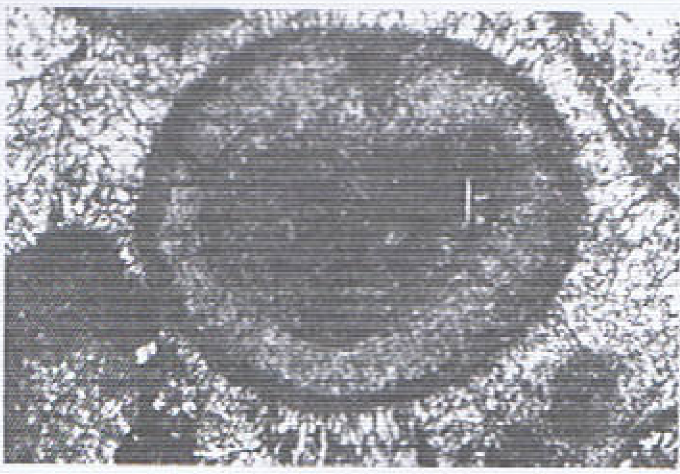

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REFERENCES

Akhtar, M., 1983. Stratigraphy of the Surgher Range *Geol. Bull. Punjab Univ.* 18, 32-45 ;

Ashraf, M., 1977. Geology and mineral composition of various lithologic units present in the Kingriali-Formation of the Surghar Range. *Geol. Bull. Punjab Univ.* 14, 55-61.

Cotter, G. de P., 1933. The geology of the Attock District, West of Longitude 72° 45′ E. *Memoirs Geol. Surv. India*, 55, 63-161.

Fatmi, A.N., 1973. Lithostratigraphic units of the Kohat-Potwar Province, Indus Basin, Pakistan. *Memoirs Geol. Surv. Pakistan*, 10, 1-80.

Flugel, H., 1982. Microfacies Analysis of Limestones, Berlin, Heidelberg, New York (Springer Verlag)

Gee, E. R., 1945. The age of the saline series of the Punjab and of Kohat.—India *Natl. Acad, Sci· Proc.* Sec. B, 14, 269-310.

Mensink, H. ; Mertmann, D. ; Sarfraz ; A. & Shams, F.A. 1985. Facies of Jurassio rocks in the Surghra Range, Pakistan (in press) in proceedings 1*st Pakistan Geological Congress.*

Shah, S.M.I., 1977. Stratigraphy of Pakistan.—*Memoirs Geol. Surv. Pakistan*, 12, 1-138.

Shah, S.M.I., 1980. Stratigraphy and economic geology of Central Salt Range. *Records Geol. Surv. Pakistan*, 52, 1-104.

Waagen, W., 1892. Preliminary note on the Triassic deposits of the Salt Range. *Records Geol. Surv. India*, 25, 182-186.

Wynne, A.B. 1880. On the geology of Salt Range in the Punjab. *Memoirs Geol. Surv. India*, 14, 1-108.

CLAY MINERALOGY OF SOME THIN COVER SOILS OF PUNJAB AND THEIR BEARING ON ENGINEERING PROPERTIES

BY

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Abstract : *Clay mineralogical studies conducted on Soil Samples from the Jhelum area (Punjab) have shown that the soils contain swelling montmorillonite in addition to other clay and non-clay minerals. The presence of this species in the foundation of a building could cause serious engineering problems.*

INTRODUCTION

A recent field survey of some places in Punjab has shown that building structures tend to develop cracks. This problem arises due to little attention being paid to engineering consequences of the changes that may occur in the soil below or in the vicinity of the foundations of building structures.

The present study has been conducted in order to relate the clay mineralogy of soils to engineering problems selecting Jhelum area due to shallow depth of the bedrock undersoil. Besides traditional petrography, detailed XRD studies were made and implications of the mineral composition are stated.

EXPERIMENTAL

Fifteen samples were collected from different parts of the Jhelum area in the Punjab (Table 1). The following studies were conducted on the samples.

Optical microscopy studies were conducted in order to visually detect clay and not-clay minerals in the soil samples (Table 2).

Measurements

pH measurements were made with pH meter taking about 10 gms. of $CaCl_2$ sample dispersed in 0.01 M $CaCl_2$ solution. The suspension was stirred occasionally upto 30 minutes and was later allowed to stay undisturbed for further 30 minutes. During the latter period, fine soil particles settled down. The pH measurements were conducted on the solution. The results are given in Table 3.

Sample Preparation and Data Acquisition for X-Ray Diffraction Analysis

The samples were air-dried in the laboratory and lightly crushed to pass through a 2 mm seive. These samples were then pulverized in an agate mortar so that the grain size was less than 10 μm. We adopted this way of sample preparation because we were interested in studying the mineralogy of these soil samples. However, one of the samples (No. 4) was purified in the following way. About 50 gms. of the sample passed through 2 mm seive was dispersed in deionized distilled water and was shaken manually for several hours. After sedimentation for about 8 hours, the $< 2\ \mu$m. fraction was repeatedly siphoned from the top 10 cm of the suspension. Clay/water suspension was then dried for analysis by X-Ray Diffraction.

For qualitative analysis by X-Ray Diffraction, about 15 g of each air-dried sample was treated with warm HCl, subsequently washed in distilled water and dried in a muffle furnace before taking X-Ray diffraction patterns.

A portion of each of samples 1 and 4 was also glycolated before taking X-Ray diffraction patterns. Also a portion of the purified sample 4 was glycolated before X-Ray Diffraction pattern was taken for it. Effect of moisture was studied by soaking sample 1 with water X-Ray pattern for soaked sample was taken just after soaking and when the soaked sample was almost dry.

X-Ray Diffraction patterns for all the original and treated samples were obtained by a Rigaku automated X-Ray diffractometer (Geigerflex, D-Max/II-A) equipped with a scintillation counter, a pulse height analyser, a ratemeter and a recorder. Ni-filered Cuk α radiation was allowed to fall on each sample pressed into appropriate aluminium holders before loading on to the wide-angle goniometer of the X-Ray Diffraction system. The slits used were : Divergence and anti-scatter slits, 1° ; and the receiving slit, 0.3 mm. The gonimeter was run at a scanning speed of 2° (2 θ)/min and the ratemeter time constant was 1 sec. X-Ray diffraction patterns were obtained for the 2 θ range of 3.5° to 40°.

The X-Ray diffraction patterns were analysed by the Hanawalt method. (Bayliss et al 1980)

RESULTS AND DISCUSSION

Lithology

Generally the soil samples look brown, reddish brown or dark brown. Their grains appear coarse on touching. Fine grained material is dominant in the samples with small rounded rock fragments of grit and pebbles size. A visual examination shows presence of plant roots. The samples appear to show irregular fracture with tendency to develop strong plain of breaking. Black grains of small size are also present. Fine to coarse grained clastic texture is evident.

Table 2 summarizes the results of this study. The soil samples are found to contain clay minerals as fine scaly grains varying from 30 to 65 percent. Fine grained quartz, calcite and elongated flakes of muscovite are present inside the aggregates. Calcite with amounts varying from 22 to 54 percent is present as fine-grained aggregates showing no cleavage or parting Some samples show rounded oolitic form of calcite cemented by fine granular calcite. Amounts of quartz vary between 7 to 22 percent ; fine to medium-sized grains are present with a tiny fraction somewhat rounded. Muscovite (1 to 3 percent) has the scattered flakes with directional cleavage. Iron are is found to vary between 0.5 and 1 percent. Limonite is rarely present.

pH Measurements

pH of the soil samples is given in Table 3. When pH is about 8, the solubility of SiO_2 increases considerably. Al_2O_3 is practically insoluble under such conditions. Therefore SiO_2 is removed in the solution as solvent whereas the hydrated Al_2O_3 will precipitate. If pH is between 8 and 9 of alkaline solution that means much more SiO_2 is present. This promotes the formation of montmorillonite.

X-Ray Diffraction

The soil samples studied are found to contain in variable amounts the clay minerals, kaolinite, illite, montmorillonite and non-clay minerals chlorite, quartz, calcite and albite. X-Ray diffraction patterns for soil samples 1 and 4 are given in Figure 1 and Figure 2 respectively. Table 4 shows details of various sample treatments. Figure 3 shows X-Ray diffraction patterns for samples 1 and 4 which were not treated with warm HCl before glycerolation and glycolation. In Figure 4 are given the diffraction patterns for purified and subsequently glycolated sample 4.

Qualitative analysis by the Hanawalt method of the diffraction patterns in Figures 1—4 is described below.

Figures 1, 2, 3 and 4 clearly show that illite (characteristic peaks : 10 A°, 5 A° and 3.34 A°) is present in all the soil samples. In the diffraction patterns of the treated samples (Figs. 1 and 2), intensity of illite reflections (for example peaks with d=10 A° and d=5.02 A°) have enhanced. Such enhancement is not evident in Figures 3 and 4. Enhancement of intensity of illite reflections in Figures 1 and 2 is probably due to the fact that, after HCl treatment and subsequent washing by deionized distilled water, the proportion of illite in the treated samples is more than in the original samples. More intensity in the illite reflections, Figures 1 (E) and 2 (E), as compared to Figures 1 (B,C,D) and 2 (B.C.D) is because of the heat treatment (at 600 °C).

Presence of chlorite (characteristic reflections : 14A°, 7.07A° and 4.72A°) and calcite (characteristic reflections : 3.03A° and 2.28A°) is clearly evident from the comparison of Figures 1 (A) and 1 (B) and Figures 2 (A) and 2 (B). Since, these minerals are dissolved in warm HCl their reflections do not appear in Figures 1 (B) and 2 (B).

Examination of Figures 1 (A) and 2 (A) shows that the clay minerals which could be present in the soil samples are kaolinite (charcteristic reflections: 7.17A° and 3.5 A°), montmorillonite (characteristic reflections:15.0 A°, 4.5 A° and 5.01 A° and vermiculite (characteristic reflections : 14 A°, 4.57 A° and 2.85 A°). Kaolinite may be confused with chlorite if 14 A° reflection of the latter is weak. Figures 1 (B) and 2 (B) show that digestion of chlorite by warm HCl leaves behind a tiny peak, which could be of kaolinite. Heat treatment at 600 °C or above breaks the crystalline structure of kaolinite (Avery and Bullock 1977). Presence of the latter is then confirmed (Figures 1 (E) and 2 (E).

In order to know whether montmorrillonite was present, the soil samples, previously treated with warm HCl, were treated with glycerine and ethylene glycol. (Grim 1968 and Cowking et al 1983). The intensity of the 14 A° reflection is decreased but shifting to the lower angle side is not quite evident on glycerolation (Figures 1 (C) and 2 (C)). Glycolated sample, however, do show a peak at about 17 A° (Figures, 1 (D) and 2 (D)). This reflection disappears on heat treatment of glycolated samples at 600 °C (Figures, 1 (E) and 2 (E)). This shows that montmorillonite may be present in the soil samples studied.

In order to confirm the presence of montmorillonite, original soil samples 1 and 4, as mentioned in the previous section, were glycolated without any treatment with warm HCl. The purified sample was also given the glycerol treatment. Figures 3 and 4 clearly show partial shifting of the 14 A° reflection. The 17 A° reflection in Figures 1 (A), 1 (B) and 2 and the 18 A° reflection in Figures 1 (C) and 1 (D) are definitely due to montmorillonite and the 14 A° reflection left behind represents chlorite whose presence has already been confirmed. Presence of montmorillonite is therefore confirmed.

Presence of vermiculite as a constituent of the soils studied is not evident from Figures 1 (B-E) and 2 (B-E). The 14 A° reflection in these figures almost shifts to either 17 A° (or 18 A°) or disappears depending on the nature of treatment.

A visual examination of Figure 1 and 2 shows that chlorite and illite are the major clay minerals present in the soils studied. Next to these are montmorillonite and kaolinite. In non-clay minerals, quartz is the major constituent whereas calcite and albite are minor phases. Figuer 5 shows the diffraction patterns for sample 1 soaked with distilled deionized water. A is the diffraction pattern for the original air-dried sample, B, for soaked sample and C for the soaked sample almost dried at room temperature. The comparison of the patterns shows that A and C are almost identical whereas B shows shifting of the 14/15 A° peak to about 20 A°. Swelling of the clay obviously due to the montmorillonite content of the sample is evident.

We have seen that both the pH measurements and X-Ray Powder Diffraction analysis of the soil samples have shown the presenoe of montmorillonite. We have observed that the clay mineral montmorillonite swells on treatment with organic matter and water. This finding is of crucial importance. If the foundation of a building structure is laid on a soil bed which contains this species, the latter will present hazarads on absorbing water.

For the buildings, source of water could be rainfall, or it could be underground water. In case of dam the course obviously is the dam reservoir. On absorbing water, the soil (containing montmorillonite) should swell, expand and then transmit a tremendous force to the foundation, thus causing damage to the building/dams.

CONCLUSION

The present study reveals that the presence of swelling motmorillonite is evident alongwith other clay and non-clay minerals. This clay absorb water, swells and could consequently put a tremendous pressure on the foundation. The building should not be errected before curing for the consequences of the presence of montmorillonite.

TABE 1

Soils collected from Jhelum Area

Station	Sample No.	Depth (m)
	1	0.6
I	2	1.2
	3	1.8
	4	0.6
II	5	1.2
	6	1.8
	7	0.6
III	8	1.2
	9	1.8
	10	0.6
IV	11	1.2
	12	1.8
	13	0.6
V	14	1.2
	15	1.8

TABLE 2

Lithological Studies

(per cent quantities)

Sample No.	Clays	Calcite	Quartz	Muscovite	Ore
1	55	30	14	10	—
2	30	50	18	1.50	0.50
3	39	50	10	1·0	—
4	45	41	10	2·0	—
5	50	45	20	1.0	—
6	45	40	16	1.0	—
7	42	40	15	3	—
8	50	35	10	5	—
9	50	36	12	1	1
10	45	38	12	2	—
11	49	40	10	1	—
12	35	54	8	1	1
13	65	22	7	1	—
14	40	50	8	1	1
15	56	34	9	1	—
Average :	(30—65)	(22—54)	(7—22)	(1—3)	(0.5—1)

TABLE 3

pH Measurements

No.	Depth (m)	Station				
		1	2	3	4	5
1	0.6	7.84	7.78	7.88	8.18	7.90
2	1.2	7.88	7.72	7.80	7.20	7.97
3	1.8	7.93	7.87	7.88	8.16	8.04

TABLE 4

X-Ray Diffraction Data of Treated Samples

(d-spacing (A°) with per cent relative intensity in brackets)

Clay Minerals	Original air-dried (A)	A Treated with warm HCl (B)	B Treated with Glycerine (C)	B Treated with Glycol (D)	D heated at 600 °C (E)
Kaolinite	7.17 (100) 3.58 (80)	same as for A	same as for A	same as for A	No reflection left
Illite	10.02 (90) 5.02 (50) 3.34 (100)	same as for A	same as for A	sam: as for A	same as for A (collapse of expansible minerals enhances 10 A°)
Chlorite	1.41 (90) 7.07 (100) 3.541 (60) 2.845 (30)	no reflection left	same as for A	same as for A	D do not contain chlorite, no effect noticed
Montmorillonite	15.0 (100)	same as for A	15.0 expands to 18.0	15.0 expands to 17.6	no, 14 A° left all to 10 A°

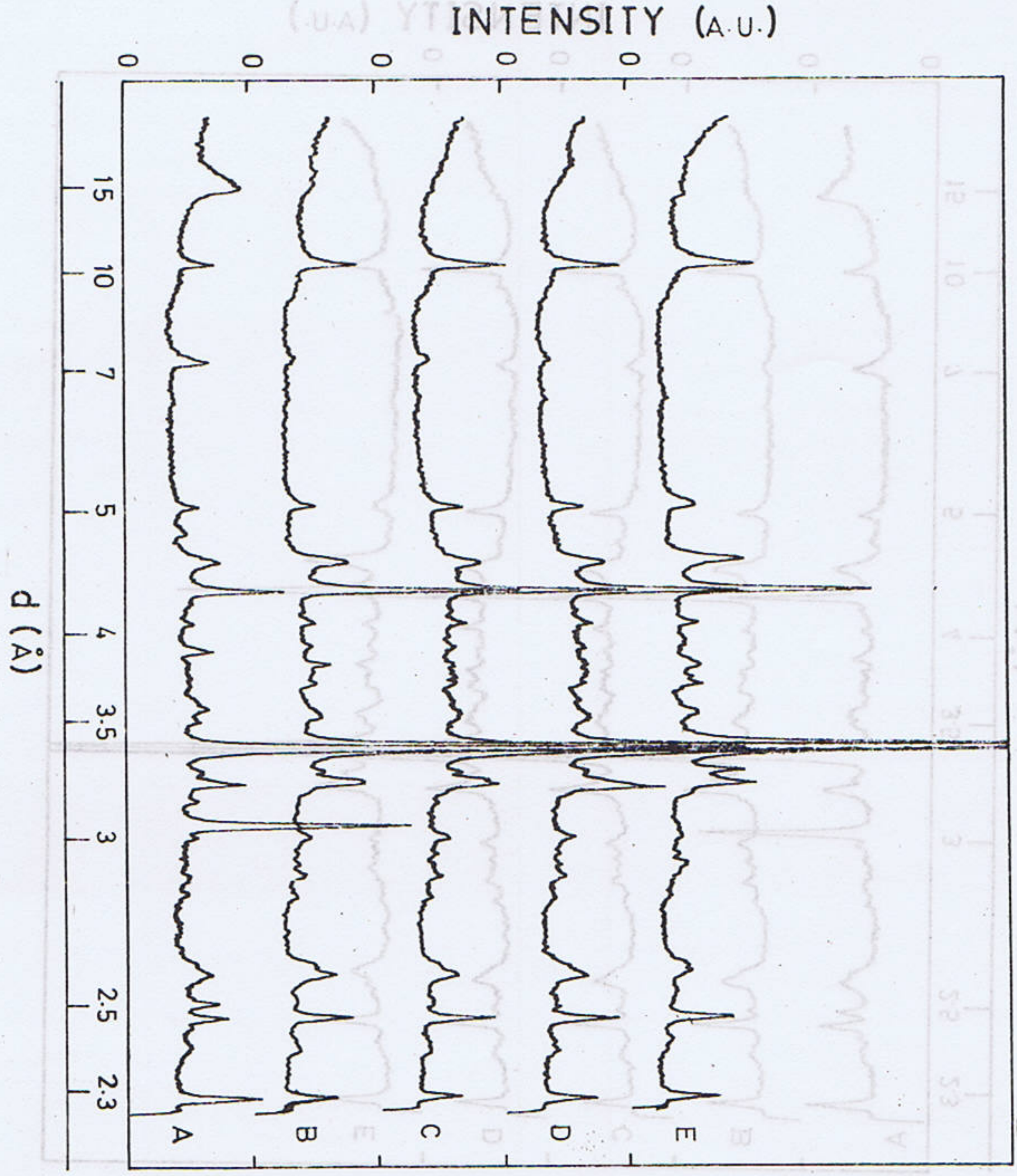


Figure 1.
X-Ray Diffraction Patterns for Soil sample 1. A : Original ari-dried, B : 'A' treated with warm HCl, C ; treated with glycerin, D : 'B' treated with ethylene glyeol, E : 'D' heated at 600 °C.

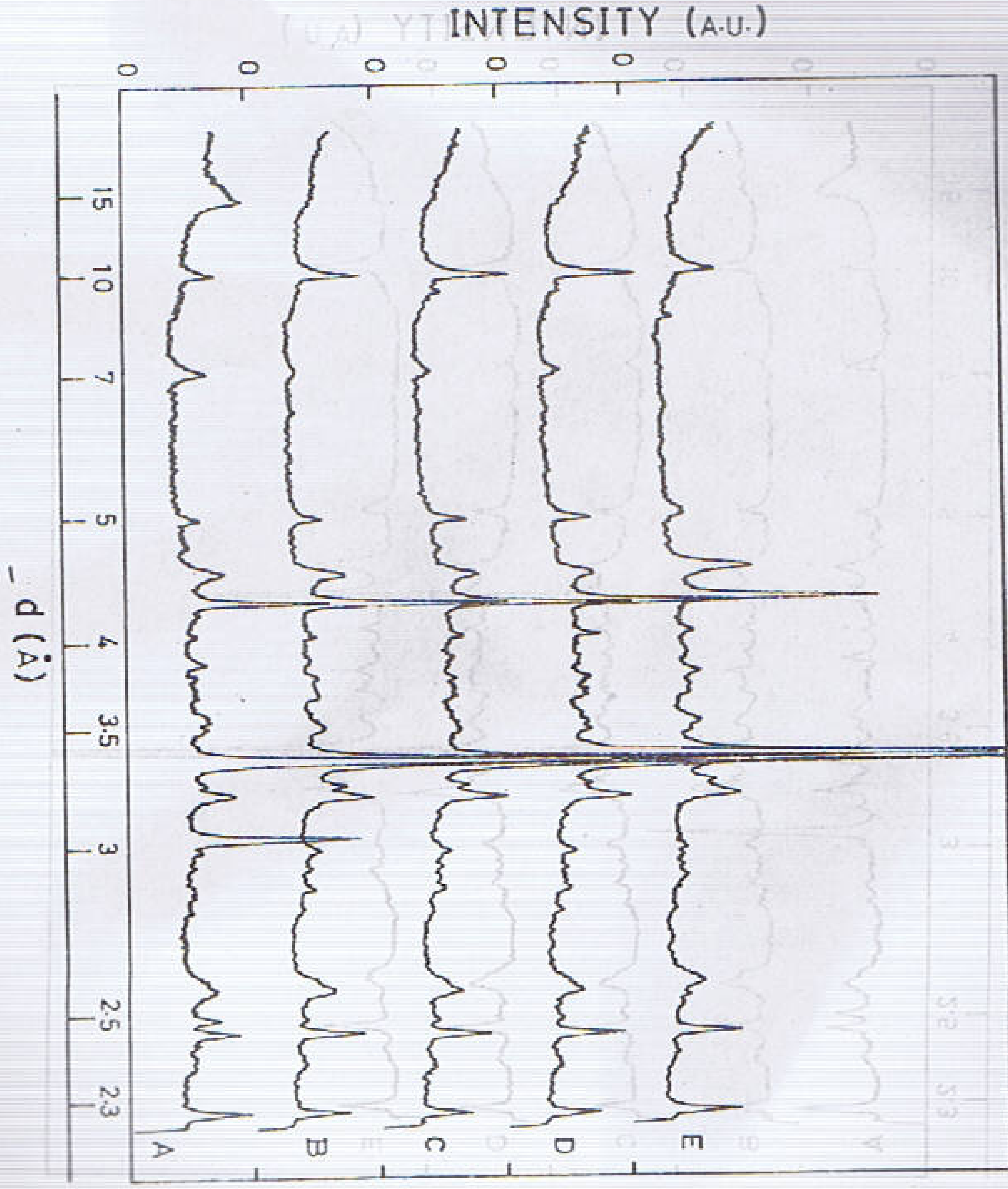


Figure 2.
X-Ray Diffraction Patterns for soil sample 4. A, B, C, D and E mean same as in figure 1.

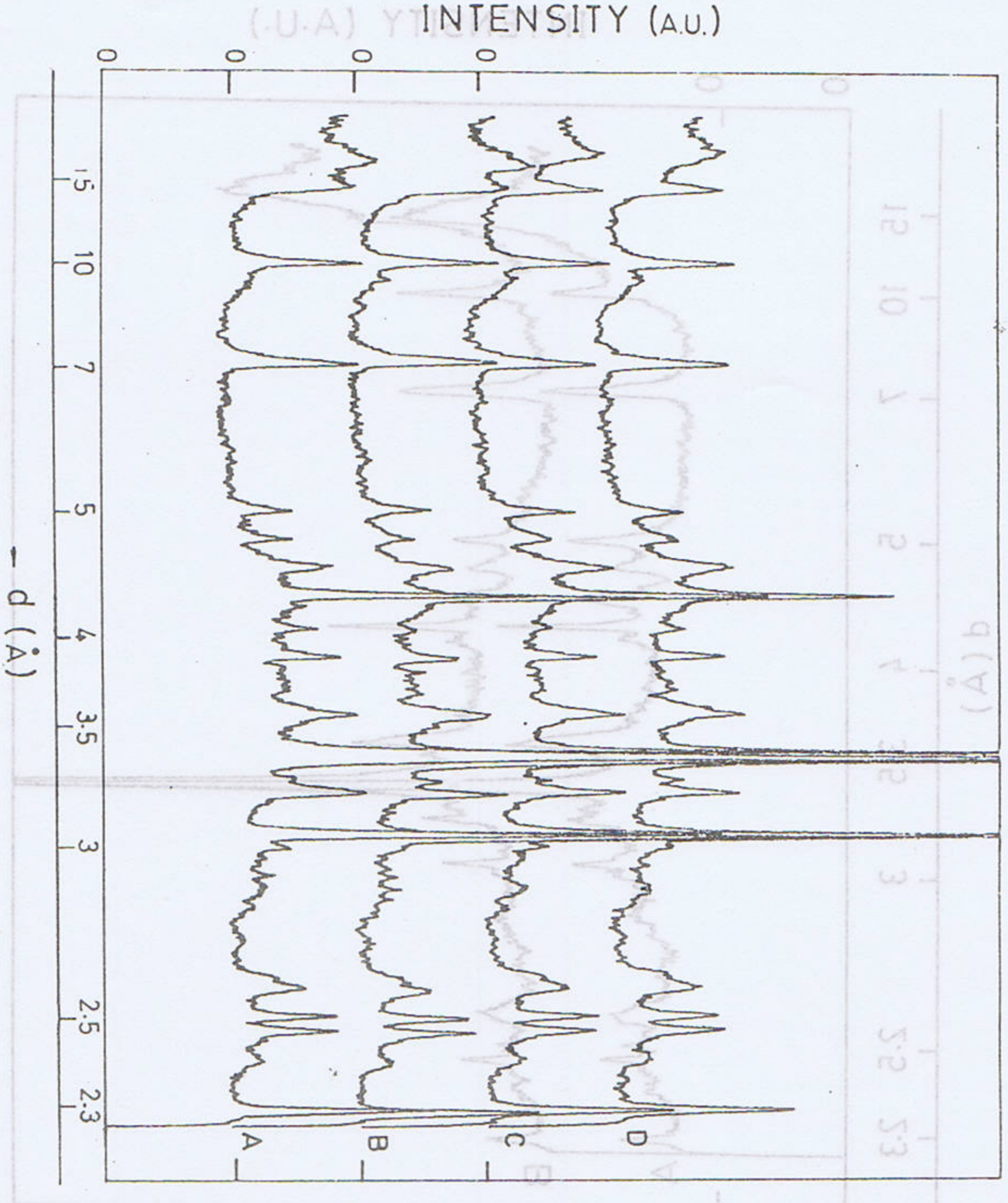


Figure 3.

X-Ray Diffraction Patterns for soil samples 1 and 4. A : original sample 1 glycolated. B : original sample 4 glycolated, C : original sample 1 glaycerolated, D : original sample 4 glycerolated.

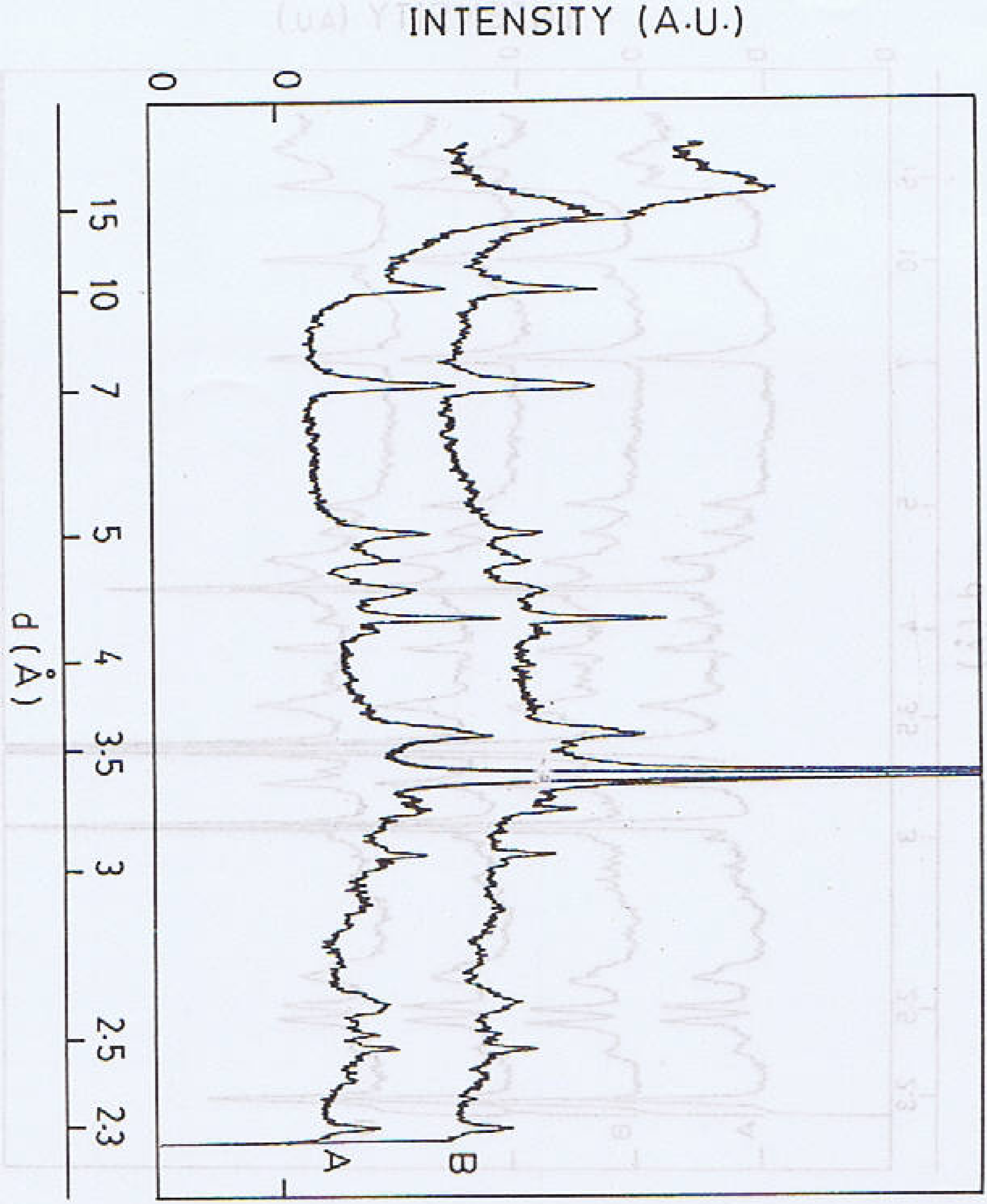


Figure 4.
X-Ray Diffration Patterns for purified soil sample 4. A : Original and B : Glycolated.

