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PETROLOGY OF THE KARAK BENTONITE - KOHAT DISTRICT N.W.F.P. PAKISTAN

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Abstract : *A detailed petrographic, chemical, mineralogical and statistical study of the Karak bentonite is being presented for the first time. A total of 46 petrographic analyses, 47 chemical analyses, 6 X-ray analyses, 11 d.t.a analyses and 11 spectrographic analyses have been discussed. The study shows it to be a mixed layered montmorillonite-illite with MgO in excess of CaO. It is originally thought to have been deposited as a montmorillonite which on a depth of burial of about 10,000 feet and in the presence of K⁺ ions has been converted to a mixed layer montmorillonite-illite. The clay is transported and well stratified. It was deposited in a shallow undulating evaporitic basin with water reduced to nearly 1/3 of its original volume and varying slightly on either side.*

INTRODUCTION

The Karak bentonite shows best development near the town of Karak (Fig. 1) in the Karak hills. The town of Karak is located at coordinates 33° 07' : 71° 06' toposheet 38 0/4. The town is 111 km south of Kohat and 53 km from Bannu. The town can be approached by a metalled road branching off from Kohat-Bannu road at Surdag 21 km West of Karak. The main bentonite deposits are from 1.5 to 3 km west of Karak.

The area has a moderate relief with minimum height of 528 m and a maximum height of 975 m above sea level. The area is devoid of vegetation affording excellent exposures. The Karak bentonite is located at an average height of 600 m above sea level. For purposes of description the area was divided into Blocks A, B, C, (Fig. 1) Garuzi and Tarakha Khui.

PREVIOUS WORK

Wynne (1875), Pasco (1920), Ahmad (1946) and Meissner et al. (1968) have described the geology of the area. The Karak bentonite was reported by them as green clay and shale from many localities of the Kohat District. Mixing and interbedding with gypsum of this clay was also noted.

REGIONAL GEOLOGY AND STRUCTURE

The sedimentary rocks of Kohat have a total known thickness of 7,012 m. To the north are Paleocene, Cretaceous and Jurassic limestones and shales forming high arcuate hill range, 11.3 to 23 km wide at the Kohat Pass. South of this range is a broad belt, 25.8 to 40.3 Km wide from north to south, underlain by rocks of Eocene and Miocene age. The Eocene sequence is composed

of limestone, clay, gypsum, bentonite at places, and salt. The Miocene sequence is 793 m thick and consists of sandstone, siltstone, shale and claystone. To the south are evaporites—salt and gypsum with associated bentonite of Early Eocene age.

The rocks cropping out at Kohat Pass are highly folded and faulted forming high hill range. The hill range is the result of uplifting and generally its northern and southern flanks have faulted contacts with the younger rocks. To the south of the hill range the Cretaceous and Jurassic rocks are thrust over the Siwalik sandstones and shales. The thrust could be traced up to Parachinar to the west.

South of the hill range of the Kohat Pass the Eocene and younger rocks have been tightly folded, forming narrow ridges of lower altitude and are

separated by broad and flat valleys. Overturning of the southern limbs of the anticlines is a common feature. The ridges of the Eocene rocks trend northeast in the eastern part and west in the western part of Kohat region.

The overturning of the anticlines on the southern flanks is often accompanied by a thrust. These overfolds and thrusts have exposed the deposits of salt and bentonite at many localities in Kohat region.

STRATIGRAPHY

The rocks exposed in the Karak hills of the Karak area range in age from Lower Eocene to Sub Recent in age. The period, epoch and lithostratigraphic units of the area are given in the following table.

Period	Epoch	Lithostratigraphic Units.
Quaternary	Sub-Recent	Sandstones, Grits, Claystone and Gravels.
Tertiary	Pliocene to Late Miocene	<i>Siwalik Group</i> (Sandstones and shales)
		<i>Rawalpindi Group</i>
		Kamlial Formation. (Soft sandstone, siltstone and shales).
		Murree Formation. (Sandstones, siltstone and shale).
	Early Miocene	Fatehjang Member. (Conglomerates).
		—Unconformity—
	Early to Middle Eocene	<i>Chharat Group</i>
		Kohat Formation. (Limestone and shale).
		Habib Rahi limestone. (Limestone).
		Kuldana Formation. (Crimson, purple and red shale, marl and sandstone).
		Jatta gypsum. (Greenish white to grey gypsum).
		Karak bentonite. (Green, greenish blue and grey shale).
		Bahadur Khel salt. (Grey and white salt).
		(Base not exposed).

For further details the reader is referred to the Detailed Geological Investigation of Karak Bentonite (1976). However the Karak Bentonite will be described in greater detail in the following.

KARAK BENTONITE

It is a poorly to moderately laminated shale. At places lamination is very well developed. Its colour is pistacho, greenish blue, greyish blue, bluish grey and azure. Gypsum intercalations are often present. Towards the base due to oil and bituminous matter it may be grey in colour. Gypsum, halite, glauconite and calcite may be recognized in some hand specimens. It is composed of more than 85.00% clay minerals. It is soft sticky and plastic clay with a greasy look. The outcrops show extensive crumbling, splintering and swelling.

PETROGRAPHY OF THE KARAK BENTONITE

In the following detailed petrography of the Karak bentonite has been described. The description includes structures, textures and mineralogy of the bentonite deposit. For the purpose of field mapping and study the area under investigation was divided into six blocks namely Karak Block A, Block B, Block C, Garuzi Block, Tarkha Khui Block and Akori Block. Accordingly, the petrography of each block has been described separately. Results of each block have been summed up, wherever necessary comparisons with other blocks have been made and at the end an overall summary of the deposit under study has been presented.

Block A: Ten thin sections have been examined in detail. Their mineral compositions are given in table 1.

The bentonite samples show poor to moderate lamination. The sample 'Adit5' shows fine laminae and small scale contortions (Fig. 2) (due to intraformational deformation). Some samples also show bands (mineral banding) and veins (secondary).

The veins are mostly diagenetic. Sample 'Channel 3' is irregularly banded and veined. The bands and veins are composed of gypsum, gypsum-calcite, and gypsum-calcite-quartz. Clay is also an essential constituent of these bands and veins. The sample 'Channel 6' shows veins and bands of recrystallized and coarser-grained material similar to the main rock material (Fig. 3). These are mainly diagenetic clay veins. Sample 'Channel 7' contains a gypsum band. Pelletoidal structure is seen in sample 'TA-76-IAK-21.' Small scale rhombohedral cracks are seen in sample 'Channel 2' (Fig. 4).

Clay is by far the most predominant mineral of the rock. Its amount varies from 60.00% to 93.00%. Seven out of ten samples contain more than 85.00% clay. The clay is microcrystalline. Its optical studies show it to be montmorillonitic clay. Its properties indicate it to be a transitional clay. Very small amount of kaolinitic and illitic clays are also indicated.

The amount of silica minerals (mainly quartz) range from 5.0% to 16.00%. They occur both as cryptocrystalline to microcrystalline silica minerals as well as discrete quartz grains. The quartz grains are mostly anhedral and are from subangular to subrounded. It is generally randomly distributed in the rock.

Gypsum also occurs in the samples studied. In sample 'Channel 7, the amount of gypsum is 23.00%. But this is not a normal sample and has been selected from gypsiferous part of the rock. In other nine samples the amount of gypsum varies from 0.50% to 2.00%. Gypsum occurs both in the body of the rock as well as in veins and bands traversing the rock. In the body of the rock it occurs as small anhedral randomly distributed grains. Relatively coarser grains of gypsum associated with quartz, calcite and clay occur in veins in samples 'Channel 3', 'Channel 4' and 'Channel 6'.

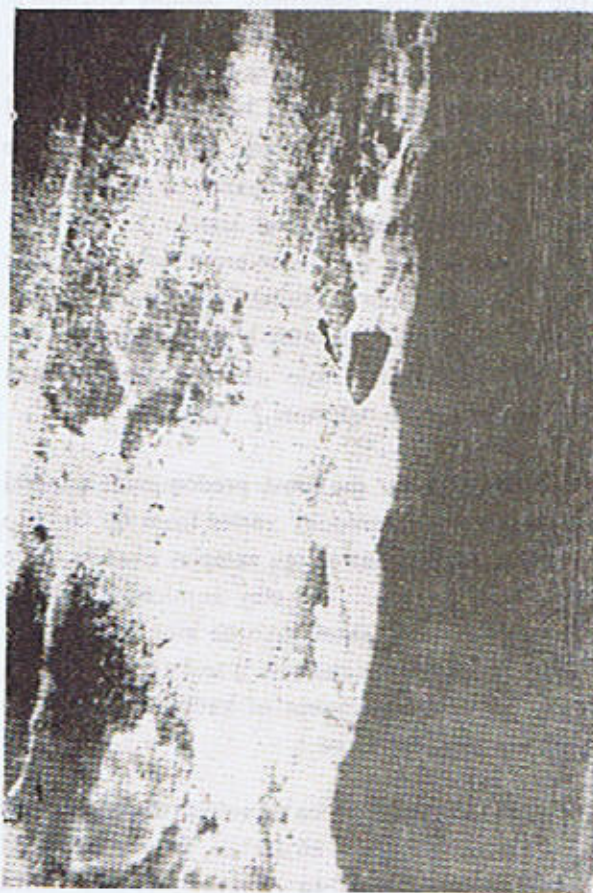


Fig. 2. Photomicrograph of fine laminae and small scale contortions (X.12).



Fig. 3. Photomicrograph of veins and bands of recrystallised material (X.12).

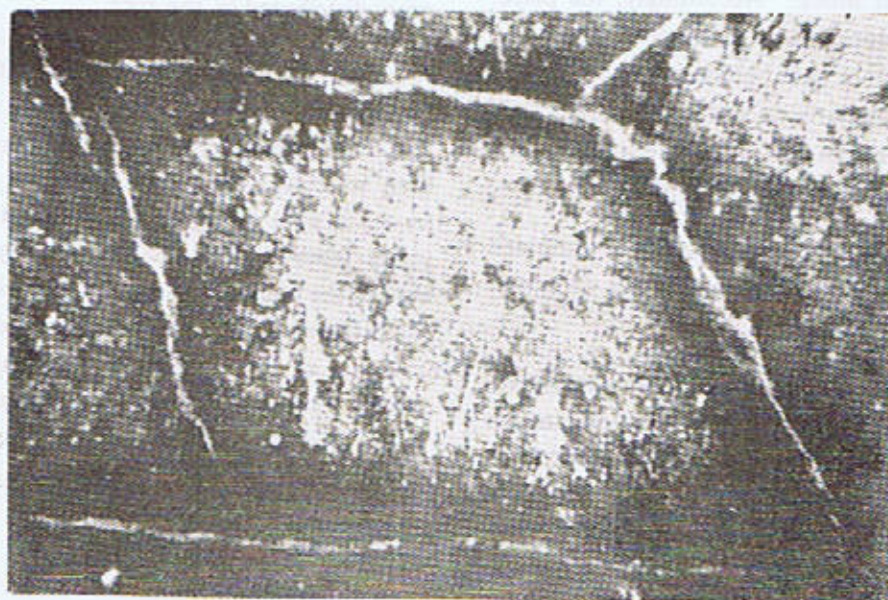


Fig. 4. Photomicrograph of rhombohedral cracks in bentonite (X.12).

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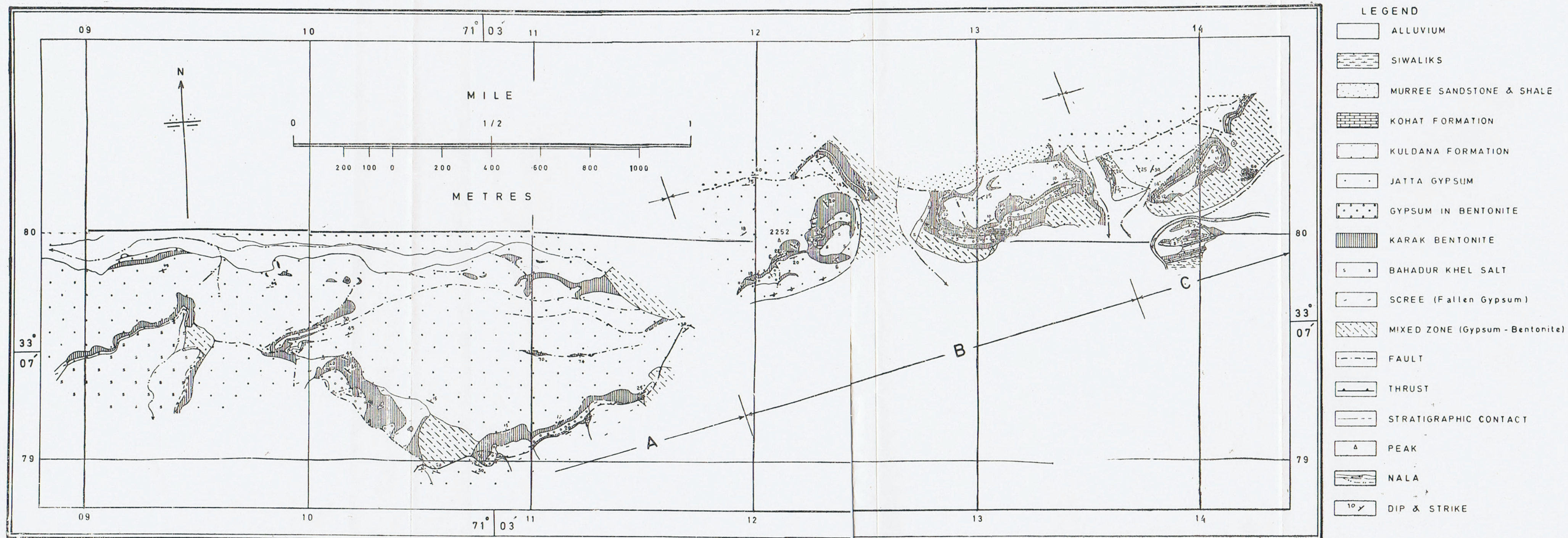


TABLE I
Mineral Compositions of the Karak Bentonite of Block A

Sr. No.	Sample No.	Clay	Quartz	Gypsum	Calcite	Haematite	Limonite	Other Minerals
1.	Channel 2	85.00	10.00	0.50	3.00	0.30	0.40	Chlorite 0.50 Glauconite 0.30
2.	Channel 3	86.00	11.50	1.00	0.50	1.00	0.00	—
3.	Channel 4	65.00	10.50	2.00	20.00	0.50	1.50	Chlorite 0.50
4.	Channel 4	88.00	10.00	1.00	1.00	0.00	0.00	—
5.	Channel 5	91.00	6.00	0.50	0.00	1.00	1.50	—
6.	Channel 6	93.00	5.00	0.50	0.50	1.00	0.00	—
7.	Channel 7	60.00	10.00	23.00	5.00	1.00	0.50	Halite 0.50
8.	No. TA-76 IAK-21	90.00	7.70	0.50	0.30	0.80	0.00	Prehnite 0.30 Epidote 0.30
9.	Adit—5	92.00	5.50	0.50	0.00	1.00	0.50	Chlorite 0.30
10.	Adit—6	78.00	16.00	0.50	3.00	1.30	1.20	—

Out of ten samples of Block A studied only two samples i.e. 'Channel 5' and 'Adit 5' did not contain calcite. The sample 'Channel 7' was taken from a calciferous part of the rock (and does not represent the normal rock type) and contains 23.00% calcite. In the other seven out of ten samples calcite ranges from 0.30% to 3.00%. Calcite, like gypsum, also occurs in the body of the rock as well as in veins and bands.

Except sample 'Channel 4' haematite occurs in all other nine samples. Its amount varies from 0.30% to 1.30%. Most commonly it occurs as small anhedral and randomly distributed grains. However, in sample 'Channel 7', it occurs as patches of small grains, in sample 'TA-76-IAK-31' it occurs as thin veins and streaks and in sample 'Adit 5' it occurs as diffused colour streaks and patches.

Limonite occurs in six out of ten samples of Block A studied. Its amount in these six samples ranges from 0.40% to 1.50%. It mostly occurs as a colouring matter, colour streaks, colour patches and as joint and crack linings. It may be intimately associated with haematite and may even be derived from it.

Chlorite occurs only in three out of ten samples studied. Its amount is only 0.50%. It occurs as very small green flakes which are intimately associated with clay. A few grains of glauconite (0.30%) were found in sample 'Channel 2A'. A few (0.30%) small anhedral epidote grains occur in sample 'TA-76-IAK-27'. Prehnite flakes (0.30%) occur in sample 'TA-76-IAK-21'. One half percent small anhedral halite grains occur in sample 'Channel 7'.

Block B: Twenty one thin sections of Block B have been studied. Their mineral compositions are given in table 2. Out of twenty one samples only six samples i.e. 'Channel 2', 'Channel 4', 'Channel 8', 'TA-76-IC-6A', 'Adit 1', and 'Adit 4B' show from poor to moderate lamination. Sample 'Channel 2' shows well developed mineral banding (Fig. 5). Samples 'Channel 4' and 'Adit 4A' show clay concretions within clay. Samples 'TA-76 IAK-13' (Fig. 6 and 6 A) shows graded bedding and from sphericular to pelletoidal structure. Sphericular structure is also shown by sample 'TA-76-IC-6A'. Samples 'Channel 7', 'TA-76-IC-5A' and 'Adit 3' contain relatively coarse-grained clay rich diagenetic veins. Sample 'TA-76-IC-7' contains veins of clay-calcite quartz. Samples 'TA-76-IAK-13' and 'TA-76-IAK-15' show pelletoidal structures as well. Samples 'TA-76-IAK-15' and 'TA-76-IAK-19', show intersecting small scale joints forming a rhombohedral pattern.

Sample 'Channel 2' represents small scale and local calcareous concentrations. The amount of clay in the other samples ranges from 81.00% to 96.20%. The clay belongs to the smectite group. Its properties indicate it to be a transitional montmorillonitic clay. Very small amounts of kaolinitic and illitic clays are also indicated. The clay is microcrystalline. It also occurs as concretions, pellets, sphericular growths and as recrystallised clay in veins.

The amount of quartz ranges from 2.00% to 13.30%. Cryptocrystalline to microcrystalline silica phases occur in samples 'TA-76-IC-1', 'TA-76-IAK-13', 'TA-76-IAK-15' and 'TA-76-IAK-19'. The quartz grains are anhedral and mostly from subangular to subrounded. It is generally randomly distributed in the rock. Where rocks show well developed lamination or graded bedding, quartz is more concentrated along some lamination planes than elsewhere.

Gypsum occurs in eight out of twenty one samples studied. Its amount varies from 0.60% to 3.20%. It occurs as elongated crystals in sample 'Channel 2'. In sample 'Channel 8' it occurs mostly as small grains along the lamination planes. It occurs in thin secondary veins and streaks in samples 'TA-76-IAK-82', 'TA-76-IAK-13' and 'TA-76-IAK-15'. In addition, in the samples just mentioned, it occurs as dispersed small anhedral grains. In the rest of the samples bearing gypsum it occurs only as small anhedral grains.

Calcite occurs in twelve out of twenty one samples described. Two samples (which are in fact two parts of the same sample) i.e., sample 'Channel 2' (carbonate poor part) and sample 'Channel 2' (carbonate rich part), which represent local calcite enrichment, contain 15.00% and 91.00% calcite respectively. In the rest of the calcite bearing samples the amount of calcite ranges from 0.50% to 4.50%.

Haematite occurs in twelve out of twenty one samples described. Its amount varies from 0.30 to 3.00%. It may occur as grains, streaks, colour spots as well as grains along lamination.

Limonite occurs in ten out of twenty one samples studied. Its amount ranges from 0.50% to 2.50%. It occurs mostly as very fine-grained and amorphous looking matter. It is either finely dispersed or occurs as a colouring matter and as diffused patches and streaks. It is often intimately associated with haematite from which it often derives.

Light green and small flakes of chlorite occur in samples 'Channel 4' (0.50%) and 'Channel 6' (1.0 %). Halite (0.50%) occurs as small grains in sample 'Channel 2'. Pyrite (1.00%) occurs as eumorphic pyritohedral crystals in sample 'Channel 6'. Small flakes of prehnite (1.00%) occur in samples 'Adit 4B' (0.50%) and 'Channel 2'. Sericite and hydromuscovite occur (0.60%) in sample 'TA-76-IAK-13'.



Fig. 5. Photomicrograph of graded bedding in bentonite (X.12).



Fig. 6. Photomicrograph of sphericular structure in bentonite (X.12).

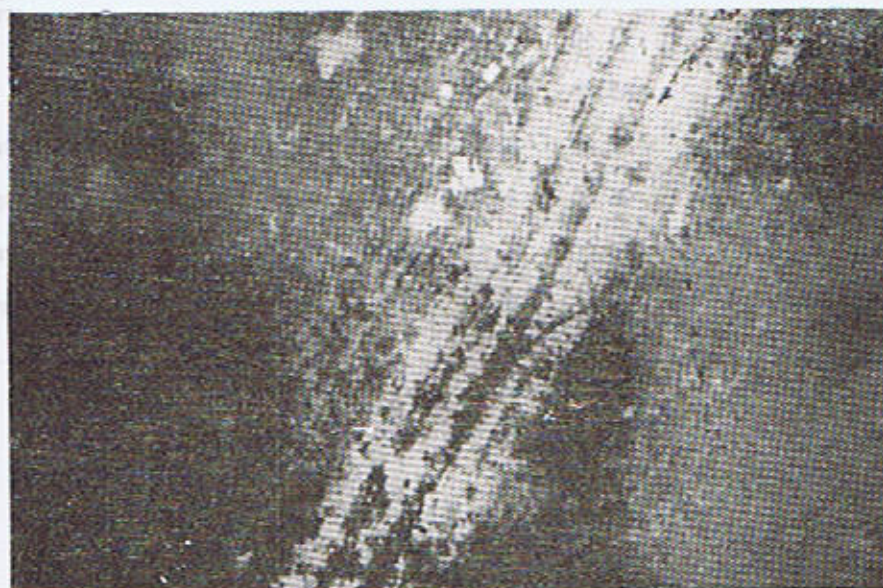


Fig. 7. Photomicrograph of laminations in bentonite (X.12).

TABLE 2

Mineral Compositions of the Karak Bentonite of Block B

Sr. No.	Sample No.	Clay	Quartz	Gypsum	Calcite	Haematite	Limonite	Other Minerals
1.	Channel 2	90.00	5.00	2.00	2.00	0.00	0.00	Prehnite 1.00
2.	Channel 2	85.00	10.00	1.50	0.00	3.00	0.00	Halite 0.50
3.	Channel 2 (Calcareous band)	81.00	3.50	0.00	15.00	0.00	0.50	—
4.	Channel 2 (Carbonate band)	8.00	0.00	0.00	91.00	0.00	1.00	—
5.	Channel 3	87.00	8.00	0.00	4.50	0.00	0.50	—
6.	Channel 4	93.00	6.50	0.00	0.00	0.00	0.00	Chlorite 0.50
7.	Channel 6	86.00	8.00	1.00	0.50	2.00	0.50	Pyrite 1.00
8.	Channel 7	92.00	3.50	0.00	0.50	2.50	2.50	Chlorite 1.00
9.	Channel 8	87.00	10.00	2.00	0.50	0.00	0.00	Organic Matter 0.50
10.	No. TA-76-IC-1	87.00	7.00	0.00	4.00	1.00	0.50	Organic Matter 0.50
11.	No. TA-76-IC-5A	92.00	6.00	0.00	0.50	0.50	0.50	Organic Matter 0.50
12.	No. TA-76-IC-6A	95.00	2.50	0.00	0.00	2.00	0.00	Organic Matter 0.50
13.	No. TA-76-IC-7	87.00	8.00	0.00	1.00	3.50	0.50	—
14.	No. TA-76-IAK-12	96.20	2.30	1.50	0.00	0.00	0.00	—
15.	No. TA-76-IAK-13	92.30	3.90	3.20	0.00	0.00	0.00	Hydromuscovite and sericite 0.60
16.	No. TA-76-IAK-15	93.50	4.00	2.50	0.00	0.00	0.00	—
17.	No. TA-76-IAK-19	83.70	13.30	0.60	0.00	0.30	0.10	—
18.	Adit—1	89.00	8.00	0.00	1.00	1.50	0.00	Organic Matter 0.50
19.	Adit—3	95.00	3.50	0.00	0.50	0.50	0.00	Organic Matter 0.50
20.	Adit—4A	95.00	2.50	0.00	0.00	1.00	0.00	Organic Matter 1.50
21.	Adit—4B	88.00	8.00	0.00	0.00	2.50	1.00	Prehnite 0.50

Organic matter occurs in seven out of twenty one samples studied. Its amount ranges from 0.50% to 1.50%. It mostly occurs as small dull black specks and their aggregates.

Block C : Six samples of Block C were studied. Samples 'Channel 2', 'Channel 4', 'TA-76-IC-9' and 'TA-76-IC-9B' are from moderately laminated to well laminated (Fig. 7). Poor lamination is seen in samples 'Channel 3' and 'TA-76-IAK-16'. However, the latter sample shows poor and irregular banding. Clay imparts a general microcrystalline texture to the rock. Sample 'TA-76-IC-9' contains carbonate poikiloblasts/porphyroblasts. Detailed mineral compositions are given in table 3.

Clay ranges from 85.00% to 94.00% (excluding sample 'Adit 7' which represents local con-

centration of gypsum). Its optical studies show it to be montmorillonitic. Its properties indicate it to be a transitional clay.

Quartz plus cryptocrystalline to microcrystalline silica range from 3.50% to 13.00%. Cryptocrystalline to microcrystalline phase (along with quartz grains) occur in samples 'Channel 3' and 'TA-76-IAK-16'. In samples 'Channel 2', 'Channel 4' and 'TA-76-IC-9' quartz occurs randomly distributed and has from subangular to subrounded grains. It shows tendency of concentration along lamination planes in sample 'TA-76-IC-9B'. The grains are generally small and sometimes masked by clay.

Gypsum occurs in three out of six samples studied. Its amount ranges from 1.00% to 2.00%. In all these three samples it occurs as small random-

TABLE 3
Mineral Compositions of the Karak Bentonites of Block C

Sr. No.	Sample No.	Clay	Quartz	Gypsum	Calcite	Haematite	Limonite	Other Minerals
1.	Channel 2	94.00	3.50	0.00	0.00	1.50	0.00	Organic Matter 0.50
2.	Channel 3	92.00	7.50	1.00	0.00	1.00	0.00	Halite 0.50
3.	Channel 4	93.00	3.50	0.00	0.00	1.50	1.50	—
4.	No. TA-76-IC-9	88.00	3.50	0.00	10.00	1.00	0.50	Organic Matter 1.00
5.	No. TA-76-IC-9b	87.00	10.00	2.00	1.00	0.00	0.00	—
6.	No. TA-76-IAK-16	85.00	13.00	1.40	0.10	0.40	0.10	—
7.	Adit—7	60.00	10.00	23.00	5.00	1.00	0.50	Halite 0.50

mly distributed anhedral grains. Sample 'TA-76-IAK-16' contains only 0.10% calcite and sample 'TA-76-IC-9b', 1.00% calcite. However, sample 'TA-76-IC-9' contains 10.00% calcite. In the former two samples it occurs as small anhedral grains, whereas in the latter sample it occurs as poikiloblasts/porphyroblasts.

Haematite occurs in five out of the six samples studied. Its amount ranges from 0.40% to 1.50%. It occurs as discrete grains as well as patches and streaks, and along joints, cracks, and lamination planes.

Limonite occurs in three out of six samples studied. Its amount ranges from 0.10% to 1.50%. It is closely associated with haematite. It occurs as very fine-grained dispersed or aggregated matter.

Sample 'TA-76-IC-9' contains 1.00% and sample 'Channel 3' contains 0.50% organic matter. It is dull black and fine-grained.

Sample 'Channel 2' contains 0.50% chlorite flakes and sample 'Channel 3', 0.50% small anhedral halite grains.

Garuzi Block: Two thin sections of Garuzi Block were studied. Their mineral compositions

are given in Table 4. They show from poor to moderate lamination. Sample 'Channel 1', contains a few thin irregular coarser bands whereas sample 'Channel 2', contains a few thin veins composed of clay, quartz and gypsum. The clay imparts a microcrystalline texture to the rock. The amount of clay is 82.00% and 85.00%. Experimental data show it to be a transitional mixed layer montmorillonitic (transitional to illite) clay.

Quartz occurs as anhedral grains both in the body of the rock as well as in bands and veins. Its amount is 11.00% and 12.00%. Small anhedral gypsum grains are 0.50% and 1.00%. Calcite occurs as anhedral grains and is 1.00% and 3.50%. Haematite is 0.50% in both the samples and limonite is 0.50% and 1.00%. Limonite occurs mostly as a colouring matter. Chlorite flakes are 1.00% and 0.30%. Sample 'Channel 2' also contains 0.20% biotite and 0.10% sphene.

Tarkha Khui Block: Two thin sections of Tarkha Khui Block have been studied. Their mineral compositions are given in Table 5. Sample 'Channel 1' is nonlaminated and porphyroblastic. The sample 'Channel 2' is poorly laminated, even grained and microcrystalline. The two samples

TABLE 4
Mineral Compositions of the Karak Bentonites of Garuzi Block.

Sr. No.	Sample No.	Clay	Quartz	Gypsum	Calcite	Haematite	Limonite	Other Minerals
1.	Channel 1	85.00	11.00	1.00	1.00	0.50	0.50	Chlorite 1.00
2.	Channel 2	82.00	12.00	0.50	3.50	0.50	1.00	Chlorite 0.30 Biotite 0.20 Sphene 0.10

TABLE 5
Mineral Composition of the Karak Bentonite, Tarkha Khui Block

Sr. No.	Sample No.	Clay	Quartz	Gypsum	Calcite	Haematite	Limonite	Other Minerals
1.	Channel 1	72.00	14.00	0.00	10.00	2.50	0.50	Chlorite 1.00
2.	Channel 2	89.00	8.00	0.00	0.00	1.50	0.00	Epidote 0.50 Prehnite 0.50 Organic Matter 0.50

TABLE 6
Mineral Compositions of the Karak Bentonites, Akori Block

Sr. No.	Sample No.	Clay	Quartz	Gypsum	Calcite	Haematite	Limonite	Other Minerals
1.	Channel 1	92.00	6.00	1.00	0.30	0.00	0.00	Prehnite 0.20
2.	Channel 2	92.00	6.00	0.50	0.50	0.00	0.50	Chlorite 0.30 Halite 0.20
3.	Channel 3	92.00	3.00	0.00	2.50	1.50	1.00	—
4.	Channel 4	91.00	3.00	0.30	0.70	4.00	0.70	Chlorite 0.30
5.	Channel 5	84.00	6.00	0.00	7.00	2.00	0.70	Chlorite 0.30

contain 72.00% and 89.00% transitional mixed layer montmorillonitic (transitional to illite) clay, 14.00% and 8.00% angular to subangular quartz and 1.50% and 2.50% small haematite grains.

Sample 'Channel 1' contains 0.50% fine-grained limonite and 1.00% light green chlorite flakes. Sample 'Channel 2' contains 0.50% fine grained dull organic matter. Sample 'Channel 1' contains 10.00% calcite in very fine as well as porphyroblastic grains (secondary local concentration).

Akori Block : Petrography of five samples of Akori Block has been studied. Their mineral compositions are given in Table 6. The samples show poor to moderate lamination. Samples 'Channel 1' and 'Channel 3' show clay concretions within clay.

Clay is the predominant mineral. In three samples it is 92.00% each and in one sample it is 91.00%. Only in sample 'Channel 5' it is 84.00%. Experimental data show it to be mixed layer (transitional to illite) montmorillonitic clay.

Quartz ranges from 3.00%—6.00%. It occurs as small anhedral grains which are from subangular to subrounded and distributed randomly.

Gypsum occurs in three out of five samples and in them it varies from 0.30%—1.00%. It occurs as small randomly distributed anhedral grains.

All the samples contain calcite. The sample 'Channel 5' contains 7.00% calcite which is irregularly distributed. In other samples it ranges from 0.30% to 2.50% and occurs as small anhedral and randomly distributed grains. Haematite occurs in three out of five samples studied and ranges from 1.50% to 4.00% in amount. In sample 'Channel 3' it occurs as randomly distributed anhedral grains. In sample 'Channel 5' it occurs as small subrounded to rounded grains.

Limonite occurs in four out of five samples studied. In them it ranges from 0.50% to 1.00%. In sample 'Channel 2' it occurs along small joints and also along bedding planes. In samples 'Channel 3', 'Channel 4' and 'Channel 5' it occurs as a colouring matter. Small light green chlorite flakes (0.30%) occur in samples 'Channel 2', 'Channel 4' and 'Channel 5'. Prehnite (0.20%) occurs only in 'Channel 2'.

Summary of All Blocks : Block A shows from poor to moderate lamination. Block B shows poor to moderate lamination but six out of twenty one samples show good lamination. Block C is generally from poorly to moderately laminated. Garuzi Block, Tarkha Khui Block and Akori Block show from poor to moderate lamination. Samples from all the blocks are traversed by thin veins and bands which are composed generally of clay or quartz—calcite and gypsum. But these veins and bands constitute a very small part of the rock. Local and small scale impregnation of bentonite with calcite and gypsum has been noted.

The most important non-clay minerals are calcite, gypsum, limonite and haematite. Of lesser impor-

tance are prehnite, chlorite, epidote, organic matter and halite (accessories). Glauconite, hydromuscovite, sericite, biotite and sphene are very rare.

The clay belongs to the smectite group and is a mixed layer montmorillonitic (transitional to illite) clay.

On the basis of 43 analyses clay is $\bar{x} = 88.73$, quartz $\bar{x} = 7.09$, gypsum $\bar{x} = 0.62$ and calcite $\bar{x} = 1.74$. The correlation data is given in table 13. Clay shows negative correlations with quartz and calcite, gypsum shows negative correlations with haematite and limonite and haematite shows positive correlation with limonite (Both of them may have been deposited together).

CHEMISTRY OF THE KARAK BENTONITE

Forty seven chemical analyses of the Karak bentonite have been presented in tables 7—12. They include nine analyses of Block A, twenty one analyses of Block B, six analyses of Block C, two analyses of Garuzi Block, four analyses of Tarkha Khui Block and five analysis of Akori Block.

These are whole rock and not mineral analyses. However, in all of these rocks clay mineral(s) are by far the most predominant. Some of the samples are composed almost entirely of clay. The main impurity is that of quartz. Other impurities of lesser quantitative importance are of calcite, gypsum haematite and limonite.

Total chemical data as well as the data of the individual blocks has been treated statistically on IBM 1130 computer using Fortran IV language (Tables 14-19). Thus, the means, standard deviations and correlation coefficients were calculated. The results are summarised and discussed below.

Block A : Nine chemical analyses of Block A were done. They gave the following results :

$\text{SiO}_2 \bar{x} = 53.44$, $\sigma = 2.98$; $\text{Al}_2\text{O}_3 \bar{x} = 20.31$, $\sigma = 3.95$; $\text{Fe}_2\text{O}_3 \bar{x} = 5.41$, $\sigma = 2.08$; $\text{MgO} \bar{x} = 4.57$, $\sigma = 1.11$; $\text{K}_2\text{O} \bar{x} = 1.24$, $\sigma = 0.47$; Na_2O

$\bar{x} = 0.63$, $\alpha = 0.37$; TiO_2 $\bar{x} = 0.59$, $\alpha = 0.28$ and L/I $\bar{x} = 10.39$, $\alpha = 2.57$.

SiO_2 shows positive correlation with TiO_2 ; Al_2O_3 shows negative correlations with Fe_2O_3 , CaO and Na_2O and positive correlation with MgO . Fe_2O_3 shows negative correlation with MgO and positive correlations with CaO and Na_2O . CaO shows positive correlations with Na_2O and K_2O . MgO shows negative correlation with Na_2O and shows positive correlation with K_2O .

The means of the Block A are not very different from the results of the overall analyses. However, the mean Al_2O_3 value is somewhat higher in this block than the other blocks and the total result except Akori Block. In this block also $\text{MgO} > \text{CaO}$, $\text{K}_2\text{O} > \text{Na}_2\text{O}$ and Fe_2O_3 is more than MgO and CaO .

Block B: Twenty one analyses of Block B were done. Means and standard deviations of the block are as follows:

SiO_2 , $\bar{x} = 53.32$, $\alpha = 3.48$; Al_2O_3 , $\bar{x} = 17.71$, $\alpha = 2.97$; Fe_2O_3 , $\bar{x} = 6.59$, $\alpha = 2.07$; MgO , $\bar{x} = 4.21$, $\alpha = 1.51$; CaO , $\bar{x} = 3.00$, $\alpha = 1.44$; K_2O , $\bar{x} = 1.44$, $\alpha = 0.57$; Na_2O , $\bar{x} = 9.90$, $\alpha = 0.34$; TiO_2 , $\bar{x} = 0.57$, $\alpha = 0.21$ and L/I , $\bar{x} = 12.03$, $\alpha = 2.83$.

The means of various constituents are fairly close to that of the overall analyses and that of Block A. Again $\text{MgO} > \text{CaO}$, $\text{K}_2\text{O} > \text{Na}_2\text{O}$ and Fe_2O_3 is more than MgO and CaO .

The correlations for this block are the same as that of the overall analyses except that Fe_2O_3 does not show correlations with MgO , K_2O and

TABLE 7

Chemical Analysis of Karak Bentonite Block A

Sr. No.	Sample No.	Coordinates	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	L/I
1.	Channel—2	080790	53.30	16.44	7.10	0.76	4.50	3.10	1.05	1.47	12.00
*2.	Channel—3	092796	51.94	14.77	9.57	0.65	3.71	3.17	1.27	1.98	14.68
*3.	Channel—4	101795	54.67	16.05	7.20	0.80	4.00	3.26	1.04	1.59	11.48
4.	Channel—5	101796	57.20	23.96	3.75	0.70	1.40	4.25	0.42	0.47	8.00
5.	Channel—6	107798	50.80	26.50	3.80	0.70	2.85	6.07	0.60	1.80	6.80
6.	Channel—7	110798	56.00	18.10	5.00	0.90	2.79	5.08	0.38	1.02	10.70
7.	Adit—5	100796	47.80	23.65	2.25	0.07	2.75	5.06	0.05	0.94	15.30
8.	Adit—6	114797	52.00	23.48	5.02	0.07	2.85	6.08	0.44	0.92	8.49
9.	Channel West	095793	57.30	19.49	5.01	0.70	2.75	5.15	0.45	0.90	8.20

PCSIR Laboratories, Lahore.

*PCSIR Laboratories, Peshawar.

TABLE 8
Chemical Analysis of Karak Bentonite Block B

Sr. No.	Sample No.	Coordinates	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	L/I
1.	Channel—1	121792	52.10	22.05	5.25	0.70	2.82	7.09	0.51	0.58	8.80
2.	Channel—2	121792	55.80	21.16	5.12	0.52	2.75	5.12	0.48	0.90	8.10
3.	Channel—3	121792	54.30	15.25	7.10	0.62	3.98	3.41	1.57	1.57	12.00
4.	Channel—3	121792	54.14	14.77	8.00	0.75	4.60	3.50	1.10	1.53	11.55
5.	Channel—4	124794	56.50	14.60	7.50	0.90	2.80	6.08	0.51	1.07	10.00
6.	Channel—4	124794	54.67	16.06	7.20	0.80	4.00	3.26	1.64	1.59	11.48
7.	Channel—5	124794	49.32	14.22	9.24	0.60	3.09	4.88	1.22	1.98	14.68
8.	Channel—7	126796	46.00	16.00	7.50	0.70	3.50	6.58	0.45	0.94	18.00
9.	Channel—7	126796	51.50	19.55	2.75	0.70	3.45	6.58	0.46	0.96	14.00
10.	Channel—8	126796	56.60	20.30	5.00	0.70	1.40	5.06	0.39	0.90	9.60
*11.	TA-76-IC-1	121792	54.09	15.81	7.97	0.12	3.58	2.42	1.03	2.10	12.68
*12.	TA-76-IC-5	125794	56.38	16.68	6.38	0.14	0.71	1.95	1.16	2.46	13.76
*13.	TA-76-IC-6	125794	54.84	17.03	4.38	0.15	0.95	2.57	1.34	2.24	16.85
14.	TA-76-IC-7	—	58.02	18.05	6.80	0.45	0.90	2.62	0.95	2.24	10.00
*15.	Adit—1	125802	53.68	15.77	9.97	0.52	2.83	3.41	0.85	1.86	10.25
16.	Adit—2	130800	47.50	19.55	5.00	0.07	2.85	6.08	1.20	1.50	15.60
*17.	Adit—3	131800	46.08	13.66	10.04	0.38	5.35	4.71	1.28	1.79	15.80
18.	Adit—4A	135802	56.00	21.67	3.75	0.07	1.40	4.05	1.02	1.20	10.10
*19.	Adit—4B	129802	50.86	14.67	9.56	0.51	5.42	3.41	0.97	1.62	12.00
20.	Adit—1 (Grey)	125802	57.20	24.20	3.75	0.70	1.40	2.02	0.91	1.00	8.80
21.	Adit—1 (Green)	125802	45.00	20.55	6.25	0.70	2.80	5.06	0.86	0.96	8.80

PCSIR Laboratories, Lahore.

*PCSIR Laboratories, Peshawar.

TABLE 9
Chemical Analysis of Karak Bentonite Block C

Sr. No.	Sample No.	Coordinates	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	L/I
1.	Channel—1	136803	50.50	21.40	7.00	0.70	2.80	5.06	0.61	0.62	11.30
2.	Channel—2	139800	53.60	16.05	5.75	0.70	2.75	7.93	0.27	1.10	11.80
3.	Channel—3	140800	49.70	19.80	7.50	0.70	2.95	6.15	0.21	0.80	12.10
4.	Channel—4	140803	51.20	18.80	3.50	0.70	2.80	6.08	0.27	1.02	15.60
5.	TA-76-IC-9	136798	58.40	18.73	4.80	0.20	0.70	2.50	1.08	2.50	11.66
6.	Adit—7	136803	39.70	16.15	3.75	0.70	8.41	9.12	0.48	0.90	20.40

*PCSIR Laboratories, Peshawar.

TABLE 10
Chemical Analysis of Bentonite Garuzi Block

Sr. No.	Sample No.	Coordinates	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	L/I
1.	Channel—1	—	54.60	17.61	5.53	0.31	2.80	3.90	1.80	1.42	12.30
2.	Channel—2	—	53.80	18.66	6.50	0.44	2.30	3.54	1.50	1.17	12.80

TABLE 11
Chemical Analysis of Bentonite Tarkha Khui Block

Sr. No.	Sample No.	Coordinates	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	L/I
1.	Channel—1	270864	54.30	16.44	7.10	0.76	4.50	3.10	1.05	1.47	12.00
2.	Channel—1	270864	48.60	15.23	5.53	0.62	5.90	5.47	0.92	1.37	16.20
3.	Channel—2	270864	54.14	14.77	8.00	0.75	4.60	3.50	1.10	1.53	11.55
4.	Channel—2	270864	45.92	6.53	15.56	6.65	5.58	0.62	0.70	1.74	16.51

TABLE 12

Chemical Analysis of Bentonite Akori Block

Sr. No.	Sample No.	Coordinates	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	L/I
1.	Channel—1	279840	55.20	23.30	5.00	0.70	2.80	6.08	0.57	0.48	6.20
2.	Channel—2	279840	57.20	25.00	2.50	0.70	1.40	5.06	0.69	0.48	6.80
3.	Channel—3	279864	46.40	24.75	3.75	0.70	3.50	7.93	0.30	0.62	12.20
4.	Channel—4	279864	51.60	24.49	5.11	0.70	2.85	4.25	0.30	0.60	10.00
5.	Channel—5	279864	51.50	18.25	6.20	0.56	3.22	5.41	1.00	1.57	11.80

*PCSIR Laboratories, Peshawar
PCSIR Laboratories, Lahore.

TABLE 13

Linear Correlation Coefficients Between Major Minerals of Karak, Garuzi, Tarkha Khui and Akori Bentonites R

	Clay	Quartz	Gypsum	Calcite	Haematite	Limonite
Clay	—	-0.7830	0.0611	0.5973	-0.1394	-0.1513
Quartz	-8.056	—	0.1234	0.0440	-0.0430	-0.0464
T Gypsum	0.391	0.795	—	-0.2912	-0.4110	-0.3805
Calcite	-4.769	0.280	-1.949	—	-0.0150	0.1520
Haematite	-0.901	-0.290	-2.884	-0.095	—	0.3690
Limonite	-0.979	-0.297	-2.634	0.984	2.538	—

n=43, the significant values of 'R' are bold.

TABLE 14

Linear Correlation Coefficients Between Major Components of Karak Garuzi, Tarkha Khui and Akori Bentonites
R

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	L/I
SiO ₂		0.1662	-0.0150	0.0598	-0.6645	-0.4776	0.1398	-0.0094	-0.6968
Al ₂ O ₃	1.130		-0.7324	-0.0030	-0.4581	0.2472	-0.4850	-0.4813	-0.5490
Fe ₂ O ₃	-0.100	-7.215		-0.0232	0.2990	0.3444	0.4394	0.4648	0.1340
TiO ₂	0.401	-0.019	0.155		0.2763	0.3235	0.2521	-0.3850	-0.1909
TCaO	-5.965	-3.460	2.101	1.928		0.3214	0.554	-0.0182	0.5307
MgO	-3.646	1.711	2.460	2.293	2.276		-0.6622	-0.5830	0.1347
Na ₂ O	0.947	-3.720	3.282	-1.747	0.371	-5.928		0.6024	0.1364
K ₂ O	-0.062	-3.683	-3.521	-2.797	-0.121	-4.812	5.063		0.2330
L/I	-6.516	-4.405	0.906	-1.304	4.200	0.912	0.923	1.606	

n = 47, the significant values of 'R' are Bold.

TABLE 15

Linear Correlation Co-efficients Between Major Components of Bentonites of Karak Block 'A'
'R'

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	L/I
SiO ₂		-0.2926	0.1700	0.6663	-0.2430	-0.2016	0.0977	-0.3768	-0.4950
Al ₂ O ₃	-0.809		-0.8532	-0.4756	-0.6985	0.7974	-0.7176	-0.4304	-0.4615
Fe ₂ O ₃	0.456	-4.328		0.4111	0.7031	-0.7190	0.9348	0.6640	0.1940
TiO ₂	2.364	-1.430	1.193		0.1940	-0.4478	0.4849	0.2971	-0.2595
TCaO	-0.662	-2.582	2.616	0.523		-0.5634	0.7340	0.7612	0.4544
MgO	-0.544	3.496	-2.737	-1.328	-1.804		-0.7477	-0.3789	-0.4981
Na ₂ O	0.259	-2.726	6.961	1.466	2.859	-2.979		0.7783	0.1087
K ₂ O	-1.076	-1.261	2.348	0.823	3.105	-1.083	3.279		0.1950
L/I	-1.507	-1.376	0.523	-0.711	1.349	-1.519	0.289	0.526	

n = 9, the significant values of 'R' are Bold.

TABLE 16

Linear Correlation Co-efficient Between Major Components of Bentonites of Karak Block 'B'
'R'

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	L/I
SiO ₂		0.3361	-0.3573	-0.0507	-7035	-0.4627	-0.0283	0.1638	-0.6981
Al ₂ O ₃	1.555		-0.8100	0.2408	-0.4606	0.1437	-0.3869	-0.5201	-0.4971
Fe ₂ O ₃	-1.667	-6.152		-0.1625	0.4890	-0.1288	0.2655	0.3733	0.1815
TiO ₂	-0.221	1.081	-0.717		0.2353	0.5655	-0.4141	-0.7123	-0.3457
T CaO	-4.314	-2.262	2.443	1.055		0.2601	0.1644	-0.1059	0.2994
MgO	-2.275	0.633	-0.566	2.988	1.174		-0.6611	-0.7509	0.0307
Na ₂ O	-0.123	-1.828	1.200	-1.982	0.726	-3.840		0.7451	0.2820
K ₂ O	0.723	-2.654	1.753	-4.423	-0.464	4.956	4.869		0.2750
L/I	-4.249	-2.497	0.804	-1.605	1.367	0.133	1.000	0.246	

n=21, the significant values of 'R' are Bold.

TABLE 17

Linear Correlation Co-efficients Between Major Components of Bentonites of Block 'C'
'R'

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	L/I
SiO ₂		0.3263	0.4260	-0.0450	-0.8091	-0.3442	-0.2254	0.1626	-0.8141
Al ₂ O ₃	0.690		0.5590	-0.0567	-0.4911	-0.6396	0.1800	0.5519	-0.5343
Fe ₂ O ₃	0.941	1.347		0.1721	-0.3542	-0.1935	-0.1443	0.2137	-0.7141
TiO ₂	0.091	-0.113	0.349		0.5095	0.7745	-0.8863	-0.5919	0.2932
T CaO	-2.753	-1.127	-0.757	1.184		0.8118	-0.3085	-0.5079	0.8859
MgO	-0.733	-1.664	-0.394	2.448	2.780		-0.7127	-0.7619	0.6397
Na ₂ O	-0.462	0.366	-0.291	-3.828	-0.648	-2.031		0.8169	-0.1882
K ₂ O	0.329	1.323	0.437	-1.468	-1.179	-2.352	2.832		-0.5177
L/I	-2.804	-1.264	-2.040	0.613	3.818	1.664	-0.383	-1.210	

n=6, the significant values of 'R' are bold.

TABLE 18

Linear Correlation Co-efficients Between Major Components of Bentonites of Tarkha Khui Block
'R'

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	L/I
SiO ₂		0.2419	0.9314	0.9902	-0.7602	-0.8972	0.5234	0.1960	-0.8949
Al ₂ O ₃	0.352		-0.1220	0.3065	-0.1460	-0.2856	-0.0596	-0.0018	-0.0952
Fe ₂ O ₃	3.620	-0.173		0.9055	-0.6799	-0.7820	0.5022	0.2645	-0.8504
TiO ₂	10.044	0.455	3.018		-0.6715	-0.8404	0.4045	0.3093	-0.8256
T CaO	-1.654	-0.208	-1.311	-1.281		0.9620	-0.9438	0.4840	0.9630
MgO	-2.872	-0.421	-1.774	-2.193	4.984		-0.8180	0.2547	0.9808
Na ₂ O	0.868	-0.084	0.821	0.625	-4.037	-2.011		-0.7006	-0.8480
K ₂ O	0.282	-0.002	0.387	0.459	0.782	0.372	-1.388		0.2377
L/I	-2.836	-0.135	-2.286	-2.069	.055	7.120	-2.263	0.346	

n=4, the significant values of 'R' are bold.

TABLE 19

Linear Correlation Co-efficient Between Major Components of Bentonites of Akori Block.
'R'

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	L/I
SiO ₂		0.0670	-0.2427	0.1190	-0.8480	-0.6086	0.4170	-0.2469	-0.8888
Al ₂ O ₃	0.116		-0.7832	0.9729	-0.3814	0.1316	-0.8041	-0.9519	-0.3780
Fe ₂ O ₃	-0.433	-2.181		-0.6728	0.6555	-0.2007	0.3261	0.6942	0.3797
TiO ₂	0.207	7.290	7.2 0		-0.3220	-0.1354	-0.8146	-0.9900	-0.4822
T CaO	-2.771	-0.714	1.503	-0.589		0.5062	-0.1993	0.4164	0.7373
MgO	-1.328	0.229	-0.354	0.236	1.016		-0.2530	-0.0934	0.3320
Na ₂ O	0.794	-2.342	0.597	-2.432	-0.352	-0.453		0.7276	-0.0606
K ₂ O	-0.441	-5.379	1.670	-2.143	0.793	-0.162	1.836		0.5977
L/I	-3.359	-0.707	0.710	-0.953	1.890	0.609	-0.105	1.291	

n=5, the significant values of 'R' are bold.

Na_2O ; TiO_2 does not show correlations with CaO and Na_2O and Al_2O_3 does not show correlation with Na_2O .

Block C: Six analyses of Block C were done. The means and standard deviations were as follows:

SiO_2 $\bar{x} = 48.84$, $\alpha = 4.38$, Al_2O_3 $\bar{x} = 18.48$, $\alpha = 4.38$; MgO $\bar{x} = 6.13$, $\alpha = 2.10$; Fe_2O_3 $\bar{x} = 5.38$, $\alpha = 1.51$; CaO $\bar{x} = 3.40$, $\alpha = 2.37$; K_2O $\bar{x} = 1.49$, $\alpha = 0.76$; TiO_2 $\bar{x} = 0.61$, $\alpha = 0.18$; Na_2O $\bar{x} = 0.48$, $\alpha = 0.29$, and L/I $\bar{x} = 13.80$, $\alpha = 3.27$.

Compared with the Block A, Block B and the overall results the mean value of SiO_2 in this block is lower. This block shows the highest MgO values. This block also shows the lowest Na_2O values. The L/I values are second highest after Tarkha Khui Block. In this block also $\text{MgO} > \text{CaO}$ and Fe_2O_3 and $\text{K}_2\text{O} > \text{Na}_2\text{O}$.