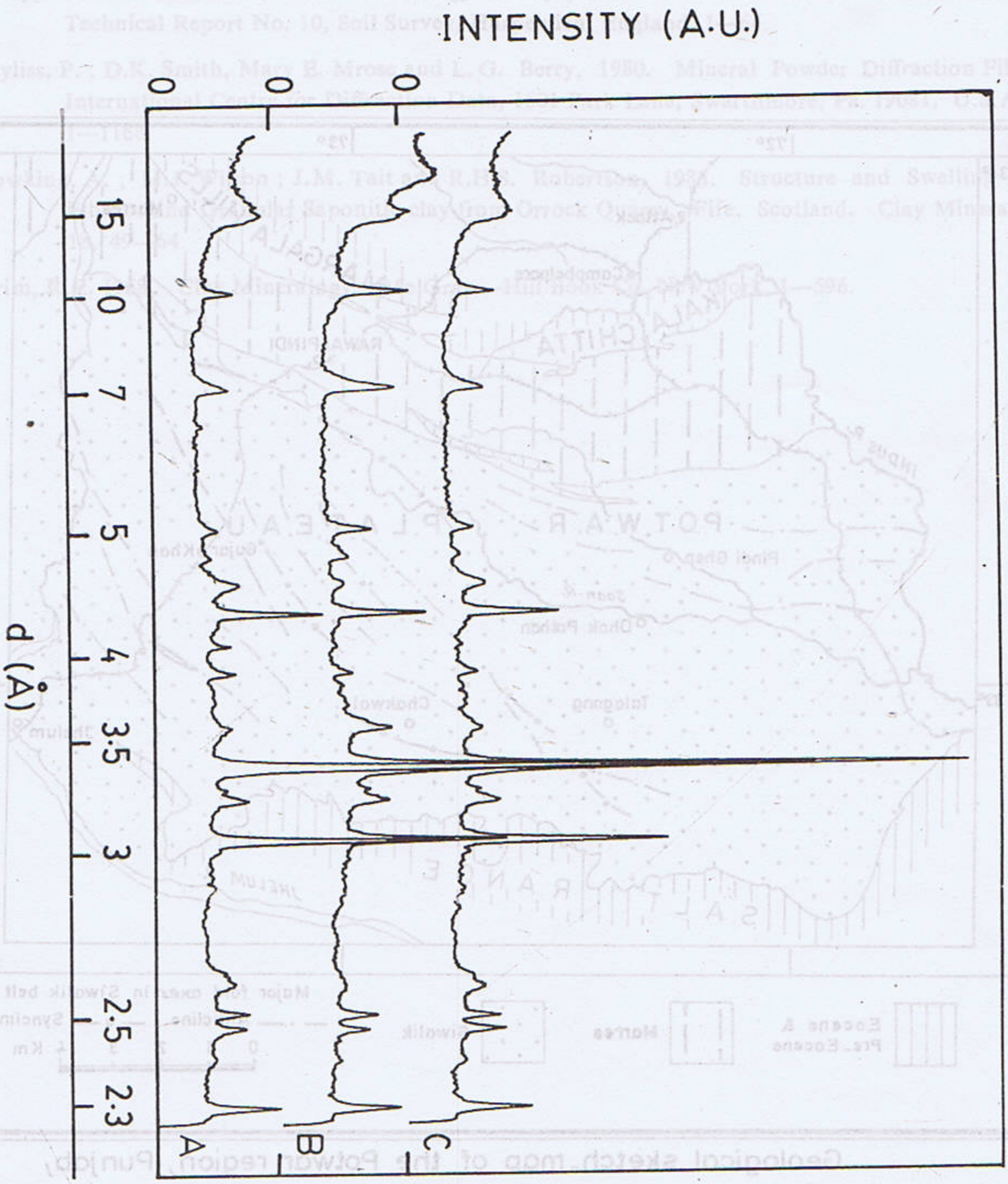
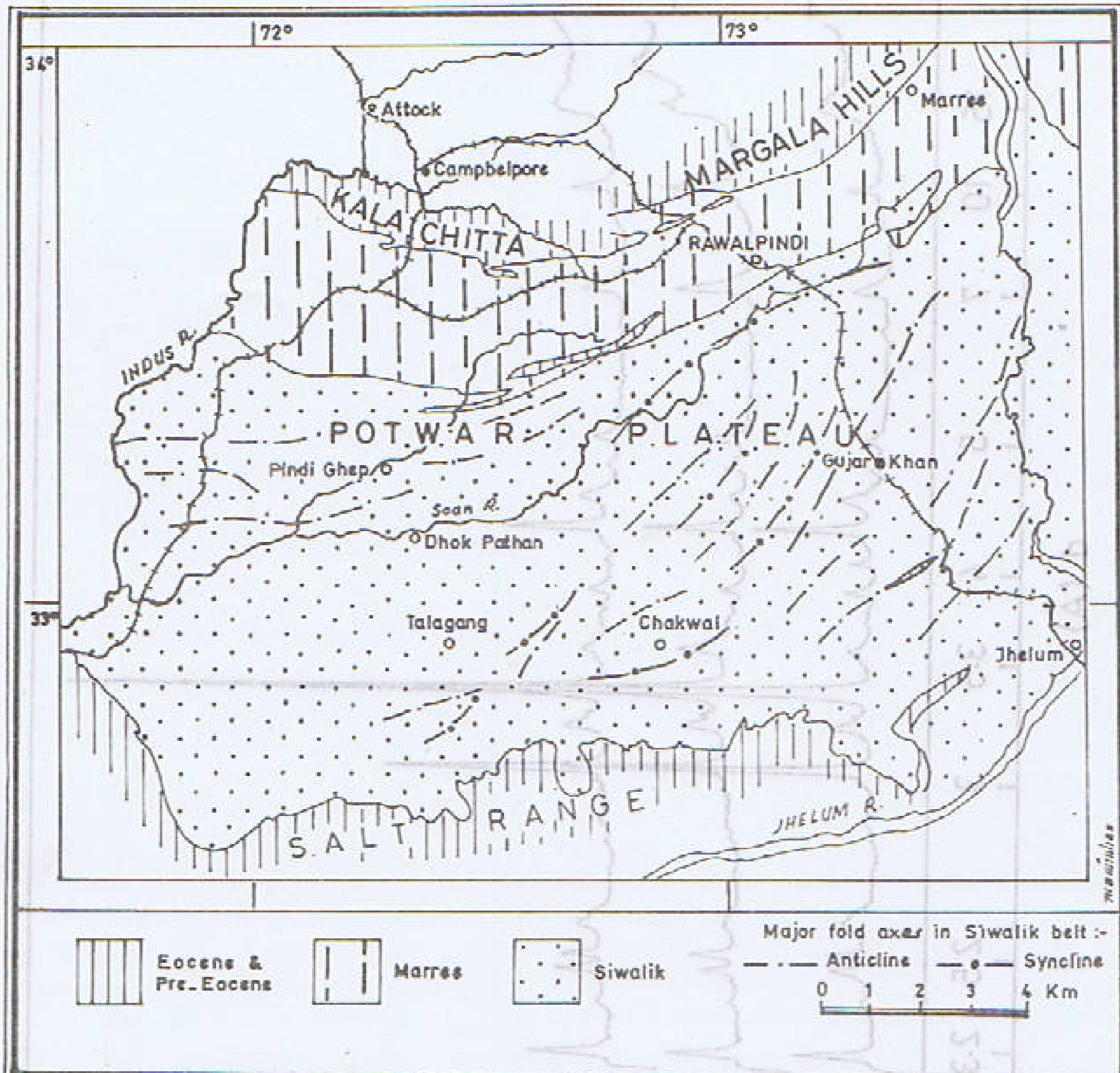


Figure 5.

X-Ray Diffraction pattern for soil sample 1. A : Original airdried, B : Original airdried sample soaked with water, and C : soaked sample subsequently airdried.



Geological sketch_map of the Potwar region, Punjab, PAKISTAN

REFERENCES

Avery, B W. and P. Bullock, 1977. Mineralogy of Clayey Soils in Relation to Soil Classification. Technical Report No. 10, Soil Survey, Harpenden, England, 1—64.

Bayliss, P. ; D.K. Smith, Mary E. Mrose and L. G. Berry, 1980. Mineral Powder Diffraction File, International Centre for Diffraction Data, 1601 Park Lane, Swarthmore, Pa. 19081, U.S.A., 1—1168.

Cowking, A. ; M.J. Wilson ; J.M. Tait and R.H.S. Robertson, 1983. Structure and Swelling of Fibrous and Granular Saponitic clay from Orrock Quarry, Fife, Scotland. Clay Minerals, 18, 49—64.

Grim, R.E. 1968. Clay Mineralogy. Mc Graw—Hill Book Co. New York, 1—596.

PETROLOGY OF DHOK PATHAN FORMATION, SIWALIKS GROUP OF KALABAGH AND MANGLA AREAS

BY

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Abstract : *Six samples of sandstones and two samples of calcareous mudstones from Mangla area and three samples of sandstones, four samples of calcareous mudstones, one sample of arenaceous mudstone and one sample of argillaceous nodular limestone from Kalabagh area were studied petrographically. Some of the samples studied were also subjected to X-Ray diffraction analysis for determining the nature of clay.*

The study shows that these rocks were derived mainly from a rising area of volcanics, sediments and low grade metamorphics. The volcanics were mainly acid to intermediate in composition, the sediments were predominantly cherty limestones with subordinate quartzites, shales and sandstones, while metamorphics were mainly slates, phyllites and low grade schists belonging to lower greenschist facies. Minor contribution from granites is not ruled out.

INTRODUCTION

The Siwalik rocks comprise mainly of argillaceous, arenaceous and rudaceous facies. These rocks are fairly widespread and occur both in Pakistan and India along the Himalayan foothills. In Pakistan these rocks occur along low foothills of Azad Kashmir, in Potwar plateau, Salt range, Surgar range and Suleman range.

The term "Siwalik" was first used by Meddlicot (1864,1868). Oldham (1893) used the "Siwalik Series", while Holland (1913) used the term Siwalik System. The Stratigraphic Committee of Pakistan following Danilchik and Shah (1967) established Siwalik Group. The following formations (Shah, 1977) were recognised i. e. Soan Formation, Dhok Pathan Formation, Nagri Formation and Chinji Formation. The application of the term Siwalik Group has now been extended to cover similar rocks of the Lower Indus Basin. The Soan Formation comprises Tatrot and Pinjor.

THE SIWALIKS OF KALABAGH AND MANGLA

The Siwalik rocks around Mangla damsites fall in the transitional zone between Dhok Pathan and Soan Formation (Tatrot and Pinjor). The rocks become younger towards Mirpur side. However, the samples selected for study belong to the Dhok Pathan Formation. The Siwaliks rocks selected for study from the Kalabagh area have also been collected from the Dhok Pathan Formation.

The lithologies studied in both the areas are predominantly subfeldspathic lithic arenites, lithic arenites, lithic wackes, arenaceous mudstones, and calcareous mudstones. A few argillaceous and often nodular argillaceous limestone bands may also be met with.

PETROGRAPHY

Six samples of sandstone and two samples of calcareous mudstones from Mangla areas and three samples of sandstones and four samples of calcareous mudstones, two samples of arenaceous mudstones and one sample of argillaceous limestone were studied petrographically from the Kalabagh area.

Mangla Area

The Mangla sandstone samples MN4 and MN5 are fine to medium grained and the grains are from subangular to subrounded. Angular and rounded grains are 10.0% and 8.0% respectively. The sample No. MN4 is a lithic wacke. The heavy matrix is composed of finer grains and clay. The binding matter is clay+carbonate+iron oxides. The pore spaces are 10%. The rock fragments are of carbonate, chert, volcanics, metavolcanics, quartzites and phyllite.

The rest of the five samples are lithic arenites. Except the sample MN5, the other samples are coarse grained. In all these samples the grains are mainly from subangular to subrounded. The grains are held together by the following types of suturing.

1. Quartz-calcite
2. Silicate-calcite
3. Quartz-quartz
4. Quartz-silicate
5. Carbonate-carbonate.

In addition there is a small amount of cement+binding matter. It is composed of a variable admixture of calcite, iron oxides and clay. Some secondary pore fillings by calcite also serve to hold the grains. These samples contain from 10 to 20% pores. Some pores have been partially filled with calcite.

These sandstones are immature and contain abundant rock fragments. The fragments are predominantly of immature rocks. The stable fragments are of chert and quartzites/sandstones while the unstable fragments are of volcanics, metavolcanics, carbonate, phyllites, slates and schists (low grade). Because of the abundance of such rock fragments these rocks are lithic-arenites or subfeldspathic lithic arenites (since they contain < 10% clay).

Quartz and rock fragments are the essential components, while calcite, clay, muscovite, biotite, K-feldspar, albite/oligoclase and limonite/haematite, are ubiquitous minor to accessory minerals. Goethite, epidote, tourmaline, garnet and magnetite are accessories which are not ubiquitous.

Kalabagh Area

Three samples of sandstone have been studied from SS2, SS3 and SS4 types of sandstones. SS2 MN1 is the best held while SS4 MN3 is a friable sandstone. The sample SS3 MN2 is intermediate in strength between the two.

Except for their relative strength they are all mineralogically similar in a qualitative sense. However, they differ significantly as regards the nature of cement. They are all fine to medium grained sandstones. While SS2 MN1 and SS3 MN2 are lithic arenites, SS4 MN3 is a subfeldspathic lithic wacke.

The sample SS2 MN1 is fine to medium grained (0.15 to 0.70 mm) and unequigranular. Carbonate is the main cementing matter. The rock is compact and relatively strong. It contains 10% voids.

The sample SS3 MN2 is also fine to medium grained. Voids are about 14%. Although carbonate is the main cement, clay, iron oxides and fine micaceous matter also serve as a weak binding/cementing matter. A few quartz-quartz and quartz-silicate sutures are also present. This sample is less well held than the SS2 MN1 sample. Subrounded to subangular grains (acid to intermediate of low greenschist facies). Presence of low albite, microcline perthite, orthoclase perthite and some dark brown biotite indicates a possible granite source also.

The presence of abundant unstable rock fragments in sandstones and their texture shows that they have formed as a result of relatively short distance transportation.

The X-Ray diffraction study clearly shows that the clay is a complex admixture of illite, kaolinite, montmorillonite and chlorite. Montmorillonite points towards a volcanic source and koalinite indicates a possible granitic source. These indicators support the conclusion derived from the petrographic study of sandstones.

The calcareous and arenaceous mudstones contain clay and silt sized particles. The fine sand grade fragments are subordinate. The calcareous matter is both detrital as well as authigenic. The nodular argillaceous limestones are a result of reconstitution in calcareous mudstones. These sediments were deposited during quiscent periods and alternated with rapid deposition of sandstones.

The Dhok Pathan Formation was derived from a rapidly rising source area composed mainly of 1) Sedimentary rocks like cherty limestones, quartzites, sandstones, quartz siltstones and possibly shales (2) Low grade metamophics like slates, phyllites, green schists of mainly lower greenschist facies. Some contribution from upper greenschists facies in the Kalabagh area is indicated by the presence of small quantities of almandine garnet (3) Igneous rocks, maily volcanics and metavolcanics of acid to intermediate composition (arc-type) and possibly some granites.

These rocks have most probably been derived from the upper and upper middle parts of the rising arc zones of Himalayas.

(for Mangla) and Hindukush (for Kalbagh) and rock fragments are accessory to minor constituents.

Optical tests indicated the clay minerals to be admixtures of illite and kaolinite with very small (probably ≤ 4 0%) amounts of smectite.

X-RAY DIFFRACTION ANALYSIS

Experimental

Each sample was pulverized and pressed gently into aluminium holders for X-Ray diffr-action analysis. Each of the aluminium holders was then mounted on the wide-angle gonio-meters of a Rigaku powder Diffractometer (Geiger flex D-Max/IIA) equipped with a scientilation counter, a ratemeter, a pulse-height analyser and a chart recorder, Ni-filtered Cuk α radiation (generated at a tube voltage of 40 KV and tube current of 25 mA) was used. The goniometer was run at a speed of 1° min^{-1}. The divergency of the X-Ray beam was kept at 1° and the receiving slit width for the diffracted X-Ray beam was 0.15 mm. The constant of the ratemeter was I s. X-Ray diffraction patterns (2θ versus Intensity were obtained for an angular range of 2θ=3° to 40°. X-Ray diffrac-tion patterns obtained for nine clay samples and five sandstones are given on a reduced scale in Figures 1—5. Some of the samples from a lot were treated with glycerol in order to know whether or not any swelling clay was present.

Results

Mineral Powder Diffraction File (JCPDS, 1980 ed.) was used to analyse the patterns (Figures 1—5) by the Hanawalt method of qualitative analysis.

The clay minerals present in the clay sam-ples as major constituents are illite, Kaolinite and Montmorillonite. Chlorite is a minor phase. The presence of montmorillonite was confirmed on glycerolation. (Pattern : 2) (Fig. 1), 1,2,3,5 (Fig. 2), 2 (Fig. 3). The maximum intensity reflections (14°A) of chlorite and montmorillo-nite overlap. The 14° A peak for montmorillo-nite shifts to about 18° A on glycerolation, while that for chlorite remains unaffected. The non-clay minerals present as minor constituents in a majority of these clays are α-quartz, orthocase, microcline, calcite and albite.

The sandstones are found to contain as major constituents α-quartz, (Orthoclase+microcline+albite) and calcite (Figures 4 and 5) α-quartz is present almost in similar amounts in all these sandstones, whereas orthoclase, microcline, albite and calcite differ in amounts. The minor constituents are found to be chlorite, illite, kaolinite and montmoril-lonite. The presence of montmorillonite is confirmed by glycerolation patterns : 2,5 (Fig. 4 and 2) (Fig. 5). The clays are almost in similar amounts in these Kalabagh and Mangla samples.

DISCUSSION ON THE SOURCE AREA

The foregoing study sets out the details of the mineral (and rock) composition, texture and structure of the sandstones, calcareous mudstones, arenaceous mudstones (of Mangla) and argillaceous limestone (of Mangla).

The study of sandstones is of special impor-tance in determining the source rocks. Such studies for Kotli and Poonch areas have been conducted by Chaudhry and Ashraf (1981,1985). Some comments on the nature of Siwaliks in Poonch were made by Lydekker (1876), Middlemiss (1896) and Wadia (1928). The sandstones are immature and contain abundant rock fragments. Seven out of nine samples range in composition from subfeldspathic lithic arenites to lithic arenites. One sample of Mangla is a lithic Wacke, while one sample of Kalabagh is subfeldspathic lithic wacke. All of them contain abundant rock fragments of carbonates, chert, phyllites, slates, lower greenschist, sandstones, quartzites, quartz siltstones, volcanics and metavolcanics (acid to intermediate of low greenschist facies). Presence of low albite, microcline perthite, orthoclase perthite and some dark brown biotite indicates a possible granite source also.

The presence of abundant unstable rock fragments in sandstones and their texture shows that they have formed as a result of relatively short distance transportation.

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These rocks have most probably been derived from the upper and upper middle parts of the rising arc zones of Himalayas.

(for Mangla) and Hindukush (for Kalbagh)

TABLE 1
Modal Mineral Composition of Sandstones from Kalabagh Area

Sample No. Rock Name	SS3, MN1 Lithic Arenite	SS4, MN2 Subfeldspathic Lithic Wacke	MN3 Lithic Arenite
Quartz	28.6	28.2	25.8
Chert/Chalcedony	5.4	5.3	5.5
Carbonate	$24.5^{\times}+6.0^{\times\times}$	$9.4^{\times}+2.0^{\times\times}$	$27.0^{\times}+8.0^{\times\times}$
Clay	2.7	10.5	0.8
V.R.F./M.V.R.F.	6.6	3.4	5.7
Q/Qst/SST R.F.	1.0	2.0	—
P/S/S R.F.	1.3	6.8	2.6
Muscovite	1.2	3.3	3.0
Biotite	3.3	6.1	3.1
Chlorite	1.0	—	—
Albite/Plagioclase	5.9	5.4	5.9
K-Feldspar	5.4	10.6	4.8
Limonite/Haematite	2.0	4.2	0.9
Amphibole	3.8	1.8	5.4
Epidote	0.4	1.0	0.5
Sphene	—	—	0.4
Zircon	—	—	0.1
Garnet	0.3	—	—
Magnetite	0.6	—	0.5

TABLE 2

Model Mineral Compositions of Sandstones from Mangla Area

Sample No.	MN4	MN5	MN6	MN7	MN8	MN9
Rock Name	Lithic Wacke	Subfelds. Lithic Arenite	Subfelds. Lithic Arenite	Subfelds, Lithic Arenite	Lithic Arenite	Lithic Arenite
Quartz	31.6	28.6	22.4	33.7	21.5	23 0
Chert/Chalcedony	4.3	3.4	4.2	5.4	7.0	5.8
Carbonate	× ×× 26.0+4.0	× ×× 18.5+6.4	× ×× 29.1+7.0	× ×× 27.8+6.0	× ×× 32.1+4.0	× ×× 24.3+3.0
Clay	19.7	3.5	4.3	1.7	2.0	2.3
V.R.F.	1.4	2.3	3.0	0.9	3.2	5.1
Q.R.F./Qst.R.F/ SST. R.F.	2.8	2.2	4.0	—	1.8	2.3
P/S/S.R.F.	1.1	17.7	15.9	7.5	9.7	13.9
Muscovite	3.1	3.3	0.8	3.2	3.3	5.7
Biotite	0.7	3.9	0.7	3.9	2.1	2.2
Chlorite	0.7	0.5	—	—	—	—
Albite/Plagioclase	1.2	2.8	2.3	2.0	5.1	5.1
K-feldspar	1.0	4.7	2.6	3.8	4.7	5.4
Limonite/Haematite	2.4	1.8	2.1	1.1	1.7	1.5
Goethite	—	0.5	—	—	—	—
Epidote	—	0.3	0.9	—	—	—
Tourmaline	—	—	0.7	1.3	—	—
Garnet	—	—	Tr	1.7	1.8	—
Magnetite	—	—	—	—	—	0.4

× *Rock Fragments.*
×× *Cement.*
V.R.F. Volcanic Rock Fragments
M.V.R.F. Metavolcanic Rock Fragments.
Q.R.F. Quartzite Rock Fragments.
Qst. R.F. Quartz Siltstone Rock Fragments.
SST. R.F Sandstone Rock Fragments.
P. Phyllite Rock Fragments.
S. Schist Rock Fragments.
S. Slate Rock Fragments.

TABLE 3

Modal Mineral Composition of Calcareous Mudstones from Mangla and Kalabagh

Sample No. Area Rock Type	MN10 Mangla Calcareous Mudstone	MN11 Mangla Calcareous Mudstone	MN12 Kalabagh Calcareous Mudstone	MN13 Kalabagh Calcareous Mudstone	MN14 Kalabagh Calcareous Mudstone	MN15 Kalabagh Calcareous Mudstone	MN16 Kalabagh Mudstone (Arenaceous)	MN17 Kalabagh Mudstone (Arenaceous)	MN18 Kalabagh Argillaceous Nodular Lst.
Clay	56.2	55.8	55.3	64.8	66.1	62.1	52.3	41.2	32.2
Carbonate	27.9	27.2	24.9	18.4	18.8	20.6	2.9	3.8	55.7
Quartz	6.6	8.5	9.8	8.6	9.4	10.8	22.8	26.5	6.5
Chlorite	4.8	3.8	5.0	2.8	2.8	2.3	3.5	2.9	0.8
Limonite/ Haematite	2.3	2.2	1.7	1.5	Tr.	1.0	3.9	2.6	2.3
Albite	1.6	2.0	2.6	2.1	1.1	2.0	1.5	3.1	0.5
Sphene	0.4	0.2	0.2	0.2	0.2	0.2	0.4	0.2	—
Rutile	0.2	0.3	0.2	0.3	0.3	0.2	0.2	Tr.	0.2
Epidote	—	—	0.3	1.3	1.3	0.8	0.8	1.3	0.5
Muscovite	—	—	—	—	—	—	6.2	2.7	0.9
Biotite	—	—	—	—	—	—	3.4	1.4	—
K-feldspar	—	—	—	—	—	—	1.6	5.8	0.4
Rock Fragments	—	—	—	—	—	—	0.5	8.5	—

Figure 1.

X-Ray Diffraction patterns of Mangla clays :

1. MN—11 ;
2. MN—11 (glycerolated) ;
3. MN—10.

Figure 2.

X-Ray Diffraction Patterns of Kalabagh Clays :

1. MN—16 (glycerolated) ;
2. MN—18 (glycerolated) ;
3. MN—17 (glycerolated ;
4. MN—14 ;
5. MN—15 (glycerolated) ;

Figure 3.

X-Ray Diffraction Patterns of Kalabagh Clays :

1. MN—13 ;
2. MN—13 (glycerolated) ;
3. MN—12.

Figure 4.

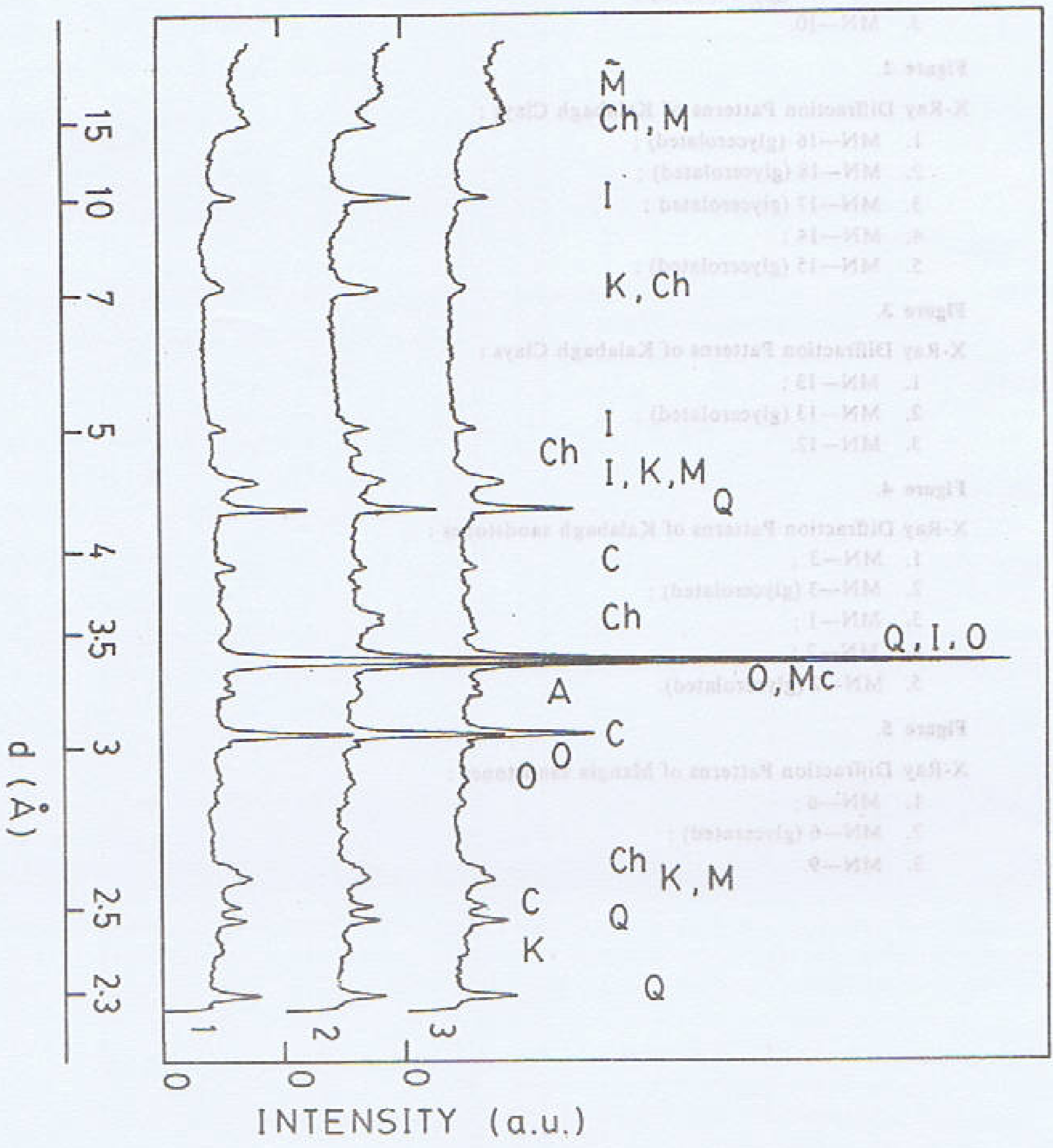
X-Ray Diffraction Patterns of Kalabagh sandstones :

1. MN—3 ;
2. MN—3 (glycerolated) ;
3. MN—1 ;
4. MN—2 ;
5. MN—2 (glycerolated).

Figure 5.