SiO_2 shows negative correlation with L/I . SiO_2 shows negative correlation with Na_2O . CaO shows positive correlations with MgO and L/I . MgO and Na_2O show positive correlations with K_2O .

Garuzi Block: Only two analyses of the Garuzi Block were done. It resembles the overall average analysis. The amount of MgO and CaO are, however, lower and the amount of Na_2O is very high. Correlations could not be calculated.

Tarkha Khui Block: Only four chemical analyses of the Tarkha Khui Block were carried out. SiO_2 $\bar{x} = 48.23$, $\alpha = 6.51$; Al_2O_3 $\bar{x} = 15.50$, $\alpha = 0.61$; Fe_2O_3 $\bar{x} = 6.78$, $\alpha = 0.89$; CaO $\bar{x} = 5.41$, $\alpha = 0.90$; MgO $\bar{x} = 4.41$, $\alpha = 1.12$; K_2O $\bar{x} = 1.52$, $\alpha = 0.13$; Na_2O $\bar{x} = 0.92$, $\alpha = 0.18$; TiO_2 $\bar{x} = 0.70$, $\alpha = 0.05$ and L/I $\bar{x} = 14.06$, $\alpha = 2.29$.

This is the only block in which $\text{CaO} > \text{MgO}$. It gives highest CaO , L/I and Fe_2O_3 values. In this block $\text{K}_2\text{O} > \text{Na}_2\text{O}$ and Fe_2O_3 is more than CaO and MgO .

In this block SiO_2 shows positive correlation

with TiO_2 . CaO shows positive correlation with MgO and L/I but negative correlation with Na_2O and MgO and shows positive correlation with L/I .

Akori Block: Five analyses of Akori Block were carried out. SiO_2 $\bar{x} = 52.37$, $\alpha = 3.69$; Al_2O_3 $\bar{x} = 23.13$, $\alpha = 2.51$; MgO $\bar{x} = 5.74$, $\alpha = 1.24$; Fe_2O_3 $\bar{x} = 4.52$, $\alpha = 1.28$; CaO $\bar{x} = 2.75$, $\alpha = 0.72$; K_2O $\bar{x} = 0.74$, $\alpha = 0.41$; TiO_2 $\bar{x} = 0.67$, $\alpha = 0.05$; Na_2O $\bar{x} = 0.57$, $\alpha = 0.26$ and L/I $\bar{x} = 9.32$, $\alpha = 2.48$. This block shows the lowest CaO values and highest Al_2O_3 values. It also shows the lowest K_2O values and lowest L/I values. In this block $\text{MgO} > \text{CaO}$ and Fe_2O_3 . Also $\text{K}_2\text{O} > \text{Na}_2\text{O}$. This block shows the lowest total alkali values also.

Summary of All Blocks: In the above, comparative chemistry of the individual blocks and the total bentonite has been considered. Certain important facts having a practical value have also been noted. In the following the chemistry of the Karak bentonite will be discussed as a whole and certain general conclusions applicable to the deposit shall be drawn.

The total data gave the following means and standard deviations of the constituent oxides and L/I . SiO_2 $\bar{x} = 52.27$, $\alpha = 4.29$; Al_2O_3 $\bar{x} = 18.71$, $\alpha = 3.47$; Fe_2O_3 $\bar{x} = 5.98$, $\alpha = 1.96$; CaO $\bar{x} = 3.22$, $\alpha = 1.54$; MgO $\bar{x} = 4.68$, $\alpha = 1.62$; K_2O $\bar{x} = 1.33$, $\alpha = 0.57$; TiO_2 $\bar{x} = 0.59$, $\alpha = 0.21$; Na_2O $\bar{x} = 0.79$, $\alpha = 0.40$; and L/I $\bar{x} = 11.86$, $\alpha = 3.05$.

The results of correlations are as follows:

SiO_2 shows negative correlations with CaO , MgO and L/I . The contents of Fe_2O_3 show negative correlation with MgO and positive correlations with CaO , K_2O and Na_2O . The contents of TiO_2 show positive correlations with MgO and negative with K_2O . The contents of CaO show positive correlations with MgO and L/I . The contents of MgO show negative correlations with Na_2O and K_2O . The contents of Na_2O show positive correlation with K_2O .

It may be noted that SiO_2 and Al_2O_3 do not show inverse relation. The contents of Na_2O and K_2O increase together but show inverse relation with MgO . The contents of Fe_2O_3 are inversely related with Al_2O_3 . The contents of CaO and MgO increase together.

The amount of MgO is more than CaO and the amount of K_2O is more than Na_2O . It is important to note that some CaO and Na_2O are present in free phases (non-clay) also i.e. in calcite and gypsum (CaO) and in halite (Na_2O —in fact NaCl). The L/I is low.

Spectrographic Analysis: The results of eleven spectrographic analyses are given in table 20. Vanadium was found to be present in ten out of eleven analyses, Cu was not detected and Ni was not determined.

MINERALOGY

The mineralogy of the Karak bentonitic clay was studied by D.T.A. and X-ray methods. The D.T.A. and X-ray data are interpreted as follows. In the interpretation help was also taken from chemical and petrographic studies.

TABLE 20
Spectrographic Analysis

Sr. No.	Sample No.	Si	Mg	Fe	Cu	Ca	Al	V	Ti
1.	TA-76-IC-1	P	P	P	A	P	P	P	P
2.	TA-76-IC-5	P	P	P	A	P	P	P	P
3.	TA-76-IC-6	P	P	P	A	P	P	P	P
4.	TA-76-IC-7	P	P	P	A	P	P	P	P
5.	TA-76-IC-9	P	P	P	A	P	P	P	P
6.	TA-76-IC-10	P	P	P	A	P	P	P	P
7.	Block A-3	P	P	P	A	P	P	P	P
8.	Block B-3	P	P	P	A	P	P	P	P
9.	Block B-4	P	P	P	A	P	P	P	P
10.	Block B-5	P	P	P	A	P	P	P	P
11.	Tarkha Khui	P	P	P	A	P	P	P	P

P—Present

A—Absent

P.C.S.I.R. Laboratories, Peshawar.

D.T.A. Studies: Eleven differential thermal analysis patterns of the Karak bentonite samples were obtained. The patterns along with samples numbers are shown in Figs. 8-9. Two of the patterns were taken after activation. In all the samples endothermic peaks were found at 140° – 150°C – 360 to 573°C and 901 – 925°C and exothermic peaks at 935° – 955°C . Tarkha Khui sample 'Channel 2' gave additional peaks at 814°C and 823°C . These peaks are possibly due to impurities like carbonates and gypsum.

The data obtained was compared with Scifax (1963) cards and with data of Kerr, Kulp and Hamilton (1949). Detailed comparisons showed that the clays are mixed layer montmorillonite-illite (mixed layer smectite clay). The fact is also supported by the chemical data.

X-Ray Analysis: X-ray diffraction patterns of four raw and two washed samples were obtained. The $d(\text{\AA})$ values and the intensity values are listed in table 21. The X-ray data was compared with A.S.T.M. (1963) cards. The lines 4.46–4.55, 4.21–4.27, 3.52–3.54, 3.33–3.36, 3.17–3.20, 3.00–3.05, 2.77, 2.50–2.58, 2.27–2.29, 2.20–2.25, 2.11–2.14, 1.98–1.99, 1.81–1.82, 1.66–1.68 and 1.50 belong to the montmorillonite group. Very strong 3.33–3.36 lines are due to illite inter-layers. The 2.57 (2.50–2.58) and 4.46–4.55 lines may also be due to illite. In the unwashed samples quartz can also contribute to the intensity of 3.33–3.36 lines. A detailed comparison showed that the clay is a mixed layer montmorillonite-illite (mixed layered smectite).

On the basis of chemistry, D.T.A. and X-ray analyses, it is concluded that the clay belongs to the smectite group. It is a mixed layer montmorillonite-illite clay.

Conclusions

Although the samples analysed were not pure clay, yet they were rich enough in clay to permit

drawing certain conclusions regarding the nature of clay and its chemistry. This becomes all the more possible, since petrographic data is also available. Thus taking into account the chemical data, its statistical treatment and taking also into account the non-clay phases, their nature and amounts, the following general and qualitative conclusions may be drawn.

1. From the chemical analyses and the average of forty seven chemical analyses and comparing this data with that given by Deer, Howie and Zussman (1962) it can be safely said that the clay is montmorillonitic.

2. The study of the contents of MgO , CaO , Na_2O and K_2O and taking into account their presence in clay and non-clay phases strongly suggests that the clay is Mg-Ca type bentonite with MgO much in excess of CaO . The higher content of K_2O (compared with Na_2O) in the clay phase suggests it to be a mixed layer montmorillonite-illite clay, i.e., the clay contains illite molecule.

3. MgO and CaO contents increase in a sympathetic fashion and so do Na_2O and K_2O .

4. Negative correlation between MgO and Na_2O and MgO and K_2O may be due to some Mg in the X position. The X-position Mg has been discussed by Foster (1951). This may contribute to the cation exchange capacity.

5. The high values of iron are partly due to free phases of iron like haematite and limonite.

6. Lower L/I values are partly due to the composition of the clay itself, its structure, its mixed layer nature and partly due to lower H_2O .

7. SiO_2 and Al_2O_3 do not show correlation. It is, therefore, a montmorillonitic dioctahedral clay.

8. On the basis of D.T.A. and X-ray data as discussed above the clay is also shown to be a mixed layer montmorillonite-illite.

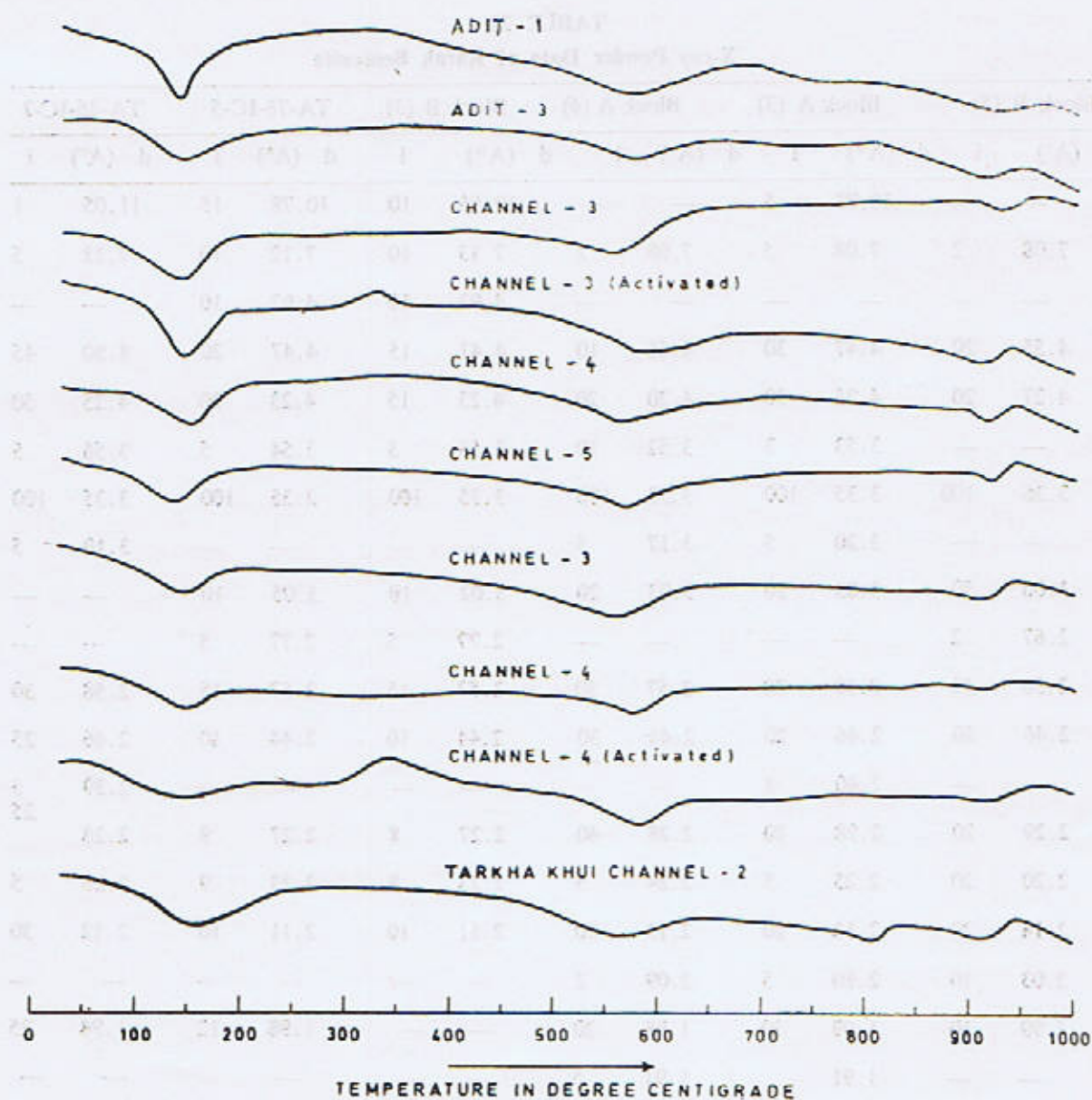


Fig. 8. Differential Thermal Analysis curves of Bentonite of Blocks A and Tarkha Khui.

TABLE 21
X-ray Powder Data of Karak Bentonite

Block B (5)		Block A (3)		Block A (4)		Block B (3)		TA-76-IC-5		TA-76-IC-7	
d (Å°)	I	d (Å°)	I	d (Å°)	I	d (Å°)	I	d (Å°)	I	d (Å°)	I
—	—	10.78	5	—	—	10.65	10	10.78	15	11.05	1
7.08	2	7.08	5	7.08	2	7.13	10	7.12	10	7.12	5
—	—	—	—	—	—	4.92	10	4.92	10	—	—
4.55	20	4.47	30	4.46	10	4.47	15	4.47	20	4.50	45
4.27	20	4.25	30	4.20	20	4.23	15	4.23	20	4.25	50
—	—	3.53	3	3.52	10	3.53	3	3.54	5	3.56	5
3.36	100	3.35	100	3.33	100	3.35	100	3.35	100	3.35	100
—	—	3.20	5	3.17	5	—	—	—	—	3.19	5
3.00	50	3.03	20	3.03	20	3.02	10	3.05	10	—	—
2.67	2	—	—	—	—	2.77	5	2.77	5	—	—
2.50	30	2.58	20	2.57	30	2.57	15	2.57	15	2.58	30
2.46	30	2.46	20	2.44	30	2.44	10	2.44	10	2.46	25
—	—	2.40	5	—	—	—	—	—	—	2.39	5
2.29	20	2.28	20	2.28	40	2.27	8	2.27	9	2.28	25
2.20	20	2.25	5	2.24	5	2.23	8	2.23	9	2.23	5
2.14	20	2.13	20	2.13	20	2.11	10	2.11	10	2.12	30
2.03	10	2.10	5	2.09	2	—	—	—	—	—	—
1.99	10	1.99	20	1.98	20	—	—	1.98	12	1.98	25
—	—	1.91	—	1.91	5	—	—	—	—	—	—
1.82	60	1.82	40	1.82	50	1.82	40	1.81	40	1.82	50
1.63	12	1.67	30	1.67	30	1.66	10	1.66	10	1.67	25
1.55	50	1.54	40	1.54	50	1.54	10	1.54	12	1.55	50
1.50	10	1.50	30	1.50	10	1.50	10	1.50	10	1.51	30
—	—	—	—	—	—	—	—	—	—	1.46	10
1.37	50	1.37	70	1.37	70	1.37	35	1.37	40	1.38	70
—	—	1.88	5	1.86	5	—	—	—	—	—	—

Radiation CuK α
Exposure 6 hrs.

PCSIR Laboratories, Peshawar.

On the basis of petrography, optics, chemistry, statistical analyses and interpretation, X-ray and D.T.A. data the Karak bentonite can be said to be a mixed layer montmorillonite-illite.

PETROGENESIS

The Karak bentonite is present within a sedimentary sequence of marine rocks. Furthermore it is sandwiched between salt and gypsum indicating evaporitic conditions. The bentonite does not mark a surface of unconformity and there is no evidence to show that it marks a disconformity. The deposit shows lamination and even graded bedding at places (indicating transportation and deposition). Gypsum layers and intercalations present were studied and found to be syngenetic. This indicated the deposition of the Karak Bentonite in an evaporite basin. All these facts show that the Karak Bentonite is a transported deposit and that it did not form in situ.

The clay contains significant MgO , ($\bar{x} = 4.68$, $\alpha = 1.62$), Fe_2O_3 ($\bar{x} = 5.98$, $\alpha = 1.96$) and CaO ($\bar{x} = 3.22$, $\alpha = 1.54$). It also contains significant K_2O ($\bar{x} = 1.33$, $\alpha = 0.57$). Judging from this it may be said that the clay formed from the breakdown of basic igneous rocks or their equivalents. Spectrographic-analyses show consistent presence of 'V' and absence of copper in these clays. This may also support the above view.

Butler (1953) reported 15 ppm vanadium in clays formed from the disintegration of adamellite and

300 ppm in clays derived from basic rocks.

The Karak bentonite is a mixed layer montmorillonite-illite clay. This may throw light on the depth of burial that this clay may have undergone. Weaver (1959) concluded that below a depth of burial of 10,000 feet montmorillonite alters to a mixed layer montmorillonite-illite. The proportion of illite increases with increasing depth. Similarly Burst (1969) has shown the conversion of swelling to non swelling clays for the Eocene of the Gulf Coast. Further more it is known from the experimental work that between $95^\circ C$ and $140^\circ C$ (corresponding to depths of 8000 to 13000 ft. and in the presence of K^+/H^+ ratios approximating to those of sea water, montmorillonite may lose its interlayer water and convert to illite (1972).

It is concluded that the Karak bentonite was originally deposited as a bentonite which with depths of burial of 10,000 ft. or so and in the presence of K^+ bearing fluids changed to a mixed layer montmorillonite-illite.

The Karak bentonite was deposited in an evaporite basin in which the salinity was slightly less than 3.35 times the original salinity for most of the time but varying on either side at different times and different places of the basin. This resulted in the formation of syngenetic gypsum layers within bentonite. This value of salinity i.e. 3.35 time the original salinity (at $30^\circ C$ is experimentally known) (1972).

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PETROLOGY OF THELCHI AREA, GILGIT AGENCY

BY

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Abstract : *Near Thelichi, Gilgit Agency, 181 square kilometer area lying along the newly constructed Karakorum Highway, has been geologically mapped and studied in detail. Detailed petrography including 49 modal analyses of various rocks is presented. Field and microscopic evidences show that there are two major dioritic plutons of Cretaceous-Eocene age, separated by regionally metamorphosed epi- and meso zonal rocks and a sill of porphyritic diorite. The metamorphics including amphibolites were derived from original sedimentary rocks of different compositions. The dioritic rocks lack pyroxenic basic rocks or ultrabasics. They show systematic mineralogical variations due to magmatic differentiation and assimilation. Residual magmatic fractions crystallized the widespread pegmatites and hydrothermal quartz veins.*

A brief survey of the economic mineral potential of the area is included.

INTRODUCTION

Thelichi area of Gilgit Agency, Pakistan, lies on the southern border of the Western Karakorum mountain range, which is an Alpine orogenic belt lying north of the Kashmir Himalayas. The area included in the present study is 181.3 square kilometers and lies between longitudes $74^{\circ} 33' 30''$ and $74^{\circ} 38' 30''$ east and latitudes $35^{\circ} 28' 30''$ and $35^{\circ} 41'$ north. The area is accessible by the newly constructed Karakorum Highway (KKH) which runs all along right bank of the Indus river in this area, and defines the southern and eastern boundary of the area. Deeper penetration into the higher altitudes is sometimes possible by foot-paths.

The area has very high relief; the highest and lowest locations within the area being, respectively; 4267 and 1433 metres above sea level.

Previous geological investigations on the Karakorum are few because of extremely high relief and tough field work conditions. Thelichi area was, however included in various studies on regional scale (Wadia, 1933; Gattinger, 1960; Desio, 1964; Gansser, 1964; Abu Bakar, 1965; Rizvi et al. 1966). The geological maps given by these workers are on small scales. Such maps are useful for many purposes, but there is need to prepare geological maps of these areas on a much larger scale. Following the construction of KKH,

Desio (1974) published a reconnaissance of the Chilas-Bisham Qila section of the KKH. Thelichi area lies in the middle part of Chilas-Gilgit section of KKH, and so the present work is similar in purpose as Desio initiated.

GENERAL GEOLOGY

The rocks of the area (Fig. 1) belong to a conformable sequence of metasedimentary rocks, intruded by the dioritic rocks which form the most abundant rock type. The oldest rocks of the area are the metamorphics which were assigned to the Precambrian Salkhala Series by Wadia (1933), Gattinger (1961) and others; and to the Permocar-boniferous Darkot Group by Rizvi et al. (1971). These are intruded by younger plutonic rocks which form a large intrusive of average dioritic composition in the southern part and crossing the southern and western boundary of the area, join the basic and intermediate plutonics of Chilas reported by Desio (1974), and which extend further west. Another similar intrusion is seen in the north. A third intrusion of dioritic porphyry forms a sill in phyllites of the metasediments of the area.

The metamorphics are composed of various lithologies including amphibolites, garnet mica schist, phyllite, marble and slate. All these rocks possess a strong general schistosity striking north-west and dipping steeply towards northeast. The contoured diagram of their schistosity (Fig. 3) using Schmidt's net shows the peak concentration in the southwestern quadrant, corresponding to average strike N46°W and dip 70°NE. Many of the metamorphics are well banded parallel to schistosity.

Later injections of pegmatites and hydrothermal quartz veins are present in all the rocks, and are especially concentrated near the margins of the northern and southern diorites. Just outside the contact of northern diorite, outcrops a zone of mixed igneous and metamorphic rocks containing also the injection migmatites and contact skarn.

PETROGRAPHY

The Dioritic Patholiths are mostly massive and plutonic non-banded rocks, except some places which show a foliated and banded structure, such as the outcrops in the Thelichi valley. Such bands are alternatively rich in quartz—feldspar and hornblende, and are usually two to six inches thick. They are coarse, hypidimorphic to allotriomorphic granular rocks. In some parts, poikilitic plates, myrmekites and other textures are seen. Many petrographic varieties compose this unit. These are, in addition to normal diorite; garnet diorite, mela diorite, quartz diorite, tonalite and granodiorite. The spatial distribution of these varieties is irregular and patchy. The modal compositions of thin sections belonging to all these varieties are given in table 1. The mineral contents show a progressive variation in the series meladiorite-diorite-quartz diorite-tonalite-granodiorite. The hornblende-rich meladiorite is more abundant near the eastern part of Gor Valley in the case of southern diorite and near the lower pegmatite outcrop (Fig. 1) in the case of northern diorite. Garnet diorite contains garnet crystals upto 3 cm. across, and is typically exposed near the Raikot bridge and the Thelichi Village. In general, the quartz content of all the dioritic varieties is higher, and increases progressively in the above series. Quartz grains occur as interstitial to hornblende and feldspar or as inclusions in them. Hornblende is often strongly pleochroic from pale green to bluish green and its extinction angle ($c \wedge Z$) varies from 11° to 23°. Simple twins are sometimes seen. Inclusions of quartz, epidote, biotite and iron ore are common. It alters to biotite and chlorite. Plagioclase is often well-twinned, rarely with curved twin lamellae. Its optically determined composition is given in table 1, which shows a regular variation in the above series. Commonly, it is partly sericitized or some times altered to zoisite or clinozoisite.

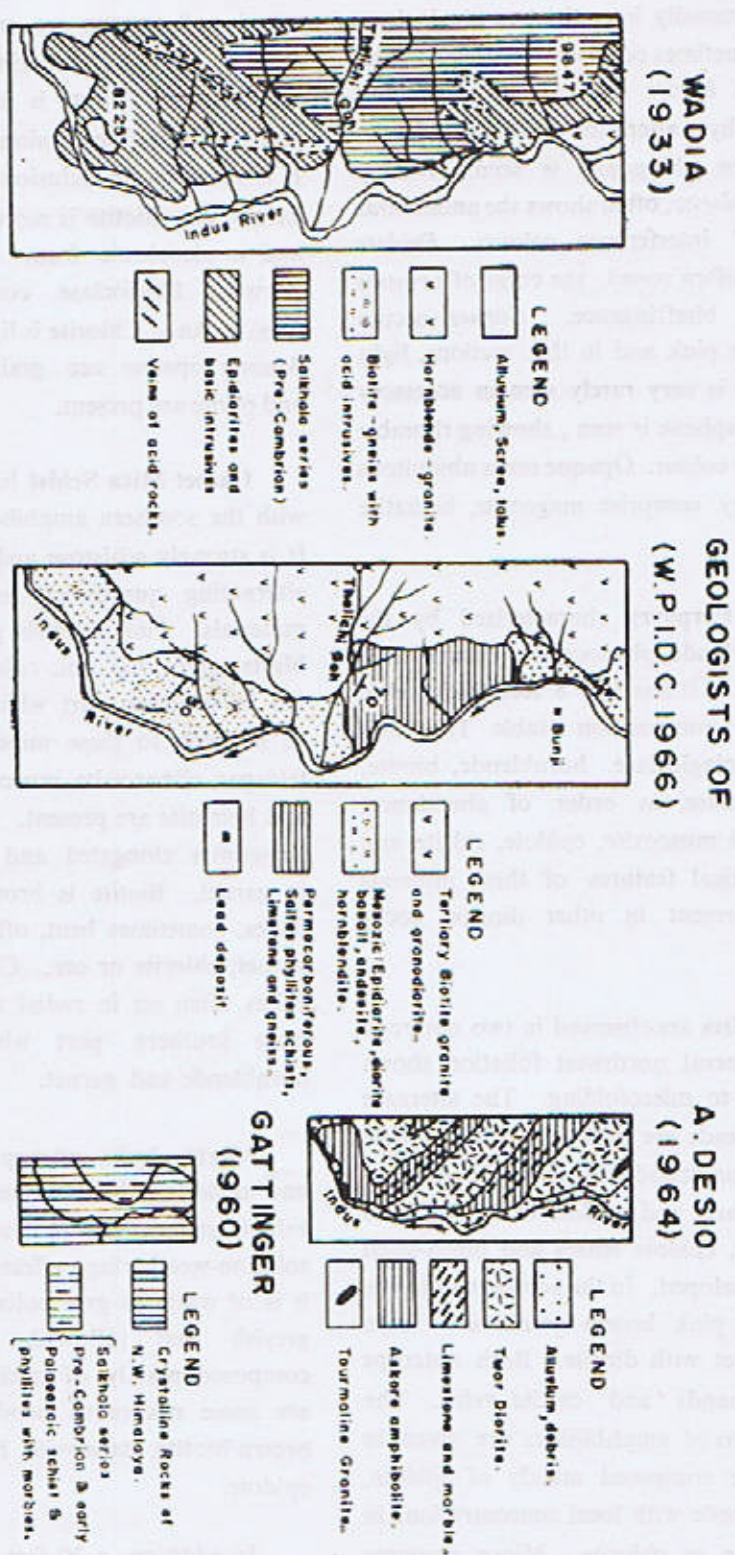


Fig. 2. Geological map of Thelichi area from previous reports. The area included is the same as that shown in Fig. 1.

Orthoclase is usually interstitial to plagioclase, is clouded and sometimes occurs as micropegmatite. Brown pleochroic *biotite* is often primary, but may also form by alteration of hornblende. Very rarely, green phlogopite is seen. Weakly pleochroic green *chlorite*, often shows the anomalous "tobacco brown" interference colours. *Epidote* is colourless and often zoned, the cores of crystals showing higher birefringence. *Garnet* occurs sporadically. It is pink and in thin sections, light brown. *Pyroxene* is very rarely seen in accessory amount. Rarely, sphene is seen, showing rhombic outlines and yellow colour. Opaque ore is ubiquitous accessory and may comprise magnetite, hematite or pyrite.

The Diorite Porphyry characterized by the presence of hornblende phenocrysts, occurs as a sill inside phyllites. It has 5 to 8 feet thick felsic interbeds. Modal composition (table 1) shows that it contains plagioclase, hornblende, biotite, quartz and orthoclase, in order of abundance. Accessories include muscovite, epidote, calcite and opaque ore. Optical features of these minerals resemble those present in other dioritic rocks described above.

The Amphibolites are observed in two outcrops (fig. 1). Their general northwest foliation shows local changes due to microfolding. The alternate felsic and mafic bands are well developed. Felsic bands are rich in quartz and feldspar in the southern outcrop and in quartz and epidote in the northern one. In the latter, epidote lenses and pinch-swell veins (fig. 4) are developed. In the southern outcrop, porphyroblasts of pink brown garnet are seen closer to its contact with diorite. Both outcrops contain marble bands and calcite veins. The modal compositions of amphibolites are given in table 2. They are composed mainly of epidote, quartz and hornblende with local concentrations in pink garnet, biotite or chlorite. Minor amounts of calcite, orthoclase, plagioclase, sphene, muscovite,

spinel and opaque ore are present. Hornblende ($c \wedge Z$, 18° to 25°) altering to biotite and chlorite is common. Quartz is usually anhedral, strained and relatively finer grained in quartz-rich samples. It is common as inclusions in hornblende, epidote, garnet, etc. Biotite is more in quartz rich varieties, and is pleochroic from light green to greenish brown. Plagioclase composition varies from An_{27} to An_{39} . Chlorite is light green and pleochroic. Among opaque ore grains, magnetite, hematite and pyrite are present.

Garnet Mica Schist has gradational contacts with the southern amphibolite as well as phyllites. It is strongly schistose and sometimes banded with alternating quartz-rich and biotite-chlorite rich materials. Pink reddish garnet forms porphyroblasts upto 4.0 cm. diameter and turns dark red in southern part where it is more abundant. In addition to these minerals, minor amounts of feldspar, clinozoisite, muscovite, hornblende, calcite and hematite are present. Quartz is often strained, sometimes elongated and may form inclusions in garnet. Biotite is brown, pleochroic and its flakes, sometimes bent, often occur near grains of garnet, chlorite or ore. Chlorite forms light green flakes often set in radial aggregates. It is absent from southern part which has more green hornblende and garnet.

Marble beds outcrop in a horizon overlain and underlain by phyllites. Its exposed surfaces exhibit yellow, grey and rusty brown colours and solution-weathering effects. On fresh surfaces, it is of white to grey colour and shows bands of greyish and yellowish brown colour. It is composed mainly of calcite and dolomite. There are some micaceous bands which may contain brown biotite, muscovite, hematite and sometimes epidote.

In addition, a 30 feet thick marble band is present in the southern amphibolite and a 10 feet

thick band in the northern amphibolite. Desio (1964), reported marble bands from within the diorite outcrop, but the present workers did not find any marble bed inside diorite.

Phyllites with greyish weathering colour and lustrous sheen of micas occur in three horizons (fig. 1). Microfolding is seen everywhere. Phyllites are composed mainly of quartz, chlorite, biotite, and muscovite. Graphite, pyrite and magnetite are present in minor amounts. Quartz is strained and anhedral. Chlorite commonly forms radial aggregates. Out of three phyllite outcrops, the southern one is more schistose, contains more of brown biotite and shows segregational banding on thin section scale.

Slates : Lie concordantly north of phyllites. They are well bedded, fine grained and at many places, microfolded. Their constituents are quartz, muscovite, biotite, epidote, graphite specks, calcite and opaque ore. Chloritoid is absent.

The Mixed Zone : (Fig. 1) is made of different igneous and metamorphic units, inter mixed and lying in between the northern diorite and metamorphics. It is mainly a migmatitic complex with minor injection of dioritic to granitic material hosted by phyllites. There is a skarn rock developed at immediate contact of diorite in addition to a good development of pegmatites in this zone. The igneous components show a hypidiomorphic granular texture, and contain plagioclase, quartz, hornblende, accessory epidote, sphene, apatite, garnet and iron oxides. Rarely, show tourmalinization. Among metamorphic units, a brownish-grey weathering phyllite is the main rock, with quartz, epidote, plagioclase, muscovite, apatite, calcite, pyrite, magnetite and hematite as its minerals. Biotite schist is seen near amphibolite outcrop, and has the following composition : quartz, 38% ; biotite, 52% ; orthoclase, 6% ; apatite, 2.5% and pyrite plus hematite, 1.5%.

Pegmatites and Hydrotherm I Quartz Veins, are present in all the rock units of the area. They are more abundant near margins of diorite batholiths. Pegmatites, hosted by the mixed zone are especially noteworthy at a place where two large parallel bodies, each about 610 metres long and 55 metres wide are exposed. The upper one contains large muscovite flakes and is coarser grained than the lower one which is biotite rich and also contains garnet. Except these two bodies, the pegmatites of the area seldom exceed 9 metres length. The minerals of pegmatites include quartz, orthoclase, microcline, perthite, plagioclase, muscovite, biotite, garnet, tourmaline, pyrite and clinozoisite. Quartz veins cut across all the rocks, including pegmatites, and are at some places, galena bearing. (See below). The pegmatites might be zoned, as indicated in certain cases by garnet occurring towards the border zones.

ECONOMIC MINERAL DEPOSITS

During the course of present study, many materials of probable economic use were noted to occur in Thelichi area. Further specialized work may be done to prove their economic use. However, the geological bodies that can be considered for such materials include :

(i) *Plutonic and Metamorphic Rocks*, such as diorites, granites, slates and greyish white marbles that can be used as dimension stone. Some of these rocks, like diorite, amphibolite and garnet mica schist, contain dark reddish brown to pink almandine garnet that can be mined for its use as abrasive. Especially noteworthy is a zone of banded and foliated diorite containing veins, lenses and bands of garnet plus quartz, and can be allowed for a considerable distance to mine both of these abrasives.

(ii) *Placers*. There are extensive fluvial placers along the course of Indus river and its tributaries. These contain important heavy

TABLE 1
Modal Composition of Dioritic Rocks

		Meladiorite			Diorite			Quartz Diorite				
		17130	17285	17287*	17293	17297	17119	17122*	17057	17155	17187	17150
Plagioclase	..	1.5	35.2	38.6	20.7	44.4	52.0	48.2	52.1	54.6	45.5	47.7
Orthoclase	..		2.0		10.5	2.5	1.0	2.0		2.0		4.0
Sericite	.			1.4		1.5		0.4				
Epidote	..		3.8	1.0	0.5	8.6	1.3		2.0		1.0	2.0
Quartz	..		1.0	4.5	12.0	5.0	4.0	10.1	7.2	8.1	8.3	8.1
Hornblende	..	50.0	52.0	46.0	38.3	32.0	38.0	34.5	29.2	28.1	40.4	25.8
Biotite	..	4.0		5.5	12.0	0.5		3.0	5.2	4.0	3.0	5.5
Chlorite	..	1.5	2.1	0.5		3.0	1.7			2.2	1.4	3.9
Muscovite	..	2.0		1.5		1.5		0.8	2.0			1.0
Apatite	..				1.5	1.0	0.5		0.3			
Opaque Ore.	..	1.0	3.1	1.0	4.5		1.5	1.0	2.0	1.0	0.4	2.0
<i>Plagioclase Composition</i>												
An%	..	49	—	42	34	—	—	35	42	42	40	36

		Garnet Diorite		Tonalite		Granodiorite				Diorite porphyry				
		17116	17107		17087*	17266	17094	17084	17079	17227	17232	17166	17177	17174
Plagioclase		56.2	46.2		34.5	25.6	44.2	48.0	48.4	45.2	52.2	44.2	23.6	44.8
Orthoclase		3.8	2.8		4.8	7.4	1.1	9.0	2.6	4.6		2.7	5.2	4.4
Epidote		4.0	2.0			1.4	2.0	3.5		2.7	2.0		1.3	3.1
Quartz		5.4	7.2		16.7	24.7	11.3	15.0	29.2	8.1	6.0	10.3	14.4	10.7
Hornblende		18.0	25.5		40.1	32.3	31.6	6.0	10.8	25.1	28.8	24.4	40.8	21.2
Biotite		4.5	3.3			4.6	6.0	16.0	6.2	10.3	8.0	14.7	12.6	15.3
Chlorite			1.8		2.7		1.5				1.0			
Muscovite								1.5	1.8			1.2		
Garnet		7.3	2.1											
Apatite		0.3								1.2				
Opaque Ore		0.5	2.2		1.2	4.0	2.3	1.0		2.8	2.0	2.5	2.1	0.5
<i>Plagioclase composition</i>														
An%		34			32	—	34	41	—	33	—	33	33	35

Sample numbers with asterik represent northern diorite, rest being from southern diorite pluton.

TABLE 2
Modal Composition of Amphibolites

		17211	17197	17213	17198	17007	17192	17190	17191	17038	17046	17201	17030	17204
Plagioclase	..	2.8	3.7	3.5	13.3	15.3	—	2.2	—	1.5	8.2	1.5	2.5	9.5
Orthoclase	..	3.9	—	—	6.2	—	5.3	—	4.6	—	4.1	6.4	4.3	5.0
Epidote	..	34.5	33.1	30.2	33.8	24.3	17.8	18.7	1.9	1.7	—	2.8	10.0	10.0
Calcite	..	1.2	—	1.4	—	—	—	—	—	—	—	—	—	—
Quartz	..	38.2	32.2	31.1	38.7	34.9	39.6	8.7	28.4	44.6	33.3	34.0	44.4	40.9
Hornblende	..	21.7	30.5	4.2	21.3	25.5	36.1	30.1	40.7	29.9	1.7	50.1	32.1	30.1
Biotite	..	—	—	6.0	—	—	—	1.2	9.2	5.2	20.1	3.2	—	—
Chlorite	..	—	—	2.6	—	—	—	34.8	15.2	14.0	1.4	1.0	1.5	—
Muscovite	..	—	—	—	—	—	—	—	—	—	—	—	0.9	—
Sphene	..	—	—	—	—	—	—	3.2	—	—	—	—	—	—
Spinel	..	—	—	—	—	—	—	—	—	—	—	—	2.4	—
Opaque ore	..	0.5	0.5	1.0	—	—	1.2	1.1	—	3.1	1.2	1.0	2.9	4.5

TABLE 3
Modal Composition of Miscellaneous Rocks from Thelichi area

		Garnet - Mica Schist		Marble		Phyllite		Slate		Pegmatite		
		17026	17020	17180	17184	17185	17178	17182	17219	17221	17186	17280
Plagioclase	..	1.5	19.3	—	—	—	—	—	—	—	21.4	20.5
Orthoclase	..	—	—	—	—	—	—	—	—	—	51.6	51.7
Quartz	..	40.6	35.6	—	—	—	59.8	43.5	34.8	25.0	15.3	14.8
Epidote	..	0.5	—	4.7	0.7	—	—	—	—	5.0	2.2	0.6
Hornblende	..	11.5	—	—	—	—	—	—	—	—	—	—
Biotite	..	39.1	17.1	0.9	—	—	9.2	29.4	20.0	5.0	1.3	2.6
Muscovite	..	0.5	2.1	3.6	—	1.0	5.1	1.5	40.0	32.0	3.7	6.4
Chlorite	..	1.2	10.1	—	—	—	25.1	21.1	—	—	—	—
Garnet	..	4.1	12.3	—	—	—	—	—	—	—	4.5	3.4
Calcite	..	—	1.6	90.3	98.2	75.0	—	—	—	20.0	—	—
Dolomite	..	—	—	—	—	23.0	—	—	—	—	—	—
Opaque ore	..	1.0	1.9	0.5	1.1	1.0	0.8	—	0.2	3.0	—	—
Pyrite	..	—	—	—	—	—	—	2.5	—	—	—	—
Graphite	..	—	—	—	—	—	—	2.0	5.0	10.0	—	—

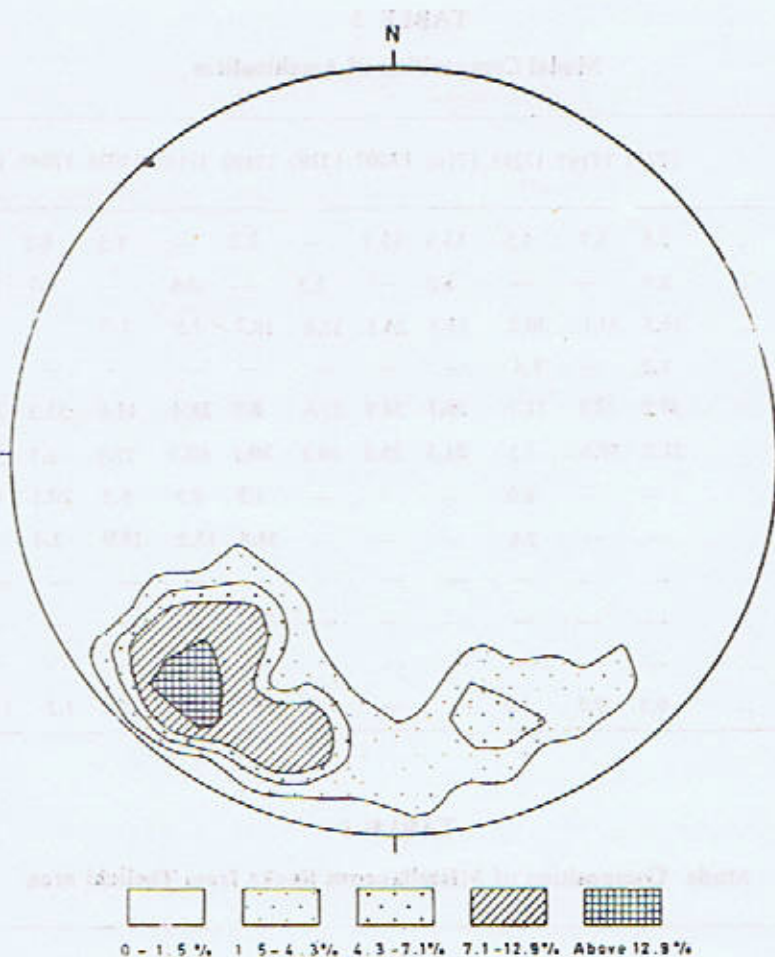


Fig. 3. Orientation diagram of foliation readings of metamorphic units plotted on Schmidt net (lower hemisphere).

minerals in their concentrates, such as gold, magnetite, garnet, etc. Considerable magnetite is present in dark grey to black sands of Thelichi valley.

(iii) *Pegmatites* of the area may yield feldspar, quartz, garnet, tourmaline and mica. For large flakes of mica, the two large pegmatites of the mixed zone may be a good source. They are

located 600 metres west of a point on KKH, 8 miles north of Thelichi R.H.

(iv) *Quartz Veins*. Such small-sized veins are present throughout the area. They may yield quartz and sulphides like galena, pyrite, chalcopryrite, etc. Such veins 8 miles south of Thelichi, are stained with copper carbonates. Quartz veins contain galena at three locations to-



(A)



(B)



(C)



(D)

Fig. 4. (A) Coarse garnet crystals standing out on the exposures of banded amphibolite. (B) Diorite traversed by quartzo-feldspathic vein, with conspicuous crystals of coarse garnet. (C) Exposure showing two garnitic dykes hosted by phyllites belonging to the mixed zone. (D) A lense of epidote (white) enclosed in the northern amphibolite outcrop.

wards north and west of Thelichi. Galena is present in Surmabat valley, 220 metres above the valley floor in a 46 metres long quartz vein. Other localities of galena-bearing quartz veins are in the Thelichi valley. Exploratory mining started at two of these points is now abandoned, but a geophysical survey and detailed study may reveal deeper extensions.

DISCUSSION AND CONCLUSIONS

According to the present work, the rocks exposed in the Thelichi area comprise a complex of dioritic rocks intrusive into an earlier metasedimentary sequence including two outcrops of paraamphibolite. From amongst the maps of

earlier authors (Fig. 2), the mapping of Desio (1964) is the nearest to our map (fig. 1). He shows two formations exposed in this area, the Twar Diorite (Cretaceous-Eocene) and Askore Amphibolite (Eocene) in addition to marble in both and a lensoid outcrop of tourmaline granite. According to Gattinger (1961), our area falls in the north-western part of the Alpine Himalayas, and is mainly made of crystalline gneiss which is the same and continuous with the Nanga Parbat gneiss. Towards west, he showed an outcrop of the Salkhala Series of Precambrian or Lower Palaeozoic age made of Schists, phyllites and marble.

The dioritic rocks of Thelichi area lack more basic types such as hypersthene diorites, norites or ultrabasics, throughout their observed part. Desio (1974, p. 350) describes similar diorites (amphibole quartz diorites with basic concentrations) from two areas of the Indus Valley: (i) between Bande Sazin and Kuma, (ii) between Herban and Shatial. At both these places, diorites are associated closely with norites and other ultrabasics of his "Middle Indus Noritic Group". In all other respects, the dioritic rocks of the area are comparable to the Middle Indus Noritic Group of Desio (1974) which is of Cretaceous-Eocene age. This group is the equivalent of the Epidiorites and Basic Intrusives (Wadia, 1933), Norites and Hypersthene Diorites (Misch, 1941), Twar Diorite (Desio, 1963) Upper Swat Hornblende Group (Martin et al. 1962) Gabbro-dioritic noritic complex of Hindu Raj (Desio, 1975) and Kohistan Basic Complex (Jan, 1970). The modal compositions of dioritic rocks show that they vary systematically in their mineral kind and proportion in the series: meladiorite-diorite-quartz diorite-tonalite-granodiorite. The garnetiferous diorites are also present. In addition to the probable magmatic differentiation process which produced the above series, the dioritic rocks were also involved in the sialic

assimilations. This is indicated by the presence of garnet diorite, the prevalence of quartz in all modal analyses, and by the fact that the only mineral is hornblende and there is no pyroxene. The available evidence suggests that the amphibolites of Thelichi area are para-amphibolites, derived mainly from calcareous pelitic sediments. The well-defined banding, association of marble bands, and gradational contacts of amphibolites with mica schists and phyllites, all point towards such an origin (Wilcox and Poldervaart, 1958; Walker et al., 1960; Heier, 1962). Some mica schists are also found as interbeds in these amphibolites. In addition, there are biotite rich bands with alternating amphibole bands. The mineralogical evidence also supports para-origin, as the rocks are made mainly of quartz and hornblende. There is no cummingtonite, and sphene and titaniferous minerals are rare.

Desio (1963, 1974, 1975) has shown this amphibolite as his "Askore Amphibolite" of Eocene age. He regarded it as a mesozonal metamorphic rock, equivalent to the Laspur Amphibolite of Chitral. According to Zanettin (1964) the source rocks for Askore amphibolite were probably the felsic intrusive rocks. But the amphibolites of Thelichi are different from those of Askore as shown above. Also, Thelichi amphibolites are part of a metasedimentary sequence that shows a variety of the lithological composition of original sediments effected by different grades of regional metamorphism.

The metamorphic degree exhibited by these rocks covers the greenschist facies, epidote-amphibolite facies and lower part of amphibolite facies belonging to high-pressure (Barrovian type ?) facies series. The greenschist facies rocks in the area are slates, phyllites and mica schists. The northern amphibolite outcrop contains abundant epidote and corresponds in metamorphic intensity to the epidote-amphibolite facies.

As regards the distribution of isogradic metamorphics in the area, relatively higher grades are found nearer the plutons. Probably they form part of the so-called "crinum-plutonic regional

metamorphic aureoles" (Zanettin, 1964, p. 164). This is also supported by the amphibolites becoming garnetiferous nearer the southern dioritic pluton.

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A CHROMIUM MUSCOVITE BEARING ZONED COMPLEX APLITE FROM HILL KHWAR, BATGRAM AREA HAZARA DIVISION, N.W.F.P., PAKISTAN

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Abstract: *A chromium muscovite bearing zoned complex aplite has been reported for the first time from the Batgram area of Hazara Division. The aplite, which occurs in the pelitic metamorphics close to the contact of the granite gneiss, shows two well developed zones i.e., an intermediate zone and a core. One chemical analysis, one spectrographic analysis and one modal analysis of each of the zones alongwith their normative composition is presented. One analysis of chromium muscovite is also presented. Both the zones contain chromium muscovite but the core is distinctly rich in this mineral. The intermediate zone contains 800 ppm and the core contains 1000 ppm chromium. The relative enrichment in chromium in such a body is attributed to contamination with the host metamorphics.*

INTRODUCTION

Only one such body has so far been found in the Batgram area. The area is composed of pelitic to psammitic schists and quartzites intruded by granites. The metamorphic rocks of the Mansehra and Batgram area have been discussed by Sabri (1965) and Shams (1967). The various facies of granites have been named and classified by Shams (1967) and Ashraf (1974a).

The aplite is located in the Hill Khwar at a distance of five miles ENE of Batgram which is connected by an all weather metalled road with Abbotabad, the headquarter of the Hazara Division.

The aplite is emplaced along a joint in the pelitic metamorphics near the contact with a granite gneiss, called the Susalgali granite gneiss.

APLITE

The aplite has two distinct zones namely intermediate and core. The intermediate zone has the assemblage microcline-albite-quartz-(green mica-biotite-sphene). Although not quite equigranular and uniform, it is never the less mainly sacchroidal and coarser aplitic. The zone is about 0.5 metre thick.

The core has the assemblage green mica-microcline - quartz - (albite - sphene - beryl - staurolite).

lite-biotite). The core is sheared and foliated. It is only 15 to 20mm thick. The two zones are described in the following :

The intermediate zone : It is mainly saccharoidal and coarser aplitic. Majority of the grains fall in 1 to 3.5 mm range.

Microcline (66.24%, Table-1) is the the main mineral. It occurs from anhedral to subhedral grains. The effects of shearing and crushing are pronounced along the grain boundaries. Along grain boundaries and along cracks myrmekites are conspicuously developed. Minor alteration to sericite and kaolinite is seen at places. Microcline is poorly perthitic and some grains show hardly any perthitic lamellae.

There is hardly any primary albite. It occurs either in myrmekitic growths or formed from them or formed by the same process that formed myrmekites.

Partial (syn or post myrmekitic) shearing/crushing seems to have separated quartz and albite of some of the myrmekitic growths.

TABLE 1

Modal Composition of Complex Zoned Aplite

	A-116'O' Intermediate Zone	A-116 'i' Core
Microcline	66.24	22.53
Albite (including myrmekitic Ab)	13.47	5.31
Quartz	16.25	18.51
Green Mica	2.57	46.23
Biotite	0.13	0.84
Sphene	0.34	4.00
Staurolite	0.00	0.15
Beryl	0.00	2.42
Apatite	1.02	0.00

Quartz (16.25%) is relatively finer grained. It mostly ranges from 0.1 to 0.4 mm but some grains are as big as 0.7 mm. The effects of shearing and crushing are most pronounced.

Green (chromium) mica (2.57%) is colourless in thin section. However, it appears slightly cloudy due to minor alteration to kaolinite. It is mostly flaky and appears elongated but tabular habit may also be seen. It clearly replaces microcline along cleavage and cracks. Its flakes are from 0.2 to 0.8 mm.

Biotite (0.13%) is brown to dark brown and distinctly pleochroic. Sphene (0.34%) is brownish red, slightly pleochroic and occurs scattered. It ranges in size from 0.1 to 1 mm in size. Apatite occurs as fine poikilitic grains.

The Core : It is foliated, showing pronounced effect of shearing. The foliation is well marked by abundant presence of green (chromium) mica (46.23 %, Table-1).

Green mica (46.23%) occurs as fine skeletal to needle like flakes as well as flakes and tabular crystals (0.2 to 1 mm). It clearly replaces K-feldspar and quartz. It shows minor alteration to kaolinite. It may enclose relics of K-feldspar and quartz.

Microcline (22.53%) occurs as subhedral to anhedral grains ranging from 0.1 to 2 mm. Crushing has also yielded finer grains. Crushing, cracking and alteration to sericite is common. Along cracks and grain boundaries myrmekitic growths can be seen. Finer bits of K-feldspar are almost completely replaced by myrmekite.

Quartz (18.51%) shows pronounced effects of shearing and crushing. Its grains mostly range in size from 0.1 to 0.3 mm although finer grains also occur.

The mode of occurrence of albite (5.31%) in the core is the same as in the intermediate zone.

Biotite (0.84%) occurs as small flakes from 0.1 to 0.3 mm. Beryl (2.42%) occurs as subhedral grains ranging in size from 0.1 to 0.15 mm. Staurolite (0.15%) occurs as tiny (0.03 mm.), subhedral and tapered elongate grains.

CHEMISTRY

One chemical analysis of each zone was carried out (of intermediate and core) according to routine classical methods (gravimetric) for SiO_2 and R_2O_3 . Fe_2O_3 and FeO were determined titrometrically, CaO and MgO by EDTA, TiO_2 and P_2O_5 by spectrophotometry and Na_2O and K_2O by flame-photometry. H_2O^+ was determined by penfield tube method. H_2O^- was determined at 110°C . The results are presented in Table-2. In Table-3 norms based on the chemical analyses of the two respective zones are given. The methods used for the calculation are after Johanssen (1939) and Holmes (1930).

A comparison of the two shows that the two zones are similar as regards their SiO_2 , Fe_2O_3 , FeO , MnO , and MgO contents. Significant differences can however be found as regards Al_2O_3 , CaO , Na_2O , K_2O and H_2O^+ .