X-Ray Diffraction Patterns of Mangla sandstones :

1. MN—6 ;
2. MN—6 (glycerated) ;
3. MN—9.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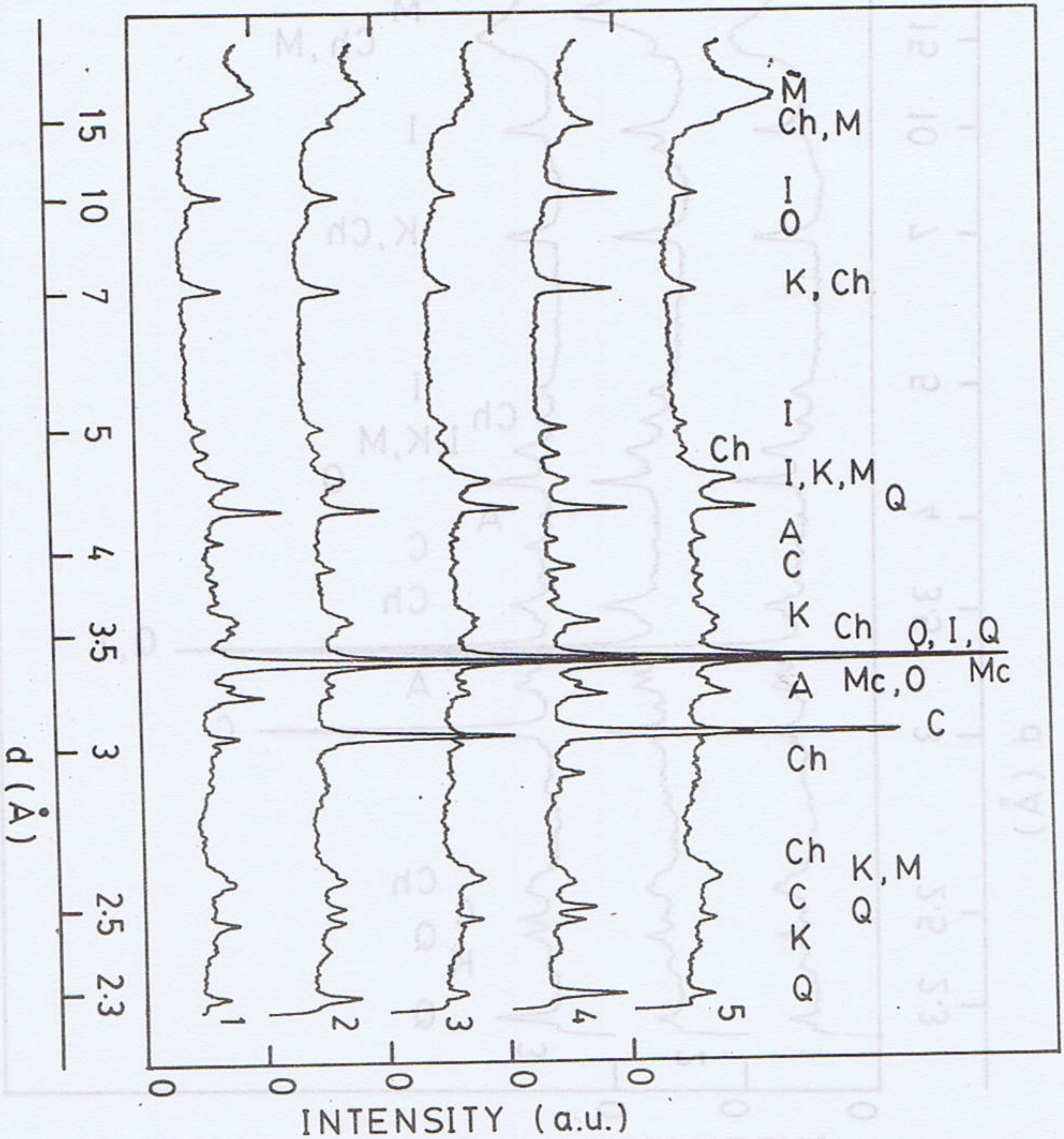
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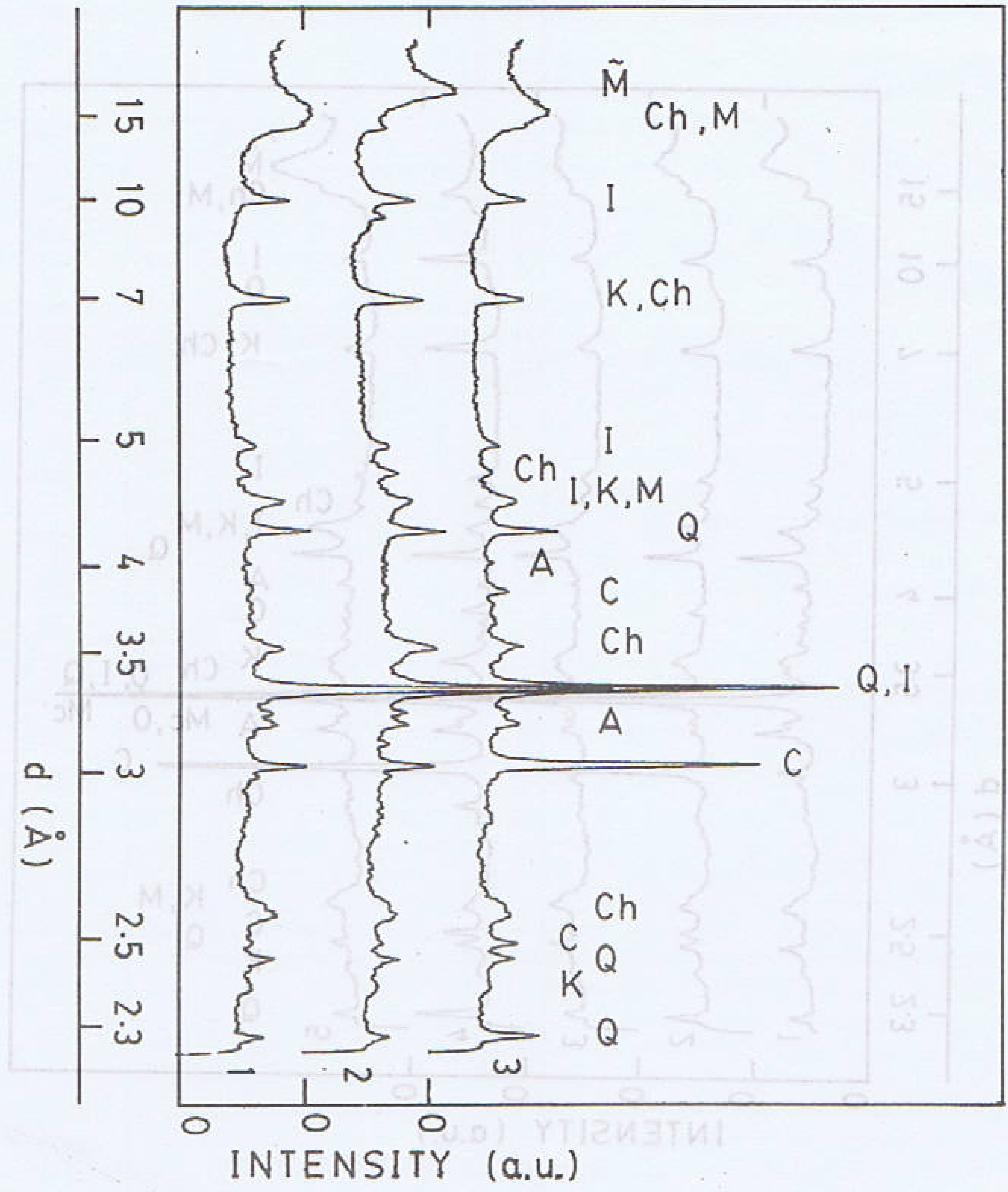
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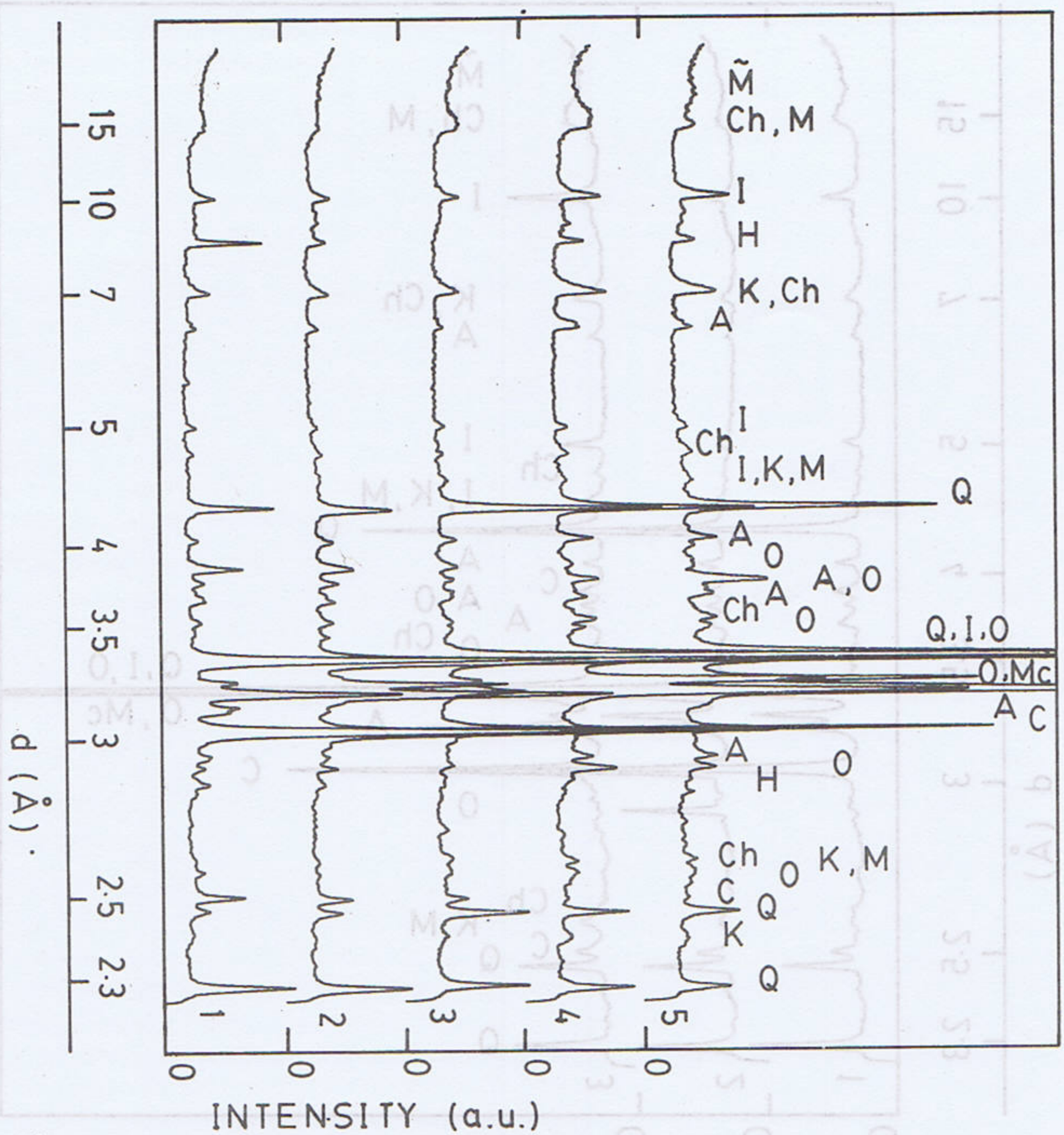
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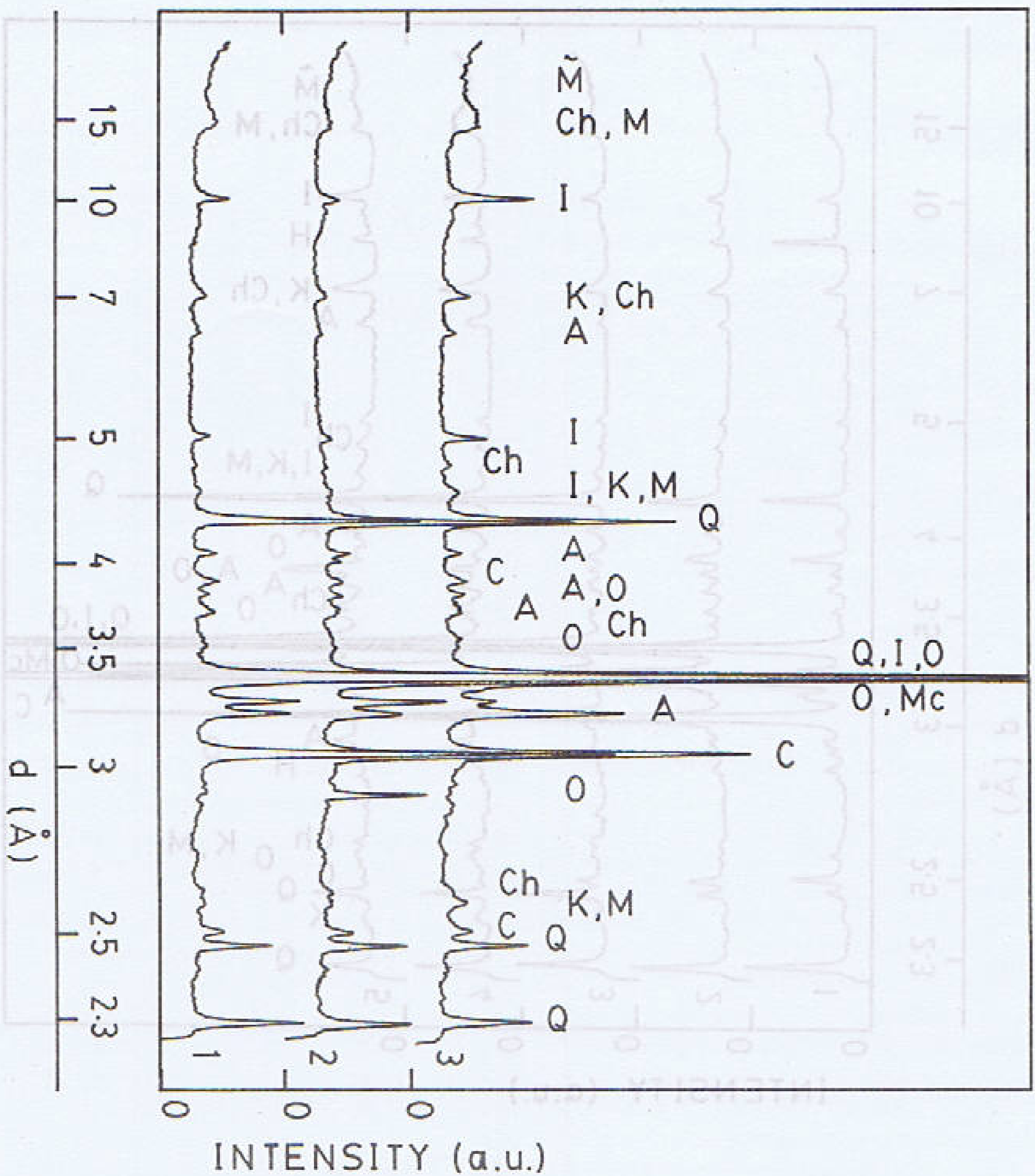
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REFERENCES

Ashraf, M., and Chaudhry M.N., 1984. Petrology of Middle Siwalik Rocks of Poonch Area, Azad Kashmir. *Kashmir Journ. of Geol.* Vol. 1 No. 2.

Chaudhry, M.N., and Ashraf, M., 1981. Petrology of Middle Siwalik Rocks of Kotli Area, Azad Kashmir. *Geol. Bull. Univ. Peshawar*, Vol, 14, pp. 183-191.

Danilchik, W., and Shah, S M.I., 1967. Stratigraphic nomenclature of formations in Trans Indus Mountains, Mianwali District, West Pakistan : *U. S. Geol. Surv., Prof. Peport (IR)* PK-33, 45 P.

Holland. T.H., and Tipper, G.H., 1913. Indian Geological Terminology. India *Geol. Surv., Mem.* V. 43, pt. 1 pp. 1—27.

Ledekker, R., 1876. Notes on the geology of the Pir Panjal and neighbouring districts. *Rec. Geol. Surv. Ind.* 9, 155.

Middlemiss, C.S., 1896. The geology of Hazara and Black Mountains. *Mem. Geol. Surv. Ind.* 26, 302.

Meddlicott, H.B., 1876. Notes on the sub-Himalayan series in Jammu Hills. *Rec. Geol. Surv. Ind.* IX, 49.

Shah, S.M.I., 1977. Stratigraphy of Pakistan. *Mem. Geol. Surv. Pak.* Vol. 12.

Wadia, D.N., 1928. The geology of Poonch State (Kashmir) and adjacent portion of the Punjab. *Mem. Geol. Surv. Ind.* 11, 2.

GEO-TECHNICAL ASPECTS OF LAHORE SOILS

BY

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Abstract : *The study is aimed at the correlations of engineering properties of soils in and around Lahore. The data regarding strength parameters have been collected, which pertains to a number of sites explored for different engineering structures. An attempt has been made to evaluate and put forth generalized idea about the bearing capacity in different areas of Lahore City.*

INTRODUCTION

A knowledge of the subsoil conditions and information about the Safe bearing-capacity of the foundation soils are useful guidence for designing of foundations.

Strength parameters have been evaluated which affect capacity of soil under foundations to bear super-imposed structural loads. The data represent more than twenty sites investigated in and around Lahore and are presented in the form of tables. An endeavour has been made to correlate the geotechnical characteristics of Lahore soils.

NATURE OF AVAILABLE DATA

The available soil data is in the form of geotechnical reports on the subsoil investigations and testing for the evaluation of Safe bearing- capacity for different projects executed by M/s. Geodrillls. The projects are scattered over Lahore area and pertain to multistory buildings, over-head water reservoirs and industrial buildings. The procedure adopted was to drill various boreholes at a site with execution of standard penetration test (SPT) at regular depth interval and to carry out laboratory tests on selected samples taken from every site during drilling Boring logs and results of SPT, moisture content, field density particle size analysis, unconfined compression test and direct shear test are available for every site. At some sites, results of Atterberg's limits, triaxial compression test and consolidation test are also given in the Reports. The depth explored in different boreholes is fifteen feet to forty feet at most of the sites. A few sites have, however, been explored to depths beyond forty feet ; however, nature of soil below forty feet cannot be correlated on the basis of available data. A brief description of available data is summarized in Table-I.

TABLE I

Site No.	Location	Engineering Structure.	No. of bore-holes explo-red	Depth ex-plored (feet)	No. of Test Results								
					SPT	MC	FD	UC	PSA	DS	AL	Triex-ial	Conso-lidation
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	G.T. Road Shahdara.	Factory Building.	1	50	15	15	15	5	15	12	4	—	2
2	Gulberg Main Market.	4-storey Commercial Building.	3	20	19	17	18	14	9	9	6	—	—
3	Kot Lakhpat Ind : Area.	Factory Building.	3	20	18	12	12	12	10	10	6	—	—
4	Niazbeg Multan Road.	3/4 storey building.	5	33	50	39	39	—	25	15	10	10	4
5	G.T. Road, Shahdara.	Water Reservoir.	2	16	10	10	10	8	10	6	5	—	4
6	Raiwind Road.	Heavy Building.	3 2	125 50	80	21	21	18	40	18	10	3	6
7	Mental Hospital.	Water Reservoir.	1	25	9	9	—	9	9	9	—	—	—
8	Amarsidhu Ferozepur Rd.	Water Reservoir.	2	20	12	12	9	6	6	6	—	—	—
9	Civil Police Lines near Sherpao Bridge.	2-storey Barrack.	3	15	12	12	12	8	10	10	—	—	—
10	Empress Road	Multi-storey Commercial Building.	1										
11	Circular Road Delhi Gate.	— do —	1	35	7	5	4	—	7	7	—	—	—
12	Raiwind Link Road.	Factory Building.	5	33	50	15	25	—	19	19	—	—	—
13	Abbot Road.	Multi-storey Commercial Building.	4	60	36	60	35	—	21	21	—	—	—
14	Township	Water Reservoir.	2	40	20	20	12	11	20	10	—	—	—
15			1	2									
16	Ghazi Road Ichhra.	Multistorey flats.	11	50	81	32	12	—	86	10	—	—	—
17	Ghalib Market Gulberg.	Multi-storey Hospital Building.	3	50	36	36	20	12	20	14	—	—	—
18	Niaz Beg.	Water Reservoir.	2	15	10	10	10	10	8	8	—	—	—
19	10 KM Sheikhupura Road.	Industrial Building.	2	20	12	12	11	5	10	8	—	—	—
20	Empress Road.	Multi-storey Building.	3	30	18	18	13	6	14	10	—	—	—
21	Upper Mall.	Mosque.	2	25	14	16	10	6	11	9	—	—	—

STRATIGRAPHY

The locations of different sites were tentatively marked on the Map of Lahore published by Scientific Society of Pakistan (1985). The borehole data available suggests two different soil classes, cohesive and non-cohesive. The cohesive soils which are generally present at the top level include clays and silts with additives of small amount of sand. The non-cohesive soils forming the second layer include sands with small amount of silt and clay. The cohesive top layer of subsoil is generally in the form of laminations while the lower sandy layer is generally continuous. The thickness of upper cohesive layer varies from about 10 feet to 22 feet. The borehole data of Geodrills as given in Table I does not contain Lahore Cantonment area and Bund Road area. Hence the soil strata at these locations (location Nos. 22 and 23) was got from another source. The borehole data alongwith the static water table at different locations is given in Table II.

TABLE II

Location/ Site No.	Depth of Cohesive Soil	Depth of non-cohesive soil	Static Water Table	Exploration Date
1 to 23	0-0′ to 12′-0	12′0 to 50′-0	15′-8″	20-5-82
	0-0′ to 20′-0″	Below 20-0	Below 20′	13-2-82
	0.0′ to 12′-0″	Below 12-0	13′-9″	22-2-82
	0-0′ to 10′-5′	Below 10-5	13′-4″	8-4-80
	0-0′ to 13-12	Below 13-12	15′-4″	20-5-80
	0-0′ to 12-5	12-5 to 40-0	4-5	12-2-85
	0-0′ to 9-0	Below 9-0	Below 25-0	4-3-85
	0-0′ to 20-0	Below 20-0	Below 20-0	14-2-85
	0-0′ to 14-15	Below 14-15	Below 15-0	8-2-85
	0-0′ to 15-5	Below 15-5	41-0	5-2-85
	0-0 to 21-0	Below 1-5	22-0	5-1-85
	0-0′ to 21-0	Below 21·0	10-0	7-11-84
	0-0′ to 13-6	Below 13-6	29-0	27-11-84
	0-0′ to 19-0	Below 19-0	22-6	9-8-84
	0-0′ to 8-5	Below 8-5	Below 30-0	15-8-84
	0-0′ so 11-0	Below 6-0	32-0	15-6-84
	0-0′ to 22-0	Below 22-0	48-2	7-4-84
	0-0° to 15-0	Below 15-0	14-9	26-12-83
	0-0′ to 10-0	Below 10-0	19-2	3-9-83
	0-0′ to 15-0	—	30-0	23-7-83
	0 0′ to 15-0	Below	25-0	30-6-83
	0-0′ to 18-0	Below 18-0	—	—
	0-0′ to 2-0	Below 2-0	—	—

SOIL PROFILE

To give a general idea of subsoil at Lahore, two soil profiles were constructed along two arbitrary and approximately perpendicular straight lines AA′ and BB′ marked on the location map given at Fig. 1. The soil profiles are given at Fig. 2 and 3. It may be realized that soil profiles do not embody much precision. Small lenses of sandy soils are accasionally present in the top cohesive layer. Also some patches of cohesive soils are present in the second non-cohesive layer. The soil profiles, however, illustrate that the top cohesive layer increases in thickness as we go from the Ravi to the Cantonment area along the line BB′. The profile along AA′, on the other hand, indicates that the thickness of top cohesive layer is minimum at Ichhra and it increases as we go away from Ichhra on either side along the line AA′.

STRATIGRAPHY BEYOND 40 FT. DEPTH

From the available data of few boreholes drilled beyond 40 ft. depth, it is indicated that another layer of cohesive soils is present below 40 ft. depth. The thickness of this layer varies from 10 to 15 ft. Below this cohesive layer, sandy strata is present up to about 80 to 100 ft. depth where another cohesive layer of about 20 ft. depth is encountered.

PENETRATION RESISTANCE

Standard penetration test (SPT) is an important and universally adopted field test performed.during drilling for geotechnical investigationThe results are expressed as N-value or penetration resistence of soil. The N-value is the number of blows of a 140 lb drive weight 30″ free fall required to drive a 2″ standard split spoon sampler into the soil through 1 ft. The N-value of soil is actually a measure of consistency of cohesive soils and of relative density of non-cohesive soils. Numerous empirical correlations of N-value and bearing capacity of soil are available in soil mechanics literature, the more significant of which are due to Terzaghi, Teng, Tomlinson, Bowles and Taylor. The bearing capacity results as calculated from above correlations are considered to be more accurate for sands and less for cohesive soils. Average N-value of soil is generally employed in the bearing capacity evaluations. Consequently, the average N-values have been computed separately for cohesive and non-cohesive soils from the said Reports. The test data revealed that N-values in cohesive soils of Lahore varies from 4 to 18 but at most of the sites, it is near 10. In sandy soils, the N-value are found to be 4 to 30 with an average value of 16. On the whole, the N-value is higher in sands than in cohesive soils. The computed average N-values for cohesive and non-cohesive soils of Lahore are given in Table-III.

UNCONFINED COMPRESSIVE STRENGTH

The unconfined compressive strength is an important characteristic of cohesive soils. The results in the available data pertains to unconfined compression tests performed on 1.5″ dia × 3″ long undisturbed cylindrical core specimens got with shell-by tubes during drilling. The test was performed with a British Standard, hand operated strain controlled field type machine which automatically graphs a stress-strain curve of soil specimen tested to failure in an unconfined state. These value are employed to evaluate the bearing capacity of cohesive soils and the results are considered to be most safe. From the test data, the average unconfined strength of the upper cohesive soils of Lahore was computed for each site and the values obtained are given in Table-III. The results reveal that average unconfined strength cohesive soils of Lahore vary from 0.82 T/Stf. to Tons/Sft. and overall average comes out to 1 Ton/Sft. The maximum confined strength values pertain to a site in Gulberg III near Garden Town round-about at Shahrah-e-Roomi while the minimum values belong to a site in Shahdara. From Table III, a fair idea about the average strength of cohesive soil at particular locality can be obtained with fair degree of accuracy.

DENSITY OF SOIL

In geotechnical computations, the bulk density of soil is often reqnired alongwith the strength parameters. Hence the values of density for cohesive and non-cohesive soils at different sites have been computed from the available data. The compuıed values ara given in Table III.

TABLE III

	Cohesive Soil					Sandy Soil			
				Shear value				Shear value	
Sl. No.	Average S. P. T. N/value	Average unconfined Lbs/sft.	Density lbs/cft.	C PSI	ϕ Degrees	Average S. P. T. N. value	Density lbs/cft	C PSI	ϕ Degrees
1	2	3	4	5	6	7	8	9	10
1	8	0.82	117.32	—	—	13	117.1	0.8	32.9°
2	11	1.06	123.9	2.4	23.4°	—	—	—	—
3	6	0.90	118.0	1.43	25.5°	11	—	0.40	31.0°
4	7	—	119.6	1.10	23.0°	18	120.0	0.55	28.0°
5	5	0.83	119.1	—	—	7	120.5	0.9	31.5°
6	4	0.9	123.0	6.8	15.0°	12	—	1.2	33.0°
7	10	—	107.0	1.6	26.0°	18.0	104.0	0.4	33.0°
8									
9	12	0.65	119.2	—	22.5°	25.6	—	—	—
10	18	1.10	122.7	3.0	25.0°	26	120.6	—	—
11	—	—	—	—	—	17	108.0	0.5	32.0°
12	11	—	117.2	1.0	29.0°	15	120.5	0.7	30.0°
13	16	—	111.8	1.2	28.0°	17	108.2	0.5	33.0°
14	10	1.04	123.0	3.06	22.67°	18	124 0	0.7	30 0°
15	11	2.0	121.0	3.75	21.0°	30	119.0	0.3	39 0°
16	6	—	—	1.50	29.0°	16	—	0.4	35.0°
17	9	1.01	119.0	2.3	29.0°	18	111.0	1.0	32.0°
18	8	0.84	125.8	3.5	20.5°	—	—	—	—
19	9	1.1	115.0	3.6	16.0°	4	95.0	0.3	31.0°
20	9	1.29	122.0	3.75	19.0°	12	93.0	0.4	34.0°
21	10	0.98	114.5	3·15	24.0°	18	108.0	0.9	35.0°
Av.	9				Average	16			

COHESION AND ANGLE OF INTERNAL FRICTION

The intamolecular cohesion and angle of internal friction of the soils were determined by direct shear tests. Direct shear tests were carried out with British Standard type, strain controlled machine with 6 cm square shear box. For sandy soils, the unconsolidated undrained shear (ϕ) tests were performed while consolidated undrained shear (QC) tests were performed on cohesive soils. From the test data obtained, average intramolecular cohesion and angle of internal friction were computed for each borehole on each site. The authors worked out the average of C & ϕ values for each site from different borehole data. The average values of C & ϕ for each site have been presented in Table III. As the cohesion (C) and angle of internal (ϕ) have very important implications for the computation of bearing capacity, the average values of the same have been worked out separately for cohesive and non-cohesive soils and are given in Table III. It is indicated from the Table III that intramolecular cohesion for cohesive soils ranges from 1.0 PSI to 6.8 PSI and overall average cohesion in cohesive soils comes out to be approximately 3 PSI. The angle of internal friction for cohesive soils vary from 15 degrees to 29 degrees with an average value of about 22 degrees. For sandy soils, however, the cohesion is small while angle of friction ranges from 28 to 39 degrees with an overall average of about 32 degrees.

SAFE BEARING CAPACITY

On the basis of technical data available from geotechnical Reports referred to above, authors worked out and gave recommendations about the foundation design parameters.

A summary of the recommendations is given in Table IV. From this Table it will be possible to have a fair idea about the soil bearing capacity of a locality within Lahore area. However, it will be understood that the above values are for a particular engineering structure at a particular place. As already mentioned and as is evident from other geotechnical literature, the soil bearing capacity depends upon so many factors including event time. The soil is a heteorogenous material laid during natural geological processes and there are many uncertainties involved. Hence, these results are only for a general evaluation of a site and the recommended values can not be applied to a particular project. For each new project, even in the close vicinity of a tested place, fresh soil investigations and testings should be carried out and the foundation design parameters got evaluated by a competent organization.

CONCLUSSIONS

1. The subsoils encountered in and around Lahore have a general pattern of cohesive top layers overlying non-cohesive sandy soils upto a depth of 40 ft. The bearing capacity of soil varies from 0.70 ton/sft. to 1.47 ton/Sft The percentage of sites have different range of safe bearing capacity is as follows :

Safe Bearing capacity Range (Ton per Sft.)	Percentage of sites
Less than 0.70	30 %
0. 0 to 1.00	45 %
More then 1.0	25 %

2. Although the data is not sufficient and the scattering of results is so great that no particular zones of bearing capacity can be suggested. However the general trend of bearing capacity is easily observed to be increasing from the area near Ravi towards the area of Gulberg and Cantonement. The study area can be divided into 3 zones.

(a) Area of low bearing capacity which comprises Shahdara, Gulshane Ravi, Allama Iqbal Town Park and Sandas.

(b) Area of medium bearing capacity which comprises Ichhra, Mozang, Muslim Town, Faisal Town, Jauhar Town, Model Town etc.

(c) Area of high bearing capacity which comprises Gulberg, Lahore Township, Kot Lakhpat and Lahore Cantonment.

2. The above zoning is only for comparison. The general principle, that each site should be investigated thoroughly may not be overlooked.