The higher Al_2O_3 value of the core can be easily attributed to higher (46.23%, green mica and 0.84% biotite) content of mica. The intermediate zone contains 3.21% Na_2O while the core contains only 1.54% Na_2O . The higher value of soda in the intermediate zone is due to higher modal albite as well as due to total normative albite (Table-3).

TABLE 2

Chemical Analyses of the Complex Aplite and Green Mica

	A-116 'O' Intermediate zone	A-116 'i' Core	Green Mica
SiO_2	63.10	63.27	48.50
TiO_2	0.74	1.18	0.88
Al_2O_3	20.34	23.11	35.58
Cr_2O_3	n.d.	n.d.	0.02
Fe_2O_3	0.02	0.04	0.58
FeO	0.06	0.07	0.13
MnO	0.00	0.00	0.00
MgO	0.25	0.25	0.50
CaO	0.35	0.98	1.12
Na_2O	3.21	1.54	0.45
K_2O	10.26	8.79	10.70
P_2O_5	0.72	0.00	0.03
H_2O^+	0.80	1.24	1.20
H_2O^-	0.80	0.00	0.30
Total ..	99.93	100.47	99.99
			$\bar{F}=1.595$ $D=2.88$

n.d.—not determined.

The higher content of K_2O (10.26%) in the intermediate zone compared with the core (K_2O 8.79%) is due to a very high percentage of microcline. The absence of P_2O_5 from the core and its presence (0.72%) in the intermediate zone may be due to the presence of small apatite grains related to an earlier pegmatitic origin rather than a pneumatolytic process. The higher values of H_2O^+ and H_2O^- in the core are due to large quantities of mica.

Spectrographic analyses of the intermediate zone and the core are given in Table-4. The higher values of Cr in the aplite may be due to contamination with the metamorphics. The relatively higher values of Zr may be due to its substitution in feldspar and perhaps in sphene (for Ti) since zircon has not been found. Kempe and Deer (1970) have made similar observations. Ba (400 ppm) is usually high in younger igneous rocks derived through a process of fractional crystallisation (Goldschmidt, 1954). Rb (300 ppm) is due to its close geochemical association with K-feldspar.

CHROMIUM MICA

It has been adequately dealt with in the petrographic description of the aplite. One sample of this mica was purified by a combination of heavy liquid, electrostatic and magnetic separation methods. Its chemical analysis, mean refractive index and specific gravity are given in Table-2. It is like any low MgO , Fe_2O_3 and FeO bearing muscovite. It however contains 0.02% Cr_2O_3 .

PETROGENESIS

The zoned complex aplite was probably emplaced as a small lens shaped complex zoned pegmatite. It originally had at least two zones i.e. an intermediate zone and a core. A thin border and/or wall zone may have been present. If so it has been completely obliterated by later crushing

TABLE 3

Normative Composition

	A-116 'O' Intermediate zone	A-116 'i' Core
Ab	27.25	13.34
Or	61.16	49.25
An	0.00	5.00
Q	4.78	18.42
C	3.77	9.18
il	0.15	0.15
Hy	0.79	0.79
Ap	1.68	0.00
Hm	0.02	0.00

TABLE 4

Trace Elements (ppm)

	A-116 'O' Intermediate zone	A-116 'i' Core
Cr	800	1000
Zr	300	300
Cu	10	10
Y	10	15
V	10	130
Ga	10	10
Pb	30	10
Ba	400	400
Sr	45	45
Rb	300	300
Li	15	15

The intermediate zone had probably and essentially the same mineralogy as at present. But the core was composed of quartz-feldspar-mica and beryl.

After consolidation sodic solutions attacked the K-feldspar during which stresses seem to have been active. It resulted in the formation of myrmekites, which on further shearing partially expelled quartz.

The chemical composition and the trace element values clearly show that the pegmatite was derived from the granite (the adjacent granite gneiss) and not through metamorphic differentiation.

The pegmatite was sheared and crushed forming an aplite, now called the 'complex zoned aplite'. At this stage perthitic lamellae were squeezed out of the microcline and the exsolved material was deposited as a second generation of myrmekite at the margins and in the cracks of the K-feldspar.

After or during this stage the chromium muscovite developed. Its development and related theories are discussed in the following.

Leo et al. (1965) has discussed and described the occurrences of chromium muscovite in the metamorphic rocks (quartzite) in three possible ways.

(1) Cr is released by the destruction of detrital chromite during regional metamorphism of sandstones and combines with silica, alumina and alkalies available in the rock to form chromium muscovite.

(2) Cr is introduced into metamorphic rocks by the hydrothermal solutions that leached it from nearby mafic and ultramafic rocks and Cr replaces Al in preexisting ordinary muscovite.

(3) The chromium muscovite is entirely metasomatic in origin, being a component of hydrothermal quartz-ankerite-sulphide-gold deposits.

According to Heinrich (1965) chromium muscovites in quartzite of Montana are of regional metamorphic origin. The chromium muscovite aplite of Hill Khwar area was possibly deposited as successive episodes forming intermediate zone and the core. The process of deposition may have been related to the process of evolution of the acid minor bodies of the Mansehra Batgram areas of Hazara Division (Ashraf 1974) which are in time and space related to Hazara granitic complex (Shams, 1967).

The introduction of chromium in the core and intermediate zone shows that the origin of chromium muscovite may be due to two processes:

(i) The chromium was possibly leached by the aplitic liquids from the metamorphics (which contain some basic dykes) while passing through them.

(ii) After the emplacement of aplite i.e., forming intermediate zone and core the hydrothermal solution containing chromium derived from metasediments must have attacked both the zones particularly the core for the development of chromium muscovite.

The latter evidence is more convincing as mica is clearly replacing both quartz and microcline in the core and in some cases relicts have also been found of the two in mica flakes.

A study of the chemical analyses of the aplite shows that not only chromium but alumina must also have been added.

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ELECTRON PROBE COMPOSITION OF THE SPINEL PHASES FROM A LHERZOLITE NEAR BAR BANDAI, SWAT DISTRICT, PAKISTAN.

BY

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Abstract : *In the light of electron probe scanning photomicrographs, the textural and compositional features of the spinel phases and their surrounding silicates from an alpine type lherzolite body outcropping near Bar Bandai, Swat District, Pakistan, are discussed.*

INTRODUCTION :

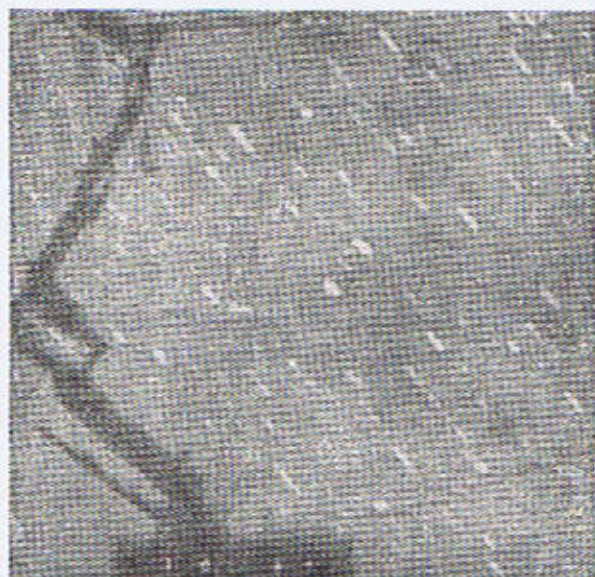
In an earlier work (Zulfiqar Ahmed and Shafeeq Ahmed, 1974) a spinel lherzolite occurring near Bar Bandai, Swat District, Pakistan, has been described. This rock conspicuously displays the minerals of spinel group ranging from chromehercynite to magnetite in composition. These minerals occur in three ways : (i) as anhedral magnetite inside serpentine veinlets, (ii) as minute, linearly oriented inclusions in pyroxene, and (iii) as euhedral to subhedral coarser grains with an outer thin rim of secondary magnetite. The present work is based on the electron probe scanning photomicrographs, and serves to illustrate the composition and distribution of six major elements (Si, Al, Fe, Cr, Mg, Ca) that compose these minerals and the enclosing silicates.

ELEMENTAL COMPOSITION

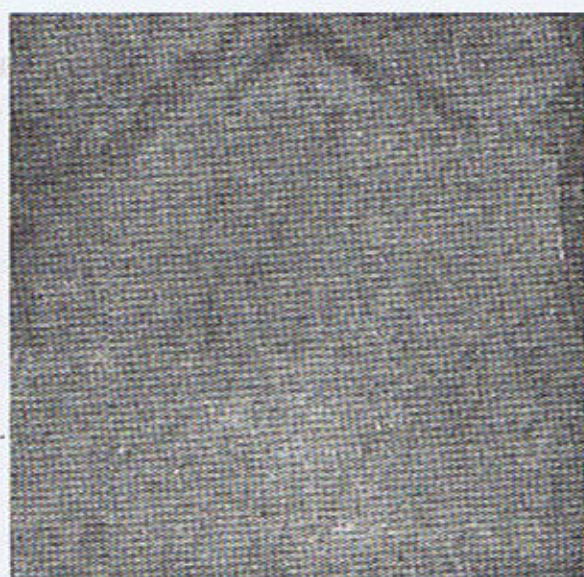
The electron probe scanning photomicrographs of minute spinel inclusions arranged in linear parallel rows inside pyroxene grains are shown in Fig. 1 A-G. These inclusions contain little Si and Ca. The host silicate (pyroxene) contains abundant Ca, Mg and Si, and smaller amounts of Fe and Al. The inclusions are made of two distinct exsolved phases with different reflectivities (Fig. 1A).

The phase with lower reflectivity is poorer in Fe and richer in Al and Cr as compared to the other phase with higher reflectivity. The pyroxene grains (excluding sites of inclusions) show homogeneous distribution of Ca, Mg, Fe and Si and heterogeneous distribution of Al.

Similar electron beam scanning pictures for the remaining two fashions of occurrence of the spinel minerals (Z. Ahmed & S. Ahmad, 1974) are given in fig. 2 A-G. The opaque ore inside the black serpentine veinlets (Fig. 2A) is magnetite and lacks Cr. The coarser oxide grain shown in the central part of the pictures consists of a 7 shaped low reflectivity grain (chromehercynite) and its high reflectivity alteration product located mainly on the upper side of this grain. Elemental distribution in these two phases shows that low reflectivity grain is richer in Al and poorer in iron compared to the high reflectivity grain. The composition of the former corresponds to chromehercynite and that of the latter to chrome magnetite. Both these minerals contain Cr but lack Si. The silicates surrounding these oxides are the olivine grains bounded and traversed by serpentine veinlets. Olivine is rich in Mg and contains enough iron but no Ca. The Mg-distribution of serpentine is similar



1 A



1 B



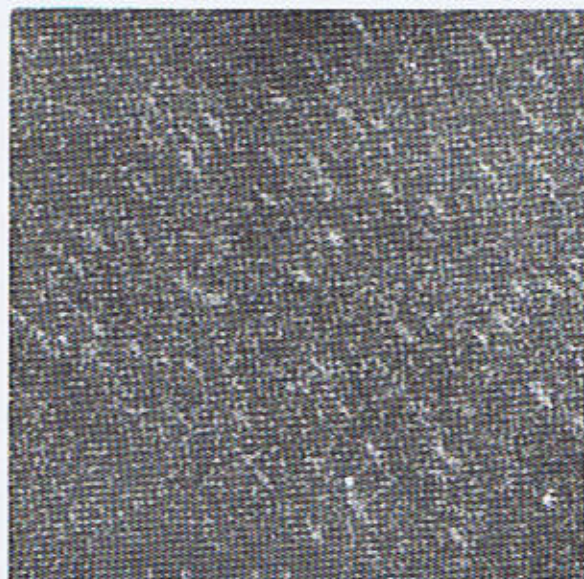
1 C



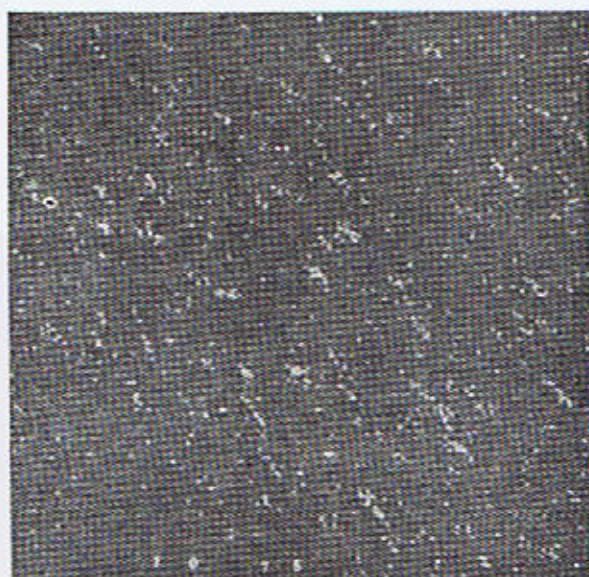
1 D



1 E



1 F



1 G

Fig. 1 A. Electron beam composition picture of a polished surface of spinel lherzolite showing two-phase spinel inclusions in pyroxene. ($\times 210$; 20KV).

Fig. 1 B-G. Showing the electron beam scanning photomicrographs for the distribution of SiK α , Al K α , Mg K α , CaK α , Fe K α and Cr k α , respectively. All represent the same area as shown in the composition picture in Fig. 1 A. All the pictures are X210 magnification images of polished samples of spinel lherzolite.



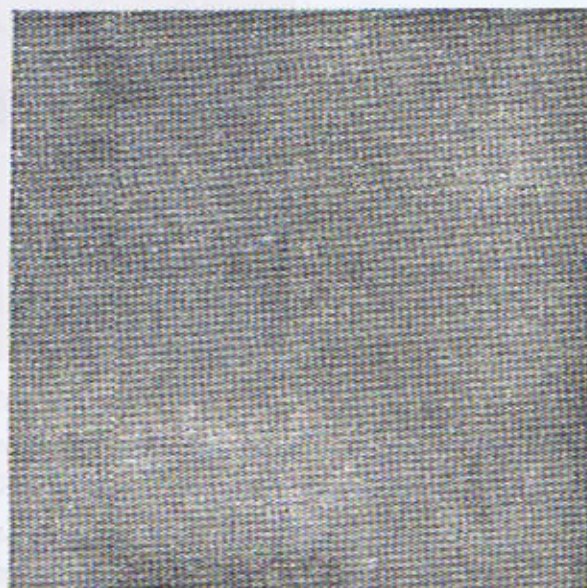
2 A



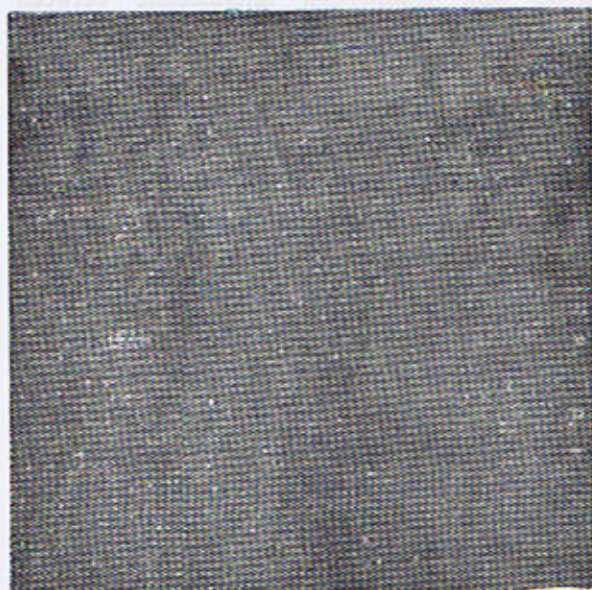
2 B



2 C



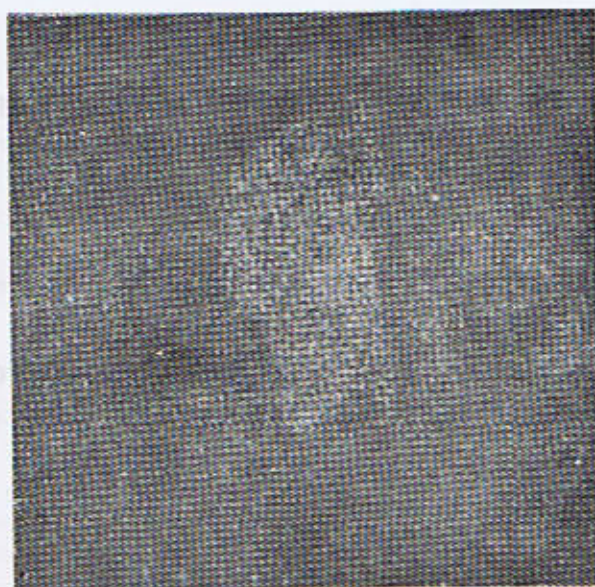
2 D



2 E



2 F



2 G

Fig. 2 A. Electron beam composition picture of a polished surface of spinel herzolite showing chromehercynite (c), chrome magnetite (b) serpentine (s) and olivine (o) phases. ($\times 210$; 20 KV).

Fig. 2 B—G. Showing the electron beam scanning photomicrographs for the distribution of Si K α , Al K α , Mg K α , Ca K α , Fe K α , and Cr K α , respectively. All represent the same area as shown in the composition picture of Fig. 2A. All the pictures are $\times 210$ magnification images of polished samples of spinel herzolite.

to that of olivine but serpentine contains very little iron and much aluminium, especially near the chrome hercynite grains. The olivine shows homogeneous distribution of Mg and Fe and has only traces of Al, Ca and Cr. The serpentine is homogeneously poor in iron.

CONCLUDING REMARKS

The photomicrographs show that in the rock under discussion primary exsolution produced two spinel phases, a chromehercynite (low reflectivity) and a "chrome magnetite" (high reflectivity). The latter type contains more iron, slightly less chromium than the former. Also, the chrome hercynite contains abundant aluminium, whereas chrome magnetite lacks it altogether. The latter type of

spinel with composition intermediate between chromite and magnetite is rarely reported from ultramafic complexes (Purvis, 1972). This spinel is not analogous to "ferritchromite" which has similar reflectivity, but formed by in situ hydrothermal alteration of chromite by increase in Fe and Cr and decrease in Al and Mg. Instead the chrome magnetite of fig. 2 G is slightly lower in Cr than the associated chromehercynite. The magnetite is spatially and genetically related to serpentinization in silicates, although partly it is formed by replacement of both the primary spinels described above. In the latter case the associated serpentine is richer in aluminium (fig. 2 C) and lacks iron which it gives to the magnetite (fig. 2 F).

ACKNOWLEDGEMENT

The author is indebted to Dr. W. Siegl of the Institut für Geologie, Montanuniversität, Leoben, Austria for assistance and guidance in taking the pictures with the electron probe microanalyzer at the Metallkunde Institut, Montanuniversität, Leoben, Austria.

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EFFECT OF GRAIN SIZE AND GROUNDMASS ON THE DETERMINATION OF MICROHARDNESS OF CHROMITE

BY

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Abstract : *Microhardness of 10 chromite grains of variable size and ground mass are presented and an attempt has been made to relate them to grain size and groundmass. Upto a certain grain size, microhardness increases with the increase in grain size, after which it does not show any significant variation. Also two curves relating grain size and groundmass for two chromite samples are given.*

EXPERIMENTAL

Chromite samples were cut to a slice of $2 \times 2 \times 0.5$ cm. The chromite pieces were mounted in N.H.P. metallurgical mounting plastic. These mounted, samples were first grinded on coarse carborundum powder of 220, 320 on steel laps, so as to remove the plastic layer from the sample surface. The samples were then grinded on 3F grade carborundum to have a smooth surface. Finally grinding was carried on carborundum of 600, 800 grades on glass plate for about fifteen minutes on each grade. The grinding material used was of Carborundum Company Ltd., Manchester, 7.

The ground samples were well washed, and dried. Final polishing was done on an aluminium paper, pasted on glass plate lap, using diamond compounds of 6, 2, 1, $\frac{1}{2}$ micron size. The instrument used for microhardness determination was G.K.N. microhardness tester using a load of 200 grams.

RESULTS AND DISCUSSIONS

Cameron (1961), described chromite to have a V.H.N. varying from 1195-1210. Whereas many workers such as Golding (1971), Hutchinson (1971), and Ahmad (1972), have observed that microhard-

ness of chromite varies from about 1200 to 1500 V.H.N. depending upon the variation in composition of chromite. However due to the present study it was observed that in addition to variation in chemical composition of chromite, there are some other factors as well, which also effect the microhardness determination. These are :—

- (i) Grain size
- (ii) Nature of groundmass.

It was observed that chromite grains, in massive chromite ore, with size less than 0.100 mm gave variable microhardness, depending upon the grain size. Similarly it was found that chromite grains in a groundmass of some carbonate mineral and grain size less than 0.150 mm gave variable microhardness depending upon the grain size. The values thus obtained in both the cases are given in Tables 1 and 2 are explained graphically in Figs. 1 and 2.

Table—1, gives values of V.H.N. of chromite grains present in a massive chromite ore, with grain size variation from 0.054 mm to 0.250 mm. Microhardness varies from 1027 to 1273 V.H.N. Fig. 1, shows that microhardness increases from 1027 to 1273 with increase in grain size and remains almost constant after 1273 V.H.N., and grain size 0.100 mm. This shows that the minimum grain

TABLE—1

Variation of microhardness of chromite grains with variation in grain size, in a massive chromite.

Grain size	Microhardness
0.054 mm	1027 V.H.N.
0.075 mm	1160 V.H.N.
0.095 mm	1240 V.H.N.
0.100 mm	1273 V.H.N.
0.200 mm	1280 V.H.N.
0.250 mm	1273 V.H.N.

TABLE—2

Variation of microhardness of chromite grains with variation in grain size, in a chromite with a groundmass of some carbonate mineral.

Grain size	Microhardness
0.045 mm	857 V.H.M.
0.095 mm	1040 V.H.N.
0.120 mm	1120 V.H.N.
0.150 mm	1211 V.H.N.
0.200 mm	1215 V.H.N.

size of chromite grain for exact determination of microhardness is 0.100mm, in a massive chromite. Table—1 shows that chromite grain of size 0.095 mm gives a value of 1240 V.H.N. Although this value lies within the range of chromite hardness, but this grain size is not suitable for accurate determination of microhardness as the previous observation shows that microhardness varies

upto a minimum grain size of 0.100 mm, afterwhich it remains constant. So in this case, it is recommended, that a chromite grain of 0.095 mm size can be used for identification purposes but for accurate determination of microhardness a grain size of 0.100 mm or higher than this should be used.

Table—2 gives values of microhardness of an-

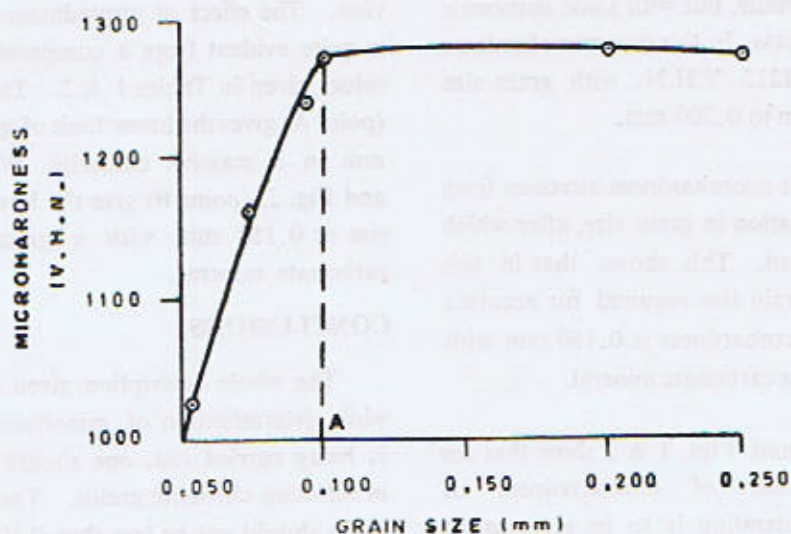


Fig. 1 Variation of Microhardness with Variation in Grain Size of a Massive Chromite.

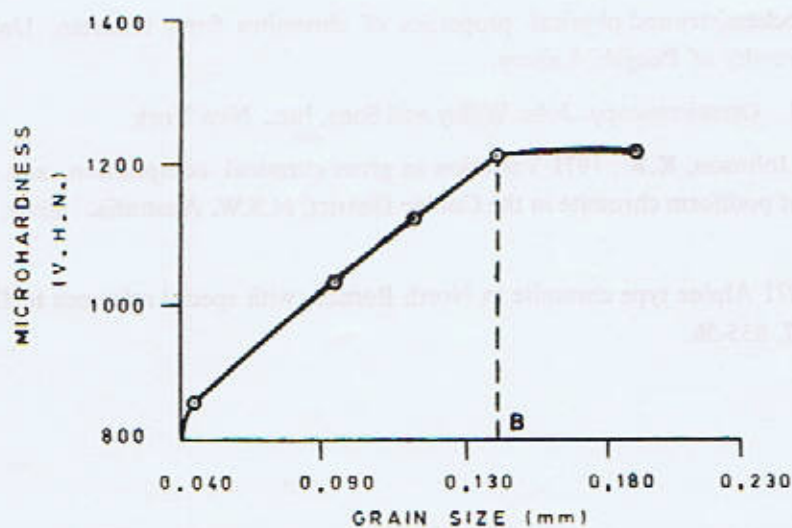


Fig. 2 Variation of Microhardness with Variation in Grain Size of a Chromite Sample with Ground Mass of Some Carbonate Mineral.

other sample of chromite, but with some carbonate mineral as a groundmass. In this case microhardness varies from 857 to 1215 V.H.N. with grain size variation of 0.045 mm to 0.200 mm.

Fig. 2 shows that microhardness increases from 857 to 1215 with variation in grain size, after which it remains unaffected. This shows that in this case the minimum grain size required for accurate determination of microhardness is 0.150 mm with a groundmass of some carbonate mineral.

Tables—1 & 2 and Figs. 1 & 2 show that for accurate determination of microhardness of chromite, due consideration is to be given to the grain size. While fixing the lower limit of grain size, the nature of groundmass is also to be kept in

view. The effect of groundmass on the grain size is quite evident from a comparative study of the values given in Tables 1 & 2. Table 1 and Fig. 1, (point A) gives the lower limit of grain size as 0.100 mm in a massive chromite. Whereas Table—2 and Fig. 2, (point B) give the lower limit of grain size as 0.150 mm with a groundmass of some carbonate mineral.

CONCLUSIONS

The whole description given above shows that while determination of microhardness of chromite is being carried out, one should be very careful in selecting chromite grains. The size of chromite grain should not be less than 0.100 mm in a massive chromite and 0.150 mm is a chromite with of some carbonate groundmass mineral.