TABLE IV

Sl. No.	Depth of investigation	Type of Foundation	Foundation		
			Depth	Width	Bearing Capacity
1	2	3	4	5	6
1	50	Simple Strip Footing.	3.3	3	0.73
2	20	—do—	3.0	3	0.85
3	20	R.R.C. Spread Footing.	3.0	3	1.16
4	33	Simple Strip Footing.	3.0	3	0.65
5	16	Raft	3.0	3	0.87
6	—	Simple Strip Footing	4.0	4	0.65
7	25	Raft	4.0	—	1.00
8	—	--	—	—	—
9	15	Spread footing.	4.0	5	0.65
10	90	Spread footing.	4.0	5	0.65
11	25	—	4.0	10	1.47
12	30	Spread footing.	4.0	10	0.64
13	60	—	3.0	10	1.00
14	40	Raft.	5.0	—	0.70
15	30	Spread.	5.0	10	1.25
16	50	Raft.	5.0	26	1.45
17	50	R.C.C. footing.	5.0	—	1.35
18	15	R.C.C. Raft.	3.0	—	0.72
19	20	Spread.	3.0	—	0.60
20	30	--	3.0	—	1.00
21	25	--	5.0	10	1.00

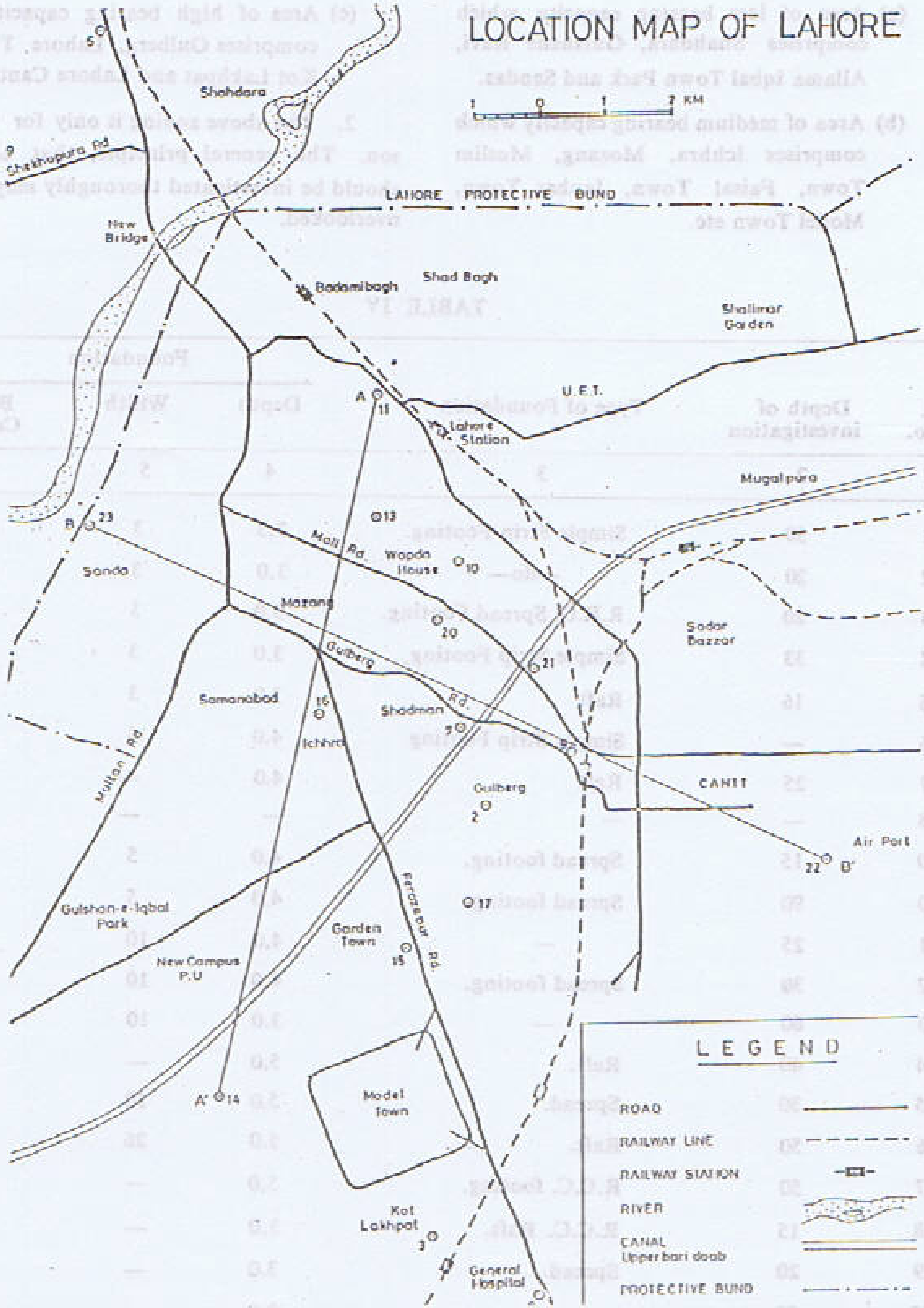
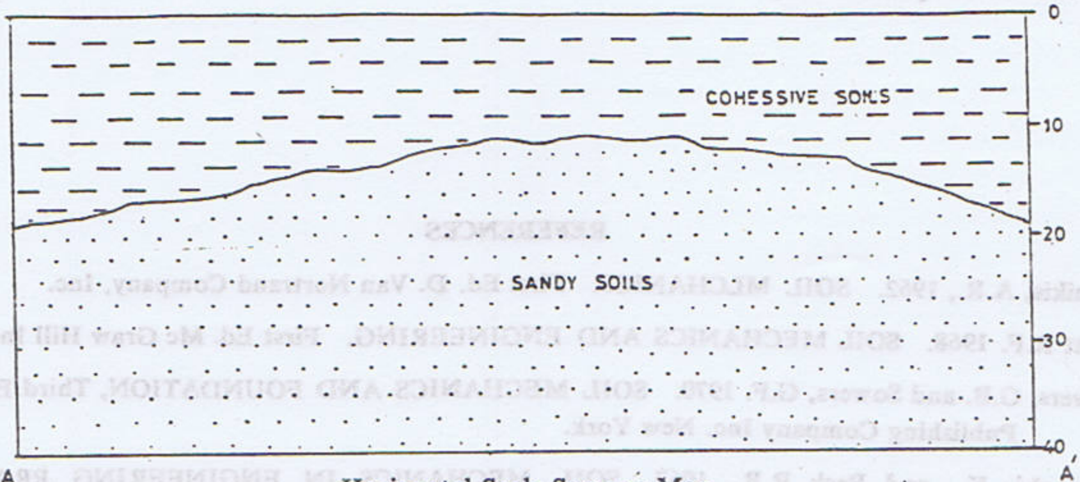


Fig-I Showing Locations of Sites Explored.

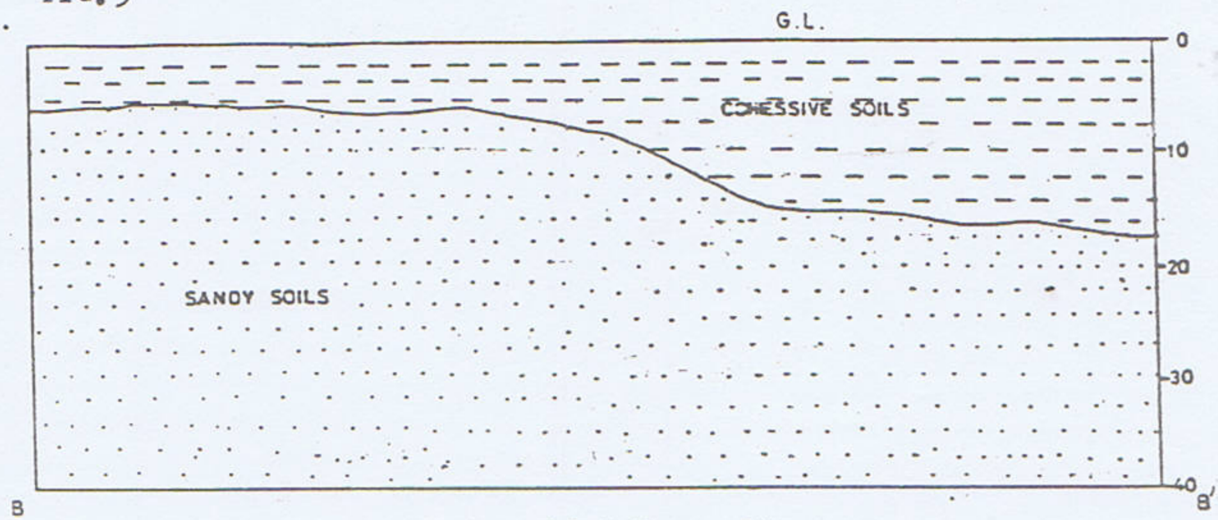
FIG. 2



Horizontal Scale Same as Map.

Soil Profile Along Line AA' marked on Fig. 1.

FIG. 3



Horizontal Scale Same as Map.

Soil Profile Along Line BB' marked on GID. I

ACKNOWLEDGEMENT

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REFERENCES

Jumikis, A.R., 1962. SOIL MLCHANICS. First Ed. D. Van Nortrand Company, Inc.

Scott R.F. 1968. SOIL MECHANICS AND ENGINEERING. First Ed. Mc Graw Hill Inc.

Sowers, G.B. and Sowers, G.F. 1970. SOIL MECHANICS AND FOUNDATION, Third Ed. Illan Publishing Company Inc. New York.

Terzaghi, K., and Peck R B., 1967. SOIL MECHANICS IN ENGINEERING PRACTICE. Second Ed. John Viley and Sons.

Technical Reports Published by Geodrills Soil Laboratory, Lahore 1980—1986.

WATER—LOGGING IN THE RECHNA DOAB :—A GEOGRAPHICAL STUDY

BY

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Abstract :—*Water logging in the Punjab province has increased enormously. As a matter of fact it has gained number one position amongst the priority problems of the country. In this province the most effected area is the Rechna Doab which covers an extensive area. Water and Power Development Authority was entrusted the responsibility of its controll. The authority, after extensive studies of the area, decided to adopt tubewell instalations methodology all over the area. This incurred huge amounts of recurrent resources to continue the process working. As the time passes the tubewell policy is loosing its efficiency and so the adequacy and effectiveness is decreasing. On the other hand is proposed that the utilization of geographical facts can help better to provide solution. For this purpose permeability zones of the province and particularly of Rechna Doab have been established. Detailed maps of Doab showing geomorphic formations, the directions of underground water, layout plans of canals and existing drains, have been shown. Finally lines of new drain channels, have been proposed. The areas of high permeability, where the main canals and major tributaries cross, have been assertained and suggested for plugging. It is believed that this study may be able lo help in the solutions of the problem.*

INTRODUCTION

Water-logging problem in the Punjab Province has gained immence importance in the national policy of agricultural planning. Extensive areas have become affected by this menace. Colossal resources have been and are being, devoted to "solve" the problem. Various schemes have been undertaken and many more might be undertaken in the future as long as the problem exists. It is also likely that the nation will have to live with it for a long period to come. New points of views, new programmes and schemes and above all the new techniques, will continue to provide incentives to the thinking and practical mind to adopt new ways of handling the problem.

The water-logging problem seems to be the consequential outcome of large scale harnessing of natural resources of water and thus disturbing the natural balance of ground water. Such an interference by human agency has not only been able to benefit, but also has set a chain reaction and interaction within the environment. Naturally the disturbed balance of nature resulted in the human suffering.

The Punjab Province in the last hundred year or so has undergone tremendous transformation due to cultural manifestations in its natural physical pattern. As a matter of fact the whole vista of the then landscape of the region has been drastically modified through human activity. It has become extremely difficult to reconstruct the past landscape.

GEOMORPHOLOGICAL SETTING OF PUNJAB

Punjab's geomorphological setting is essentially of fluvial nature. The geology of the plains is simple and presents an alluvial basis with minimum variability in its regional characteristics. The Northern Section (Fig. I) of the province is mountainous. Here the Salt Range is a prominent and dominating feature. The whole region is ravine and gully ridden area with no drainage problem of any kind. There is however scarecity of level—land to be cultivated through irrigation. Only at places fluvial fans are fed with spring-water supply.

Similarly the south-western Section of the province is occupied by a foot-hill region comprised of Dera Ghazi Khan which is also a dry, sandy region, studded with courses of seasonal streams that descend from the Suliman range. Presently only a narrow strip of land along the the river is agriculturally viable. Here establishment of an irrigational system of canals is in progress. The land gradient is considerably steeper and sinks into the Indus river basin.

On the Nort-East, the extension of Jammu foot-hills joins another hilly area. It has a rolling topography with many streams, as is common in the foot-hill regions. Here the soil is a mixture of boulder and sandy material covered by soil wash due to heavy rains and occasional overspilling of many water courses from the hilly region. This region projects considerably into the plains. Rest of the Province is consituted by plains with fairly gentle gradient to the South-West direction. The interflueves or bars slope gently towards the shallow river valleys. There is an odd feature of Kirana ridge, visible at places in the form of small hillocks. The subterranian axis of the ridge lies along the South-West-North-East line.

Almost all the plain, apparently, is a flat extensive region. The inter-flueves comprise of a few feet elevated humps very gently sloping towards the shallow pan-like river beds. These river beds are wide in which the lateral rolling of water has given rise to meander formations. This plus the interference through harnessing measures, have rendered them fairly tortuous as a free passage for water. Consequently whenever there is excess of discharge they overspill and innudate extensive areas. These floods cause widespread damage to life, crops, and property.

On the basis of the above discussion permeability regions of the Province have been demarcated (Fig. I). They are more or less related to the geomorphological divisions. The mountainous parts, being well provided with streams, is not considered in this study which is not related to the water logging problem. There are two regions of high permeability. One is the dominently Sandy region occupying the Sindh-Sagar doab in the North-Western section, and the vast sandy Tract of Bahawalpur division, which is an extension of Indian Thar desert. Here, to establish canal irrigation system without proper lining (specially designed and prepared bricks or tiles or other material) of canal courses, can be considered negligence leading to disastrous consequences of water-logging. Here, the soil being sandy, is prone to hig seepage. Irrigational pursuit, without taking appropriate measures, was supposed to become problematic and has proved so.

The other region of high permeability is found in the North-Eastern section of the Province. It is an extension of Jammu foot-hills into the plains. The gravelly soil here provides fairly good medium for high seepage. The canals which traverse this region, offer considerably large amount of water to the underground aquifer reservior and hence contribute to the underground water storage. The rest of the region may be considered as of moderate permeability.

After the general review of Punjab's permeability, Rechna doab is taken as a case study. This region, infact, is the most probed and experimented area of the Province. All kinds of tests have been under taken to get the quantitative and qualitative information. Here in this study a probe will be made to bring to light the hitherto unconsidered geographical factors, which if considered, may help to add to the efficiency, effectiveness and adequacy in the control of the problem.

THE RECHNA DOAB

Map (Fig. 2) shows a detailed geomorpho. logy of Rechna Doab It is comprised of simple sedimentary belts, with an odd exception of Kirana ridge, referred to before. The greater part of it is constituted of old and presently active flood plains of rivers Chenab and Ravi. The old flood plain constitutes a large area of the central part of the doab. Here the land surface possesses traces of large former stream courses that once traversed the bars region. These oblitrated stream courses merge to form a wide plain to the N-E & S-W with their long fingerlike extensions.

The area is characterised by traces of meanders, old bars, levees and oxbow-shaped features. The bar-upland area is further rigned by a low-level bar-upland. The North-Eastern part of the doab is occupied by a large outwash plain. The plain is of interfluve nature and possesses a somewhat undulating topography. There is a narrow meander belt along the river course. The Map also indicates the underground alignment of subterranien water-flow along the length of doab. It is roughly in N-S direction, which corresponds to the general direction of the old channels shown on Map. The Map also shows the approximate position of Kirana ridge in Rechna doab. The ridge devides the underground reservior into two distinct basins, one to the N-E, called Sheikhupura Basin and other to the S-W of the ridge, called Faisalabad basin. The flow of water from Sheikhupura basin to other is considerably restricted due to unfavourable geological material, like clay, deposited around the ridge. The area available for the flow of water through the Chiniot, Shahkot gaps and river Ravi is not of much significance. Any how the outflow of groundwater from the Sheikhupura basin is much less than the inflow into it. At present two areas possess high underground water level. They are one along the Lower Chenab and Jhang branch canals and the other along the Gughera branch. The high water level is obviously due to the greater seepage from these major canals. Water from these canals flow down into the intervening groundwater through or into the surrounding low lying flood places.

Permeability Zones of Rechna Doab

The Map (Fig. 3) has been compiled to show the areas of high and low permeability. The regions of high permeability are the main contributing areas to the groundwater storage. There are three such areas. The area along the Chenab river is considerably extensive whereas it is small along the Ravi river. Keeping in view the general land gradient of the whole doab, the Chenab river-side area largely contributes to the underground reservoir. A look at Map (Fig. 2) reveals that the old flood plains of the Chenab in the middle of doab gets maximum supply of water from these high permeable areas. Also the outwash foothill plain might be contributing to the underground reservoir. As a matter of fact it is the former flood plain of the Chenab river that is highly water-logged. On the other hand river Ravi-side highly permeable areas might be helping the draining of excessive supply to the river instead.

The other problem area, though not permanently bogged, is that of active Ravi flood plain (Fig. 2). Here high rain fall supplemented by hill torrents submerge the area for a time during the rainy season. The water generally is drained away by streams of the area. The rest of the doab is more or less normal due to being comprised of low permeability soils.

Present Methods of Control

Water logging was foreseen in the nineteen thirties. Its solution was sought in the provision of a sub-surface drainage system. The whole area was surveyed carefully and drains were provided to drain the sub-surface water on considerably large scale. Approximately 2240 K.M. of drains were provided. It is worth considering that in the presence of considerably large system the water-logging problem rapidly achieved an alarming enormity. Here it seems an accumulative effect of more than one component. As a matter of fact the perenniality of the canals has gained more or less position of permanent water courses. This is due to considerable increase in the irrigated area. Also intensity of cropping in all over the middle and upper Punjab, where canal supply irrigation is available, is somewhat on the increase. This has forced the canal system to work to the optimum capacity without getting suitable respite of clearanceand maintenance. The overworking of the water-supply system naturally resulted in the breaking of soil resistence against percolation over long time. As for as the spread of water over extensive field tracts in a thin film is concerned, its contribution to the underground reservoir may be taken as negligible. It is because the vegetational transpiration and soil evaporation in the extreme weather conditions reduce margin to the minimum. Similarly the field supply channels as well as tertiary and other smaller distributary channels can also be ignored as they are normally sheilded by higher order vegetation like trees, which reduce the chances of water addition through seepage to a large extent.

WAPDA'S WATER LOGGING CONTROL POLICY

WAPDA, Water and Power Developmgnt Authority, Lahore, is the sole organization authorised to seek and adopt ways and means for the solution of the water logging problem in Pakistan. This has put in great effort to do detailed geological, soil and hydraulic surveys of the areas affected by this problem. A clossal amount of data have been collected. Regions of priority have been demarcated in the form of scarps to be undertaken for reclamation. WAPDA's main objective seems to lower the water table to a reasonable level and further to take steps to keep it so. The procedure adopted to achieve this is the instalation of tubewells to lift the subsurface water to the surface and thence to be used for irrigation. This water is occasionally of saline nature and can be utilized onlyfor irrigation after mixing with fresh canal water. Generally the results of such a supplementation have not been encouraging.

The above choice of water-logging control involves colossal amount of money in the form of technology, material, energy and man-power, leaving aside the development of other infrastructural components essential to such an undertaking. Also the operational and maintenance costs of such projects are fairly high and recurrent. At the same time the life of such tubewells is generally not more than 5 to 6 years after which they become repairable or in most cases unworkable. Then, again, the process of replacement or reinstalation has to begin. This way the cycle reinstalation will have to be started and completed again. This is shown by data given in Table I.

TABLE 1

Statistical Data pertaining to Rechna Doab

Sr. No.	Project	Period of construction years.	No. of Tubewells	Installed capacity cusecs	Capital Cost (Rs. million)	Tubewells replaced in phase-I	Cost of tubewells replaced in phase-I (Rs. million)	No. of tubewells to be replaced in phase-II	Estimated cost of tube-wells to be replaced phase-II (Rs. million)
1	SCARP-I	3/59 to 11/62	2069	6033	240.0	475	118.57	223	74.74
2	SCARP-IV	6/67 to 6/74	935	3785	310.98	104	25.96	162	54.29
3	S. Kamalia	12/75 to 10/77	101	169	61.21	—	—	—	—
4	Satiana	3/76 to 6/77	71	140	36.927	—	—	—	—

Data provided by WAPDA information Cell.

Now the question is how long nation can afford policy of injecting huge amounts into the deep or some rethinking should have to be done. Here rethinking seems to be the prime need as this process is already proving very costly— rather an unbearable burden for the country.

It is also believed that tubewell strategy may also bring in its wake some unmanageable situation. This may result in greater infiltration of water especially of rain, in areas flooded by rivers. It may also have induced greater seepage from canals and rivers. This infact has resulted in an appreciable increase of the annual potential ground water recharge. This might be due to speedy increace in potential difference between the surface sources and ground water. Therefore it seems imperative to adopt some other methods instead of tubewell procedure.

It is, therefore, essential that the water-logging control programme should be reshaped and methodology be changed to reduce the recharging of underground reservoirs to the minimum. This should help the drain of stored water in such a way that it should show gradual lowering of water. Only in this way a lasting potential balance can be achieved.

The Map (Fig. 3) shows the approximate extent of highly permeable zones of the Doab. The Map also shows traversing of main canals and their distributaries. The existing drains and proposed drains also have been shown in the Map. The Map divides the whole Doab into 4 categories. The Highest and High permeability are situated alongside left bank of the Chenab river and extends SW-wards fairly over a long distance. Regions of medium and low permeability lie further towards the Ravi river. Also general subterranean water flow is shown in Map (Fig. 2). Keeping these two facts in view, it would be possible to design and organize draining efforts keeping in view the general subterranean flow. The bogged and water-logged area can only be drained toward the Ravi river. Fig. 3 also shows the drains established in the nineteen thirties. These drains are obviously inadequate in number and extent and also less deep as required for effective draining.

It is esrential, therefore, that in the light of the above facts it would be useful, and is also feasible by virtue of the available modern technology, to try to orgaize efforts on the same basis. The existing drains should be cleared and deepened. Further attention should be paid to provide more drains in all the Highest and High permeability regions. The adequately placed drains will help to provide permanent outlet for the subsurface aquifers. Also, once established, will demand minimum funds and other resources for their upkeep. There is every reason to believe that 'below level' drains not only will reduce the recharge rate of the subterranean pools but may help also to reduce their size. It is imparative that the drain channels be given a depth after careful investigation. For this purpose numerous completed investigations exist and only there is a need to scrutinise them carefully. It is believed that if a "dig-in" depth is maintained at 6 meters then the situation will become stable. This will provide fairly good slope to underground water. The under surface level then may become static and stable at about 4, 5 meters of depth. This will provide more than sufficiently safe distance to keep the manace from root-depth of crops and even secondary growth etc.

The most economical and effective will be to utilize the old abondened river beds. Their extent and direction in relation to the affected areas, which they will drain, is visible from the Map (Fig. 2). Leaving aside the active flood plain of river Ravi, rest of the doab is suitably covered be four such abondened river-bed lines. If these lines are followed than a set of 4 major channels can be established. All the existing secondary and new drains can be connected with them. In this way a reliable system of drain-channels will come into existence which will assure an adequate and long lasting solution to the water-logging problem.

There is strong evidence to believe that 'dig-in' drains will provide solution to the problem ; such as the link canals, being "dug-in', are acting as antilogging factors. For example, the Qadirabad link canal has proved so in the Jaranwala district where water logging has disappeared. This is also visible in other regions through which other link canals pass. Also the Highest and High permeable regions (Fig. 3), through which major cannals and some of the important tributary channels pass, are manageably extensive. Here lining of canals, partially or wholy can be undertaken. This will decidedly help to plug the high seepage zones. In the present age it will not be difficult to manufacture tiles mechanically from suitably chosen soil material. Thus concluding the above discussion, the establishment of drains along suitable lines and plugging of high seepage together will help to reduce the sinking of water to a large extent. The best way to achieve this is that a part of the resources meant for tubewells be diverted towards this work and gradually increased. This way a lasting control of the menace can be achieved. Surely th e tubewells are not and can not offer a lasting solution to the problem.

Fig_1

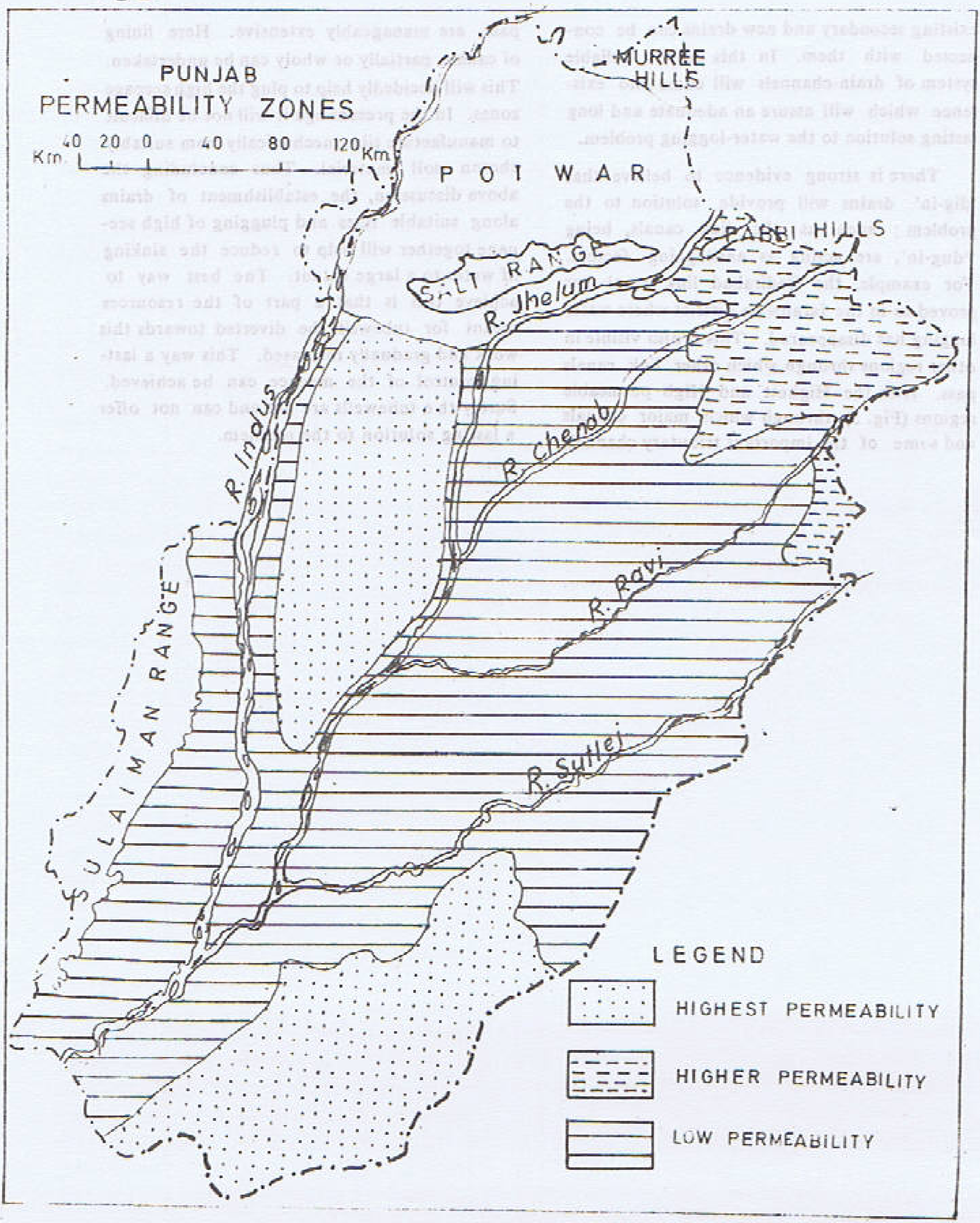
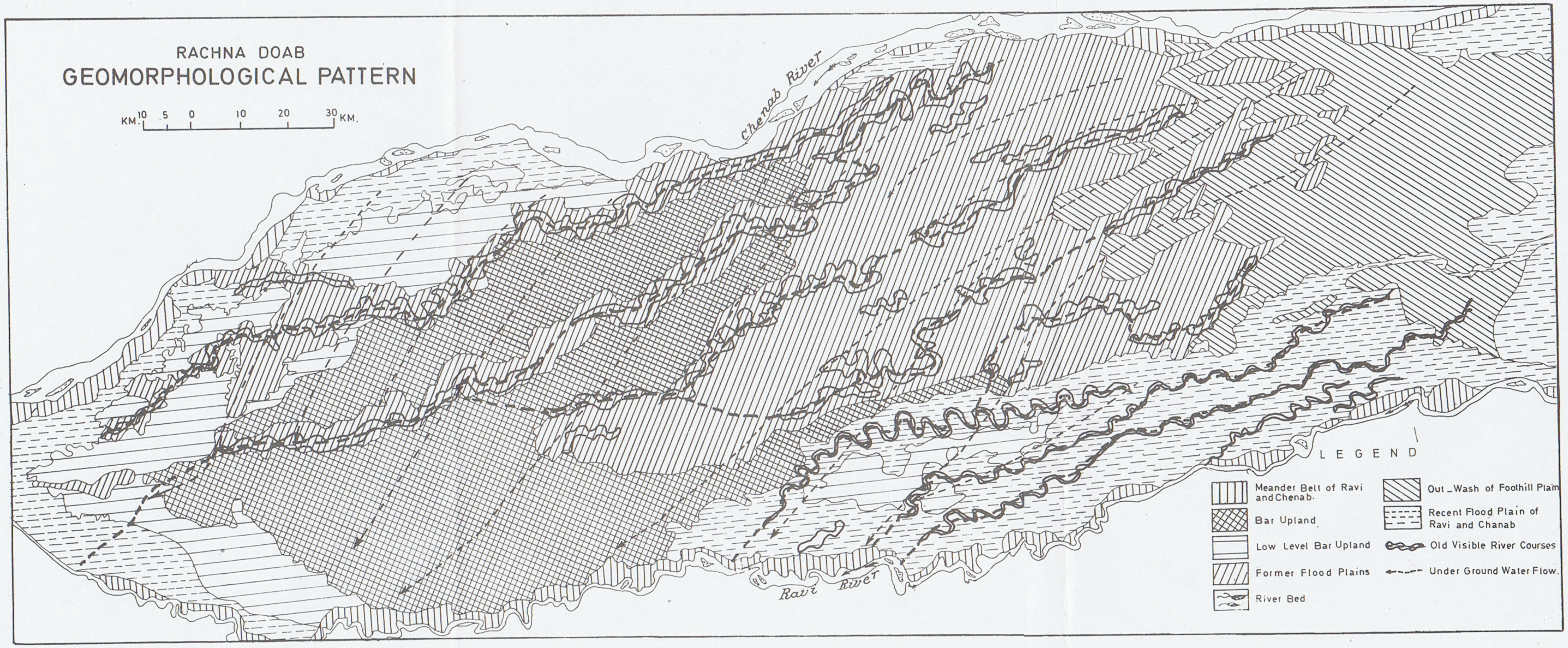
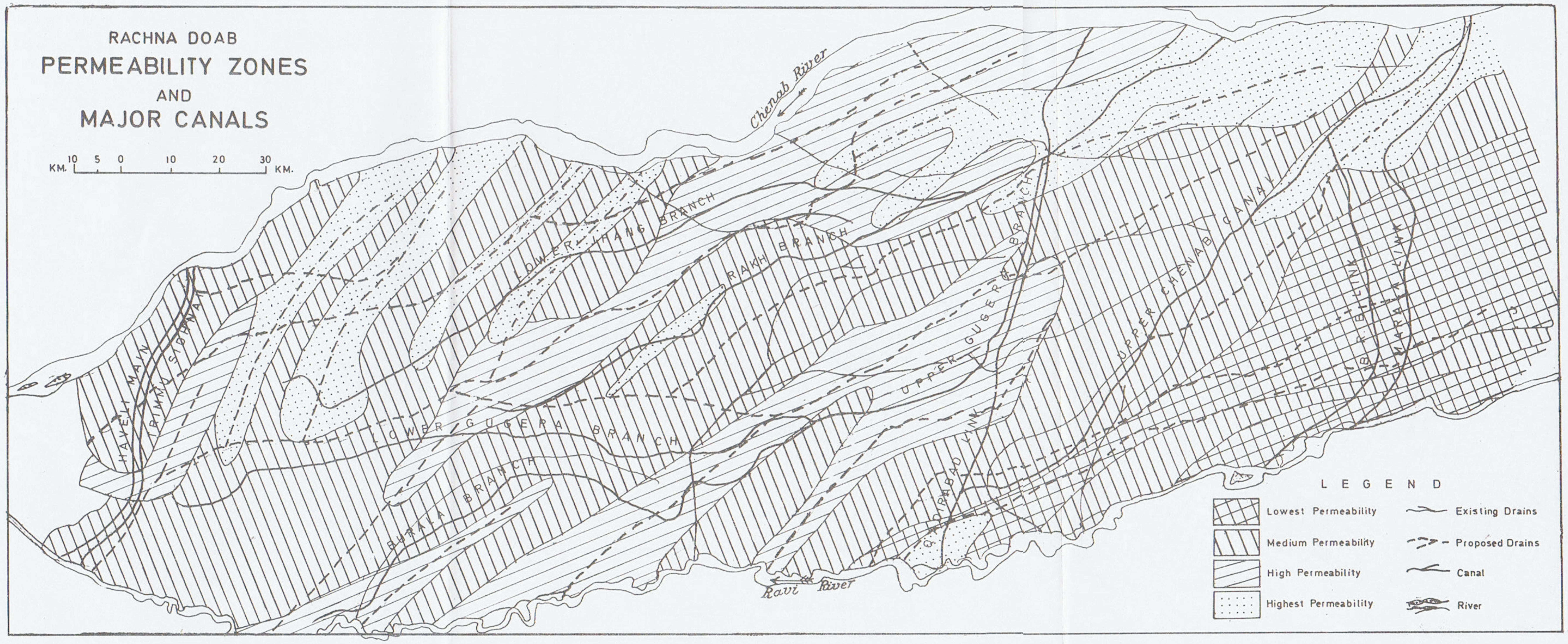

PUNJAB
PERMEABILITY ZONES
40 20 0 40 80 120
Km. Km.
POTWAR
MURREE HILLS
KABBI HILLS
SALT RANGE
R. Jhelum
R. Indus
R. Chenab
R. Ravi
R. Sutlej
SULAIMAN RANGE
LEGEND
HIGHEST PERMEABILITY
HIGHER PERMEABILITY
LOW PERMEABILITY

FIG _2 57


RACHNA DOAB
GEOMORPHOLOGICAL PATTERN
KM. 10 5 0 10 20 30 KM.
Chenab River
Ravi River
LEGEND
Meander Belt of Ravi and Chenab.
Bar Upland
Low Level Bar Upland
Former Flood Plains
River Bed
Out _Wash of Foothill Plain
Recent Flood Plain of Ravi and Chanab
Old Visible River Courses
Under Ground Water Flow.


RACHNA DOAB
PERMEABILITY ZONES
AND
MAJOR CANALS
KM. 10 5 0 10 20 30 KM.
Chenab River
Ravi River
LOWER JHANG BRANCH
RAKH BRANCH
LOWER GUGERA BRANCH
BURALA BRANCH
UPPER GUGERA BRANCH
UPPER CHENAB CANAL
QADIRABAD LINK
HAVELI MAIN
RIMMU SIDHNAI
B.R.B.D. LINK
MARALA RAVI LINK
LEGEND
Lowest Permeability
Medium Permeability
High Permeability
Highest Permeability
Existing Drains
Proposed Drains
Canal
River

REFERENCES

Geological Survey of Pakistan, Vol. X Part-3 Plates, 1,4,6 Fig. 6, p 20, p 8.

Statistical Data pertaining to Rechna Doab, Tubewells, WAPDA.

Geological Survey of Pakistan Table 1, Vol. X, Part-3, Plates, 5, 6 and 7.

Kazmi, A.H. 1964 Report on the Geology and groundwater Investigations in Rechna Doab, West Pakistan.

Auden, J.B. 1950 Introductory report on the Groundwater resources of Western Rajestan, *Geol. Surv. India Bull.* Ser. B, 1.

Bowoer, W.E. 1954 Report of the Govt. of Pakistan on Soil Survey and Land use., F.A.O. Report No. 315, Rome.

E , H.M. 1910 The Influence of earth's relation upon the lateral erosion of streams. *Jour. Geology*, Vol. 18, 435—442.

Glemie, E.A., 1936, 1938 Subsoil water levels Survey of India, Geol. Report.

Heron, A.M. 1913 The Kirana and other hills in Ghaj and Rechna Doab. *Geol. Survey of India, Recs*, Vol. 53.

Khan, A M. and Gilani, M.A.S. 1959 Earth resistivity Survey in Rechna Doab.

Wadia, D.N. 1949 Geol. of India, London.

WAPDA, 1959 Report on salinity control add water logging, Project No. 1, Water and Power Dev. Auth, West Pakistan, Lahore.

Wilsdon, B.H., and Base, N.K., 1934 A Gravitational Survey of the Sub-alluvium of the Jhelum-Chenab- Ravi Doabs and its application to problems of water logging, Punjab Irrigation Res. Inst. 6, No. 1.

COMPARISON OF THE UPPER DEVONIAN MIOSPORE ASSEMBLAGES OF NEW YORK STATE AND PENNSYLVANIA WITH DIFFERENT AREAS OF THE WORLD

BY

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Abstract : *An attempt is made to correlate the miospore assemblages recovered from the Upper Devonian strata of New York State and Pennsylvania U.S.A. with those known from sediments of similar age elsewhere. The areas with which comparison is made are Belgium, the British Isles, North Africa, Poland, U.S.S R. and Australia.*

Samples from four formations namely the Java, Canadaway, Chadakoin and Cattaraugus have been investigated. The lithology of the material composed of shale, silstone and silty sandstone (the study of which) yielded very promising results.

INTRODUCTION

External correlation is afforded by strikingly close similarity between the microfloras discovered during the present investigation and those reported previously from the Upper Devonian of other parts of the world. Detailed correlation of these Famennian deposits with those from North America, Western Europe and Australia shows that *Vallatisporites vallatus* var. *hystricosus* and *Retispora lepidophyta* appear in the same horizon in Famennian (approximately at the base of Fa2d) in the area investigaed as in other sequences so far described from northern and southern hemispheres. Inter-regional correlation based on miospore assemblages has indicated that the Dexterville Member of the Chadakoin Formation is equivalent to the Evieux beds ; whilst the Ellicott Member, of the Chadakoin Formation, and overlying Cattaraugus Formation are probably coeval stratigraphically to the Comblain-Au-Pont beds of Belgium (Table 1). In terms of Belgian substages, the age of the strata investigated is shown to range from F3 to Fa2d (Upper Frasnian to middle Famennian in terms of standard European stages). In terms of North American nomenclature, the series range in age from Upper Senecan to Chautauquan.

DESCRIPTION AND COMPARISON

Belgium

In 1974 Streel (in Becker *et al.*) established six 'florizones' of the Upper Frasnian to Lower Tournaisian (Fr-Tn1a) sediments of Belgium. With some reservations the present palynological data (Upper Frasnian to Upper Famennian) seem to fit the Streel's assemblages. Some of the Belgian species are important quantitatively in the Belgian strata and are also well-represented in New York State and Pennsylvania. For instance *Aneurospora greggsii* is well-represented almost throughout the sequences in both the U.S.A. and Belgium. Miospores with multifurcate processes and laevigate spores with "banded" curvatuarae e.g. *Aneurospora incohata* are present in the U.S.A. and Streel's assemblages. *Synorisporites variegatus* Sarfraz (1978) (under the name *Rugospora flexuosa*) has been frequently recorded as almost being restricted to the Upper Famennian horizon in Belgium as well as in the area presently under investigation.

The miospore assemblages reported by Streel from the Matagne Barvaux beds, are similar to those described from the Java Formation of New York State. The following species are regarded to be coeval stratigraphically in both areas. *Punctatisporites glaber*, *Aneurospora greggsii*, *Apiculiretusispora plicata ?* *Samarisporites inusitatus* and miospores with multifurcate processes. This assemblage conforms with LT assemblage zone of Streel and indicates the Upper Frasnian age (Table 1).

The overlving Senzeilles—Montfort beds of Belgium yielded, in addition, *Aneurospora incohata. A. greggsii* var. *minuta* Sarfraz (1978) (as *Geminospora sva bardiae*), *Samarisporites kedoae* (as S. sp. cf. *H. acanthyrugosus*). *Auroraspora solisorta* and *Ancyrospora acadensis* Sarfraz (1978) (as *A. langii*). The presence of these species in the Canadaway Formation of New York State may indicate that the GP-GM zones of Streel correlate with the Canadaway Formation and indicate Fa1a-Fa2b ages. From the overlying Evieux beds of Belgium, Streel recorded *Pulvinispora depressa*, *Retusotriletes caperatus* (as R. sp.) *Synorisporites variegatus* (as *Rugospora flexuosa*), and *Grandispora cornuta* (as *G.* cf. *uncata*). This assemblage which has been described by the present author from the Dexterville member of New York State conforms with the VU zone of Streel indicating the Upper Famennian Fa2c age.

The presence of the internationally recognized fossils *Vallatisporites vallatus* var. *hystricosus* and *Retispora lepidophyta* in the Chadakoin and Cattaraugus Formations of New York State and Pennsylvania, indicates that the latter are probably startigraphically equivalent to the Comblain-Au-Pont beds of Belgium. This assemblage corresponds to the PLi zone of Streel and indicates the Upper Famennian Fa2d age.

In short, of a total of 26 form genera recorded by Streel, 23 have been recorded during the present investigation At the specific level, 70 miospore forms were observed from the Belgian Upper Devonian, of these 25 are present in the material investigated from New York State and Pennsylvania. U. S. A. Four species are regarded to be endemic to the Belgian Upper Devonian (see Table 2). A striking dissimilarity in terms of miospore assemblages between these two areas is in the absence of distinctive large pseudosaccate forms such as *Aurorasoora torquata* and *Auroraspora pseudocrista* Sarfraz (1980) in the Belgian strata. The former has been abundantly reported from south-east Ireland.

The British Isles

Clayton *et al.* (1974) described miospore assemblages from the lower part of the Cork Beds of southern Ireland. Their assemblage of "type 1" is almost comparable with the HL zone described from the present material, Sarfraz (1978). In addition to index forms some stratigraphically important species are also present, not seen in Irish material described by Clayton *et al.* Those forms are as follows : *Ancyrospora multifurcata* (Winslow) Sarfraz (1978), *Auroraspora pseudocrista*. *Auroraspora torquata*. Other accessory species have been described by the present author, see Sarfraz (1978). The miospore assemblage obtained from the Cattaraugus Formation compares with the assemblage described from Breamrock and Holeopen Members from Old Head of Kinsale section, Killowen and Carrigadda Member from South Ringabella section and Fennels Bay Member of North Ringabella section in southern Ireland.

Higgs (1975) gave an account of miospore assemblages from Hook Head, County Wexford, Upper Devonian and Lower Carboiferons transition beds of southeast Ireland. On the basis of selected records he recognized three palynological assemblages. Miospores described from sample K and J in his first assemblage cover approximately the HL zone of the present material. The taxa in common are shown by Sarfraz (1978).

On the basis of *Retispora lepidophyta, Vallatisporites vallatus* var. *hystricosus, Aneurospora inchoata, Streelispora catinata, Knoxisporites literatus, Synorisporites variegatus* Sarfraz (1978) *Auroraspora torquata, A. versabilis, A. commutata and A. poljessica* our miospore assemblage assigned to the HL zone may probably lie somewhere approximately 80m. below the top of the Old Red Sandstone in Ireland. The upper sequence of the HL zone in the investigated area is also more or less similar to the HL (PL) zone assemblage at Burrington Combe in the Mendip Hills, England and to the West Angle Bay, South Wales recorded by Dolby (1970) In these areas our HL zone can possibly be compared with assemblages from approximately 7 and 13m. below the base of the Lower Limestone Shales.

Utting and Neves (1970) also investigated the palynology of the Lower Limestone Shale Group (Basal Carboniferous Limestone Shale) and Portishead Beds (Upper Old Red Sandstone) of the Avon Gorge, Bristol, England. Their assemblages 3 recognized in sediments from the Portishead beds approximately 37.5m. below the *Rhacophyton* Beds compares closely with moispore assemblage HL described from New York State and Pennsylvania, U.S.A. The species in common include *Ancyrospora multifurcata, Retispora lepidophyta, Synorisporites flexuosus, Aneurospora incohata* and *Retusotriletes incohatus.*

Among the lowest two zones (PL and NV) proposed by Neves *et al.* (1972) which were based mainly on the work of Neves and Dolby (1967), Dolby (1970), Dolby and Neves (1970) and Utting and Neves (1970) from the British Isles, our HL zone probably compares with their lowest PL assemblage zone.

British workers recorded altogether 43 moispore species from the Upper Devonian deposits ; of these 26 have been recorded from New York State and Pennsylvania, U S.A. Five species are considered to be endemic to the British Upper Devonian deposits, see table 2.

Poland

Polish assemblages do not have any great points of similarility with the Upper Devonian miospores from the areas under consideration. However, Turnau's (1975) assemblage 4 reported from the northern Poland, is more or less comparable with the HL zone described in the present work. The Upper Devonian miopore assemblages from the U.S A. and North Poland are characterized by the presence of *Retispora lepidophyta, Auroraspora versabilis, Aneurospora incohata,* and *Punctatisporites solidus.*

The miospore species that occurred in the Polish Tournaisian sediments but have been observed from the Upper Devonian deposits during the present investigation are *Punctatisporites glaber, P. stabilis, Aneurospora greggsii, Knoxisporites literatus, K. pristinus, Auroraspora micromanifesta* and miospores with multifurcate spines.

A striking difference is in the absence of distinctive species *Synorisporites flexuosus* in Turnau's assemblages.

Of the eleven miospore forms reported from the Polish Upper Devonian deposits, only four have been regarded as common to both the U.S.A. and Polish assemblages. Only one species is considered to be endemic to the Polish Upper Devonian sediments table 2.

Soviet Union

Detailed comparative studies of miospore assemblages from various parts of the U.S.S.R. are hampered by the independent nomenclatural system used in the Soviet Union, the poor (inadequate) description of microfossils and the nature of their illustrations and the time taken for Russian publications to become available outside the U.S.S.R. especially as translations.

Despite the above difficulties, a number of distinctive miospore species have been encountered from the area under consideration which can be compared with those documented in the Russian publications.

The first important and major work to be published was that of Naumova (1953). She described eight miospore assemblages from the Upper Frasnian and Famennian deposits of the Russian Platform four corresponding to the Frasnian and the rest from the Famennian. In general there is little similarity between the composition of the Russian (Naumova's) assemblages and those recorded from the present material. It has been observed that a close similarity exists between miospores with pseudosaccate structural organization. Nevertheless, simple laevigate and cingulate forms also occur in both areas. The following species recorded by Naumova have been encountered from Chadakoin and Cattaraugus Formations during the present investigation. *Lophozonotriletes curvatus*, *Auroraspora varia* and *Grandispora echinula*. Two species described by Naumova *Hymenozonotriletes rugosus* and *H. platrugosus* are thought to be comparable with *Auroraspora varia* var. *multifaria*.

Anchor spined miospores have been recorded in the Russian literature (reported from the Russian Platform and the Pripyat Depression), but none are regarded to be idential with the present forms. However, the nature of sculptural pattern developed on the miospores from both areas is worthy of special mention.

The next major work was that of Kedo (1957a, b, 1962, 1963), and Goloubtsov *et al.* (1968). Kedo and co-authors established fourteen miospore suites from the Pripyat Depression of Bielorussia S.S.R. The strata they investigated range in age from lower Famennian to Upper Tournaisian. Six miospore assemblages belonging to the Zadonsk, Elitsk, Lebedian, Dankov and Ozersk Khoransk Formations are in Famennian and the remaining eight are confined to three units belonging to the Tournaisian namely, Malevka, Cherepet and Kizel Formations. Following Naumova, Kedo established most of her miospore "complexes" on the relative abundance of certain species rather than on those forms with restricted vertical range.

In terms of miospore content the Russian stratigraphical units from the Zadonsk Formation to Upper Dankov Lebsdian Formation in the Pripyat Depression are comparable with the Canadaway to Cattaraugus Formations exposed at New York State and Pennsylvania, U.S.A.

Although all kinds of miospores have been observed in both areas, those possessing pseudosaccate structural organization are more common than the others. The following species are regarded as similar in both area. *Auroraspora varia*, *A. commutata*, *A. versabilis*, *A. poljessica*, *Retispora lepidophyta*, *Grandispora echinula* and *Lophozonotriletes curvatus*.

There are also some varied elements including smooth, cingulate and pseudosaccate miospores which have been encountered in the Famennian deposits during the present study that are confined to the Tournaisian strata in the Pripyat Depression. Those forms are : *Calamospora nigrata*, ? *Dictyotriletes trivialis*, *Knoxisporites literatus*, *Valatisporites vallatus* var. *hystricosus*, *V. vallatus* var. *major*, *Grandispora macroseta*, *Auroraspora pallida* and *A. submirabilis*.

The absence of miospores with banded

curvaturae such as *Aneurospora greggsii* and species with multifurcate appendages in the Russian deposits is a characteristic difference. Both of these forms have frequently been encountered during the present study and from other parts of the nothern hemisphere.

It may be that some of the anomalies in the distribution of these elements may be more apparent than real.

North Africa

Massa & Moreau-Benoit (1976) pubished an account of Devonian palynology western Libya, Rhadames Basin. At the generic level a broad similarity exists between the miospore assemblages from Libya and that of U.S.A. Of the 33 forms genera recorded during the present investigation, 28 are common to both continents. Twenty-two miospore forms are considered to be identical to both areas. Eleven species are regarded to be endemic to the Libyan Upper Devonian deposits, table 2. The miospore species that make their first appearance below the Fransnian in Libya but range sporadically up to the Famennian in both are ; *Retusotriletes goensis*, *Aneurospora greggsii* var. *minuta* (as *Geminospora svalbardiae*), *Apiculiretusispora plicata*, *Emphanisporites rotatus*, *E.* cf. *annulatus*, *Auroraspora micromanifesta*, *Rhabdosporites langi* and *R. parvulus*.

In a broad sense palynological zone eleven investigated from the Tahara Formation is more or less comparable with the HL zone described in this work. Miospore zones nine and ten described from Aouinet Ouenine IV Formation are probably identical to the FV zone shown herein (Table 1). However, the absence of major difference. *S. flexuosus* makes its stratigraphyical debut together with *V. vallatus* var. *hystricosus* and *R. lepidophyta* in the Libyan sediments. Miospores with mutifurcata processes have also been observed in Libyan deposits, see Paris *et al.* (1985).

In summary, Massa & Moreau-Benoit's palynological zones 8-11, though differing slightly in accessory elements, can be compared with Java-Cattauraugus Formations investigated during the present study.

Australia

Balme & Hassell (1962) published on the palynology of the Upper Devonian of Canning Basin, Western Australia. They made an attempt to correlate their material with Libyan latest Devonian sediments and with the Famennian assemblages from the Russian Platform described by Naumova (1953). The absence of apparent *Retispora lepidophyta* in the latter assemblage probably indicates strata older than the Australian material. Since no miospore assemblages from Upper Devonian strata of other parts of northern hemisphere had been described at that time in the literature no comparison could be made by these authors.

On the whole Australian assemblages do not have any great points of similarity with the Upper Devonian miospores from New York State and Pennsylvania, U.S.A. However, twenty two genera were recovered by Balme & Hassell and the miospores attributed to eleven genera are common to the two continents.

At the specific level apart from *Retispora lepidophyta*, *Pulvinispora depressa* and probably *Hystricosporites* sp. cf. *H. porrectus*, no other similar form was encountered in the material under consideration. Apart from *Hystricosporites* sp. aff. *H. porrectus* which is probahly not identical to Australian species, the association of the above forms suggests that Australian miospore assemblages are comparable with those assemblages confined between the top of the FV and almost top of the HL zone in the present material (Table 1). If one includes *Hystricosporites* sp. aff. *H. porrectus* within the morphographic circumscription of Balme & Hassell's species the range of the Australian miospore assemblages covers almost the entire stratigraphic range of the miospore species recorded from New York State and Pennsylvania, U.S.A.

By far the most comprehensive and up to date published palynological report on western Australian sediments is that of Playford (1976). In fact Playford enlarged on Balme & Hassell's (1962) observations by re-examining core sample Nos. 17 and 18 from borehole B.M.R. 2, Laurel Downs, in the Fairfield Formation. The samples he investigated ranged from Upper Devonian to Lower Carboniferous and came from the marine (shallow water) sediments of the Fairfield Formation in the Canning Basin. The litholgy comprised biogenic limestone and calcareous clastic sediments.

The Upper Devonian (Fa2d) microfloras, (*Retispora lepidophyta* assemblage described by Playford) bear only a superficial resemblance to the HL zone in New York State and Pennsylvania, U.S.A. investigated in the present work (Table 1).

The species which are infrequently associated with index forms in both areas (U.S.A. and western Australian) include *Pulvinispora depressa*, *Knoxisporites literatus*, *K. pristinus* and *Auroraspora micromanifesta*.

It is of interest to note that Playford (loc. cit.) did not include in his systematics or in his range chart, simple, leavigate taxa such as *Calamospora*, *Leiotriletes* and *Punctatisporites*. This was because of their insignificant stratigraphical value and scarcity in his samples. The genus *Retusotriletes* is represented by only two new species which have not been encountered during the course of the present study. Comparison has, therefore, not been made with such smooth and/or laevigate groups of miospores.

The absence of *Vallatisporites vallatus* var. *hystricosus* in Balme & Hassell's (1962) report and only two more or less similar representatives, in Playford's assemblage may indicate that such miospore forms, if present, are not abundant in the Australian sediments.

The most obvious difference between the present material and the Australian sediments is in the absence of miospores with multifurcate processes and a distinctive species *Synorisporites flexuosus* in the miospore assemblages reported from western Australia.

Blame & Hassell and Playford recorded altogether 53 miospore species from Devonian deposits ; of these only 8 have been recorded from the material under investigation. Twenty-four species are regarded to be endemic to the Australian Upper Devonian (Table 2).

CONCLUSION

Detailed comparative study has been undertaken to delineate the floral provinces in the Upper Devonian sediments. It is not intended to provide a complete check list of the miospore species that are found ubiquitous to the Upper Devonian strata in the northern and southern hamisphere since these have been dealt with in detail by the present author (Sarfraz 1985). However, some forms are regarded to be endemic to the Australian material. The miospore form *Granulatisporites frustulentus* is found to be most abundant and persistant of the endemic forms of the Australian miospores. Consequently the miospore assemblage reported from Australian continent is referred to as the *Frustulentus suits* (Sarfraz 1985).

As will be evident from table 2 that so far 53 miospore forms have been reported from the Upper Devonian deposits of Australia ; of these only 8 are considered comparable with the miospore discovered from the material of New York State and Pennsylnanica. Twenty species are regarded to be endemic to the Upper Devonian of the Australian deposits.

It can be concluded the miospore records from western Europe and North Africa mirror those of U.S.A. and Canada. The presence of miospore having multifurcate spines seems to be cosmopolitan in these sediments.

It is worth mentioning that the miospore assemblages described from the Soviet regions do not contain any additional elements. In contrast the Soviet areas are characterized in negative sense as they do not possess distinctive forms with multifurcate appendages. At the present state of knowledge the miospore assemblage revealed from the U.S.S.R. may conveniently be grouped with those miospore assemblages discovered from western Europe, North Africa and North America.

In fact the Australian deposits do not have any additional element with multifurcate processes. The miospores from Australian continent are distinguished by the profusely represented endemic form *Granulatisporites frustulentus* which has not been recorded in any of the areas outside Australia.

The results of miospore investigations into North Africa, North America, western Europe (including Belgium, the British Isles and Poland) U.S.S.R. and Australia signal that palynologically Australia is probably a distinct continent. However, a minority of indiginous elements in the Australian sediments e.g. *Granulatisporites frustulentus*, *Convolutispora fromensis* and *Diaphanospora riciniata* is hardly sufficient to warrant the term province (Middlemiss *et al.*, 1971) unless more data on the Upper Devonian miospore are accumulated, floral province is difficult to delineate.

In the author's opinion widespread occurence of particular species in the Australian material such as *Retispora lepidophyta*, *Knoxisporites literatus* *K. pristinus*, *Auroraspora micro-manifesta*, *Pulvinispora depressa*, *Hystricosporites porrectus*, *Punctatisporites solidus* that have also been reported from northern hemisphere indicate the provincialism in the Upper Devonian is difficult to interpret.

The lack of floral provinces may also be attributed to uniformity of environments throughout the world. In adequate sample coverage may be another reason for the results obtained so far.

Miospore Zones	NEW YORK STATE & PENNSYLVANIA PRESENT WORK: Formation	Member	BELGIUM STREEL 1974: Stratigraphic units	Subdivision of stage	Spore 'Horizons'	THE BRITISH ISLES HIGGS 1975	NORTH AFRICA MASSA ET AL 1976	POLAND TURNAU 1975	U S S R: PRIPYAT DEPRESSION KEDO 1962	U S S R: RUSSIAN PLATFORM NAUMOVA 1953	AUSTRALIA PLAYFORD 1976
HL	CATTARAUGUS	Undifferentiated	Comblain - Au - Pont	Fa2d	HL (PL)	Old Red Sandstone facies	Tahara Formation Zone Eleven	Babilon 1 borehole	Dankov ?	Dankov-Lebedian	Fairfield Formation
	CHADAKOIN	Ellicott							Lebedian	?	
FV		Dextervi-lle	Evieux	Fa2c	VU		Aouinet Ouenine IV			Agramatch	?
	CANADAWAY	Northeast	Montfort	Fa2b	GM		Zone Nine & Ten		Eletsk		
		Shumla							?	?	?
		Westfield		Fa2a	GH	?					
		Laona		Fa1b							
CN		Gowanda						?	Zadonsk	Zadonsk	Napier Formation
		South Wales	Senzeilles	Fa1a	GP		Aouinet Ouenine III				
		Dunkirk				?	Zone Eight				
	JAVA	Hannover	Matagne	Fr	LT						
?		Pipe creek	barvaux								

Table .1. A correlation of the Upper Devonian sequences of New York State and Pennsylvania with those from other parts of the world, based on miospore assemblages.

REFERENCES

Blame, B.E. & Hassell, C.W., 1962. Upper Devonian spores from the Canning Basin, Western Australia. *Micropalaeontology*, 8 1-28.

Clayton, G., Higgs, K, Gueinin, K.J. & Van Gelder, A., 1974. Palynological correlations in the Cork Beds (Upper Devonian-Upper Carboniferous) of southern Ireland. *Proc. R. Ir. Acad.* 74 B : 145-155.

Dolby, G., 1970. Score assemblages from the Devonian-Carboniferous transition measures in south-west Britain and southern Eire. *Congres et Colloques Univ. Liege.* 55 : 267-274.

Dolby, G. & Neves, R., 1970. Palynological evidence concerning the Devonian-Carboniferous boundary in the Mendips, England. *C. r. 6th Cong. Avanc. Etud. Strauger. Geol. Carb., Sheffield* 1967, 2 : 631-646.

Goloubtsov, V.K. ; Krylova A.K. ; Lutkevich, E.M. & Makhnatch, A.S., 1968. Le Devouian de la Bielorussia. *Proc. Int. Symp. Devonian system. Calgary* 1967 : 367-377.

Higgs, K., 1975. Upper Devonian and Lower Carboniferous miospore assemblages from Hook Head, Country Wexford, Ireland. *Micropuleantology*, 21 (4) : 393—419.

Kedo, G.I., 1957a. Stratigraphic signicance of *Hymenozonotriletes pusillites* sp. n. *Dokl. Akad. Nauk. BSSR.* 1 : 21-23. (In Russian).

—, 1957b. Spores from the supra-salt Devonian deposits of the Pripyat Depression and their stratigraphical significance. *Rep. Palaeont. Strat. Byelorussian SSR*, 2 : 3-43. (pp. 1-69 English Translation).

—, 1962. Spore assemblages of Upper Famennian and Turnian deposits and the border of Devonian and Carbonian in the Pripyat Depression. *Trans. Soveit Palynologists, Acad. Sci. Moscow.* pp. 73-79.

—, 1963. Spores of the Tournaisian stage of the Pripyat Basin and their stratigraphic significance.—*Rep. Palaeont. Strat. Byelorussian SSR*, 4 : 3-121. (In Russian).

Massa, D. & Moreau-Benoit, A., 1976. Essai de synthese stratigraphique et palynologique du system Devonian en Libye occidentale.—*Revue de L'institut Francais du Petrol.* 31 (2) : 287-333.

Middlemiss, F.A., Rawson, P.F. and Newall, G., 1971. Faunal Provinces in space and time. *Seel House Press, Liverpool.*

Naumova, S.N., 1953. Spore-pollen assemblages of the Upper Devonian of the Russian Platform and their stratigraphic significance.—*Trans. Inst. Geol. Sci., Acad. Sci. U.S.S.R.* 143 (Geol. Ser. 60) : 204 pp. (In Russian), 128 pp. French Trans.).

Neves, R. & Dolby, G., 1967. An assemblage of miospores from the Portishead Beds (Upper Old Red Sandstone) of the Mendip Hills, England.—*Pollen et Spores*, 1 (3) : 607-614.

Guein, K.J. ; Clayton, G. ; Ioannides. N & Neville. R. S. W., 1972.—A scheme of miospore zones for the British Dinantian —*C. r. 7th Cong. Avanc. Etud. Straugr Geol. Carb., Krefeld* (1971). (1) : 347-353.

REFERENCES

Blame, B.E. & Hassell, C.W., 1962. Upper Devonian spores from the Canning Basin, Western Australia. *Micropalaeontology*, 8 1-28.

Clayton, G., Higgs, K, Gueinin, K.J. & Van Gelder, A., 1974. Palynological correlations in the Cork Beds (Upper Devonian-Upper Carboniferous) of southern Ireland. *Proc. R. Ir. Acad.* 74 B : 145-155.

Dolby, G., 1970. Score assemblages from the Devonian-Carboniferous transition measures in south-west Britain and southern Eire. *Congres et Colloques Univ. Liege.* 55 : 267-274.

Dolby, G. & Neves, R., 1970. Palynological evidence concerning the Devonian-Carboniferous boundary in the Mendips, England. *C. r. 6th Cong. Avanc. Etud. Strauger. Geol. Carb., Sheffield* 1967, 2 : 631-646.

Goloubtsov, V.K. ; Krylova A.K. ; Lutkevich, E.M. & Makhnatch, A.S., 1968. Le Devouian de la Bielorussia. *Proc. Int. Symp. Devonian system. Calgary* 1967 : 367-377.

Higgs, K., 1975. Upper Devonian and Lower Carboniferous miospore assemblages from Hook Head, Country Wexford, Ireland. *Micropaleantology*, 21 (4) : 393—419.

Kedo, G.I., 1957a. Stratigraphic signicance of *Hymenozonotriletes pusillites* sp. n. *Dokl. Akad. Nauk. BSSR.* 1 : 21-23. (In Russian).

—, 1957b. Spores from the supra-salt Devonian deposits of the Pripyat Depression and their stratigraphical significance. *Rep. Palaeont. Strat. Byelorussian SSR*, 2 : 3-43. (pp. 1-69 English Translation).

—, 1962. Spore assemblages of Upper Famennian and Turnian deposits and the border of Devonian and Carbonian in the Pripyat Depression. *Trans. Soveit Palynologists, Acad. Sci. Moscow.* pp. 73-79.

—, 1963. Spores of the Tournaisian stage of the Pripyat Basin and their stratigraphic significance.—*Rep. Palaeont. Strat. Byelorussian SSR*, 4 : 3-121. (In Russian).

Massa, D. & Moreau-Benoit, A., 1976. Essai de synthese stratigraphique et palynologique du system Devonian en Libye occidentale.—*Revue de L'institut Francais du Petrol.* 31 (2) : 287-333.

Middlemiss, F.A., Rawson, P.F. and Newall, G., 1971. Faunal Provinces in space and time. *Seel House Press, Liverpool.*

Naumova, S.N., 1953. Spore-pollen assemblages of the Upper Devonian of the Russian Platform and their stratigraphic significance.—*Trans. Inst. Geol. Sci., Acad. Sci. U.S.S.R.* 143 (Geol. Ser. 60) : 204 pp. (In Russian), 128 pp. French Trans.).

Neves, R. & Dolby, G., 1967. An assemblage of miospores from the Portishead Beds (Upper Old Red Sandstone) of the Mendip Hills, England.—*Pollen et Spores*, 1 (3) : 607-614.

Guein, K.J., Clayton, G., Ioannides, N & Neville, R. S. W., 1972.—A scheme of miospore zones for the British Dinantian.—*C. r. 7th Cong. Avanc. Etud. Straugr. Geol. Carb., Krefeld* (1971). (1) : 347-353.