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GEOLOGY AND MINERAL COMPOSITION OF VARIOUS LITHOLOGIC UNITS PRESENT IN THE KINGRIALI FORMATION OF THE SURGHAR RANGE

BY

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Abstract: *Kingriali Formation of Triassic age has seven lithologic units which can be distinctly recognized in the field on the basis of colour, porosity, and compaction of the rocks. The thickness of individual units varies from 8 to 42 metres. The thickest unit is massive, white to pink coloured and porous at places (sucrosic dolomite). The deposits were evaluated in the laboratory for their microscopic, chemical, differential thermal analysis (D.T.A.) and X-ray properties. The studies clearly indicate that most of the units are quite rich in dolomite mineral, (as MgO is 20 to 21% and CaO is 29 to 31%) with minor amount of kutnoharite and ferrian dolomite.*

ACKNOWLEDGEMENT

The author is thankful to Dr. S. S. H. Rizvi of Physical Research Division, PCSIR Laboratories, Karachi for carrying out X-ray studies of the dolomite samples. He is indebted to Mr. M. Hanif of Glass and Ceramics Division for his help in carrying out chemical analysis.

INTRODUCTION

The paper deals with the geological, mineralogical and chemical investigation of the dolomitic rocks occurring in the Kingriali (Dolomite) Formation of Triassic age (Fatmi, 1974) in the Western Salt Range and the Surghar Range (the Trans Indus continuation of the Salt Range). It is best developed in the latter range from Kuch near Kalabagh to the area beyond Makarwal. In the present study, area between Chichali and Chapri was investigated by Petrographic, Chemical, D.T.A. and X-ray methods to know the mineralogy of the dolomites.

Field work was carried out twice i.e., once in

1973 for reconnaissance survey and preliminary collection of the samples. Detailed sampling of the dolomites was done in April 1975.

The dolomite is one of the most useful raw material for making refractories both for ceramic and metallurgical industries. It is also used for making good quality sheet glasses (Ashraf 1972, Faruqi 1967).

GENERAL GEOLOGY

The Kingriali (Dolomitic) Formation of the Surghar Range contains about seven different lithologic units. This formation is fairly developed at most places in the Trans Indus Range. This formation extends from Kuch near Kalabagh to Mulla-khel near Makerwal in a 65 kilometre long belt. The dolomitic deposits have about 115 metres (maximum) thickness near Chapri though the general thickness varies between 65 to 98 metres (Khan and Gowher, 1966).

The approach to the area is by unmetalled road from Kalabagh. The area for the present studies was investigated between Chichali Nala in the north and Kutki in the south. The rock formations are well exposed throughout the area from Permian to Siwaliks. The main constituents of the formations are limestone, shale, loose to compact sandstone, dolomite, ironstone etc. The structure of the area is anticlinal and faulted.

Geology of Dolomites : The Kingriali Dolomite overlying the Tredian Formation of Middle Triassic age is well exposed at most places in the form of

different lithologic units which could be distinctly differentiated in the field, having variety of colours, degrees of compaction and hardness. The various colours of dolomite are light grey, grey, yellowish and pinkish. The compactness of the rocks also varies from one unit to another. The hardness varies from sample to sample and depends on the impurities present in the rock i.e., it is higher in rocks containing large amount of quartz.

Following is the lithologic description of the different units from top to bottom.

Approximate thickness	No.	Description
6 metres	MNK—1	Dolomite, thick bedded, yellowish grey to cream coloured.
12 metres	MNK—2	Dolomite, medium to thick bedded, soft and brittle alternating with porous pinkish grey and hard dolomite.
42 metres	MNK—3	Dolomite, very thick bedded to massive, porous at places white to pink coloured.
14 metres	MNK—4	Dolomite, with intercalations of sandstone and shales, greyish to creamish coloured.
8 metres	MNK—5	Dolomite, sandy medium to thick bedded with zones of shales, creamish, pink and grey coloured. Dolomite sandy medium to thick bedded, yellow, pink and grey.
15 metres	MNK—6	Dolomite, white to pink coloured having dense structure.
18 metres	MNK—7	Dolomite massive sandy greyish, pink and partly porous.

PETROGRAPHY

The dolomitic rocks are very fine to fine-grained having grain size in the range of 0.001 to 0.06 mm. Occasionally the grains coarsen upto 0.1 mm. The rocks (MNK-2, 3 & 6) are porous having pore size from 0.02 to 3 mm but in other rocks the pores are fine-enough to be resolved under ordinary polarizing microscope. The pores are semi-round to oval

shaped having dendritic shape. Distribution of quartz in the rocks is even whereas other minerals like limonite, haematite, siderite and clay material is quite erratic. Oolitic structure is present only in MNK-3 rock. The oolites are 0.1 to 3.0 mm in diameter.

Carbonate Minerals : Mostly the rocks consist of dolomite as is evident from chemical, X-ray

and D.T.A. studies. The dolomite grains are usually 0.001 to 0.015 mm in size but the grain size varies considerably from rock to rock. It is 0.004 to 0.008 mm in MNK-1, 0.003 to 0.015 mm in MNK-2, 0.002 to 0.008 mm in MNK-3, 0.002 to 0.004 mm in MNK-4, 0.004 to 0.006 mm in MNK-5, 0.001 to 0.002 mm in MNK-6, and 0.002 to 0.004 mm in MNK-7. Generally the grain size increases in porous rocks near the voids. They are usually subhedral in shape while grains near pores are euhedral.

Quartz : It is a minor constituent of most of the dolomite rocks, but exceptionally high amount is present in rock MNK-4. The quartz grains are evenly distributed throughout the rock. At places intergrowth of dolomite and quartz is present. The growth of both the minerals is possibly syngenetic while epigenetic grains are also present as quartz aggregates forming pods. The amount of quartz in this rock is about 40%. In all other rocks the amount of quartz varies from less than 1 to 5%.

Accessory Minerals : The accessory minerals present in the rocks are in the form of limonite, haematite, siderite and clay specks. These accessories occur as aggregate, specks and alteration product. Their grain size is usually coarser than carbonate minerals.

POROSITY AND FORMATION OF DOLOMITE FABRIC

According to Blatt et al. (1922) porosity may occur between the crystals of the mud and in some of the polycrystalline grains, that grow by replacement of a calcium carbonate sediment. If the volume of calcium carbonate rock is more than 57% CaCO_3 , then that volume will be able to provide sufficient calcium to produce solid dolomite crystals (Murray, 1960 and Weyl, 1960). Magnesium

is derived directly from the water and calcium is also derived from the water because dolomitization is a solution-precipitation reaction, in which 12 to 13% less volume will be created due to smaller molar volume of dolomite. The final product of such a process is a rock composed of dolomite rhombs largely separated by pore space that was created by the dissolution of limestone from beyond the limits of each dolomite rhomb. This is a sucrosic dolomite texture.

The sucrosic dolomite texture is persistently developed in the Kingriali dolomites. This texture is not developed in some of the zones which are rich in SiO_2 (quartz) or Al_2O_3 (clay minerals). The development of the sucrosic dolomite texture in the most cases shows that the development of the dolomite is a case history of replacement of original limestone layers as laid down by Blatt et al. (1972), or Murray (1960) and Weyl (1960) as briefly described above. The field evidences show that the Kingriali Dolomitic rocks show typical sucrosic texture due to the fact that large pore spaces are available alongwith dolomite rhombs.

These lithologic units of Kingriali Dolomites which are rich in quartz and clay mineral do not show typical sucrosic texture, there might be two reasons for that :

(i) Due to mild shearing the presence of excess amount of quartz might have occupied the pore spaces because quartz is very susceptible to stress and thus can occupy the available pore space.

(ii) The clay minerals due to their smaller particle size can also fill in the pores available in toto thereby making the rock dense and non-porous.

In a previous study on Hazara and Mardan dolomites Ashraf et al. (1972) found that they were non-sucrosic because the dolomites were found in a highly disturbed area (tectonically) and has a Cambrian age (Latif, 1974).

CHEMICAL COMPOSITION

Chemical analyses were carried out by standard gravimetric and rapid methods. Calcium and magnesium were determined by EDTA titration method, Fe_2O_3 and MnO by calorimeter, FeO by titration with $\text{K}_2\text{Cr}_2\text{O}_7$, SiO_2 and R_2O_3 were determined by gravimetric method.

The composition of dolomite is usually very close to $\text{Ca Mg}(\text{CO}_3)_2$, even then many dolomites contain small amounts of Fe^{+2} replacing Mg . Deer et al. (1962) restricted the term dolomite to material with $\text{Mg: Fe} > 4$ while Palache et al. (1951) extend the compositional range to $\text{Mg: Fe} = 1$.

From table—1 it is evident that all the samples

have FeO from 0.20 to 0.60% which might be replacing MgO . MnO is also present in the samples from 0.03 to 0.04% possibly also replacing MgO (Hurlburt, 1957). The presence of MnO could also be visualized due to some sort of pinkish colour of many samples. Hurlburt considers Fe , Mn substituting Mg so he thinks that Pb substitutes for Ca , but Pb has not been encountered in the present analyses.

The amount of CaO and MgO in the analyses carried out in most cases are less than the standard values. The deviation from the ideal composition is possibly due to some impurities in the form of quartz, clay and haematite.

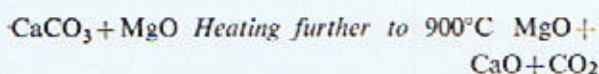
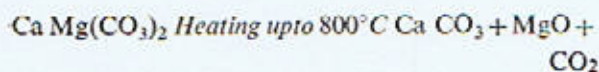
TABLE—1

Chemical Analysis

	MNK-1	MNK-2	MNK-3	MNK-4	MNK-5	MNK-6	MNK-7
SiO_2	4.82	0.70	0.43	0.50	46.30	0.50	0.70
Al_2O_3	3.17	1.25	1.05	0.95	1.75	1.85	3.35
Fe_2O_3	0.41	0.15	0.09	0.15	0.11	0.26	0.35
FeO	0.69	0.50	0.36	0.30	0.64	0.64	0.35
PbO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.04	0.04	0.03	0.03	0.04	0.03	0.03
MgO	17.47	21.10	20.61	21.78	10.82	20.60	21.10
CaO	29.20	30.50	31.73	29.60	16.26	30.39	29.22
L/I	44.60	46.20	46.68	46.92	24.48	46.42	45.00
Total :	100.40	100.44	100.98	100.23	100.40	100.69	100.10

DIFFERENTIAL THERMAL ANALYSIS

The D.T.A. of the dolomites shows two distinct endothermic reactions. The temperature at which both occur are slightly variable either due to the presence of some alkalis or due to finely ground material. Dolomites have been studied by D.T.A. by Beck (1950) showing endothermic reaction at 815° and 965°C. Cuthbert and Rowland (1947) found endotherms at 780° and 830°C; Kerr and Kulp (1948) studied endotherms at 760° and 940°C, 815°C and 965°C in two samples. Faust (1949), found endotherms at 792°C and 960°C. Anyhow from these two endothermic reactions it has become clear that the dissociation of dolomite takes place in two stages:



These reactions however, show the break down of dolomite at certain temperature giving rise periclase and CaCO_3 around 800°C and periclase and lime at higher temperature (around 900°C).

In the present studies it has been observed that first endothermic reaction is vigorous than the latter one. Sometimes second peak is slightly enlarged (as in sample MNK-4). Anyhow, in present studies the first endothermic reaction takes place at 750°, 740°, 765°, 780° and 758°C and the second endothermic peaks are found at 835°, 839°, 860°, 871°, 875° and 880° in the samples MNK-1, MNK-2, MNK-3, MNK-4, MNK-5, and MNK-6 respectively. The peak temperature, in some dolomite samples are lower than those in literature quoted. The anomaly may be due to finer grain size in the ground samples as compared to the earlier workers who have not given any indication about the size of the ground samples they have used.

X-RAY POWDER METHOD

X-ray powder patterns of the four samples MNK-2, MNK-4, MNK-5 and MNK-6 were taken with filtered Cu K α radiation using 19cm camera. The pattern of MNK-2, MNK-4, and MNK-6 are found to be identical and their powder data is given in a single column. The X-ray pattern of MNK-5 essentially compares with the above mentioned three samples yet it also shows some additional 'd' values.

From the X-ray data given in Table-2 it is clear that samples MNK-2, MNK-4 and MNK-6 are essentially dolomites with no variation of larger amount. It is, therefore, concluded that these samples are pure dolomites as their 'd' values are comparable with standard 'd' values of the ASTM (American Standard of Testing Materials) given in Table-2. The strongest 'd' values obtained in the three samples are 2.834/S, 1.988/M, 1.786/M and 1.769/M as compared with ASTM 2.886/100, 2.015/15, 1.786/30 and 1.781/30. Similarly the succeeding 'd' values are also mostly comparable.

The presence of ferrian dolomite and kutnoharite is also possible in small amount because some ferrous iron and manganese oxides are also present in these sample (Table-1). The possibility is evident as some 'd' values for ferrian dolomite and kutnoharite do overlap with normal dolomite near 2.02, 1.548, and 0.976 (ferrian dolomite), and 2.04, 1.294 and 0.976 (Kutnoharite).

CONCLUSIONS

(1) Geological and microscopic investigations of the Kingriali Formation show that seven distinct lithologic units essentially of dolomite exist.

(2) Chemical studies show that out of seven five are good dolomitic rocks having 20.60 to 21.78% MgO, 29.22 to 31.73% CaO, 0.09 to 0.26% Fe_2O_3 and 0.03 to 0.04% MnO.

TABLE—2

X-ray Diffraction Data of Dolomites.

MNK-2, 4 & 6		MNK-5	
d 'A'	I	d 'A'	I
2.834	S	4.24	MW
2.489	F	3.62	F
2.044	F	3.33	S
1.988	M	2.83	MS
1.786	M	2.68	F
1.554	F	2.49	F
1.452	W	2.44	F
1.434	F	2.39	F
1.419	F	2.28	F
1.340	W	2.20	WF
1.289	WF	2.12	F
1.261	F	2.00	W
1.230	WF	1.965	F
1.191	F	1.81	M
1.091	F	1.78	MW
1.005	WF	1.66	WF
0.971	F	1.535	M
0.959	W	1.46	F
0.945	VF	1.37	MW
0.928	VF	1.33	F
0.922	W	1.28	F
0.909	F	1.26	F
0.893	F	1.25	WF
0.860	WF	1.23	F
0.844	WF	1.22	F
0.835	WF	1.19	W
0.821	WF	1.175	W
		1.15	F
		1.1	F
		1.06	W

ASHRAF

(3) D.T.A. and X-ray studies show that the rocks consist essentially of dolomite and might be containing kutnoharite and ferrian dolomite on minor scale.

(4) The chemical, D.T.A. and X-ray studies reveal that five out of seven units can be explored economically for their uses in glass sheets, ceramic glasses, refractories and steel manufacture.

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A PETROGRAPHIC, CHEMICAL AND MINERALOGICAL STUDY OF CLAYS FROM THE HUB DAM AREA

BY

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Abstract : *Nine samples of one batch, which shows cracks and three samples of the second batch which does not show cracks, were studied petrographically, chemically and by X-ray and D.T.A. methods. It was found that the samples which show cracks contain predominantly hydromica and illite and higher amounts of soluble salts compared with the samples which do not show cracks. The latter in addition were found to contain smectite group clays in small but significant amounts along with small quantities of kaolin.*

INTRODUCTION

Two types of clays are found in the vicinity of Hub Dam. One type shows well developed cracks and the other type is without cracks. Both the groups were found to belong to non-plastic to poorly plastic varieties. Both of them showed low values of P.I. Differences of plasticities were therefore not considered contributing to the development of cracks. In view of this possibility chemical, petrographic and mineralogical causes were studied.

PETROGRAPHY

Nine samples of the batch which shows cracks and three samples of the batch which does not show cracks were studied petrographically. Their

mineral composition is given in Tables 1 and 2. The samples of the batch which contain cracks showed a heterogeneous texture and structure. The samples contained concretions, flocculated lumps, clots and silty powder. The concretions are calcareous. The samples of the batch which do not show cracks did not have clots or flocculated lumps. But calcareous concretions were present.

In all the samples studied, calcite occurs both as concretions as well as small subhedral grains. The concretions are from a few mm upto 2.5 cm. Quartz occurs as small subrounded to subangular grains.

Hydromuscovite and illite are the predominant clay minerals in all the samples. They mostly occur as slender, elongate extremely fine grains. They show high interference colour, often higher than muscovite. In addition in the batch which does not show cracks there appears to be significant amounts of smectite and some kaolin.

Alkali salts, mostly halite, are present in all the samples. But in the samples which show

cracks, their average amount is higher than the batch which does not show cracks.

Fine-grained organic matter is present in all the samples in accessory amounts. However, the two batches do not show significant difference in their organic contents.

Feldspar, magnetite, haematite, limonite, sphene, tourmaline, hornblende and epidote are the accessory minerals.

TABLE 1
(Shows cracks)

	Sp. 1	Sp. 2	Sp. 3	Sp. 4	Sp. 5	Sp. 6	Sp. 7	Sp. 8	Sp. 9
Calcite	20.00	23.00	28.30	15.00	20.00	12.60	25.50	20.00	22.50
Quartz	41.20	36.10	28.30	46.00	40.00	39.20	34.50	35.10	38.50
Clay	30.00	31.00	31.00	30.00	31.00	41.00	30.00	37.50	31.10
Alkali Salt	5.00	7.00	8.00	5.00	4.00	4.00	6.00	4.50	5.00
Chlorite	0.60	0.20	0.60	0.50	0.30	0.50	0.50	—	0.20
Limonite	0.35	0.50	0.50	0.30	0.50	0.40	0.50	0.40	0.50
Haematite	0.35	0.50	—	0.50	0.30	0.30	0.50	—	—
Amphibole	0.30	0.20	—	—	—	—	—	0.20	—
Organic matter	2.20	1.00	2.00	2.20	1.70	1.50	1.50	0.50	1.50
Tourmaline	—	0.20	—	—	—	—	—	—	—
Sphene	—	0.30	0.30	0.20	0.20	—	—	0.30	0.20
Feldspar	—	—	0.50	—	2.00	—	—	1.50	—
Epidote	—	—	0.50	—	—	0.20	0.50	—	0.20
Magnetite	—	—	—	0.30	—	0.30	0.50	—	0.30

TABLE 2

(Does not show cracks)

	Sp. 10	Sp. 11	Sp. 12
Calcite	15.00	22.00	19.20
Quartz	46.20	36.00	35.00
Clay	33.50	35.00	36.50
Alkali Salt	2.00	3.00	3.50
Chlorite	0.40	0.20	0.30
Limonite	—	0.30	0.50
Haematite	0.20	0.20	0.50
Magnetite	0.20	—	0.20
Amphibole	0.20	—	—
Organic matter	1.50	1.50	1.50
Tourmaline	—	0.30	0.20
Sphene	0.30	—	0.30
Shelly matter	0.50	—	—
Feldspar	—	1.50	2.00
Epidote	—	—	0.30

CHEMICAL ANALYSIS

The contents of SiO_2 , CaO and MgO were determined gravimetrically. The contents of Na_2O and K_2O were determined flamephotometrically. H_2O^+ was determined by the Penfield method. The contents of TiO_2 and Fe_2O_3 were determined colorimetrically. The contents of ferrous i.e. FeO was determined by titration. The contents of Al_2O_3 were determined by difference. Semi-quantitative determinations of chlorine were also made.

A comparison of the two batches shows the following differences on the basis of oxide composition :

Batch Showing Cracks

- (1) Na_2O content is fairly variable, the average Na_2O in the batch is higher.
- (2) Average K_2O is somewhat lower.
- (3) Average total alkali is higher.
- (4) Significantly higher in ferric iron.

- (5) CaO outside CaCO_3 is lower.
- (6) Sample has pH values from 6.0 to 6.5 (Acidic).
- (7) Average soluble alkali salts are higher, values reach upto 8%, varying from 4 to 8%.

Batch Without Cracks

- (1) Na_2O content is less variable, average Na_2O is lower.
- (2) Average K_2O is somewhat higher.
- (3) Average total alkali is lower.
- (4) Significantly higher in ferrous iron.
- (5) CaO outside CaCO_3 is higher.
- (6) Sample has pH of 6.0 (acidic).
- (7) Average alkali salts (soluble) lower; 2 to 3.5% range.

For other variations Tables 3 and 4 may be consulted.

MINERALOGY OF THE CALCAREOUS CLAYS

X-ray photographs of eleven samples provided in two lots of eight and three were obtained from their powder mounts. The equipment used was a 19 cm camera. The radiation was Ni filtered $\text{CuK}\alpha$ with a voltage of 40 KV and current of 21 mA.

Measurements were made, intensities estimated and 'd' spacings in Angstrom (\AA) units calculated for virtually all lines in the photographs. The minerals present were identified by comparison with 'd' values in the ASTM file (1963).

The 'd' values (Table 5) were compared with the ASTM cards and it was found that in the samples provided, there are four major phases; they are of quartz, calcite, illite and hydromica, and in a few cases a little amount of some mineral related to montmorillonite or smectite group is found.

The presence of quartz is shown by the 'd' spacings at 4.24, 3.34, 2.42, 2.12, 1.96, 1.81, 1.53, 1.37, 1.26, 1.18, 1.08, 1.03, 1.91, 0.98, 0.96, with minor variation at first and second place of decimal. Due to strong values obtained at different places which of course overlap with the clay minerals it is obvious that quartz is one of the major minerals.

The 'd' values at 3.07, 3.0, 2.46, 2.29, 2.13, 2.09, 1.91, 1.87, 1.6, 1.51, 1.42, 1.18, 1.15, 1.04, 0.97, 0.96 with minor variations at first and second place of decimal are for calcite. The 'd' spacings for calcite do not occur necessarily with other minerals and essentially account for moderate-strong, moderate, moderate-weak, weak etc. These intensities of lines show that considerable amount of calcite is present (which may be about 20 to 30% in different samples).

The comparison of 'd' values shows that illite is dominant clay group present in the samples, for the 'd' spacings obtained at 4.24, 3.66, 3.34, 2.58, 2.42, 2.28, 2.22, 2.12, 1.96, and 1.66. The results are in agreement with the petrographic examination. It is found in the thin sections that in most cases the distinct presence is that of hydromica. This mica is polymorphic form of illite and is therefore, included in illite group. This thing has very well been elaborated by Grim (1968, p. 98) that it is conceivable that all gradations can exist between illite and well crystallized, muscovite and biotite on one hand and smectite on the other hand. As a consequence of smaller substitution the silica-to-alumina molecular ratio of the illites is higher than that of well crystallized micas, and net unbalanced charge deficiency is reduced from 2 per unit cell to about 1.3 per unit cell. The potassium ions between the unit layers may be partially replaced by other cations, possibly Ca^{++} , Mg^{++} , H^+ . There is some randomness in the stacking of the layers in the 'C' direction, and the size of the illite particles occurring naturally is very small, of the order of 1 to 2 microns or less.

TABLE 3

Chemical Analysis

	Sp. 1	Sp. 2	Sp. 3	Sp. 4	Sp. 5	Sp. 6	Sp. 7	Sp. 8	Sp. 9
SiO ₂	51.03	48.05	43.58	59.83	55.83	65.94	50.16	50.76	50.68
TiO ₂	0.16	0.16	0.12	0.17	0.21	0.19	0.31	0.09	0.22
Al ₂ O ₃	12.47	11.18	10.94	11.39	11.43	14.37	12.91	15.55	13.19
Fe ₂ O ₃	1.20	1.29	1.47	1.48	1.02	1.26	0.88	1.88	0.82
FeO	0.13	0.13	0.12	0.08	0.11	0.13	0.09	0.11	0.07
MgO	1.75	1.92	1.75	2.03	1.94	1.75	2.06	1.80	1.90
CaO	12.46	13.83	14.10	7.47	11.71	3.40	12.50	10.77	12.95
MnO	0.21	0.10	0.09	0.28	0.17	0.18	0.18	0.15	0.13
Na ₂ O	2.10	3.50	4.70	2.15	1.85	2.00	2.45	1.70	2.15
K ₂ O	1.40	1.40	1.40	2.01	1.60	2.20	1.80	1.30	2.00
H ₂ O ⁻	3.02	2.88	3.47	3.14	2.22	2.42	1.91	2.87	2.27
H ₂ O ⁺	2.83	2.59	2.39	1.71	1.33	2.17	2.60	3.07	2.09
CO ₂	10.04	10.07	12.19	6.08	9.18	2.62	10.08	9.30	9.88
TOTAL*	98.80	97.10	96.32	97.82	98.60	98.63	97.93	99.35	98.35
PH	6.0	6.5	6.5	6.5	6.0	6.5	6.5	6.5	6.0

*The balance is mostly chloride ion (chlorine).

The presence of hydromica as shown and when compared with ASTM file overlaps with illite at 3.66, 3.34, 2.58, 2.12 and 1.96 but may be found independently or overlapping with some other lines of certain minerals. The independent lines are at 3.18, 2.28, 1.53, 1.37, 1.28 and 1.26.

In the case of three samples namely Sp. 10, Sp. 11 and Sp. 12 'd' lines are essentially the same with major occurrence of quartz, calcite and illite + hydromica, but instead there is possibility of presence of smectite minerals, which have been confirmed by D.T.A. curves.

TABLE 4
Chemical Analysis

	Sp. 10	Sp. 11	Sp. 12
SiO ₂	66.05	53.27	57.48
TiO ₂	0.10	0.14	0.18
Al ₂ O ₃	12.18	10.44	9.30
Fe ₂ O ₃	0.68	0.52	0.42
FeO	1.36	1.65	1.79
MgO	2.65	3.90	1.92
CaO	6.63	11.13	12.55
MnO	0.18	0.20	0.16
Na ₂ O	1.25	2.00	1.95
K ₂ O	2.60	2.47	2.20
H ₂ O ⁺	1.19	2.50	1.92
H ₂ O ⁻	0.23	0.23	0.26
CO ₂	4.14	9.37	7.98
TOTAL*	99.24	97.82	98.11
pH	6.0	6.0	6.0

*The balance is mostly chloride ion (chlorine).

D.T.A. studies carried out on eleven samples indicate the presence of calcite in all the samples except three which have been just mentioned above. In the samples studied due to vigorous endothermic reaction around 807-88°C the presence of calcite is confirmed while due to overlapping reaction between quartz and illite group perhaps there is no net result. In the case of three samples there is

definite endothermic reaction at around 600°, 680° and 780°C. The first reaction at 600°C might be due to the presence of nontronite (a smectite mineral). According to Grim (1968) most dioctahedral smectites with relatively small amount of iron and magnesium replacing aluminium show an endothermic reaction due to loss of OH lattice water with a peak temperature at about 700°C.