Paris, F ; Richardson, J.B. ; Riegel, W. ; Steel, M. & Vanguestaine, M., 1985. Devonian (Emsian-Famennien) Palynomorphs.—*J. micropalaeontology*, 4 (1) : 49—82 (in Palynostratigraphy of Northeast Libya).

Playford, G. 1976. Plant microfossils from the Upper Devonian and Lower Carboniferous of the Canning Basin, Western Australia.—*Palaeontographica, Abt. B.*, 158 : 1-71.

Sarfraz, A. 1978. Palynology and biostratigraphy of some upper Devonian deposits of Western New York State and northern Pennsylvania, U.S.A. London University. Ph. D. Dissert., unpub. 1-355.

—, 1980. Some forms of the genus *Auroraspora* from the Upper Devonian of New York State and Pennsylvania, U.S.A. *J. Univ. Kuwait* (*Sci.*), 7 : 227-243.

—, 1985. Geographical variations in the Upper Devonian miospore assemblages. *Kashmir Journal of Geology*, 3, No. 3.

Streel, M. 1974. Similitudes des assemblages de spores d'Europe, d'Afrique du Nord et d'Amerique du Nord, au Devonian terminal.—*Sci. Geol.. Bull.*, 27 : 25 : 38.

Turnau, E. 1975. Microflora of the Famennian and Tournaisian deposits from boreholes of northern Poland.—*Acta Geologica Polonica*, 25 (4) : 505—528.

Utting, J. & Neves, R. 1970. Palynology of the Lower Limestone shale Group (basal Carboniferous of Limestone series) and Portishead Beds (Upper Old Red Sandstone) of the Avon Corge, Bristol, England.—*In Colloque dur la stratigraphie du Carbonifere, Liege, Univ., Congr. Colloq.*, 55 : 411-422.

A NEW STEGODONT FROM THE UPPER SIWALIKS OF RATHIAN, PUNJAB, PAKISTAN

BY

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Abstract : *An anteriorly damaged right lower last molar and a left horizontal mandibular ramus bearing last molar have been described. Both belong to the same individual. The specimen P.U.P.C.* 69/364 was collect-d from the upper most beds of Tatrotian near Rathian, district Jhelem, Punjab, Pakistan. Regarding the number of ridge-plates, it was the most advanced species of the genus, Stegodon. The name Stegodon rathiansis has been assigned to this new species.*

INTRODUCTION

First scientific mention of the Siwalik Stegodonts was made by Falconer and Cautley in their Fauna Atiqua Sivalensis in 1846. It was based upon three species i. e. *Elephas insignis, E. ganesa* and *E. bombifrons.* All the 3 species were transferred to the genus *Stegodon* by Lydekker in 1886. No significant research on the Siwalik Stegodonts was carried out during rest of the 19th century and first quarter of the 20th century. It was in 1929, that Osborn added a new species *Stegodon pinjorensis.* In 1977, Sarwar made an addition by transferring the species, *Stegolophodon lydekkeri* of Osborn to the genus *Stegodon.* In the same year, two more species were added by the same author. These are *Stegodon dhokawanensis* and *S. sardhokensis* Of all the species mentioned above, the species, *Stegodon pinjorensis* was considered to be the most advanced regarding the number of ridge-plates. The specimen, P.U.P.C. 69/364, which is being described here, shows 18½ ridge-plates in its last lower molar and thus it not only exceeds any of the known Stegodont but also approaches the advance members of the genus *Elephas.*

Systematic Account

Order	PROBOSCIDEA Illeger
Suborder	ELEPHANTOIDEA Osborn
Family	MAMMUTIDAE Cabrera
Subfamily	STEGODONTINAE Osborn
Genus	*STEGODON* (Falconer and Cautley)

***STEGODON RATHIANSIS* new species**

Holotype :

P.U.P.C. 69/364, right and left lower third molars with a part of left mandibular ramus.

Hypodigm :

Type only.

Locality :

Rathian, District Jhelum, Punjab, Pakistan.

Horizon :

Upper Siwaliks (Tatrotian).

Diagnosis :

Mandible rounded and shallow. Cheek teeth low-crowned with semi-circular ridge-plates. Number of ridge-plates higher than any Stegodont. Pre-sinus present. Ridge-plate formula :

$$M3 \frac{\quad}{18\frac{1}{2}}$$

* P.U.P.C. Panjab University, Lahore Palaeontological collection of the Zoology Department.

DESCRIPTION

Lower Dentition

THIRD MOLAR (P.U.P.C. 69/364), Figs. 1—4 :

In r. M_3, the last nine ridge-plates and a talon are preserved. In l. M_3, an anterior dentinal plate, twelve ridge-plates and the hind talon are preserved. The anterior dentinal plate is made by deep wear of the two ridge-plates. Thus, the l. M_3 bears fourteen ridge-plates and a talon. All these were nourished by the anterior rootfang, the tooth must have 18½ ridge-plates with a fore- and aft talon. Teeth are moderately worn. The ridge-plates are quite semi-circular in anteroposterior view and so the teeth are brachyodont. Cement is very well developed and covers the apices of the ridge-plates as well as the transverse valleys. Thus, in unworn condition, the valleys are indicated by shallow but sharp grooves only. Cingulum is altogether absent.

There is no indication as to the presence of a median longitudinal sulcus at least in the preserved portion. Counting from the posterior end, the ninth, tenth and eleventh ridge-plate in l. M_3, Produce a prominent loop in the middle of the anterior enamel border. There is no indication as to the presence of posterior sinus. The ninth ridge-plate in r. M_3 is comparatively less worn and so does not show the anterior sinus. Seventh and eighth ridge-plates are surmounted by eight transversely compressed but anteroposteriorly elongated conelets. Dentine can be seen as minute rounded or oblong islets. Enamel margin is quite thick (Table I) but wavy due to conelets. Cement is absent at the sides of the first ridge-plate which is probably due to weathering. Due to wear, the three consecutive transverse valleys posterior to the ninth ridge-plate have become almost flat. Eighth ridge-plate is slightly worn and dentine can hardly be seen. Seventh ridge-plate is just touched by wear and consists of seven conelets in r. M_3 and eight in l. M_3. The sixth ridge-plate is still partly embedded in the cement and six conelets are exposed. The other ridge-plates are essentially unworn and completely covered by a thick coating of cement. Thus the number of conelets cannot be observed. The post-talon is well-developed and is not much less in thickness than the last ridge-plate.

TABLE I

Measurements (in mm.) of lower last molars (P.U P.C. 69/364) in *Stegodon rathiansis* new species

	Right M_3	Left M_3
Number of preserved ridge-plates	+9+½	+14+½
Estimated number of ridge-plates	18	18
Anteroposterior crown length (preserved)	254	330
Lamellar frequency (for preserved length)	4.0	4.5
Transverse width of the crown	89	88
Vertical height of the crown	60	60
Height/width index	67	68
Enamel thickness	4	4

DISCUSSION

The tooth is low crowned with semi-circular ridge-plates. The ridge-plates are transitional between those of the genera *stegolophodon* and *Stegodon*. All these are the characteristics of the genus *Stegodon* (Falconer and Cautley, 1846; Osborn, 1942 ; Piveteau, 1958).

In size and high number of ridge-plates, the specimen P.U.P.C. 69/364 surpasses all the known Stegodont species (Table II). *Stegodon pinjorensis* and *S. airawana* are the nearest regarding these features. The former is known from just below the boulder conglomerates of Siswan (Lower Pleistocene), India (Osborn, 1929). It is known only by a cranium having the last molar of either side with 14 ridge- plates and an aft talon. The later is known from kendeng (Middle Pleistocene), Java (Martin, 1890). The lower last molars in this species consists of 15½ ridge-plates (Osborn, 1942). In P.U.P.C. 69/364, 14½ ridge-plates can be seen on the posterior root fang only. Including those nourished by the anterior root fang, the tooth must have been 18½ ridge-plated. Thus, it is much larger

TABLE II

Comparative number of ridge-plates in M3 in P.U.P.C. 69/364 and in other Stegodont species

		No. of ridge-plates (above line)	No. of ridge-plates (below line)
1.	P.U.P.C. 69/364	—	18½
2.	*Stegodon elephantoides* (clift)	6½	8½
3.	*S. bombifrons* (falconer and cautley)	7½—9½	8—9½
4.	*S. insignis*	9—11½	9—13
5.	*S. ganesa*	6½—10½	7½—10½
6.	*S. pinjorensis*	14½—15	—
7.	*S. orientalis*	1/8—11—1/8	½—13
8.	*S. airawana*	12—14	13—15—½

than the molars of the above mentioned species. In P.U.P.C. 69/364, a significant pre-sinus can be observed in the worn ridge-plates whereas, none of the corresponding teeth of *S. airawana* show this feature. In the upper last molars of *S. pinjorensis* pre- and post sinuses exist together. The jaw appears to be relatively shallower in P.U.P.C. 69/364 than that of *S. airawana*. The crown height in P.U.P.C. 69/364 appears to be comparatively less than either of the species *S. pinjorensis* and *S. airawana*. Keeping in view the foregoing discussion, it is evident that P.U.P.C. 69/364 differs from all the known stegodont species and it represents a new species. The name *Stegodon rathiansis* new species is being proposed for this new form of the genus.

Stegodon rathiansis new species was an advanced species of the genus regarding the number of ridge-plates. However, it remained primitive in crown height. The large tooth was quite advantageous to this browsing from and enabled it to survive to a fairly late date of the Pleistocene epoch. Ultimately, it had to be compete with the advanced members of the genus *Elephas* and thus became extinct close to the end of the epoch.

1

2

3

4

Fig. 1. *Stegodon rathiansis* new species. Crown view of left M_3 (P.U.P.C. 69/364).
Fig. 2. *Stegodon rathiansis* new species. Lateral view of left M_3 (P.U.P.C. 69/364).
Fig. 3. *Stegodon rathiansis* new species. Crown view of right M_3 (P.U.P.C. 69/364).
Fig. 4. *Stegodon rathiansis* new species. Lateral view of right M_3 (P.U.P.C. 69/364).

All Figures × 1/3

REFERENCES

Falconer, H., and Cautley, P. T., 1846. *Fauna Antiqua Sivalensis, being the fossil zoolygy of the Siwalik Hills in the North of India.*

Lydekker, R., 1886. Addenda to synopsis of Siwalik and Narbada Mammalia. *Mem. Geol. Sur. India. Palaeont. Indica*, (X), III, pp. 11—24.

Martin, K., 1890. Ueber neue Stegodon-Reste aus Java. *Verh. AK. Amst.*, 28 : 14 pp.

Osborn, H.F., 1929. New Eurasiatic and American Proboscideans. *Amer. Mus. Nov.* New York, 393 : pp. 1—23.

Osborn, H.F., 1942. *Proboscidea*, Vol. II (Ibid.) pp. 805—1675.

Piveteau, J., 1958. *Traite de Puleontologie.* Tome 6, Vol. 2.

Sarwar, M., 1977. Taxonomy and Distribution of the Siwalik proboscidea. *Bull. Dept. Zool. Univ. Punjab (N.S.)* Art. 10 : pp. 1—172.

GEOLOGY OF BHUNJA-BATAKUNDI AREA, KAGHAN VALLEY, DISTRICT MANSEHRA, PAKISTAN

BY

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Abstract : *The part of Kaghan Valley between Mahandari and Batakundi has been geologically surveyed and mapped, at 1 : 17,000 for the first time. Besides a detailed field description of rock units, brief description of structure and comments on metamorphism, stratigraphic correlation and geomorphology are included. The rocks range from limestones, greenstones, tillites, pelites, calcareous pelites to psammites in the biotite to silliminite grade. Some locally produced granites and a beautifully developed migmatite unit are also present. Stratigraphically the sequence becomes older towards north. A tentative correlation of the rock units has been attempted with Panjal series, Tanol Formation, Hazara slates and Precambrian Sharda Group (Salkhalas) successively to the north. Major structures consist of a number of asymmetric and at places, overturned folds separated in the form of blocks by high angle north dipping thrusts. Graphite, gypsum and marble are potential economic deposits.*

INTRODUCTION

"The syntaxis of north-west Himalaya, its rocks, tectonics and orogeny", a work published by Wadia (1931) remained the principal work on the geology of Kaghan Valley until 1968. In 1968 joint work by Geological Survey of Pakistan (GSP) and United States Geological Survey (USGS) was submitted as Reconnaissance Geology of Balakot and Mahandari Quadrangles, Hazara District, West Pakistan—a project report by Offield and Abdullah. This work later became part of a Geological Survey pofessional paper 716-C by Calkin, Offield, Abdullah and S. Tayyab Ali published in 1975.

Both Wadia and the GSP-USGS joint team and more recently Bossart et. al. (1984) paid attention to the rocks and structure of the part of Kaghan Valley mainly down-stream of Mahandari, the region of Hazara-Kashmir Syntaxis.

A survey of the geology of Kaghan Valley upstream of Khannian, north of Mahandari, was thus undertaken by the present writers for the first time during the summer of the 1985 while supervising a party of M.Sc. students* of Punjab University Lahore.

* The student party comprised Mazhar Qayyum, Ibrar Ahmad, Mohammad Amin, Amjad Cheema, Munawar Iqbal Gondal, Mahmood Ahmed, Ziaullah Ranjha and Ali Mardan.

The mapped area stretches for about 42 miles along the road between Bhunja and Batakundi. Across the road it generally extends about one to three miles on both sides of the river. The road moves throughout along the river on its left bank within the mapped area. Following the direction of the river the area has an arcuate shape. Between Bhunja and Kaghan it stretches north-south across a major semi-circular bend in the river while from Kaghan to Batakundi the area stretches from southwest to northeast. In all, the area covers nearly 400 square km or about 160 square miles of terrain and in main has been mapped for the first time. The field mapping was done at the approx. scale of 1:17000 (6 cm = 1 km).

The geological mapping of the rock units in the area when viewed together gives tentative clues to the stratigraphic correlation. For a better stratigraphic understanding there is need for field correlation of the geology of Neelum Valley, Kaghan Valley, Mansehra area and Kohistan.

DESCRIPTION OF ROCK UNITS

Stratigraphic sequence

Panjal Series.	Panjal basic volcanics and associated Ling, Bhunja and Shino bands of limestone/marbles.
Agglomerate Slate Series.	Chushal graphitic schist and metaconglomerates and tuffs.
Tanol Formation.	Jared quartzites and quartz mica schists.
	Biari quartzites, metaconglomerates, quartz mica schist, calc-schist and pegmatites.
	Doga schists, marbles, quartzites and metaconglomerates.
	Phagal quartz mica schists and quartzites.
	Lohar Banda marble.
Kaghan Formation (Cambrian to Precambrian).	Kamalban quartz mica schists, quartzites, calc-schists and marbles.
	Kaghan pelites.
	Rajwal quartzites, quartz mica schist, pegmatites, aplites and granite.
	Paludaran graphitic schist
	Batal quartzites and quartz mica schist.
Sharda Group (Salkhala Fm Precambrian).	Naran garnetiferous calc-pelitic gneisses, graphitic gneisses and pelitic gneisses with sheet granites and migmatites and amphibolites.

Naran Garnetiferous Calc-Pelitic Gneisses, Pelite Gneisses, Graphitic Gneisses. Sheet Granites and Migmatites and Amphibolites.

The principal lithology is indicated in the title of the unit. Garnet is generally well developed and large. There are in addition to calc-schists a few bands of marble and also thin bands of dark grey amphibolite closely associated and intercalated with marble. The granites are in the form of thin sheets.

Most are whitish grey, light grey brownish lithologies grey on fresh surface and dark grey or dark brownish grey on weathered surface.

This extensive unit occurs on the roadside from close to Naran Youth Hostel to beyond Batakundi. It extends in a NW-SE direction on both sides of the road. Along with the granites and migmatites (included in it) it covers the area of Naran, Dhumduma, Sohch and Batakundi near the roadside and Danna, Saifal-Maluk lake, Leda, Hans Dar, Mohri, Randi and Sohch Danna away from the roadside.

The Naran unit may be stratigraphically considered the equivalent of Sharda group (Ghazanfar et al 1983) or the Salkhala Formation of Wadia. In the mapped area of Kaghan valley it comprises the following lithologies :

(i) Garnetiferous Calc-Pelitic Gneisses.
(ii) Marbles.
(iii) Graphitic Schist.
(iv) Granites and associated rock types.
(v) Migmatites and Quartz Mica Gneisses and Schists.

Garnetiferous Calc-Pelites with Amphibolites. Three separate outcrops of this lithology occur in the area. The largest of these outcrops occurs between Naran and Sohch on the roadside and extends in an arcuate fashion from south to north underlying the villages of Naran (partially), Leda Gali, Dhumduma, Bagnar, and Randi. The other outcrop stretches NW-SE between Naran Youth Hostel to short of Batal Katha on the roadside and also occurs in Darseri Katha, Danna da Katha, Gorian Katha and left bank of Kapan da Katha. The third outcrop extends NE-SW above Lalazar from Mohri to Dadar Nar.

The calc pelitic gneisses are generally light grey and light brownish grey on fresh surface and dark brownish grey or yellowish brown on the weathered surface. They are banded and show differential weathering with the micaceous and schistose layers appearing as positive ribs on the weathered surface. Their texture is gneissic and porphyroblastic, and they are composed of calcite, garnet, biotite, muscovite and quartz. The garnets are mainly subidioblastic. Accessory to trace amounts of pyrite and graphite may also be present. The garnet is a grossularite. However pelitic horizons lack carbonates and contain almandine instead of grossularite. The garnet is generally very prominent, the size varying generally between 1 mm to 10 mm but, at times, the garnet reaches 30 mm., as at Danna above Danna da Katha at the back of Naran. At times more than 50% of the rock is comprised of garnet.

The calc-pelitic gneisses are interbedded generally with impure bands of marble. The impure marble bands are prophyroblastic and poikiblastic. They are often composed mainly of garnet and carbonates with accessory to trace amounts of quartz, biotite/phlogopite, pyrite and graphite. There are some few metres thick pure marble bands also. These are typically granoblastic.

Less prominent are the interbedded amphibolites The amphibolite bands generally range from one cm to 3 m in thickness although a few bodies are much thicker like the one above Leda Gali and the one above Mohri leading into Hans Dhar Katha. The amphibolites are fine to medium grained, well foliated dark greenish grey with shining fresh faces and garnetiferous. At places they are subporphyroblastic to porphyroblastic and even poikiblastic. They are invariably garnetiferous. They are composed of plagioclase, amphibole and garnet. Quartz, sphene and magnetite are accessories while chlorite and epidote are retrograde products. The garnet is most probably grossularite. The thin amphibolite bands are so closely associated and intercalated with marbles that it appears to be a para-amphibolite. But ortho-amphibolites are also present. Except the metaigneous (often metavolcanic) discordant bodies, it is sometimes difficult to distinguish between para and ortho-amphibolites. Above Leda Gali an amphibolitic band of medium thickness was seen folded with the granitized gneisses near the contact with calcpelites.

Above Mohri and on the Danna above Danna da Katha the calc-pelites have developed elongated prisms of grey transluscent andalusite.

The garnetiferous calc-pelites are generally more prone to chemical weathering. At places where the rock has weathered much as on Danna slopes above Danna da Katha it releases rounded garnets which make the slopes slippery to climb.

Occasional graphitic bands are also found.

Marbles. The interbedded marble bands constitute a subordinate lithology. They are white, light grey, or yellowish and yellowish grey on fresh surface and greyish brown or yellowish brown, mustard or brown on weathered surface. They are generally medium bedded and medium grained. However, one band on Danna slopes above Danna da Katha is white, coarse grained and sugary. The thin intercalated bands are impure but the relatively thicker bands are pure and massive.

The close association of some intercalated amphibolites with some marble bands indicate that some of these thin amphibolite bodies might be metamorphosed impure marbles.

Some impure marbles are garnetiferous. They, in addition, may contain small quantities of quartz, biotite, fuchsite and phlogopite. The last named three minerals do not occur together, they, on the other hand occur at different places and horizons in the impure marbles. Rarely, muscovite also occurs in the impure marbles. The pure white sugary marbles are massive and granoblastic.

Graphitic Schist. An important band of graphitic schist occurs at quite some height on the right bank slopes of River Kunhar. It stretches NE-SW across Sohch Katha, Dhumduma Katha and Bharjali da Nar.

It is a fine to medium grained rock. It shows a very well developed foliation. Quartz, muscovite and graphite are the main minerals, while pyrite, feldspar, tourmaline and biotite are the accessories. Graphite is from distinctly crystalline to microcrystalline. The crystalline variety is, however, predominant.

Granites. The granite outcrops are in the form of one major sheet-like body, the Saiful Maluk Granite, and a number of thin sheet-like bodies folded concordantly with the major structure in the Naran unit.

The Saiful Maluk Granite extends NE-SW from Sohch Danna through Sohch above Leda Gali to the right bank upper slopes of Saiful Maluk Katha and Saiful Maluk Lake. From Saiful Maluk it extends NW passing through Naran on the right bank slopes of River Kunhar.

Generally speaking the Saiful Maluk Granite is a non-porphyritic fine to medium grained strongly foliated biotite granite gneiss with thin pegmatite veins. The granite at many places contains abundant relics of transformed (granitised) metasediments and shows effects of metamorphism. To illustrate the great variation in many parts of this unit we take for instance the right abutment of Sohch bridge where following six components are present in the granite over an area of an about 600 square meter.

(i) Non porphyritic fine to medium grained but mostly fine grained granite gneiss ; garnetiferous. It, at places, looks aplitic but is nevertheless, gneissic.

(ii) Aplitic granite patches, poorly foliated to non-foliated, garnetiferous. The patches are fine to medium grained and relatively leucocratic.

(iii) Biotite rich well developed porphyritic granite gneiss. This granite gneiss, at places, has an augen structure. This third type like the above two types is also garnetiferous.

(iv) Metapelites in various stages of transformation to granite.

(v) Later simple unzoned mica pegmatites 10 cm to 1 m thick at this place.

(vi) Quartz veins. These are sheared and folded along with the country rock (synkinematic).

Most of the granite in the vicinity of Sohch is well foliated but massive, fine to medium grained gneiss. The foliation is tectonic and not flow foliation. Ghost stratigraphic structures (Schilleren, etc.) are present. The porphyritic gneiss looks like transformed metapelites but generally the outcrop is non-porphyritic.

The Saiful Maluk granite, as seen on the slopes of Saiful Maluk Lake, is extremely well foliated dark coloured biotite granite gneiss with irregular leucocratic bands (less biotite). It appears to be a transformed granitised paragneiss. The modified metamorphic element appears to be considerable, especially in the dark granite gneisses. The gneiss is granitised and aplitised frequently. The pegmatite veins are generally thin, ranging in thickness from 0.5 cm to 30 cm. These bands are unzoned simple and only slightly coarser than the gneiss with which they are associated. They are composed of quartz, felpspar, mica, tourmaline and eumorphic, transluscent to transparent, sheared pink garnet. At places they contain porphyroblasts of potash feldspar of a later period of formation as they often cut across the fabric of the rock. The pegmatite veins are generally parallel to the structure and foliation of the surrounding rock and may make similar type folds alongwith the gneiss. The pegmatite veins sometimes contain boudins with occasional light greenish grey porphyroblasts of potash feldspar. One such porphyroblasts measured 8 cm × 5 cm.

The granite gneiss weathers and breaks into slab type joint blocks which on the low hills around Saiful Maluk Lake have accummulated as clitter.

Small dolerite sills are also present.

Saifal Maluk Hornfelses. Hornfelsing has developed along both contacts of Saifal Maluk Granite. It is relatively more preserved at the granite contact with calc-gneisses while at the granite contact with migmatites and pelite pssammite gneisses they are only partially preserved due to faulting.

The hornfelses developed at the granite contact with garnetiferous calc-pelites can be seen on the left bank of Kapan da Katha near Naran. Here the hornfelsing is developing in a metapelite band. These are garnet andalusite hornfelses, dark greenish grey with white elongate andalusite prisms and cracked reddish garnet porphyroblasts, banded in dark grey and light grey bands. On the weathered surface they are dark grey. The rock is massive to subfoliated.

The andalusite hornfelses developed at the contact with pelite psammite gneisses and migmatites are also garnetiferous. They can be seen above Dhamnar on the left bank slope of Shanak Katha and, here too, the thermal aureole is not very wide.

The hornfelses show a typical decussade texture. They are subporphyroblastic and poikiloblastic. They are rich in biotite and andalusite. They are composed mainly of quartz, biotite, andalusite and muscovite. Shattered garnet and its relics are common. Accessory amounts of tourmaline, sillimanite and feldspars are also present.

Petrogenesis of Saif-ul-Maluk and associated granite

Pending detailed petrological work the following observation can be made regarding the origin of these bodies.

The Saif-ul-Maluk granite is very hetrogeneous. It is composed of quartz, feldspar, garnet, tourmaline and abundant micas, particularly biotite. Only about 40% of this body looks like a granite while the rest is composed of migmatites, partially transformed and granitised gneisses, screens and xenoliths of partially feldspathised metamorphites. In this body phlebitic, stromatic and agmatic structures are common. Even in its parts that look like granite, neubilitic structure, schilleren and ghost structures are present.

All the above characteristics suggest that these granites represent mobilizates in an advanced stage of metatexis of selective lithologies. They were later emplaced during metamorphic and anatectic stage as sheet like bodies in somewhat cooler environment causing hornfelsing and feldspathisation at contacts. Contemporaneous or subsequent movements have folded the granite bodies along with metamorphics.

Dharir Migmatites and Pelite-Psammite Gneisses : Mixed pelitic psammitic gneisses and granitic component of brown grey hue make one of the best developed sequence of migmatites so far reported from any approachable part of Pakistan. Similar horizons from Nanga Parbat have however been reported by Misch (1949).

The outcrop stretches in a NE-SW direction in the extreme north of the mapped area underlying the area of Sohch, Dhamnar, Dharir, Old Batakundi and Hans Dhar.

The migmatites have developed in a mainly pelitic psammite unit (Palaeosome). At the contact of this unit with granite on the slopes above the left bank of Shanak Katha some andalusite hornfelses have developed. The actual contact, however, is obscure because of moraine but evidence of hornfelsing and migmatisation is unmistakable. The thermal aureole seems to be limited and not very wide.

Beyond the hornfelses the garnet-staurolite and garnet mica gneiss becomes rapidly coarse grained and feldspar starts developing in them. One can distinguish two types of rock, coarse mica gneisses and porphyroblastic (feldspar porphyroblasts) garnet mica gneisses and migmatites.

The migmatites, hard and tough mixed rock, containing garnet tourmaline, as well as psammitic elements appear to have been sweated out and developed due to, at least partial, in situ transformation. Both injection migmatites (auto injection), with simple as well as ptygmatic folded veins, and permeation gneisses are developing. These should be called in situ migmatites. Ptygmatic folding is common. Material of relatively pure psammatic composition shows less granitisation and transformation. Occasionally the migmatites contain enclosed screens and xenoliths of feldspathised amphibolite (agmatites). Some thin (few mm to 20 mm thick) pegmatitic and aplitic veins are also present.

The migmatisation of pelitic gneisses decreases beyond the Dharir Danna towards Batakundi and on the roadside at old Batakundi only pelitic psammitic gneisses are found.

The components which can be distinguished in this unit are

(1) Partially trasformed metapelites (Palaeosome).

(2) Partially transformed metapsammites (Palaeosome).

(3) Partially transformed amphibolite (Palaeosome).

(4) Veins, patches and pods of granitic matter (Neosome).

(5) Veins, patches and pods of aplitic matter (Neosome).

(6) Veins, patches and pods of pegmatite matter (Neosome).

(7) Cryptic migmatites (Neubulitic).

All the above seven components are very closely and intimately associated Their distinction in very many cases is arbitrary, since gradations are very common.

The first two types are gneissic to moderately foliated rocks which are being feldspathised and tourmalinised. They are composed of quartz, biotite, muscovite, garnet, staurolite (at places) and feldspars + tourmaline. The rocks either contain thin quartzo-feldspathic layers (phlebitic) and veins (stromatic) or small irregular patches and areas of aplitic, granitic and pegmatitic components (leucosome, neosome). Additionally the rocks may be transformed in such a way that more or less uniform feldspathisation of the rock has taken place (neubilitic).

The amphobolite patches (melanosome) or zones may show varying degrees of feldspathisation. The rock often becomes distinctly porphyritic, It is now composed of amphibole, garnet, feldspars, quartz, magnetite and tourmaline. At places, the amphibolites are feldspathised via aplitisation. All compositions from garnet-amphibolites to foliated garnet-quartz (meta) diorite, garnet (meta) syenodiorite and garnet (meta) adamellites may be observed.

The granitic component is from hypidioblastic and subporphyroblastic to prophyroblastic. It is from fine to medium grained. It may occur as veins, patches, pods and irregular areas. It is generally composed of quartz K-feldspar, albite/oligoclase, muscovite, biotite, garnet, tourmaline and magnetite. Porphyroblasts of smoky to bluish grey K-feldspar may be present. At places schilleren and ghost structures of pre-transformation origin are still very well preserved. So much so that relics of pre-existing small folds in metamorphics can be clearly seen.

Aplitisation and pegmatisation are common in these mixed rocks. The aplites may grade into granitic and pegmatitic types. The aplites are sacchroidal white coloured rocks which, at places, contain small garnet crystals. They are composed mainly of feldspar, quartz and muscovite. Garnet, biotite and tourmaline are accessories.

The pegmatites occur as veins, patches and pods. They are simple in composition, unzoned and often vein, patch and pod-like. Regular pegmatite sills and dykes are rare. They are composed essentially of microcline, quartz, muscovite and tourmaline. At places garnet, biotite and magnetite are also present. The term cryptic (neubilitic) migmatites is used for truly mixed types which are often hard to split into component parts in hand specimen. These are gneissic, uniform looking rocks composed of closely intermixed pre-transformation metamorphic components and syntransformation introductions. They are composed of K-feldspar, albite, quartz, muscovite, biotite, garnet and tourmaline. Magnetite and pyrite may occur as accessories.

The migmatite outcrop has Saifal Maluk sheet granite on one side and garnetiferous calc-pelites on the other. It was observed that in the preserved portion of the pelite migmatite unit at the contact near Saifal Maluk granite, the migmatisation of pelites decreases as at Sohni between Naran and Batakundi. The migmatite therefore may not be related to any outside injections, for example, from Saifal Maluk granite which by itself is a product of migmatization/granitisation. On the other hand the migmatites may be a product of in situ sweating out of granitic material under conditions of high grade regional metamorphism.

Batal quartzites and quartz mica schist

Dominantly quartz mica schist and quartzites with thin sheet granites, subordinate marble and some thin amphibolite bands and a few chlorite schist patches.

Most rocks are light grey to brownish grey on the fresh surface and grey to dull brownish grey on the weathered surface.

On the main Kaghan roadside the Batal unit extends between right bank of Batal Katha and Chitta Katha. On the right bank of the river it extends in a northwest direction under the villages of Darseri, Barthi, Chamber and Sangal. On the left bank of Kunhar it extends into Batal Katha and then to the southeast crossing Chitta Katha, Surmai Katha and Gori Katha, at the back of Paludaran bazaar, after which it is faulted against the Kaghan Pelites.