X-ray Diffraction Data

Sp. 1		Sp. 2		Sp. 3		Sp. 4		Sp. 5		Sp. 6		Sp. 8	
I	'd'	I	'd'	I	'd'	I	'd'	I	'd'	I	'd'	I	'd'
F	4.4	MW	4.26	WF	4.2	WF	4.4	MW	4.25	W	4.2	WF	4.2
W	4.2	S	3.33	S	3.3	WF	4.2	F	3.9	WF	3.65	W	4.42
F	3.7	MS	3.05	M	2.9	MS	3.41	S	3.33	F	3.5	S	3.28
F	3.6	VF	2.9	WF	2.41	MS	3.28	F	3.2	S	3.3	M	2.98
W	3.4	F	2.58	M	2.28	F	3.08	MS	3.07	WF	3.16	F	2.55
S	3.3	W	2.44	WF	2.1	W	2.98	VF	2.9	W	3.0	WF	2.42
WF	3.18	M	2.28	VWF	1.95	W	2.42	WF	2.58	F	2.8	MW	2.26
F	3.1	F	2.24	W	1.89	W	2.27	W	2.46	WF	2.54	F	2.11
M	3.08	WF	2.12	W	1.86	F	2.21	MW	2.29	W	2.44	WF	2.08
WF	2.53	WF	2.08	M	1.8	WF	2.11	W	2.13	F	2.37	WF	1.95
W	2.44	WF	1.97	F	1.65	F	1.96	F	2.09	MW	2.28	W	1.89
MW	2.28	W	1.89	WF	1.6	MS	1.8	F	1.99	F	2.22	W	1.86
F	2.22	W	1.86	W	1.54	F	1.66	W	1.91	MW	2.11	M	1.80
W	2.11	M	1.81	S	1.37	WF	1.58	W	1.87	W	1.98	W	1.65
W	2.09	W	1.74	WF	1.28	MS	1.53	M	1.82	F	1.90	W	1.58
F	1.95	W	1.66	WF	1.25	F	1.39	W	1.67	F	1.86	M	1.54
W	1.88	F	1.59	WF	1.22	F	1.44	W	1.6	MS	1.81	MF	1.5
W	1.86	M	1.54	MW	1.19	MS	1.37	MW	1.54	F	1.76	F	1.42
MW	1.8	F	1.50	M	1.17	MS	1.36	F	1.51	MW	1.65	S	1.37
W	1.65	VF	1.46	MW	1.15	WF	1.28	F	1.45	MS	1.54	W	1.28
WF	1.59	S	1.37	MW	1.08	W	1.25	F	1.42	F	1.59		
MW	1.54	VF	1.28	MW	1.05	F	1.22	MS	1.37	W	1.45	W	1.25
F	1.50	VF	1.25	F	1.028	M	1.19	VS	1.34	F	1.41	WF	1.22
F	1.45	VF	1.20	MF	1.01	M	1.75	W	1.28	S	1.375	MW	1.19
F	1.44	MW	1.19	WF	.999	MW	1.15	W	1.25	W	1.28	M	1.17
F	1.41	M	1.17	WF	0.975	MW	1.09	W	1.22	W	1.25	MW	1.15
S	1.37	W	1.15	WF	0.96	F	1.04	MW	1.19	F	1.22	MW	1.18
W	1.28	F	1.14	WF	0.915	F	1.93	MV	1.18	M	1.18	MW	1.045
W	1.25	W	1.08	WF	0.899	F	1.01	W	1.15	M	1.16	W	1.035
W	1.22	F	1.06	W	0.831	W	0.986	W	1.08	W	1.15	WF	1.012
WF	1.18	MW	1.045	W	0.828	WF	0.975	MW	1.044	M	1.08	F	0.989
MW	1.17			MW	0.794	W	0.959	MF	1.034	MW	1.045	F	0.975
W	1.15	WF	1.035	W	0.791	M	0.912	F	1.01	MW	1.038	MW	0.96
W	1.075	F	1.01					WF	0.988	W	1.01	F	0.945
F	1.06	WF	0.988					F	0.975	M	0.99	MW	0.915
W	1.04	WF	0.975					MW	0.96	MW	0.955	WF	0.898
W	1.03	W	0.96					M	0.915	W	0.912	F	0.89
W	1.01	MW	0.914					W	0.899			F	0.85
W	0.984	WF	0.899					W	0.888			F	0.831
F	0.073	WF	0.888									F	0.828
W	0.958											F	0.813
F	0.94											F	0.811
MW	0.812												
W	0.835												
W	0.888												
F	0.875												

TABLE 5 (Contd.)

Sp. 9		Sp. 10		Sp. 11	Sp. 12
I	'd'	I	'd'	'd'	'd'
MF	4.2	MW	4.24	4.24	4.24
S	3.3	F	3.66	3.66	3.66
M	2.9	S	3.34	3.34	3.34
WF	2.45	F	3.18	3.18	3.18
M	2.28	MW	2.99	2.99	2.99
W	2.12	F	2.58	2.58	2.58
W	2.09	W	2.42	2.42	2.42
WF	1.95	W	2.28	2.28	2.28
WF	1.90	F	2.22	2.22	2.22
WF	1.87	W	2.12	2.12	2.12
M	1.80	F	2.07	2.07	2.07
WF	1.75	W	1.96	1.96	1.96
WF	1.65	F	1.89	1.89	1.89
WF	1.6	F	1.86	1.86	1.86
M	1.54	MS	1.81	1.81	1.81
S	1.37	W	1.66	1.66	1.66
WF	1.28	F	1.60	1.60	1.60
WF	1.25	M	1.53	1.53	1.53
WF	1.23	F	1.45	1.45	1.45
MV	1.155	F	1.41	1.41	1.41
WF	1.106	MS	1.37	1.37	1.37
WF	1.05	F	1.28	1.28	1.28
WF	0.01	W	1.26	1.26	1.26
WF	0.999	WF	1.22	1.22	1.22
WF	0.975	MW	1.18	1.18	1.18
WF	0.96	MW	1.17	1.17	1.17
WF	0.915	W	1.15	1.15	1.15
		MW	1.08	1.08	1.08
		F	1.064	1.064	1.064
		W	1.042	1.042	1.042
		MF	1.032	1.032	1.032
		F	1.01	1.01	1.01
		W	0.98	0.98	0.98
		F	0.978	0.978	0.978
		W	0.96	0.96	0.96
		MW	0.916	0.916	0.916
		W	0.899	0.899	0.899
		F	0.890	0.890	0.890
		F	0.880	0.880	0.880

From the X-ray and D.T.A. investigations and petrographic studies it is obvious that the samples are highly complex in nature due to intimate mixture of clay minerals. The complexity of clay minerals is due to various polymorphic and transitional forms of illite which possibly occur together compositely and thus do not render net result of certain form. Illite and hydromica appear to occur together. In the three samples the D.T.A. investigations reveal that in addition to illite and hydromica some minerals of a smectite (of montmorillonite type) occur too, as a rather minor constituent in the form of nontronite, and Mg-Fe smectites.

The X-ray report (Table 5) has also been carefully studied. This has confirmed the results on the nature of clay minerals presented earlier. The second batch (which does not show cracking) shows a mixture of smectite and illite. There is Mg-Fe smectites and nontronite. Non-carbonate calcium in the chemical analysis of the second batch suggests fixation of Ca in clay. The results of petrographic and mineralogical studies match very well. However, the petrographic studies indicate some kaolin in the 2nd batch which

does not show cracking.

CONCLUSIONS

1. The results of the detailed petrographic, chemical and X-ray analyses match well as regards the presence and relative amounts of various clay and other minerals.
2. The above detailed analysis has revealed that in the samples where no cracks have developed, small but significant amount of Mg-Fe smectites together with small percentage of nontronite (montmorillonite group) and kaolin are present.
3. The chemical analysis has revealed the presence of higher percentages of soluble salts comprising of mostly sodium chloride, in the samples which give rise to cracks. However the second batch of samples, where no cracks have been observed, show low percentages of soluble salts.
4. The presence of higher percentages of sodium soluble salts, being effected by rain, moisture and variation in temperature, may have contributed in developing the cracks.

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PETROLOGY OF THE ENVELOPE ROCKS OF THE MELDON APLITE IN THE GRANULITE QUARRIES, DEVONSHIRE, ENGLAND.

BY

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Abstract: *A detailed petrographic and a brief chemical account of the envelope rocks of the Meldon aplite, Devonshire is presented in the following. Fifty two modal analyses and eighteen chemical analyses of the clonctact hornfelses/skarns are presented. They have formed by the metamorphism, metasomatism of a metadolerite at contact with an aplite dyke called the Meldon aplite. The skarn formation involves addition of calcium, manganese, boron, ferrous iron and carbon and depletion in silicon, aluminium, titanium, sodium, ferric iron, magnesium, phosphorous and sulphur. In addition a brief petrographic account of the associated calc-flintas and argillaceous, rocks is being presented. Petrogeneses of the rocks is briefly discussed.*

INTRODUCTION

The Meldon aplite, near Okehampton, is a sodium and lithium-rich aplite dyke about 60 to 80 feet in thickness, which occurs three quarters of a mile northwest of the main Dartmoor granite (Worth, 1920). In the Meldon aplite quarries (commonly known as the granulite quarries) south of the main Railway Quarries, it forms contact skarns with a meta-dolerite dyke and calcareous shales to the south, with calcflintas (meta-sedimentary rocks with alternating calcareous and siliceous bands) to the northeast and with the calcareous shales to the northwest. Albite, quartz, lepidolite and orthoclase are the essential minerals and elbaite, topaz, fluorite, apatite and petalite are the accessory minerals of the aplite. The skarn formation in calcareous shales and calc-flintas is very poor and may even be absent at places. The maximum development, both in extent and in variety of mineral assemblage, is taking place in the metadolerite dyke. This paper deals mainly with these skarns. The skarn formation starts

at contact and along joint faces and works its way outwards. The skarns range from a few inches to about 6 feet in maximum thickness.

THE PETROGRAPHY OF THE ENVELOPE ROCKS

The envelope rocks belong to the following three petrographic types.

- (1) The dark igneous series.
- (2) The calc-flintas (the calcareous shale group rocks).
- (3) The shaly quartzites (intercalations).

The calc-flintas are exposed in the northeastern "granulite quarry". The 'dark igneous series' lie at the southern contact of the aplite intrusion in the southwestern "granulite quarry". These rocks have been reconstituted, to varying degrees, by the metamorphic-metasomatic processes connected with the intrusion of the Meldon aplite and the Dartmoor Granite. The 'dark igneous series' have been reconstituted to a far greater extent and to far

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greater mineralogical and petrographical diversity than the other two types. They will be considered in detail, followed by brief descriptions of the other two types.

The descriptions which follow are restricted entirely to the rocks within and immediately adjacent to the metamorphic-metasomatic aureole of the Meldon aplite. Detailed petrography and classification of the rocks, of which these rocks form a constituent part has been given by (R.N.) Worth (1895), (R.H.) Worth (1920), McMahon (1894) and Mennell (1916, 17).

THE DARK IGNEOUS SERIES

This unit occurs as a dyke to the south of the southwestern "granulite quarry". Before dealing with the appreciably reconstituted parts of this rock, a brief petrographic description of this dyke at the outermost margin of the metamorphic-metasomatic aureole of the aplite will be given. Here it occurs as a compact medium grained, buff or brownish black rock. Plagioclase is the chief mineral of this rock (fig. 1). It occurs as medium to coarse laths which are heavily sericitised and kaolinised. Petrographic methods indicate a composition ranging from oligoclase to andesine.

The second most important mineral is a light green and poorly pleochroic amphibole. It occurs as short columnar crystals, often intergrowing with and occasionally enclosed by the plagioclase, (fig. 2). Sphene is an important accessory mineral, which may in some cases constitute up to 10% of the whole rock, (fig. 3). Sphene rich zones occur just outside the metamorphic aureoles (fig. 4). Dark brown colour of some rocks is due to the abundant development of sphene. Occasionally sphene as well as amphibole segregate into small brown and light green patches respectively. Besides these three minerals, small amounts of quartz, chlorite,

calcite, pyrrhotite and epidote may also occur. This rock bears a superficial resemblance to a slightly altered dolerite, but it differs in the following two important points.

- (1) It has a higher proportion of light coloured to dark coloured minerals.
- (2) It contains a much higher proportion of sphene.

The reconstitution of this rock is strongly allochemical in nature. As a consequence, the resultant mineral assemblages can not be classified into the standard equilibrium assemblages, since they apply only to the dominantly isochemical reactions. In view of this difficulty those minerals which are sensitive to the changes in temperature will be used for a general classification. These minerals are chlorite, amphibole and pyroxene.

The skarns, due to their high content of pyrrhotite and characteristic garnet-pyroxene mineral pair form a distinct class. Outside the skarns, depending upon the exclusive presence or dominance of one of the three minerals, chlorite, amphibole and pyroxene, the rocks are divided into the following three classes.

- (1) Pyroxene-axinite-hornfels.
- (2) Amphibole-axinite-hornfels.
- (3) Chlorite-axinite-hornfels.

These classes have been arranged in order of their decreasing temperatures of formation. The term 'hornfels' is used here exclusively to indicate thermal rather than dynamothermal changes. Each of these classes will be discussed in the following. These classes form very irregular lithologic units varying widely in their thickness from place to place. All the units are very heterogeneous both in their quantitative mineral compositions as well as their textures. Not all the above classes may be present in a given cross-section.

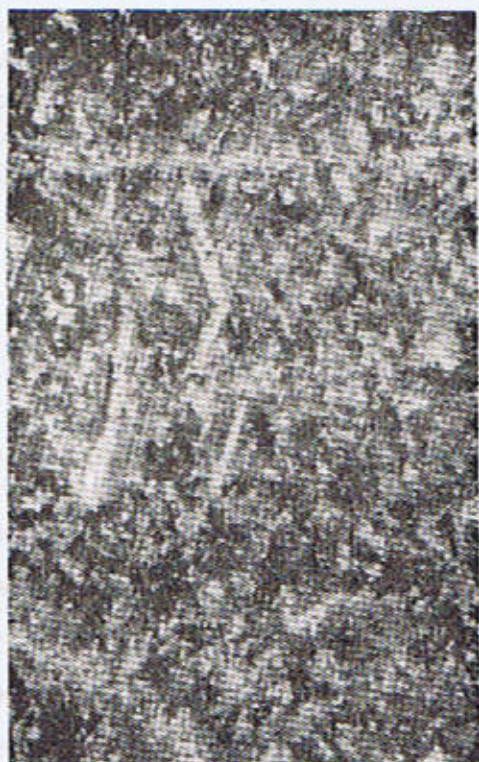


Fig. 1



Fig. 2



Fig. 3



Fig. 4

Figs. 1 and 2. 'The dark igneous series' consisting of altered plagioclase, sphene and amphibole. (X 26, x.p.).

Fig. 3. Sphene rich 'dark igneous series'. Dark high relief grains are sphene. (X 26, p.p.l.).

Fig. 4. Sphene rich zone just in front of the reconstituted 'dark igneous series'. (X 26, p.p.l.).

THE SKARNS

Nineteen modal analyses of the skarns, as well as the 'pyroxene-axinite-hornfelses', have been grouped together in table 1. The analyses have been arranged according to the decreasing amount of pyroxene. This grouping has been

done, because the two groups, as can be seen from table 1, can not be clearly distinguished. Even those rocks in this table which do not contain pyrrhotite in the thin sections analysed, in fact contain it in parts of the hand specimens. The term 'skarn' is used here for the ore bearing high grade metamorphic-metasomatic rocks.

TABLE I
Skarns and the Pyroxene-Axinite-Hornfelses

	Pyroxene	Garnet	Pyrrhotite	Axinite	Sphene
M64	59.00	2.92	6.31	24.92	1.08
M28	58.78	37.62	1.66	0.76	0.00
M123	55.02	34.07	0.00	10.72	0.19
M7	52.95	3.51	43.16	0.38	0.00
M98	52.20	42.36	0.00	4.66	0.39
M94	50.90	6.68	0.00	41.34	1.08
M25	50.28	0.00	48.86	0.30	0.00
MN35	50.06	0.00	0.00	23.34	2.00
M29	40.97	45.69	0.00	12.01	0.00
M96	37.49	44.82	4.72	11.48	1.49
M95	37.05	48.09	0.00	13.15	1.35
M24	32.63	47.80	6.69	1.55	0.00
M26	26.97	0.00	65.51	0.00	0.99
M113	23.00	1.31	53.80	8.85	0.00
M22	14.02	26.35	0.00	58.13	1.03
MN36	11.73	18.07	0.00	66.36	2.65
M29	1.66	14.43	6.46	54.08	0.76
MN110B	1.54	65.66	6.43	23.09	0.40
MN110A	0.69	61.05	0.00	35.03	1.11

TABLE 1 (Contd.)

Skarns and the Pyroxene-Axinite-Hornfelses

	Chlorite	Amphibole	Quartz	Calcite
M64	0.69	0.00	5.08	0.00
M28	0.33	0.00	0.85	0.00
M123	0.00	0.00	0.00	0.00
M7	0.00	0.00	0.00	0.00
M98	0.00	0.00	0.00	0.39
M94	0.00	0.00	0.00	0.00
M25	0.56	0.00	0.00	0.00
MN35	0.46	6.01	18.13	0.00
M.29	0.00	0.00	0.00	1.33
M96	0.00	0.00	0.00	0.00
M95	0.00	0.00	0.00	0.00
M24	0.00	0.00	11.33	0.00
M26	0.43	0.00	6.10	0.00
M113	1.05	0.00	11.99	0.00
M22	0.00	0.00	0.00	0.47
MN36	0.00	0.36	0.00	0.83
M29	0.00	15.72	2.28	4.61
MN110B	2.88	0.00	0.00	0.00
MN110A	1.43	0.00	0.69	0.00

The skarns show a very irregular development both in their thickness and their lateral continuity. At some places they may even be absent altogether. They are coarse and uneven textured compact rocks, varying in colour from buff to tan. However, in some places, due to the abundant

development of pyrrhotite, they assume a tarnished bronze colour. The following assemblages have been found in these skarns.

- (1) Pyrrhotite-garnet-hedenbergite.

- (2) Pyrrhotite-(garnet)-diopside-axinite-(sphene)
- (3) Pyrrhotite-garnet-diopside-(axinite-sphene)
- (4) (Pyrrhotite)-diopside-(amphibole)-axinite.

The minerals given within brackets are either of lesser quantitative importance or non-essential. The first assemblage is the highest temperature skarn. The second is derived from the third by extensive replacement of this assemblage by axinite. The fourth assemblage represents a transition between the skarn and the non-skarn lower temperature rocks and represents the lowest temperature assemblage.

The pyroxene is generally diopside, however at places near the immediate contact hedenbergite may also occur. The hedenbergite is very light green and non-pleochroic. It generally occurs as aggregates of subhedral to anhedral crystals (figs. 5 and 6). The low relief brown diopsidic pyroxene occurs only as big crystals. Both andradite and grossularite (fig. 7.), occur. However, grossularite is commoner of the two. The andradite is light green, high relief and generally slightly anisotropic mineral. Very close to the contact it occurs in aggregates of small crystals, but away from the contact, it occurs as big and somewhat anisotropic porphyroblasts.

The axinite occurs in very variable amounts. In some cases it may even be absent altogether. It occurs either as typical wedge-shaped crystals or as stringer-like and xenomorphic forms, replacing, working into and even enclosing garnet (fig. 8) as well as pyroxene. In some cases it attacks garnet so strongly that only small bits of it are left in the axinite porphyroblasts. The axinite varies in colour from almost brownish black to dark brown. Pyrrhotite varies very widely in amount. In some cases it occurs only as a minor constituent, whereas in others it may be the chief mineral of the skarns. It freely encloses axinites, garnets and

pyroxenes. Sometimes it may alter to limonite, haematite or even thin films of malachite. Sphene, calcite, quartz and chlorite may or may not occur. Significant quantities of quartz may be introduced in some cases.

THE PYROXENE-AXINITE-HORNFELSES

By decrease in the amount of ore content, the 'skarns' grade into the 'pyroxene-axinite-hornfelses'. These rocks like skarns show macroscopic segregation of their constituents. Due to this reason the modal analyses can only be regarded as approximate. They follow the skarns, and at places, where the skarns are absent, they may develop directly against the aplite. It is difficult to draw a line between the skarns and the 'pyroxene-axinite-hornfelses' because with decrease in the amount of pyrrhotite, the skarns grade into the latter. The pyroxene-axinite-hornfelses have low pyrrhotite content and the pyroxene is generally diopside rather than hedenbergite. These rocks consist essentially of three chief minerals, namely pyroxene, axinite and garnet. In addition to these minerals there may occur small amounts of quartz, sphene, calcite and pyrrhotite. These rocks are generally non-porphyroblastic. The individual minerals occur as subhedral to anhedral crystals, often intergrown. Axinite, pyrrhotite and calcite replace the other minerals.

THE AXINITE-AMPHIBOLE-HORNFELSES

Twelve modal analyses of the 'axinite-amphibole-hornfelses' are listed in table 2. Both amphibole and axinite show a remarkably wide range of variation. In some cases, especially in the amphibole rich rocks, axinite may be absent altogether. Generally speaking, the amphibole rich rocks also contain notable amounts of pyrrhotite (fig. 9).

The sample M105 is an amphibole vein within the 'dark igneous' series and is unusually rich in sphene. The sample M13 A is a strongly prehnite-



Fig. 5



Fig. 6



Fig. 7



Fig. 8

Figs. 5 and 6. Pyrrhotite-pyroxene skarns. (X 26, xp.).

Fig. 7. Garnet-pyroxene-axinite rock. (X 26, X. P.).

Fig. 8. Axinite replacing garnet. (X 26, p.p.I.).

TABLE 2

Axinite-Amphibole-Hornfelses

	Amphibole	Axinite	Pyrrhotite	Sphene	Chlorite	Pyroxene
MN332	88.73	0.00	9.27	0.00	1.50	0.00
MN315	82.41	0.00	13.59	0.00	2.10	0.00
MN316	77.01	0.00	18.00	0.00	3.87	0.00
M105	76.57	5.31	1.80	14.70	1.00	0.00
M124	74.17	0.00	19.24	1.32	1.09	0.57
M42	72.04	6.56	0.00	1.00	0.00	0.00
MN13A	61.99	0.46	0.46	0.00	0.00	0.00
MN30	57.58	5.42	26.46	0.24	0.00	0.00
MK34	40.28	41.50	0.00	1.22	0.00	0.00
MN77A	18.35	27.63	5.65	0.36	5.50	0.00
M114	17.28	48.96	2.25	7.71	4.50	0.00
MN109	9.89	75.43	2.35	5.27	3.60	0.00

	Garnet	Quartz	Calcite	Muscovite	Prehnite	Epidote
MN332	0.00	0.00	0.50	0.00	0.00	0.00
MN315	0.00	0.00	1.90	0.00	0.00	0.00
MN316	0.00	0.00	1.12	0.00	0.00	0.00
M105	0.00	0.62	0.00	0.00	0.00	0.00
M124	2.69	0.92	0.00	0.00	0.00	0.00
M42	0.00	18.82	0.20	0.00	0.00	1.38
MN13A	0.00	0.00	0.00	0.00	37.09	0.00
MN30	0.00	0.00	0.43	9.87	0.00	0.00
MK34	0.00	0.00	17.00	0.00	0.00	0.00
MN77A	0.00	21.41	0.00	21.10	0.00	0.00
M114	0.73	18.57	0.00	0.00	0.00	0.00
MN109	0.00	3.46	0.00	0.00	0.00	0.00

tised 'axinite-amphibole-hornfels'. Significant amounts of quartz may occur in some rocks.

These rocks develop on a much larger scale than either the skarns or the 'pyroxene-axinite-hornfels'. At some places the 'pyroxene-axinite-hornfels' and the skarns may both be absent, and here the 'amphibole-axinite-hornfels' come in direct contact with the aplite. These rocks show a strong tendency towards the segregation of their two chief constituents (fig. 10), namely the axinite and the amphibole. They segregate into patches, streaks and irregular bands. These segregations range from only a few millimetres to an observed maximum thickness of about 8 cms. Sometimes this segregation is so complete that the individual segregates may consist of more than 80% of the two main minerals.

Most of the amphiboles belong to the hornblende group. The iron rich varieties occur closer to the contact than the relatively iron poor varieties. The axinite occurring in the amphibole-axinite-hornfels, is lighter in colour, more euhedral, less poikilitic and more often twinned and zoned than the axinite occurring in the 'pyroxene-axinite-hornfels'. Tiny euhedral crystals of quartz are practically the only important inclusions occurring in axinite. The axinite varies in colour from light brown, away from the contact to darker brown, towards the contact.

Epidote group minerals are very rare. Euhedral, wedged-shaped, brown or green-brown sphene is a common accessory mineral. Closer to the contact these rocks may be impregnated with small aggregates of quartz and calcite. The calcite commonly occurs as small stringers cutting across the rock or forming discrete crystals in it. The amount of calcite increases rapidly towards the outer margins of this class. Pyrrhotite generally occurs in small amounts, but at some places closer to the contact, considerable amounts of pyrrhotite may occur associated with the otherwise, pure amphibole rock.

THE CHLORITE-AXINITE-HORNFELS

Twenty-one modal analyses of the 'chlorite-axinite-hornfels' are listed in table 3. Extremely wide range of axinite is the most striking feature of these rocks. Some rocks are almost pure axinite-rocks, whereas the others have only minor amounts of this mineral. The range of quartz, muscovite and calcite is also fairly large. Sphene and pyrrhotite are either absent or present in only small quantities. Generally speaking, the rocks poor in axinite may contain fairly large amounts of quartz+muscovite+chlorite+calcite (figs. 11, 12 and 13).

The 'chlorite-axinite-hornfels' represent the lowest temperature metamorphic reconstitution of the 'dark igneous' series. On the inside these rocks merge into the 'amphibole-axinite-hornfels' and on the outside they split into veins which eventually merge into the 'dark igneous series'. The 'chlorite-axinite-hornfels' are particoloured, white, light green and pink colours appear due to the irregular and poor local segregated development of calcite, mica, chlorite and axinite.

Axinite occurs as subhedral poikilitic crystals of pink to light brown colour. The inclusions consist of subhedral to euhedral quartz and the spherules of chlorite and mica. Both chlorite and mica occur as radial to spherular aggregates. These spherules show best development in the calcite patches. They are suppressed against axinite and quartz. The spherules of mica and chlorite are either closely associated into or intergrown with each other. The chlorite occurs in various shades of green or yellow-green. They show strong pleochroism. Some varieties show normal first or second order interference colours, whereas the others show anomalous pale blue interference colours. The green mica shows either grey or upper first order colours. The calcite occurs as veins patches as well as individual coarse plates.



Fig. 9



Fig. 10



Fig. 11



Fig. 12

Fig. 9. Contact amphibole pyrrhotite rock. (X 26, x.p.).

Fig. 10. Banded amphibole-axinite-hornfels. Axinite band is light coloured and the amphibole band is dark coloured. (X 26, p.p.l.).

Figs. 11 and 12. Chlorite-axinite-hornfels containing radial and fibrous chlorite and mica, twinned calcite and high relief and cracked axinite. (X 26, x.p.).

TABLE 3

Chlorite-Axinite-Hornfelses

	Axinite	Chlorite	Muscovite	Quartz	Calcite	Sphene	Pyrrhotite
MN13	98.25	0.73	1.02	0.00	0.00	0.00	0.00
MN121	89.27	1.11	2.01	0.58	7.03	0.00	0.00
MN123	89.11	1.23	1.19	0.53	7.94	0.00	0.00
MN63A	88.23	0.00	0.00	0.00	10.75	1.02	0.00
MN73	87.60	4.49	7.91	0.00	0.00	0.00	0.00
MN66B	83.56	5.91	7.12	3.41	0.00	0.00	0.00
M128	82.43	15.02	1.29	1.26	0.00	0.00	0.00
MN124A	82.09	1.66	0.00	0.12	16.13	0.00	0.00
MN80A	76.14	2.94	2.53	13.44	0.00	3.54	1.41
MN80B	73.90	4.00	3.93	11.53	1.60	3.38	1.66
M105	57.52	23.57	0.00	6.69	12.22	0.00	0.00
MN103	53.53	25.78	0.00	6.64	14.05	0.00	0.00
M63B	45.42	0.00	0.45	0.00	50.89	0.38	2.86
MN120	40.69	8.09	0.00	6.55	43.71	0.48	0.48
MN12	27.57	13.83	27.32	4.80	26.40	0.00	0.08
MN127	26.99	19.38	19.58	15.13	17.34	0.00	1.58
M77	18.59	2.94	26.22	23.00	20.59	0.00	8.66
MN9A	16.44	21.26	19.95	1.13	40.70	0.52	0.00
MN10	15.10	19.90	21.50	6.50	37.00	0.00	0.00
MN9B	14.15	19.00	24.38	3.36	38.50	0.61	0.00
M8	5.04	19.16	31.67	17.85	24.93	1.10	0.25

THE CALC-FLINTAS

The banded 'calc-flintas' occur in the northeastern "granulite quarry". These rocks consist of alternating bands of the calcareous and arenaceous composition (figs. 14 and 15). The individual bands generally do not exceed a couple of inches in thickness. The 'calc-flintas' lying outside the thermal aureole of the Meldon aplite have undergone recrystallisation, but the metamorphic minerals like garnet, idocrase and wollastonite etc., so common in the Railway Quarry are scarce here.

The calcareous bands consist of granular and recrystallised calcite with small amounts of quartz, whereas the arenaceous bands consist of fine granular quartz with small amounts of calcite, mica and tourmaline. Inside the metamorphic aureole of the Meldon aplite, a number of metamorphic and metasomatic minerals are formed. Close to the contact certain bands of calcareous composition are totally replaced by the lilac axinite. Along the joint faces and at the interfaces between the calcareous and the arenaceous bands, rings of blue fluorite develop, from the circumferences of which, the axinite develops in a radial pattern. The arenaceous bands are recrystallised and fairly large amounts of light green mica, brown tourmaline and fluorite form. The medium green epidote is a common accessory mineral, which occurs both in the calcareous and the arenaceous bands. Very seldom small amounts of acicular amphibole may develop in the arenaceous bands close to the contact.

Scapolite is an important accessory mineral. In most cases it develops at the joint faces. But occasionally, it may develop in such quantities that the bands across their full thickness may be replaced by scapolite rock. This scapolite belongs to the 'marialite' variety. Associated with it there occur small amounts of pyrrhotite, idocrase and grossularite. But such replacements are rare. Light green prehnite occurs as late hydrothermal veins or as a late replacement mineral.

THE SHALY QUARTZITES

The shaly quartzites are speckled black compact rocks. The specks are due to the development of chiastolite (fig. 16) porphyroblasts. The ground-mass consists chiefly of fine granular quartz with small amounts of sericite, organic matter and haematite. These intercalations are restricted to the northern contact of the southwestern granulite quarry.

CHEMISTRY

Eighteen chemical analyses are presented. They include slightly to moderately reconstituted metadolerite as well as totally reconstituted hornfels skarns. Cationic gains and losses have been calculated (Chaudhry and Howie, 1974) during metasomatism. It has been shown that during metasomatism an overall addition of calcium, manganese, boron, ferrous iron and carbon and an overall depletion in silicon, aluminium, titanium, sodium, ferric iron, magnesium, phosphorous and sulphur has taken place.

PETROGENESIS OF THE ENVELOPE ROCKS

The envelope rocks of the Meldon aplite lie in the outermost part of the thermal aureole of the Dartmoor Granite. Here the 'calcareous shale group' rocks are represented by the banded calc-flintas, with alternating black or grey arenaceous and argillaceous and white calcareous bands. But minerals like wollastonite, garnet and diopside are scarce. The arenaceous bands consist of quartz, mica, calcite and accessory minerals like tourmalines etc. The argillaceous bands have assumed a slaty form. The calcareous bands commonly consist of calcite, quartz, mica and a host of accessory minerals. The 'dark igneous series' are composed of heavily kaolinised and altered intermediate plagioclase with subordinate amounts of acicular amphibole, sphene, calcite and a little iron ore.



Fig. 13



Fig. 14



Fig. 15



Fig. 16

- Fig. 13. Chlorite-axinite-hornfels, being replaced by mica, chlorite and quartz. (X 26, x.p.).
 Fig. 14. Banded calcareous-shale group rock (calc-flinta) consisting of dark arenaceous-argillaceous and white calcareous bands. (X 26, p.p. 1.).
 Fig. 15. Fine grained arenaceous band. (X 36, x.p.).
 Fig. 16. Chiastolite-hornfels. (X 26, x.p.).

TABLE 4
Chemical Analysis

Sample No.	M9	M 83	M 9B	MN 313	MN 315	MN 397	MN 396	GHS	M110
SiO ₂	40.49	36.58	32.70	54.13	49.88	43.16	52.68	42.52	36.80
TiO ₂	0.00	1.70	1.84	0.37	0.69	0.15	0.88	0.37	0.37
Al ₂ O ₃	19.06	13.40	15.52	14.90	4.82	8.72	13.70	14.18	12.68
Fe ₂ O ₃	1.91	0.69	1.98	1.15	2.69	1.31	0.87	2.61	4.13
FeO	6.46	5.12	6.66	6.01	18.24	9.85	7.68	8.78	18.19
MgO	2.82	3.98	3.02	7.73	11.50	13.62	1.78	7.78	0.79
CaO	19.57	24.04	19.94	9.22	9.02	18.51	15.51	20.80	16.17
Na ₂ O	0.19	0.21	0.19	1.54	0.13	0.19	2.00	0.15	2.30
K ₂ O	1.94	0.88	1.94	0.60	0.05	0.13	0.35	0.04	0.30
MnO	2.20	2.14	2.13	0.12	0.33	1.93	1.93	2.10	2.27
H ₂ O ⁺	1.87	2.03	1.87	2.68	0.91	0.81	1.24	0.33	0.64
H ₂ O ⁻	0.16	0.20	0.16	0.21	0.06	0.07	0.17	0.08	0.12
B ₂ O ₃	3.08	3.01	2.99	0.06	0.08	1.13	0.25	0.33	2.80
S	0.12	0.23	0.16	0.30	2.90	0.42	0.43	0.31	4.26
P ₂ O ₅	0.07	0.08	0.07	0.00	0.02	0.09	0.52	0.04	0.09
CO ₂	0.42	5.89	9.02	0.28	0.09	0.41	—	0.15	—
S-O	0.06	-0.13	-0.08	-0.15	-1.45	-0.21	-0.22	-0.17	-2.13
	100.30	100.05	100.11	99.15	99.96	100.29	99.77	100.40	99.78

Due to the metasomatic metamorphism the 'dark igneous series' have been strongly reconstituted from a few inches to a few feet from the contact. The metasomatism starts along the contact, joints

and fractures, and works outwards and sideways. During metasomatism substantial amounts of boron, water, iron, manganese carbon and calcium have been introduced. But this influx was preceded

TABLE 4 (Contd.)
Chemical Analysis

Sample No.	MN 26	MK 33	MK 30	MN 391	MN 25	MN 29	MN 80	MN 312	MN 398
SiO ₂	47.93	47.97	47.57	47.67	47.91	43.20	64.98	42.48	41.69
TiO ₂	2.75	2.25	2.70	0.56	1.99	3.79	0.06	0.06	0.44
Al ₂ O ₃	22.33	16.64	20.29	13.69	18.48	16.89	8.79	17.43	12.07
Fe ₂ O ₃	0.62	1.04	0.25	1.67	3.87	1.90	1.06	0.87	0.93
FeO	5.61	5.19	3.11	7.17	5.79	3.11	8.59	8.04	5.68
MgO	4.63	5.07	3.66	5.61	4.73	5.19	0.90	1.72	6.99
CaO	10.56	16.72	18.65	17.60	10.35	20.82	7.10	19.20	17.92
Na ₂ O	2.73	2.48	1.10	2.55	2.91	1.60	0.15	0.00	0.10
K ₂ O	0.51	0.06	0.45	1.05	0.51	0.45	0.85	0.40	0.09
MnO	0.47	1.00	0.25	1.67	0.62	0.85	1.66	3.93	3.33
H ₂ O ⁺	0.76	0.61	1.21	0.71	0.96	1.21	1.08	1.14	1.25
H ₂ O ⁻	0.11	0.15	0.14	0.18	0.13	0.13	0.18	0.09	0.16
B ₂ O ₃	Traces	—	—	—	0.10	0.28	3.12	4.57	3.92
S	1.15	0.33	0.70	—	1.08	0.21	0.38	0.21	0.50
P ₂ O ₅	0.64	0.36	0.03	0.36	0.64	0.03	0.08	0.03	0.26
CO ₂	—	—	—	—	0.25	0.31	1.66	0.26	0.33
S—O	-0.58	-0.17	-0.17	—	-0.54	-0.11	-0.19	-0.11	-0.25
Total	100.22	99.70	99.78	100.49	99.78	99.86	100.45	100.40	100.36

by thermal metamorphism (with small introductions of metal ions, specially iron) which produced minerals like pyroxenes, garnets, amphiboles and chlorite. This was followed by an influx of boron, manganese, iron, calcium carbon and water. This resulted in the replacement of pyroxenes, garnets and even amphiboles by axinites. Large amounts of pyrrhotite crystallised at the contact skarns

and along the joint faces. Due to rapid thermal metamorphism followed by replacement by introduced volatiles and recrystallisation the equilibrium has not been established. This is reflected by irregular segregation of individual minerals which imparts a marked petrographic heterogeneity to these rocks. Large introductions of manganese, calcium and boron have resulted in the formation

of large quantities of axinites. This has caused the removal of magnesium, aluminium, silicon, potassium, titanium and sodium. Magnesium, aluminium and silicon form chlorite segregates, whereas potassium, aluminium and silicon form mica segregates. These two minerals, often associated together, crystallise as patches, spherules and veinlets in the lower temperature metasomatic zones. Sodium, potassium, aluminium and silicon result in the formation of quartzo-feldspathic veins. Titanium is expelled during reconstitution, and it concentrates at the margins of the metasomatic rocks, forming dirty pale or flesh margins and patches.

The 'calc-flintas' are only mildly reconstituted. The effects of the metasomatic metamorphism are restricted from a few millimetres to a few centimetres from the contact or on either side of the joint faces and fractures. At an early stage, the chlorine-bearing sodium-aluminium melts working along the arenaceous bands or along the contacts of the arenaceous and calcareous bands have formed marialite variety of scapolite. Along the calcareous bands at the contact some epidote, tourmaline and amphibole may sometimes form. Occasionally aggregates of scapolite, garnet and pyrrhotite may also form. At a later stage iron, manganese, boron and fluorine are introduced from the aplite. This results in the formation of axinite-fluorite aggregates. The argillaceous intercalations are generally

reconstituted, without significant metasomatism, to chialstolite hornfels. However sometimes axinite and acicular amphibole may form along joints at contact with the aplite.

Summing up, iron manganese, boron, carbon and calcium have been added to the 'dark igneous series'.

But in the 'calc-flintas' chlorine and fluorine have also been added. The added materials generally fall away as the distance from the contact with aplite increases, till finally feldspar-amphibole rocks are encountered. Therefore the aplite is considered to be the source of these elements. There is good reason to believe that during the pneumatolytic stage the aplite residuum contained fairly large amounts of iron, boron, calcium and manganese. This is proved by the late stage metasomatic generation of iron rich lepidolites, tourmalines and fluorite in substantial amounts. Similar metasomatic additions have also been reported from other localities around the Dartmoor Granite. The whole process of reconstitution consisted of thermal metamorphism, pneumatolytic introduction of boron, calcium manganese, iron, carbon chlorine and fluorine followed by the introduction of sulphides (accompanied by or followed by prehnitisation). Such a general sequence is rather common in skarns (Osborne, 1932).

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NOTICES, ABSTRACTS AND REVIEWS

A DISCOVERY OF CARBONATITE FROM MALAKAND

GENERAL GEOLOGY

Carbonate rocks carrying vermiculite and iron oxides were reported by Fayyaz and Shafiq from near the village of Silai Patti which is 19 miles from Dargai (in the Malakand Agency) on the Dargai Bajaur road.

The authors studied the area and carried out laboratory studies on the rocks and concluded that the rocks were carbonatite bodies. Following is a brief description of the occurrence.

The carbonatites occur as dykes, sills and ring type bodies in the pelitic-psammitic schists of possibly Pre-cambrian age (The dykes and sills are from 50' x 10 feet to 300' x 60 feet). The pelitic rocks have been thrust against calcareous and quartzitic rocks of Cambrian age intruded by granites (Chaudhry et al. 1976, E.C.L. 1977).

PETROGRAPHY

The rocks are composed of calcite, arfvedsonite, siderite, ilmenite, magnetite, vermiculite, apatite, chlorite and some feldspar. The minerals show uneven distribution and local segregation.

The rocks are coarse grained and from porphyritic to subporphyritic. Calcite is the main mineral and ranges from 50 to 90% in most cases. However, where Fe-Ti oxides or vermiculite increase

in amount the amount of calcite may fall below 50%. Some siderite crystals are also present.

Vermiculite occurs unevenly distributed and ranges in size from 1mm to 3 mm and occasionally upto 8cm in size.

Fe-Ti oxides (magnetite/ilmenite) are generally below 5% however at a few places they may be as high as 50% (as pods and lenses). These oxides occur from subhedral to anhedral crystals.

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

Apatite ranges from 2 to 12%. It occurs as subhedral to anhedral crystals. It may be partly enclosed by the carbonates.

Vermiculite and amphibole at places alter to chlorite.

K-feldspar ranges from 0 to 5%. It occurs as randomly distributed crystals.

CHEMISTRY

Rare earths bearing minerals are also present. Work is in progress to identify and describe them.

Analyses for some of rare earths showed them to be present in significant amounts. Some of the results are as follows :—

	Nb	Sr	V	Y	Zr	La	Sc*	Yt*
SPT-77-AFM-C4	0.03	0.3	0.01	0.01	—	0.04	Tr	Tr
SPT-77-FS-C5	0.01	0.3	0.01	0.02	0.01	0.04	Tr	5
SPT-77-FS-C6	0.01	0.3	0.01	0.02	0.01	0.04	Tr	3

*ppm. rest in percentage.

ORIGIN

No alkaline rocks were found in the immediate vicinity. Structural observations indicate these intrusions to be in the cap rocks below which may lie the alkaline rocks. It is regarded to be a part of the alkaline province lying between Loc Shalman (Khyber) and Chamla (further extensions of this province are not known).

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PETROGRAPHY

The rocks are composed of calcite and dolomite, with minor amounts of quartz, epidote, hornblende and green schist. The minerals show various distributions and local concentrations. The rocks are coarse grained and from porphyritic to microphyritic. Calcite is the main mineral and ranges from 10 to 90% in some cases. Dolomite ranges from 10 to 90% in some cases.

Sp. No.	Ca	Mg	Fe	Si	Al	Na	K	Sum
SP-71-15-1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06
SP-71-15-2	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06
SP-71-15-3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.06

*Sum in percentage

OIL AND GAS PROSPECTS OF THE BASINS OF PAKISTAN

GENERAL

The history of petroleum investigations in Pakistan is very old and can be traced back to the middle of 19th century. However, oil in commercial quantities was found in 1914 at Khaur, by the Attock oil company. Since then, several companies have carried out extensive survey of the country and exhaustive information on petroleum geology has been accumulated, though most of this work is not open to the public. Some of the works available are those of Rahman (1963), Movshovitch (1968) Sokolov (1971) and others. Classification of areas of Pakistan into oil and gas and possible oil and gas basins has been worked out by these authors.

Before proceeding further it will be plausible to understand the term "basin" and the sense in which it is being used in the present work. Olenin (1977) defines oil and gas basin as a geological body within the limits of a large element of the stratisphere which is structurally immersed as a whole relative to its limiting elements. Thickness, form and composition of the sediments forming this body and its hydrogeological characteristics guarantee in its generation and accumulating of dispersed hydrocarbons and conservation of pools of oil and gas.

BASINS OF PAKISTAN

Pakistan comprises of the following basins; Punjab Oil and Gas Basin (Kohat-Potwar Oil and Gas Basin); Multan Oil and Gas Basin; Sind Gas Basin and two possible oil and gas basins of Makran and Kandhar.

The former three oil and gas basins are confined to the foredeeps, conjugated with relative slopes of the Indian platform and the later two are

located in the rear troughs. According to Serogin and Sokolov (1968), oil and gas basins of Pakistan belong to the type of basins forming at the contact of platform and folded structures; Brod (1965) to the foredeeps; and Olenin (1966) heterogeneous basins of bordered depressions. As a rule, these basins have assymmetric profile, wide external platform flanks and narrow internal folded flanks, coinciding with the folded zones of the foredeeps. These basins are filled with thick sediments of Palaeozoic, Mesozoic and Paleogene sediments, represented by subplatform sea and continental rocks and Neogene molasses. Oil and gas occurs in the rocks of Paleogene in Punjab, Multan and Sind basins and also in Jurassic of the Punjab Basin.

Possible oil and gas basins of Pakistan are situated within the internal parts of the Alpine—Himalayan Folded Belt, and are classified as intermontane basins connected with synclinoria.

Almost all of the discovered oil fields, except recently discovered oil field at Dhodak, are concentrated in the Punjab Basin. Dhodak oil field has been found in the Multan Basin. Gas fields are confined mainly to the High, dividing the Multan and Sind basins.

In the Sind Basin, represented by a vast area of submergence, a number of features influencing the formation and distribution of hydrocarbons are noted. In this basin, rocks of Upper Jurassic are absent in the section. At the end of Cretaceous, conditions of continental deposition prevailed. Basins of sedimentation are displaced in plan. Only one regional clayey cap rock is known in the upper parts of Lower Eocene. Just below this cap rock are confined almost all the discovered accumulations of oil and gas.

The occurrence of gas only in the Sind Basin may be explained with the help of the theory, "Principal phase of oil formation and vertical zonation of disposition of the pools of oil and gas", Vassoevich (1967). In the Sind Basin, in the highest fields, productive horizons occur at depths from 0.6 to 1.2 km—Mari, Lakhra, Khairpur, Jacobabad, Zin and Uch. Uncombustible components predominate in the gas composition; nitrogen, CO_2 etc.; methane is less than 50% and heavier homologues are absent. In the deeper fields like Sui—1.27 km, Khandkot—1.9 km, Sari Singh—1.2 km, Kundi—km the quantity of CH_4 increases upto 88% and heavier homologues of methane increase upto 3.5%. Such a type of change in the gas composition is also observed with depth even within the limits of a single field. In the deepest pools appear condensate and thin oil layer. Apart from this, in the folded zones, bordering the basin, oil showings are known in the formations of Lower Paleogene and Upper Cretaceous (Gokot, Mughalkot and others). The above statement when considered from the point of view of principal phase of oil formation clearly confirms that the major part of the generating complex of Paleogene has not yet entered the zone of action of middle catagenetic stage. On the other hand, the deeply immersed

parts underwent these effects comparatively later, during the Quarternary Period. This is also convincingly confirmed by the change of character of gas composition of gas fields of the basin.

In the Punjab Basin the main productive rocks are of Eocene and Jurassic age at depths varying from 2.3—2.7 km (Dhulian), & 4 and 4.5 km (Kot Sarang and Tut). Oils of Potwar are distinguished by low gas factor, which increases with depth. Gas pool is known at deeply immersed field of Dhulian. Punjab Basin, in the beginning underwent significant submergence, but afterwards it was somewhat uplifted and is therefore devoid of gas accumulations of the upper zone of gas formation. Oil accumulations of the Punjab Basin correspond to the middle catagenetic stage of the principal phase of oil formation.

RECOMMENDATIONS

The Sind Basin is located at a stage of mollasse formation. The discovered gas pools occupy uplifted traps. It is therefore possible to forecast that in the Sind Basin oil pools corresponding to the main phase of oil formation occur deeper, while on the other hand in the Punjab Basin, gas of late catagenetic stage is expected, at further depth.

Stage and substage of lithogenesis.		Zones of generation of hydrocarbons and range of their generation.	Temperature (°C)	Average depth of zones of generation (in Km) in Sedimentary basins dry or covered by shallow water Seas.
Diagenesis		Diagenetic, Gas generating.	10-20	0.1-0.5
C A T A G E N E S I S	Early	Upper Catagenetic, Gas generating.	20-65	0.5-1.5
	Middle	Catagenetic, Oil & gas generating.	65-150 PPO	1.5-5
	Late		150-250	5-7
		Lower Catagenetic, gas generating	250-350	7-9
Metagenesis (metamorphism)			> 350	> 9



Liquid hydrocarbons Formation.



Gas hydrocarbons Formation.



Principal phase of Oil Formation.

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

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ORE MICROSCOPY OF PYRRHOTITE—PYRITE—CHALCOPYRITE VEIN FROM PATTAN, INDUS KOHISTAN, PAKISTAN.

INTRODUCTION

During an investigation of the geology of the lower part of Indus Kohistan, "a fifteen feet thick brecciated zone" located in a road cut about 2 miles north of Pattan (Long : $73^{\circ} 1'$; Lat : $35^{\circ} 12'$) and containing "quartz, feldspar and arsenopyrite" was noted by Jan & Tahirkheli (1969).

At the author's request Jan kindly provided specimens of the vein for ore microscopic studies. Following is a brief account of the mineralogy and ore petrography of the specimens.

PETROGRAPHY

In the hand specimen the ore consists of massive, medium grained sulphide minerals containing fragment of gangue material. Massive, fine grained pyrrhotite is locally traversed by thin veinlets of pyrite. As seen in thin section, the fragments mainly consist of plagioclase, amphibole, quartz and garnet (in order of relative abundance). The brecciated rock is coarse-grained, granular mildly cataclastic with warped and fractured plagioclase twin lamellae and hornblende grains.

Plagioclase (An 40%) occurs as euhedral to subhedral grains upto 7 mm long. The crystals are usually argillized and sericitized on margins.

Quartz grains are coarse (about 5 mm across) and show strong undulose extinction.

Hornblende occurs as coarse euhedral to subhedral grains which are partially altered along cleavages to chlorite.

Garnet forms euhedral, colourless grains (upto 1 mm across) and is usually associated with hornblende and opaque ore.

Epidote and chlorite are secondary after plagioclase and hornblende and occur usually at their contacts with opaque ore.

Veins of ore cut other minerals grains, including those of quartz. At opaque ore—plagioclase contact, the former replaces the latter along cleavage planes.

ORE PETROGRAPHY

Ore minerals present include pyrrhotite, pyrite and chalcopyrite. Arsenopyrite, as reported by Jan and Tahirkheli (1969) has been noticed by the author in the specimens studied.

Pyrite occurs in two generations ; (i) as subhedral crystals which are at places fractured along cleavage planes. Fractures are locally filled with pyrrhotite and chalcopyrite and gangue. Pyrite grains are, as a rule, coarser than those of pyrrhotite and chalcopyrite. Some Pyrite also occurs as thin, branching, veinlets upto 1/2 mm thick cutting across pyrrhotite. (ii) as oval, concentrically layered, microscopic bodies alongside cracks in pyrrhotite showing what is commonly known as "bird's eye texture". Absence of discernable anisotropism indicates that the mineral constituting the "birds' eye texture" is pyrite and not marcasite.

Pyrrhotite is the predominant sulphide mineral in the ore and occurs as an aggregate of fine interlocking grains. Lamellar twinning may be seen in a few grains under crossed nicols.

Chalcopyrite is the least abundant ore mineral in the specimens studied. Its age relationship with pyrrhotite is not clear. However, chalco-

pyrite grains are mostly localized along the contacts of pyrrhotite and gangue. Chalcopyrite (with minor pyrrhotite) infiltrates gangue minerals).

Limonite forms irregular veinlets cutting across the sulphide and gangue minerals alike.

Marcasite is seen replacing pyrrhotite at one place alongside the limonite vein.

CONCLUSIONS

The mineralogy and texture of the rock fragments indicates them to belong to a metamorphic rock of almandine amphibolite facies.

A brecciated zone in the above rock appears to have been invaded by hydrothermal solutions. The rock association, as well as the presence of pyrrhotite, indicates a high temperature origin for the ore.

Pyrite appears to be the oldest ore mineral and it is cut by veins of pyrrhotite and chalcopyrite; but this evidence is conclusive. Pyrite is fractured along cleavage indicating cataclasis during which the softer pyrrhotite and chalcopyrite may have become pressed into the harder, but not necessarily older, pyrite. Some pyrite which occurs as veinlets cutting across the ore, is of course, younger than the pyrrhotite.

Regarding the relative ages of pyrrhotite and chalcopyrite, lack of any clear "cross cutting" or "inclusion" relationship indicates the two minerals to have crystallized, at least in part, contemporaneously. However, the location of most of chalcopyrite along pyrrhotite gangue contacts indicates a somewhat later deposition of chalcopyrite.

Late stage, low temperature phenomena include replacement of pyrrhotite by pyrite showing the typical "bird's eye texture". Finally occurrence of limonite veins indicates replacement of sulphide minerals under oxidizing sub-areal or low temperature and pressure conditions at shallow depth.

It is interesting to note that chalcopyrite in preference to pyrrhotite and pyrite, infiltrates gangue minerals and is inter-grown with them.

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