Quartz Mica Gneiss is the main lithology of the unit. It is brownish grey on the weathered surface. At some places garnet has developed while at others it cannot be seen with the naked eye. The pelites have numerous interbeds of grey coloured micaceous quartzites. This interbedded rock (especially where in the form of isolated boulders) shows differential weathering. When differentially weathered the quartzite shows light grey positive flat faced ribs and the pelites (with garnet and biotite) as dark grey negative ribs. Another unit the Naran Garnetiferous Calc-Pelitic Gneiss, also shows differential weathering. In this, however, the schist makes positive ribs which are also not flat faced like the quartzite ribs of Batal unit. Finally the calc-pelites show minor similar flow folds which are generally absent in the more competent Batal unit.

The quartz mica schist shows segregated quartz bands stretched into boudins and at times, these boudins appear just like pebbles of a conglomerate.

Within the quartz mica schist some distinctive green chlorite schist patches are found which may either represent retrogressive metaporphism or metaigneous material of volcanic affinity. These along with the presence of the amphibolite bands may also indicate the presence of an old volcano-sedimentary sequence.

Paludaran Graphitic Schist

This unit is mainly composed of graphitic schist, quartz mica schists and gneisses with some calc-schists and occasional marbles.

Graphitic Schist. It is dark grey on fresh surface and dark grey to dark brownish grey, at times rusty brown, on weathered surface. Pyrite crystals are present which weather out leaving square cavities behind. Quartz veins and boudins are also present which are usually stained rusty brown.

The rock is lepidioblastic. It is composed mainly of muscovite, graphite and quartz. Pyrite, goethite, limonite, haematite, tourmaline and biotite are accessories.

Quartz Mica Schists and Gneisses. It mainly comprises quartz, feldspar, biotite, mica and some garnet. Tourmaline, graphite and calcite may occur brownish grey on the weathered surface. Apart from quartz veins and boudins some fine pegmatite veins are present. At few places the gneiss has been feldspathised and some feldspar porphyroblasts have developed. Metadolerite sills containing garnet are also developed,

Calc-Schists and Marbles. Subordinate bands of calc-schists and schistose marbles are present intercalated with graphitic schist. The marbles are white and cream coloured on fresh surface and weather yellowish brown to dark brown. Partings of biotite schist may be present which in general give the rock a slightly darker shade. The calc-schists are generally medium grey.

They are composed of calcite, muscovite, biotite, quartz and pyrite. The marbles are granoblastic. The calc-schists are lepidioblastic to hypidioblastic.

The Paludaran graphitic schists are well exposed on the roadside between Chitta Katha and Surmai Katha. At one place the exposures are strikingly black.

Both the upper and lower contacts of the Paludaran graphitic schist unit are faulted against the Rajwal and the Batal units.

Rajwal Quartzites, Quartz Mica Schist, Pegmatites, Aplites and Granite

The principal lithology of this unit is indicated by the title above. Where the lithology is pelitic the colour of the fresh surface is generally shining brownish grey and when it is psammatic the colour of the fresh surface is generally whitish grey with brownish schist partings and porphyroblasts of biotite and muscovite. The pegmatites are greyish brown. On the weathered surface the unit generally has a yellowish brown or rusty brown colour and is sometimes earthy grey. The colour of the fresh surface and the weathered surface markedly distinguishes it from the Kaghan pelites. The latter are shining greenish grey. Compared to Kaghan pelites the Rajwal unit shows much less micro-folding and the strain slip cleavage is also generally absent.

Description

This unit is composed of the following lithologies :

(i) Metapelites

(ii) Metapsammites

(iii) Migmatites

(iv) Pegmatites/Aplites

(v) Granites

(vi) Marbles

(vii) Quartz Mica Micro-augen Gneisses.

The above five lithologies are so closely intermixed that it is not possible to map them separately at the present scale of mapping i.e., 1 : 17000. In this complicated unit the metapelites and metapsammites are affected by granitization especially in the lower part of the unit so that in some cases it becomes difficult to name the rock. Such complication reaches its maximum in the Bhimbal Katha northeast of Paludaran. Towards the upper part of the unit as near Kundi Ka Maidan and in upper part of Por Katha (Chambar Katha of the map) granitisation is absent and pegmatites and aplites decrease and the unit consists mainly of garnetiferous quartz mica schist and micaceous quartzites with few thin bands of white sugary marbles which weather yellow.

Occasional dolerite dykes are also found.

Metapelites : These generally comprise garnetiferous quartz mica schist and gneisses and make up the principal lithology of the Rajwal unit in the almandine grade. The metapelites are composed mainly of quartz and micaceous minerals (muscovite, biotite and chlorite) almandine garnet, tourmaline (schrolite and magnetite are subordinate or accessory minerals). These rocks are at places, porphyroblastic. In the lower part of the unit these are interbedded with quartzites and intruded by pegmatites/aplites while in the upper part they contain some intercalations of marble. At some places, this lithology is migmatised.

Metamorphic differentiation and migmatisation has produced biotite rich layers composed of biotite, chlorite, garnet, quartz and muscovite and light coloured layers composed mainly of quartz, feldspar, mica and a little tourmaline. However in many cases dark and light layers represent original pelitic and arenaceous bands. The dark and light coloured layers often represent melanosome and leucosome.

Metapsammites : The metapsammites are well developed in both pure and impure forms. The metapsammites comprise feldspathic quartzites. The feldspathic quartzites show xenoblastic to subporphyroblastic texture. They are composed mainly of quartz and feldspar. They contain subordinate to accessory amounts of mica, tourmaline, garnet and magnetite. They are arkosic to subarkosic, banded grey quartzites and feldspathic micaceous quartzites.

The feldspathic quartzites are generally present in the lower part of the Rajwal unit. On the fresh surface they are creamish white while on the weathered surface they are generally rusty or creamish. They are fractured and jointed but massive and hard on hammering. Quartz, feldspar, biotite, muscovite and tourmaline can be distinguished with the naked eye.

The banded grey quartzites are generally better developed in the middle part of this unit. They are white and greyish white on fresh surface while light to dark grey on weathered surface. This fractured and jointed unit is well developed in Bhimbal Katha.

The micaceous quartzites are better developed towards the upper part of the Rajwal unit. On the fresh surface they are whitish or creamish grey while on the wheathered surface they are creamish grey to rusty brown. Sometimes the micaceous quartzites have creamish or rusty brown schist partings and occasionally they have bands of garnetiferous quartz mica schist. The micaceous quartzites are composed mainly of quartz and muscovite with subordinate amounts of biotite, feldspar, garnet chlorite, magnetite and tourmaline.

The micaceous quartzites are followed by a graphitic band.

Quartz veins and boudins are present abundantly in the metapsammites. These are white on fresh surface while creamish or rusty on the weathered surface and are highly fractured. Quartzofeldspathic veins are also well developed. These veins are poor in micas and are composed predominantly of bluish grey to dirty white feldspar and quartz. Tourmaline is a ubiquitous accessory.

Migmatites : The mixed rocks are well developed in the lower part of the Rajwal unit exposed in the lower reaches of Bhimbal Katha. Sometimes the migmatites are banded with bands of quartz mica gneiss and of acidic material. At other places these materials are present in the form of patches or so complexly intertwined that the two materials have lost their individual identity. Simple as well as ptygmatically folded migmatites, injection gneisses, permeation gneisses and feldspathised gneisses, are all present. When the acidic (granitic) material is dominant the colour on the fresh surface is whitish and on the weathered surface it is earthy white. When metapelites predominate the rock weathers grey and colour on fresh surface is light grey. The metapelites are composed of quartz and biotite rich laminae while the acidic material in most cases is granitic in composition and contains feldspar, quartz, muscovite and biotite and sometimes garnet and tourmaline crystals. At other times, however, the acidic (granitic) material is composed of quartz and feldspar with rare tourmaline crystals (mica is either absent or present in traces). These are all in situ migmatites. They show a variety of forms such as neubilitic, phlebitic, stromatic and rarely agmatitic. Melanosomes and leucosomes and palaeosomes and neosomes can often be distinguished. The migmatites are massive and very hard on hammering and moderately jointed.

Granites : These are mainly present as small bodies, i.e. in veins and patches and are much smaller in proportion to the pegmatites. On the weathered surface the colour is creamish brown to rusty brown. The granites are sub-porphyritic to porphyritic. On the fresh surface minerals like feldspar, quartz, biotite, muscovite, magnetite and tourmaline can be recognised with the naked eye. Sometimes garnet crystals are also developed. These may be regarded simply a textural variety of the leucosome at the neosome formation stage.

Pegmatites/Aplites: The most distintive characteristic of the lower and middle part of the unit is the presence of pegmatites/aplites. The pegmatite/aplite bodies which are present in the form of veins and patches can vary from a few inches to over 50 feet (in the case of pegmatites) in thickness. On the fresh surface they are greyish white while on the weathered surface they can be whitish grey or rusty.

The main components are feldspar, quartz, muscovite and biotite. The feldspar (mainly microcline) on fresh surface is milky white or light grey and sometimes bluish grey. Chlorite, tourmaline and garnet may also be present. The pegmatites are simple in composition.

At places sacchroidal white to off-white aplite veins occur closely associated with pegmatites. They are composed of feldspar and quartz. Muscovite, garnet and tourmaline may also be present.

The pegmatites/aplites show a variety of forms. They are mainly tabular and lensoid, but sheet like, patchy, spindle shaped, irregular and boudinaged forms are also present. Quartz veins and boudins are frequent. The quartz veins are stretched and boudinaged.

Marbles: The marbles constitute a subordinate lithology and are present mainly in the upper part in the form of thin bands or intercalations. They are granoblastic and white on fresh surface while creamish grey or yellowish on the weathered surface. They are composed predominantly of carbonate but small amounts of quartz, pyrite and muscovite may also be present.

Microaugen gneisses: This lithology belongs to the uppermost part of the Rajwal unit after a graphitic horizon. It is exposed well at Kundi Ka Maidan. This gneissic lithology is complicated and contains a number of variations including garnetiferous quartz mica gneiss, quartzofeldspathic microaugen gneiss, aplites and pegmatite. In the quartz mica gneiss the garnetiferous layers are intercalated with quartzofeldspathic layers with porphyroblasts of feldspar. The garnetiferous layers contain occasional needles of amphibole.

The microaugen gneisses are quartzofeldspathic and contain 1 to 5 mm long porphyroblasts of feldspar which are bluish grey in colour. The rock type itself is greyish white on fresh surface and whitish grey on weathered surface. The rock is composed mainly of quartz and feldspar with thin brownish partings of biotite. The rock also contains greenish brown generally 1 to 3 inches long nodular patches of what appear to be schist relics or porphyroblasts of biotite, chlorite and quartz, filling cavities in the gneiss. These schist patches are weathered out leaving circular hollows behind. The pegmatites are simple, unzoned and composed mainly of microcline and quartz with subordinate amounts of muscovite, albite and sometimes tourmaline and garnet. The aplites are sacchroidal and are composed mainly of microcline, quartz and albite. Some muscovite and occasionally a little tourmaline and garnet are present.

The upper contact of Rajwal unit is with Kaghan Pelites and the Lower contact is with Pludaran Graphitic Schist. The upper contact is generally abrupt and faulted while the lower contact is also quite sharp and partially faulted within the mapped area.

Kaghan Pelites

Although this rock unit comprises at least four different and distinct lithologies viz quartz mica schist, graphitic schist, marble and gypsum, it is the great and monotonous predominance of greenish grey quartz mica schist by which it is distinguished. The subordinate lithologies of graphitic schist, marble and gypsum are present mainly towards the upper part of the unit.

The Kaghan Pelites have a very thick northeast-southwest trending outcrop in the mapped area. The unit is exposed on the roadside for about eight miles between Rajwal and Khannian upstream and downstream of Kaghan township.

The villages of Seri, Kinari, Rawalkot, Maidan, Asman Banda and Putandes are located on it west of the roadside and of Lari, Mamekh, Makhniayan, Jhag etc are located on it east of the roadside, Further it extends to greater heights and peaks where no villages are present.

Quartz Mica Schist : This is by far the dominant lithology in the unit constituting over 90% of the whole. The quartz mica schist has a distinctive silvery greenish grey colour on the fresh surface and is greenish grey to greenish brown or creamish on weathered surface. The rock is studded with white lenticular quartz boudinaged veins. At times very thin greenish grey micaceous layers can be distinguished from the white quartz layers in hand specimen in section at right angle to foliation. The quartz mica schist is garnetiferous (garnet occurring as brownish black protrusions) but the size of the garnet is small (1 to 3 mm) and decreases still further towards the upper side of the Kaghan Pelites until it becomes indistinctive at Khannian. The upper contact of quartz mica schist of Kaghan Pelites also marks the garnet isograd which thus passes through Khannian, Shinkiari and Mamekh The quartz mica schist of Kaghan Pelites is also characterised by well developed schistosity, numerous crenulations and the ubiquitous presence of strain-slip cleavage. The rock type is composed mainly of quartz and micaceous minerals (i.e. biotite, muscovite and chlorite). Garnet is a ubiquitous accessory to minor mineral. It is an almandine garnet. Tourmaline, pyrite and graphite occur from accessory to traces.

Graphitic schist : Occasionally the quartz mica schist is graphitic. This change occurs simply by graphite assuming the status of an essential mineral and increase in the quantity of pyrite. One such band occurs below gypsum on the right bank of river Kunhar between the villages of Asman Banda and Putandes. The graphitic schist occasionally shows square cavities produced by the weathering out of pyrite crystals.

Marble and Gypsum : More than one bands of marble occur in the unit but the marble occurring in intimate association with gypsum towards the upper part of Kaghan Pelites unit is the most distinctive. It is generally yellowish on weathered surface and cream or white on fresh surface. This marble has thin micaceous partings of greenish or brownish schist and in part is thinly intercalated with gypsum.

A well developed gypsum outcrop occurs on the path from Kaghan to Putandes on the right bank of the river Kunhar. However, the best development of this gypsum is to the southeast of Kaghan at a height of over 11500 ft. below Sirul Danna. The gypsum here is found as thick bands and thin ones, too, intrerbedded with yellow weathering micaeous marble. The main bands of gypsum together are over 250 ft. thick. This high level outcrop can be seen (when not covered by clouds) looking southeast from the roadside from near Kaghan.

Gypsum has a special weathering style in the sense that it is soft and does not yield much fragmental debris. So one does not find gypsum debris until very close to the outcrop. The extra-bright white colour of the outcrop is, however, distinctive and sets it quite apart from other rock types.

Gypsum is often well foliated and is from subporphyroblastic to granoblastic at places. The gypsum band is composed predominantly of gypsum with accessory to trace amount of carbonates. However the amount of carbonate increases where it is interbedded with marble. Here some muscovite and pyrite are also present.

The upper contact of Kaghan Pelites is faulted on the roadside against quartzites of Kamalban rock unit though it appears to be normal but sharp against quartzites at Shinkiari and below Mamekh. The lower contact is also sharp and abrupt and faulted against the Rajwal quartzites unit.

The unit may be called the Kaghan Formation. The dominant pelitic compositions and the presence of gypsum may be called upon to relate the Kaghan Formation to the Hazara Slates.

Kamalban Quartz Mica Schists, Quartzites, Calc-schists and Marbles

The principal components of the rock unit are indicated by its title. On the fresh surface most components are whitish light green, light brown and light grey and are generally banded. On the weathered surface the marbles are yellowish and greyish, the schists are dark greyish brown and the quartzites are rusty and creamish yellow.

Quartz Mica Schist. Proportionately this is the main lithology but quartzites, marbles and calc-schists are more striking and prominent.

The quartz mica schist is shining greenish grey on fresh surface and brownish grey or brown and sometimes whitish on the weathered surface. It contains quartz boudins much like those in the Kaghan Pelites. Fracturing and jointing is common and may obscure foliation. Schistosity is well developed and generally a strain slip cleavage can be seen in addition to the bedding plane schistosity.

The quartz mica schist indicates a biotite grade. At times prophyroblasts of chlorite can be seen.

It shows well developed schistosity. At places micaceous minerals also develop along planes of cleavage which cut across the schistosity. It is often subporphyroblastic to porphyroblastic and is composed mainly of quartz and micaceous minerals, (muscovite, biotite, and chlorite). Magnetite, tourmaline and occasionally calcite occur as accessories.

Quartzites : Alongwith the quartz mica schists there are a number of orthoquartzite bands. These bands are granoblastic. They are composed mainly of welded and sutured quartz grains. Muscovite, biotite, chlorite and pyrite are the accessories. These pure quartzites are white, cream or light green and grey and generally banded on the fresh surface while on the weathered surface they are creamish yellow, rusty brown and yellowish grey. A number of such bands are met with. One on the roadside near Khannian is massive and pure, others seen in the river near Dhanu bridge near Mahandari and also near Khannian is medium bedded, massive and well jointed greenish grey and brownish white banded and with quartz veins.

The quartz-mica schists and micaceous quartzites are often schistose at places and from subporphyroblastic to porphyroblastic. The porphyroblasts are of micaceous minerals. These rocks are composed of quartz, muscovite, biotite and chlorite. Magnetite and pyrite are accessories.

Thin bedded micaceous quartzites, whitish on fresh surface and whitish grey and rusty grey on weathered surface are also found on the roadside between Khannian and Kandlan. At times, prophyroblasts of biotite are found in the greyish green quartzites, as near Kandlan and downstream of Lohar Banda a band of quartzite has a few silver grey talcose schist layers possibly the result of shearing along some local fault.

Calc-Schist. The calc-schist is generally greenish grey on fresh surface and brownish grey, yellowish grey or dark grey on weathered surface. It may be banded in the form of schist and marble bands. Sometimes there is a gradation between calc-schist and marbles. It is common to find schist and thin bands of marble intercalated in varying proportions. The calcareous material itself can be white, grey, green or yellowish. For example we may have intercalations of creamish white marble with greenish grey schist including white marble streaks.

The calc-schist, too, contains lenticular quartz boudins but these veins apart from quartz also contain 20 to 30% calcite. Quartz appears white or pale white and the calcite showing negative differential weathering is yellow and crystalline.

The calc-schists are subporphyroblastic and at places poikiblastic. They are composed of carbonates, quartz, chlorite, muscovite while biotite, pyrite and magnetite are the accessories.

Marbles : Apart from the thick marble units at Kandlan, Phagal and Lohar Banda which border the Kamalban unit a number of small marble horizons occur within the unit. At least two such bands occurring above Kamalban, near Khannian and above Phagal, are massive and about 20 to 30 ft. thick. The other marble horizons individually are generally 1 to 5 ft. thick and are generally associated with calc-schists.

The marbles are either grey, brownish grey or yellowish on weathered surface and grey, white, light green or creamish white on fresh surface. The creamish coloured marbles are distinctly schistose, the schist laminae being of greenish colour. The white marbles are generally sugary with faint grey bands. At times the marbles show solution effects like pitting but generally these are limited to differential weathering with the schist laminae making positive features.

At least two marble bands, one extending from Khannian to above Phagal and the other in the Kamalban reserve forest have been mapped within the Kamalban unit.

The marbles are medium grained and distinctly granoblastic to subporphyroblastic. They are composed mainly of carbonates. Quartz, pyrite, muscovite, biotite and chlorite occur as accessories.

The rock is foliated and composed of carbonate and quartz with subordinate amounts of biotite, chlorite, muscovite and traces of garnet. The rock is medium grained and non prophyroblastic.

Lohar Banda Marble

The Lohar Banda marble has been mapped as a separate rock unit because of its distinctive nature which acts as a marker horizon for field mapping.

It is mainly white, light grey and light green banded marble with some calc-schists. On the weathered surface it is generally grey.

The Lohar Banda marble is present in the area in the form of two distinct outcrop bands which can be traced over a long distance. One band is exposed on the roadside just upstream of Lohar Banda. Further west it moves across the river (except for a brief second exposure on the roadside near Phagal) to Rajri Kamalban and further west to Birla. Eastwards this band moves on the slope above the road until it again appears on the roadside at Mahandari. The other band appears on the roadside at Kandlan near Khannian. Westwards it moves into Birla, most likely joining with the first band. Eastwards it moves up the left bank slopes of the valley passing above Phagal and then further east through Bastan, over Shir Ka Danna into the valley of Manur Katha.

These two bands of marble, one exposed on roadside at Lohar Banda and the other at Kandlan, are considered to be a single horizon repeated on the two limbs of an isoclinal fold. The two bands are quite similar in nature, colour, thickness and stratigraphic sequence.

The Lohar Banda Marble on the right bank of river Kunhar between Rajri Kamalban and Kamalban makes dipslopes and, therefore, here its outcrop becomes much wider.

The marble is fine to medium grained, medium bedded and white with light green and light grey bands, on the fresh surface. On the weathered surface it is medium grey to dark grey and sometimes yellowish. This marble is typically granoblastic to subporphyroblastic. It is composed mainly of carbonate but accessory to trace amounts of quartz, pyrite biotite, muscovite and chlorite are often present. At places traces of graphite were also detected. Because of its lighter weathering colours and relatively softer nature of its outcrop sometimes it, can be recognized from a distance.

Within the marble outcrop there are one or two bands of quartz mica schist.

Both above and below the main marble band there is a gradation into the adjoining quartz mica schist through a sequence of calc-schist and thin marble bands. The calc-schist is cream to greenish grey. The micaceous parts are greenish and the calcareous parts are yellowish. The calc-schist also contains quartz veins and boundins. These veins, however, contain 15 to 20% calcite apart from quartz. The calcite in these boudins is recognised by yellow weathering colour and negative differential weathering, while on the fresh surface it is white and crystalline. The quartz is white or stained pale white.

The contact of Lohar Banda marble with Phagal quartzites, quartz mica schists and the contact with Kamalban unit are gradational with passage through calc-schists and thin bands of marble.

Phagal Quartz Mica Schists and Quartzites

This unit comprises quartz mica schist and quartzites with subordinate calc-schists and marble. On the weathered surface it is generally dark brownish grey and rusty.

On the roadside the Phagal unit is exposed at the back of the road bend in Lohar Banda Katha where its pelitic and psammatic nature is quite apparent. Away from the road the outcrop occurs in an arcuate fashion between Kandlan in the west and Manur Katha in the east passing under the villages of Kandlan, Chakrial, Phagal, Chantha, Lohar Banda, and Dheri, Kalas, Chaphra and Tipar.

The quartzites are medium bedded both ortho—and micaceous types. They are grey, light brownish grey and white on the fresh surface while brownish grey to rusty brown on the weathered surface. The quartzites are medium grained and often granoblastic The grains are welded and sutured. Quartz is the main mineral while muscovite, biotite, magnetite and tourmaline are from traces to accessories.

Quartz Mica Schist : The quartz mica schist is greenish grey on fresh surface and dark brownish grey on the weathered surface. They contain veins and boudins of quartz. The quartz mica schists are poorly to moderately schistose. They are composed mainly of quartz with subordinate but essential quantities of muscovite and biotite. Chlorite, magnetite and tourmaline are the accessories.

The calc schists are medium grained and poorly to moderately foliated. They are granoblastic to hypidioblastic. They are composed of calcite, quartz,muscovite, biotite, chlorite and accessory to trace amounts of pyrite and graphite (rare).

Marbles : The marbles are medium grained and granoblastic. They are composed mainly of carbonate with accessory to trace amounts of muscovite, chlorite, biotite, pyrite and magnetite.

Doga Schists, Marbles, Quartzites and Metaconglomerates

The principal lithologies in this unit are indicated by its title. The schists include both quartz mica schist and calc-schist. The main difference from the Kamalban unit is the presence of meta-conglomerates and quartzites with porphyroblasts of chlorite and biotite.

The unit occurs in a limited area on and to the south of the ridge top between Parhti, Doga and Danna.

It is much like the Kamalban unit except that it includes fine grained metaconglomerates apart from other lithologies and also the fact that its quartzites and quartz mica schists show porphyroblasts of chlorite and biotite.

The Biari unit to its north on the other hand differs from it in the presence of numerous [illegible] pegmatites and also a greater proportion of metaconglomerates and quartzites.

The Doga quartzites are banded, light greenish grey with green porphyroblasts and some intercalations of grey marble.

The marbles are generally banded, light grey or white with schist partings and weather to light earthy brown, creamish and grey colours. Occasionally the marble bands may be greenish white. The micaceous marbles and calcschists are intercalated with quartzites.

Biari Quartzites, Metaconglomerates, Schists, Calc-Schists and Pegmatites

The principal lithology is indicated by the title of the unit. This unit resembles the Doga unit but differs in the fact that it contains ubiquitous pegmatites. Also the calc-schists are subordinate and the metaconglomerates are much more prominent. The quartzites of Biari unit as well as that of Doga unit are mostly micaceous and in this respect differ from the quartzites of Kamalban unit which are mostly orthoquartzites. Some quartzites in Biari unit are impure and look porous. This unit is also characterised by the general absence of graphite schist. The general colour of the unit is banded grey, brownish grey and greenish grey.

A number of dolerite dykes are also present.

Quartzites : The quartzites are generally banded grey, brownish grey, greenish grey and whitish on fresh surface and dark brownish grey and rusty brown on weathered surface. They are generally micaceous, containing porphyroblasts of green chlorite and sometimes brown biotite and intercalations of quartz mica schist. The intercalations of schist are dark grey with prominent brown biotite. The banded quartzites with porphyroblasts of chlorite and intercalations of schist make the dominent lithology in the unit. The quartzites are well jointed. At one place below Doga the micaceous quartzite contains fine white specks. At times when the quartzite with micaceous porphyroblasts is cut oblique to foliation the surface gets the appearance of fish scales.

Metaconglomerates : The pebbles in the metaconglomerates stand out on the weathered surface The pebbles are generally dark grey or dark greenish grey in colour while the ground mass is light grey to light greenish grey in colour.

Quartz Mica Shist : It is generally light grey, greenish grey and brownish grey on fresh surface while on the weathered surface it is dark brownish grey to dark grey. It is interbedded with quartzites, metaconglomerates and marbles. They contain some quartz veins in the form of thin boundins. Chlorite and biotite are prominent flaky minerals.

Calc-Schist and Marbles : A few thin grey and white marble bands are present, especially towards the Doga unit. The marbles have thin micaceous partings. The calc-schists are distinguished by differential weathering.

Pegmatites : The Biari unit like the Rajwal unit is distinguished by the ubiquitous presence of pegmatites. However, these pegmatite bodies are generally small (at times only few inches thick veins) compared to those of Rajwal unit and appear badly crushed and sheared, especially towards the faulted contact of the unit with Jared quartzite and quartz mica schist unit towards south. The pegmatites are greyish white in colour and mainly composed of quartz and feldspar. The feldspar is generally light grey or sometimes bluish grey. Muscovite, biotite and tourmaline (up to 1 cm in cross section) are subordinate and sometimes not seen Occasionally the pegmatites show dark grey thin patches of graphite/chlorite as coatings on granular minerals. The pegmatites also contain some associated quartz veins.

The presence of syntectonic pegmatites is related to the generally quartzitic and sheared nature of the unit. Most bodies appear parallel to the foliation.

One contact of the Biari unit is with the Jared quartzite and quartz mica schist. This contact is faulted throughout the mapped area. A few thin pegmatite bodies which are characteristic of Biari unit were also seen in the Jared unit in Ochri Katha.

The other contact with the Doga unit is partially faulted but is partially intact and gradational east of Doga.

Jared Quartzites and Quartz Mica Schists

The rocks between Jared and Tutan on the roadside are distinguished by their arenaceous/psammatic lithology represented by interbedded quartzites and quartz mica schists. There is a marked absence of calcareous and graphitic material. On the fresh surface the general colour is light brownish grey for quartzites and greenish grey for schists.

Occasional dolerite sills are also present.

Quartzites : Most quartzites are banded, micaceous and relatively thinly bedded. They are generally light coloured on the fresh surface. They can be greenish grey, light grey or brownish grey and occasionally green and white banded. On the weathered surface they are earthy brown, brownish grey and dark brownish grey and at times rusty brown. Individual beds are generally from 5 cm to 15 cm thick.

The quartzites are often granoblastic to xenoblastic. They are fine to medium grained and composed mainly of sutured and welded quartz grains with subordinate to accessory amounts of muscovite, greenish biotite, chlorite, feldspar, tourmaline and magnetite.

Some quartzites with thin micaceous or quartz mica schist intercalations may be better called quartz mica gneisses. Occasionally the quartzite contains micaceous porphyroblasts.

Towards their contact with Chushal

graphite schists the Jared quartzites contain some thin pegmatite veins (2 cm to one metre) with quartz, feldspar, muscovite and tourmaline.

Quartz Mica Schists : The other main lithology of Jared unit comprises quartz mica schists which are greenish grey, at times whitish to light brown, on fresh surface and dark brownish grey on weathered surface. Some schists in cross section can be seen to comprise very thin green and white (quartz) layers.

These rocks are foliated but poorly to moderately schistose. They are fine to medium grained and composed of quartz and muscovite. Some chlorite, biotite (green) and tourmaline may also be present.

The upper contact of Jared unit with Chushal graphite schist is faulted except near Utli Baseri within the mapped area. Near Utli Baseri the contact appears to be gradational with the content of graphitic material gradually increasing in the quartz mica schist of Jared unit.

The Lower contact with Biari unit in the west towards Chushal and Biari and with the Kamalban unit in the east towards Duhar is faulted throughout the mapped area.

Stratigraphically the Jared quartzites and quartz mica schists may be considered the equivalent of Tanol Formation in Kaghan Valley.

Chushal Graphitic Schist and Metaconglomerate

Between Shino marble and the Jared quartzites there is a relatively thin but very prominent sequence of graphitic schists, metaconglomerates with occasional thin bedded marble bands, calc-schist and quartzofeldspathic microgneisses. This represents the so-called Agglomeratic Slate unit of Kashmir. In Kashmir the sequence contains well defined acid to intermediate volcanic rocks but in the Kaghan Valley well defined volcanics are difficult to find though sedimentary material derived from volcanics is present.

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

Marble. It is medium grey, thinly laminated with fine white partings and intercalated with calc-schist. The Marble and calc-schist occurs towards the contact of Chushal unit with Jared unit.

Metaconglomerates. The metaconglomerates are best exposed on the path from Chushal Village to Kamil digali. It consists of rock pebbles of graphitic schist, quartzite, marble, calc-schist and of granite. The rock is poorly sorted but shows a degree of foliation. Most pebbles are subangular indicating short distance transportation. The matrix is coarse grained and gritty. A few quartzofeldspathic veins are present. The conglomerate shows two varieties, one is coarse grained and the other is relatively fine grained. The coarse variety contains boulders one foot or more across. The conglomerate is dark brownish grey on weathered surface and grey on fresh surface.

The conglomerate sequence also contains a band of impure quartzite, medium grey on fresh surface and brownish grey on the weathered surface. It is highly fractured.

Panjal Volcanics and limestone marbles

Panjal Trap. On the [illegible] the Panjal Trap comprises a few thick bands of [illegible] volcanics which alternate with few thick laminated calcareous bands. The whole sequence has suffered low grade metamorphism. Only a part of this thick series of rocks occurs within the mapped area.

The trap is the volcanic part of the Panjal series and occurs as two thick bands. The band in contact with the Shino marble extends on the roadside from near shino hatchery to close to the Bhunja bazaar. The colour of the rock is dark greyish green. Large porphyroblasts of chlorite are commonly developed. At places the rock shows pillow like lenses which appear to be relics of pillow structure.

The contact with shino marble appears to be gradational though it is quite distinctive. The upper contact of the trap band exposed in the mapped area is with a microgneiss exposed near Bhunja Bazaar.

The trap outcrop becomes thinner towards the apical side of the syntaxial bend.

Shino Marble. The Shino Marble is best exposed on the roadside opposite the Shino Hatchery where it is making overhangs on the roadside. The unit consists of sugary arenaceous marbles and calcareous quartzites. Most of these are coarse grained light grey or yellowish grey. At the contact with Chushal unit the Shino unit comprises fine grained marble which is medium grey on fresh surface and creamish yellow or yellowish brown on weathered surface. The lower contact with Chushal unit is sharp while the upper contact with the Panjal Trap is well defined but shows some gradation.

Stratigraphically the Shino Marble may be considered a part of the Panjal series.

Line and Bhunja Limestone/Marbles. The greenstones are interbedded and folded with contemporaneously deposited sediments, now comprising three major bands of fine grained, crystalline, slightly metamorphosed limestone/ marble.

The Ling band outcrops at Ling village near Malkandi forest rest house ; the Bhunja band is exposed near Bhunja bazaar four miles upstream of Paras and the Shino band outcrops where Shino fish hatchery is located on the roadside about two miles downstream of Jared.

The Ling and the Bhunja limestone/ marble bands are fairly similar to each other. They comprise fine grained, thinly laminated, medium grey limestone/marble with thin white and yellow partings. Both outcrops also contain some thin greenish grey phyllite bands. The Bhunja outcrop in addition shows one or two quartzite bands.

The upper contact of Ling limestone/ marble is faulted against sedimentary Jurassic limestone while all other contacts of Ling and Bhunja appear gradational and/or conformable

The Ling and Bhunja bands are often fine grained and granoblastic to hypidioblastic. However, on closer examination the crystals appear stretched and strongly strained. The quartz/chalcedonic matter is often so strongly stretched in some cases that they assume the form of long lamellae. These rocks are fairly pure and are composed of calcite with minor amounts of quartz, chlorite and pyrite. At places quartz and chlorite may assume the status of primary minerals.

The Shino band is rather impure. It, in addition to calcite contains significant amounts of quartz and sometimes chlorite. At places quartz appears secondary and may be developing after chalcedony.

DISCUSSION

Regional Metamorphism

The grade of regional metamorphism increases from south to north and ranges from biotite to kyanite in the areas mapped.

A careful study of the metapelite horizons of the Lohar Banda, Phagal, Kamalban, Doga, Biari and Jared units shows that they fall in the biotite grade of regional metamorphism. While biotite is ubiquitous in these units, almandine garnet is absent. Sporadic tiny garnet crystals do occur south of Lohar Banda unit. But this garnet occurs within calcareous meta-pelites and is andraditic in nature.

The Kaghan pelites contain ubiquitous almandine garnet. This thick unit falls in the almandine grade of regional metamorphism.

The Batal, Paludaran and Rajwal units certainly represent a distinctly higher grade of regional metamorphism Beginning of partial metatexis in the suitable compositions of Rajwal and to a lesser extent in the Batal unit indicates a grade of regional metamorphism higher than almandine grade. Staurolite grade is, therefore, certainly indicated, though the mineral staurolite could not be found

Development of Kyanite in the pelitic lithologies of the Naran unit and the Dharir unit clearly shows that these two units are in the kyanite grade of regional metamorphism.

Thermal Metamorphism

Due to extensive faulting, morainic deposit cover and at places, migmatisation and feldspathisation, the hornfelse outcrops are rare. The only well developed hornfelse is on the left bank of Kapan-da-Katha near Naran. Here biotite rich andalusite hornfelse represents a thermal aureole of Saifal Maluk granite. The second poorly exposed hornfelse outcrop is near Dhamnar, Sohch.

Migmatites

Migmatites are well developed in the Rajwal unit as well as the Dharir unit. But the migmatites in the Dharir unit are particularly well developed.

In neither case is a granite directly involved in the formation of these migmatites In the case of Rajwal, no granite body is associated with the migmatites.

In the case of the Dharir migmatites there indeed is a granite body i.e. Saifal Maluk granite in the vicinity, but field relation do not support the possibility of direct involvement of this granite.

The migmatites are not directly in touch with the Saital Maluk granite, instead there is an intervening meta calc-pelite and meta pelite unit. This unit is only slightly effected by migmatisation This unit is preserved intact between Sohni and Batakundi on Naran-Batakundi road.

These migmatites as well as Rajwal leucosomes can not be products of injections. They are in-situ migmatites formed by metatexis of meta-pelites, meta-arkoses, acid meta-tuffs (?) and meta-feldspathic psammites. They show a wide variety of structures within leucosomes. They show stromatic, phelabitic and neubilite structures In Dharir unit the palaeosomes and neosomes show a particularly complex relationship. Agmites and resisites are also common. Schilleren, ghost structures and stratigraphy can be seen in the neubilites The resisites are orthoquartzites, calc-pelites, amphibolites and marbles. The pelites with minor carbonate contents also tend to survive metatexis (Mehnert, 1968).

The leucosomes as against melanosomes (palaeosomes) assume a variety of textural and structural forms. Granitic, aplitic and pegmatitic textures are all well represented.

The presence of micas and ubiquitous tourmaline indicates that water and halogens were well represented during metatexis.

The metatexis was taking place well within staurolite and kyanite grades of regional metamorphism.

The meta-arkoses, meta-feldspathic quartzites and meta-pelites with low calcium content are the first to melt. The anatexis starts at 650° C and at pressures more than 2 Kb (Winkler 1967, 1974). Experimental work (Winkler 1974) shows that meta-arkoses and acidic tuffs are first to melt while feldspathic meta quartzite and pelites follow. The orthoquartzites, calc-pelites and amphibolites survive as resisters while arkosic, pelitic and tuffaceous rocks reach a stage of diatexis provided sufficient water and halogens are available.

The metatexis most probably occurred between 650° to 680° C in the presence of limited amounts of water and volatiles for Rajwal unit while in the case of Dharir unit the temperatures exceeded 680° C and most probably reached 20° C since a wider variety of rock i.e. even-pelites have been effected. These probable estimates are based on the gross lithology of the rocks involved and the proportions of melts formed. These temperature ranges are in accordance with the experimental work of Walton (1960) and Tuttle and Bowen (1958), Tuttle (1955) and Winkler (1974). The amount of melt does not solely depend upon temperature, it also depends upon the content of water, volatiles i.e. halogens and above all the nature of rocks. Increasing quantities of water and halogens decrease the temperature of melting of rocks of different composition at given pressures while the increase in the calcium content elevates the temperature of melting (Winkler 1974, 1967, 1954, Winkler and Platen 1958 and Barth 1952).

STRUCTURE

The general and regional strike of the rocks and other geological features is northeast-southwest in the region between Bhunja and Chitta Katha, a distance of about 26 miles along the road. Then for a short distance of 4 miles along road between Chitta Katha and Naran the strike changes to northwest-southeast and then again from Naran to Batakundi another distance of 12 miles along the road the strike becomes northeast-southwest.

The regional dip is NNW from Bhunja to Kalas and then NW from Kalas to Chitta Katha. Between Chitta Katha and Naran the regional dip is NE. Between Naran and Batakundi the regional dip is SE.

A look at the geological map (p.) readily gives a general idea of the structure of the mapped area.

Faults

From Bhunja in the south to Batakundi in the north there are some seven major faults namely, Murree fault, Shino Fault, Tutan fault, Jared Fault, Khannian fault, Rajwal fault and Batal fault.

It is interesting to note that the major faults in the Kaghan valley and in the terrain generally to the north of the sedimentary zone of hill ranges of Abbotabad, Nathiagali, Thandiani etc. are indicated by fault breccia, crush zones and fault gouge, etc. On the other hand the faults in the Thrust belt of Abbottabad Nathia-Gali have got to be recognised mainly on the basis of missing stratigraphic units.

The faults in the mapped area are not very obvious because of vegetation, high relief, scree and other superficial deposits. However, stratigraphic breaks, structural anomalies, fault breccias, crushed zones, sharp contacts and geomorphic indicators link up to demarcate the major faults. Most faults are high angle thrusts which dip to the northwest except the Batal fault which dips northeast.

Murree Fault. It is a major thrust dipping steeply to the NE or being vertical at places. It separates the sedimentary sequence from the metamorphic rocks. It has been folded as part of the Hazara Kashmir Syntaxis. It is exposed in the Bhunja Katha in the mapped area.

Shino Fault. A nearly vertical thrust dipping steeply to to the north and northeast in the mapped area. It is exposed near the mouth of Chushal Katha. The fault occurs between the Chushal Graphitic Schist and the Shino Marble units and has been folded as part of the Hazara Kashmir Syntaxis. The Chushal Graphitic Schist has provided a plastic horizon for slippage.

Tutan Fault. This fault separates the Chushal Graphitic Schist (the Agglomeritic Slates) to its south and the Jared quartzites (Tanol Formation) to its north. Within the mapped area its outcrop extends from Danna in the west through Chushal, Nake Tutan (roadside) and Ochri Katha, in the east. This high angle thrust (75° near surface) dips to the north and northeast. It can be seen on the roadside at Tutan and in a section just across the river on its rightbank. This fault has also resulted from the mobility provided by the g raphitic Chushal unit. However, the contact between Chushal graphitic schist and Jared quartzites does not appear to be faulted everywhere. On the other hand it appears to be gradational near Baseri and to its east. The contact also appears to be gradational elsewhere around the syntaxial bend as at Badhawa (Ghazanfar and Chaudhry 1984).

On the right bank of the Ochri Katha at one point a slice of Panjal Trap occurs at the contact between the Chushal graphitic schist and Jared quartzites along this fault.

Jared Fault. The Jared fault is a major fault with a fairly straight line outcrop running east to west throughout the width of the mapped area. This fault which runs along the lower side of the Jared quartzites and quartz mica schist has created tremendous brecciation and crushing especially in the Jared unit. This has led to the accumulation of huge and impressive scree and colluvial deposits between Mahandari and Jared on both sides of the river especially on its left bank on the roadside. This brecciation and crushing is also evident in the drainage of Kayyan village and the opposite drainage of Dadar village. The crushing is also evident on the slopes between Chushal Danna and Biari and in the crushed nature of pegmatites of Biari unit.

This fault separates the Jared unit to the south from the Biari, Doga and Kamalban units to its north. The trend of the latter units abruptly truncates against it.

This thrust fault is nearly vertical or dips steeply to the north near the surface.

At Shalai, near Mahandari, a northeast-southwest trending fault, coming out of Manur Katha along a band of graphitic schist, joins the larger Jared Fault.

Khannian Fault. The Khannian fault appears on the roadside just upstream of Khannian bazaar. It separates the Kamalban unit (which here has been greatly reduced in width due to this fault) from the Kaghan Pelites to its north and northwest. From Khannian this fault extends NE to Barth Danna through Shinkiari. It is a thrust fault which dips steeply to the north west. The Khannian fault has also truncated the extension of gypsum outcrop below Sirul Danna.

Rajwal Fault. The Rajwal Fault is a thrust fault which dips steeply to the north and west. Its outcrop extends from Rajwal in the west along a nearly (straight ENE trending line across Por Katha Chambar Katha) and across Gori Katha (which drains out at Paludaran).

Within the mapped area this fault has the Kaghan Pelites to its south and obliquely truncates three different units, the Rajwal unit, Paludaran unit and the Batal unit to its north.

This fault has produced prominent crushed zones especially in the Por Katha drainage. Some drainage lines near Kalas village and some segments of Por Katha also follow the ENE trend of this fault.

Batal Fault

The Batal Fault is a northeast dipping high angle fault which separates the Naran garnetiferous calc-pelites to the north and the quartzitic Batal unit to its south. This fault has produced a fair amount of shearing and crushing in the Batal tributary of Batal Katha.

Folding

Only the major folds have been charted and will be discussed below Nearly all major structures are separated from each other by major faults and relate to a particular fault block. In some cases the fault blocks also separate major stratigraphic units and since the stratigraphic units have their distinct overall litho'ogy the rocks in such fault blocks have their own folding style as well

Baseri, Ochri and Chushal Folds

The Chushal Agglomeratic Slate and the overturned overlying units Shino Marble and Panjal Traps along with other units to the south constitute the eastern limb of the Hazara Kashmir Syntaxis. Within the mapped area the units of this limb are folded in a broad open manner, constituting three folds the Baseri Antiform, the Chushal Antiform and intervening Ochri Synform. The Chushal Antiform to the west constitutes the main bend of the syntaxis after which the NW strike from Kashmir turns gradually to E-W to form the apical portion of the syntaxis in the region of Paras, Bela and Sacha. The limb of Chushal Antiform exposed in the Chushal is badly shattered and internally folded. The general strike here is NW-SE and dip to the NE. The other limb strikes NE-SW and dips to the NW. In crestal region the dips are nearly vertical and at places reversed to the south. The Chushal Antiform showse intense de formation within the limbs and th crestal region.

Kamalban and Phagal Folds

Between the Kannian Fault in the north and the Jared Fault in the south lie a series of rock units which include Phagal unit, Lohar Banda unit, Kamalban unit, Doga unit and Biari unit. All these rock units are characterised by a substantial amount of calcareous material apart from quartz mica schist and other lithologies. Within the mapped area all these units are folded together in the form of one tight anticine and one tight syncline both outlined by Lohar Banda Marble. The limbs strike NE-SW, the general dip is towards northwest and the folds are overturned to the southeast.

Kaghan Synclinorium

The Kaghan Pelite unit which extends on the roadside from Rajwal in the north to Khannian in the south is broadly as synforms and few tighter antiforms.

The Kaghan Pelites show ubiquitous microfolding, crenulation, strain-slip cleavage and lineation.

Paludaran Antiform

This is again a major structure extending over many miles between Kalas near Kaghan where its southern limb or the Paludaran limb is cut by the Rajwal Fault and Batal Katha near Naran where its northern or the Bhimbal limb is limited by the Batal Fault It is an open antiform plunging to the ENE. Its plunging nose can be seen in Batal Katha (left bank) near the latter's bifurcation into Batal Katha and Danna da Katha. The Paludaran limb strikes NE-SW and dips SE while the Bhimbal limb strikes NW-SE and dips NE. The two limbs themselves have open drag flexures and numerous minor folds. Some such microfolds are seen near the crestal portion of the antiform at the mouth of Chitta Katha on its left bank on the roadside near the bridge. The Paludaran antiform is outlined on the geological map by the Paludaran graphitic schist unit which moves on the left bank slope of Bhimbal Katha from Chambar or Chitta Katha to Dheri and also from Chitta Katha to Paludaran upto the Por Katha Gali where it is truncated by the Rajwal Fault. The Paludaran Antiform thus has Batal quartzites and mica schist unit on the outside and the Rajwal quartzites, quartz mica schist and pegmatite unit in the core.

Naran Antiform

The Naran antiform has been formed in the Naran garnetiferous calc-pelites and granite gneisses. The granite gneisses are sheet like bodies which have been folded along with the calc-pelites. It is a huge structure extending from Batal Katha in the south to Batakundi in the north. It is an overturned antiform with its axial plane dipping to the NE and fold axis plunging SE. The southern limb or the Naran limb has a northwest-southeast strike and dips generally 50° to 60° NE. The northern or the Sohch limb extends from close to Naran to beyond Batakundi. Close to Naran the Sohch limb dips steeply but towards Batakundi it dips more moderately at 30° to 40° towards SE. In the core of the anticline which is exposed on the roadside between Naran and Dhumduma (right bank of the river) there are numerous tight folds in the garnetiferous calc-pelites and the dip-strike trends change rapidly. Near and upstream of Naran Circuit House a large number of tight minor folds are present within the Naran limb close to the core (each with one limb striking NW dipping NE and the other limb striking. approx. E-W and dipping N.) Occasionally minor granite bodies can be seen involved in the folds.

Economic Geology

In the area mapped, the following minerals are of potential economic value :

1. Marble.
2. Quartzite.
3. Gypsum.
4. Graphite.
5. Mineral shows of Chromite/Nickel/Asbestos/Corundum/Ruby/Sapphire.

Marble. The marbles beds occur in Kamalban, Phagal, Lohar Banda and Naran calc-pelite units. (For details, please refer to the description of these units and the geological map). The marble horizons range in thickness from 2 to about 250 feet. These marbles are white off-white, banded white and dull green or white and dull grey. They are mostly granoblastic, hard, compact and medium grained. They yield blocks from less than 25 cm. cube to 1.50 m cube. The Lohar Banda unit is mainly a marble which is exposed along the main Kaghan road. It is white to snow white, medium grained, hard and compact. Its thickness is about 200 feet.

The area mapped holds extensive reserves of marble Their exploitation, however, will depend upon the condition of road and the availability of power. If transported as blocks to the markets in Punjab, it may not compete with Swabi-Mardan marble. The latter are nearer to the markets and the source areas are well connected with good roads to the market. However if finished products are prepared near the site of the Kaghan deposits, transport charges on per unit (finished) product may well bring it within economic range of exploitation.

Quartzite. Quartzites occur within Doga, Biari Phagal and Kamalban units. But Kamalban unit contains some white to snow white and pure beds of orthoquartzites. These beds merit further study and evaluation for glass, ceramics and chemical use. For occurrence and general description please refer to the geological map and descriptions.

Gypsum. Gypsum occurs as a distinct horizon about 250 to 300 feet thick towards the top of the Kaghan meta-pelite unit. For its occurrence and description please refer to the relevent section and map. The gypsum crosses the main Kaghan road near Julgran and crops out on the left bank of Kunhar near Putandes. Being a material of low unit value it cannot take a high transport charge. Its exploitation as a constituent of cement or use as gypsum plaster or agri-gypsum may have to wait the development of a better infrastructure.

Graphite. There are two distinct graphite bearing horizons in the area mapped (leaving out Chushal unit which is of no economic interest and other minor Bands in Kamalban, Kaghan pelites and Rajwal units).

The Paludran horizons is a distinct zone which occurs in between the Batal and Rajwal units. This unit is composed of marble and graphite meta pelite schist horizons. There are at least three graphite bearing beds in this horizon. The aggregate thickness of graphite schists here is at least between 50 to 100 m. It is a mixture of crystalline and microcrystaline graphite. The graphite content in this unit ranges from 12 to 25%. This unit has crystallised within staurolite grade of regional metamorphism.

The second graphite horizon occurs within the Naran Meta-calc-pelites This horizon is well exposed near Randi on the left bank slopes of river Kunhar near Sohch. It is about 30 to 70 m thick. The horizon, compared to Pludran unit, occurs within a high P-T environment. It contain 8—20% graphite. This graphite occurs within metapelites of Kayanite grade of regional metamorphism. The graphite is mainly of a crystalline variety.

Both these horizons definitely merit further studies and evaluation.

Chromite, Nickel, Asbestos, Corundum, Sapphire, Ruby. North of Ledi starts the "Southern Melange Zone" of Chaudhry, Ghazanfar, and Ashraf (1983, 84). A sizeable ultrabasic body occurs near Ledi. Floats and shows of chromite, pentalandite and millerite were observed north of Ledi. Outside the area mapped were observed shows of chromite, asbestos and nickel minerals in the "Southern Melange Zone". Additionally good quality serpentine was also observed. This zone near Ledi passes into Kohistan and then continues to Pushto, Ilahi Kohistan, Darra, Jijal, and Dubair. In this belt granites are also present. Some of them may belong to the Himalayan orogeny. This raises the possibility of the extension of emerald belt into Kohistan, Kaghan and even North Neelum. The Naran Meta-graphite-calc-pelites are cut by dykes and sills of basic compositions. The "Southern Melange Zone" also cuts this unit.

Marble's contacts with these basic to ultra-basic bodies need particular attention. Products of desilication like corrundum, sapphire and ruby/spinel should not be overlooked.

GEOMORPHOLOGIC NOTE

Drainage

From its emergence at Balakot to its head at Babusar Top the road along the river Kunhar is over 95 miles long. This gives an idea of the length of the Kunhar valley. The river, however, extends beyond Balakot for another about 20 miles until it meets the river Jhelum near Muzaffarabad in Azad Kashmir.

The river is known for its speed, ferocious turbulence and cold water. It receives a large number of tributaries on its way. From Batakundi to Mahandari the major left bank tributaries include Dadar Nar, Por Katha, Saiful Maluk Katha, Batal Katha, Chitta Katha, Surmai Katha, Gori Katha, Chambar Katha, Kaghan Katha, Lohar Banda Katha and Manur Katha. On the right bank the major tributaries, within the same section, include——-——Katha, Shanak (Dhamnar) Katha, Sohch Katha Dhumduma Katha, Bhimbal Katha (Nili Nar), Rajwal (Kalas) Katha, and Rajri Katha. In terms of discharge the largest (from both banks) are Dadar Nar, Saifal Maluk Katha, Batal Katha, Chitta Katha, Surmai Katha, Gori Katha, Kaghan Katha, Putendes Katha (right bank), Lohar Banda Katha, and Manur Katha.

The right bank tributaries of river Kunhar drain the Kohistan watershed and the left bank tributaries drain the Kaghan watershed (between river Neelum of Azad Kashmir and river Kunhar). Generally speaking those tributaries with large discharge drain the Kaghan watershed and join river Kunhar on its left bank. The left bank receives a large amount of snowfall and upstream of Kaghan township glaciers and avalanches pose a constant hazard to the road. Furthermore left bank in this section faces west and receives less sunshine while on the east-facing right bank, exposed more to the sun, the snow melts fast. Between Kaghan and Batakundi most village settlements are on the right bank. If the road between Kaghan and Batakundi is shifted to the right bank, in accordance with the historical experience of the people, it could remain open most of the year and also require much less maintenance.

By and large the water in the tributaries is the product of snowmelt. The rainfall is limited to certain times of the year.

Slopes

The main spurs have a convex slope profile made up of mostly rectilinear segments. However, glaciated cliffs near the main watershed make a concave break with the rest. The main spur slopes vary between 5° and over 40° with roughly 30% being at less than 10°. Roughly 40% which falls between 10° and 30° at some places is either cultivated or covered with forest and at others it shows outcrop exposures. Those sections of ridge tops which form benches generally constitute grassy pastures, locally called mahlies. The width of these 'mahlies' may vary from 50 ft. to over 200 ft. These mahlies occur at roughly 11,000 ft. altitute in the region of Batakundi and Bas; above 10,000 ft. in the region of Naran, and Rajwal (Kundi); between 9,000 ft. and 10,000 ft. at Charnat, Shiri, Utli Baseri and Doga; and between 7,000 and 8,000 ft at Shogran.

Another important slope segment is the river side cliff which is present along the river and indicates the latest spurt of erosion by Kunhar

Valley Profiles

The river and its principal tributaries are generally without any waterfalls Waterfalls occur in the upper reaches of some major tributaries (such as at Dheri in Nili da Nar) especially where the glaciated part of the valley meets the mainly fluvially eroded long profile. Such waterfalls can divide the valley into two parts. The upper part has a gentler long profile and an open cross profile with scree and moraine fans on the sides (such as in upper part of Dhumduma valley, Saifal Maluk valley above lake Saifal Maluk, Rajwal (Kalas)

Katha valley at Kundi and parts of Kunhar Valley itslf at Batakundi and Lalazar). The lower part of these valleys are V-shaped and much more affected by fluvial processes.

The cross-profile of river Kunhar is V-shaped and the valley at the base is generally narrow below Kaghan with interlocking spurs while above Kaghan the valley floor is more open especially where it receives important tributaries.

The Kunhar River itself has many rapids especially in the upper reaches above Paludaran. Many of these, however, are not cyclic and are the result of partial and temporary blockades of the river by glaciofluvial material dumped by its major tributaries.

Processes

From the point of view of processes we may consider the Naran to Kaghan Section as trasitional. Downstream of this section the fluvial processes become increasingly more prominent (except in the uppermost reaches of principal tributaries near the main watershed). Upstream of this section the fluvial processes still dominate but the modifying effects of glacial processes can be increasingly felt and even more so towards the heads of principal tributaries.

Effects of glacial erosion are manifested by cirques, lakes, aretes, horns, truncated spurs and the cross profile of the glaciated regions of the valleys.

Deposits along Kunhar

In an area like Kaghan Valley where stream erosion is very active preserved depositional landforms can only be very limited.

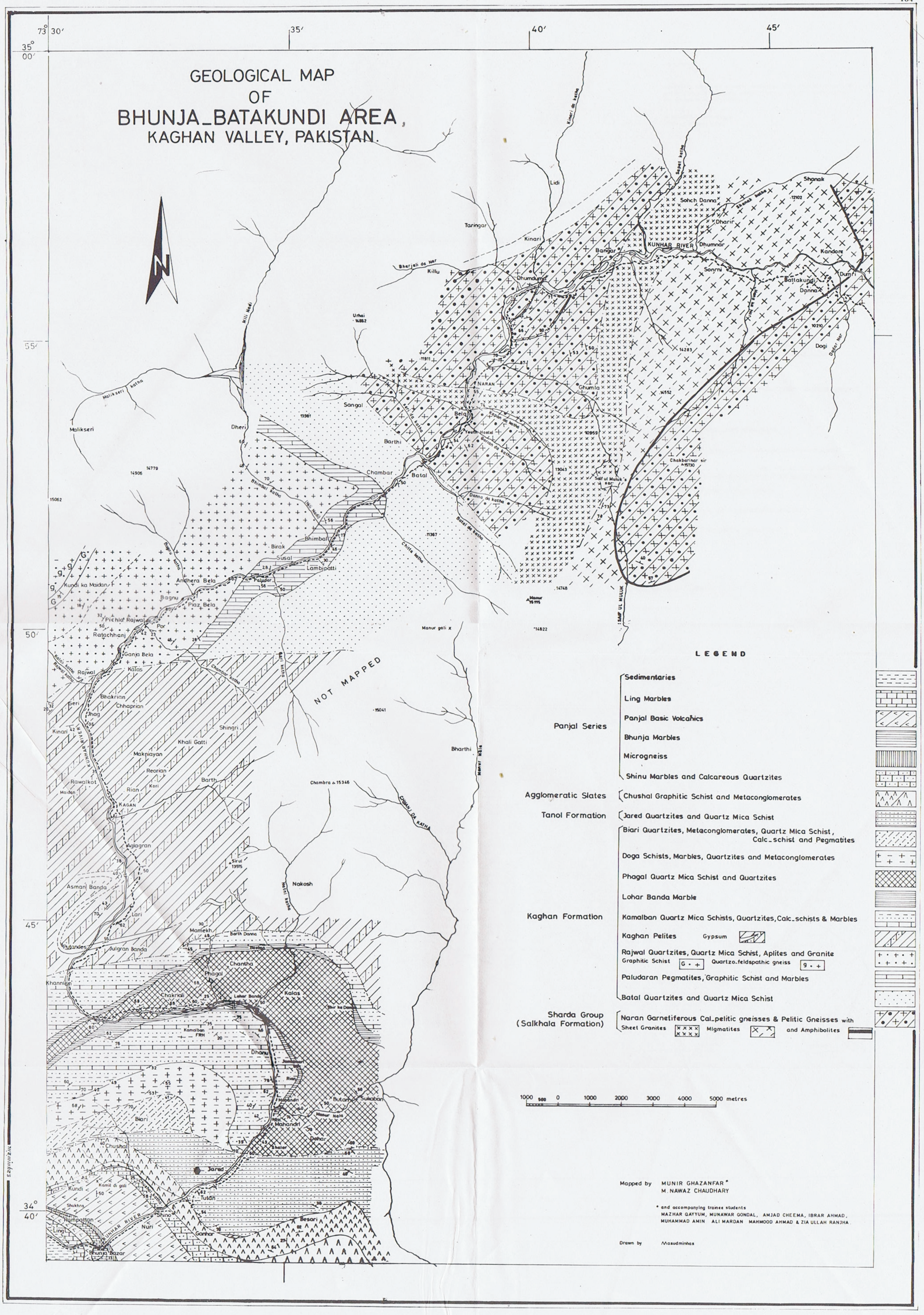
Downstream of Kaghan most fluvial deposits are in the form of terraces like those at Paras, Mahandri, [illegible], [illegible], [illegible] Kandian, and Kaghan. The material of these terraces contains substantial colluvial component. From Kaghan upstream, however, glaciofluvial cones and fans start mixing with the material of Kunhar terraces. For example the village of Kaghan is mainly located on a fan at the mouth of Kaghan Katha while the extensive area under cultivation by the Kaghan Agricultural Research Farm is a river terrace. Similarly the terraces at Rajwal and Bagnu are of a mixed character.

Perhaps the largest river terrace in the area occurs at Kaghan. Most other terraces are small, patchy and elongated. Where the valley is narrow the terraces, if developed, are narrow and elongated and are locally called Lambipatti.

Upstream of Kaghan the valley generally widens and the terraces, where they occur, are fairly wide as at Jhag, Rajwal, Bagnu and Paludaran but occur at a lower level generally 10 to 25 ft. from the river. An older much higher terrace level is preserved at the mouth of some big tributary streams as at the mouth of Bhimbal and Rajwal and Kalas Kathas. This level is over 100 ft. higher from the river bed.

Near Naran and further northwards the superficial deposits are mainly in the form of glaciofluvial fans and cones. These have a perfect fan shape with a gently convex crest and a convex cross profile. The present day stream that flows over them is generally confined to one side or one part of this fan. The larger fans are extensively cultivated and habitated like the Darseri fan, Dhumduma fan, Sohch fan, etc. The material of these glaciofluvial fans varies generally from silt to boulder size. There is some clay, too, and some boulders are extra large size, over 3 m across. Apart from the major glaciofluvial fans there are small glaciofluvial cones which are steeper in gradient and generally covered with scree.

Near Batakundi the glaciofluvial fans give way to direct glacial moraines in the valley and especially on the side slopes. The valley of River Kunhar Itself has scree slopes on the right bank above Kandore near Batakundi. These glacial scree slopes are now hanging above the river as the later has cut by about 100 ft. through and below them. This scree blanket on slopes is like a wedge which becomes progressively thinner and steeper in angle upwards towards the cliff which normally occurs above them.


GEOLOGICAL MAP
OF
BHUNJA_BATAKUNDI AREA,
KAGHAN VALLEY, PAKISTAN.
NOT MAPPED
KUNHAR RIVER
LEGEND
Panjal Series
Sedimentaries
Ling Marbles
Panjal Basic Volcanics
Bhunja Marbles
Microgneiss
Shinu Marbles and Calcareous Quartzites
Agglomeratic Slates
Chushal Graphitic Schist and Metaconglomerates
Tanol Formation
Jared Quartzites and Quartz Mica Schist
Kaghan Formation
Biari Quartzites, Metaconglomerates, Quartz Mica Schist, Calc_schist and Pegmatites
Doga Schists, Marbles, Quartzites and Metaconglomerates
Phagal Quartz Mica Schist and Quartzites
Lohar Banda Marble
Kamalban Quartz Mica Schists, Quartzites, Calc_schists & Marbles
Kaghan Pelites
Gypsum
Rajwal Quartzites, Quartz Mica Schist, Aplites and Granite
Graphitic Schist
Quartzo_feldspathic gneiss
Paludaran Pegmatites, Graphitic Schist and Marbles
Batal Quartzites and Quartz Mica Schist
Sharda Group (Salkhala Formation)
Naran Garnetiferous Cal_pelitic gneisses & Pelitic Gneisses with
Sheet Granites
Migmatites
and Amphibolites
1000 500 0 1000 2000 3000 4000 5000 metres
Mapped by MUNIR GHAZANFAR*
M. NAWAZ CHAUDHARY
* and accompanying trainee students
MAZHAR QAYYUM, MUNAWAR GONDAL, AMJAD CHEEMA, IBRAR AHMAD,
MUHAMMAD AMIN ALI MARDAN MAHMOOD AHMAD & ZIA ULLAH RANJHA.
Drawn by Masudminhas