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EVOLUTIONARY MORPHOLOGICAL VARIATIONS IN MIOSPORE GENUS *AURORASPORA**

BY

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Abstract : *Sixty four samples from four formations namely the Java, Canadawav, Chadakoin and Cattaraugus of the Upper Devonian of New York State and Pennsylvania U.S.A., have revealed profuse assemblages of Palynomorphs. All of these Famennion deposits which are from classic areas of North American Devonian stratigraphy, yielded a characteristic pseudosaccate miospore genus* Auroraspora. *Excellently well preserved miospore forms of this taxon have been found particularly useful since these are abundant and exhibit distinctive pattern of folding developed to varying degrees on different forms of the genus which resulted in the recognition of broad evolutionary, biostratigraphical and morphological subdivisions. A gradual evolutionary change in the nature of folding, from very conspicuous to simple, of the genus from the base to a point almost at the top of the sequence is observed. These* Auroraspora *complexes, which coincide with the miospore zonations delineated from the present material, have been established. These are in ascending stratigraphical order : the* Auroraspora pseudocrista, A solisorta *and* A. commutata *complex. The material investigated is lithologically composed of blue grey shales and siltstones weathered to olive green colour.*

INTRODUCTION

The objective of this article is to describe the *Auroraspora* complexes and the evolutionary changes of the taxon observed in the miospore assemblages of some Upper Devonian deposits, the Java, Canadaway, Chadakoin and Cattaraugus Formations of western New York State and northern Pennsylvania U.S.A. All of the miospores discussed herein have been described already, consequently systematic treatment is not given. The rocks were usually bluish grey in colour but occasionally weathered to olive green. For an outline account of the miospore genus *Auroraspora* readers are referred to Richardson 1960 and Ahmed 1980.

DISCUSSION

Distinctive patterns of folding, developed to varying degrees on different forms of the *Auroraspora* result in a morphological series. Some species of *Auroraspora* recorded during the present investigation have, therefore, been grouped into three complexes, controlled not only by stratigraphical intervals but also morphological variations. It will be evident from studying fig. 1 that there is a gradual change in morphology from the base of the section to a point almost at the the top of the strata investigated. It is also rather interesting to note that these tentative and may be endemic morphological variants coincide to some extent, in terms of numbers and characters of species, with miospore zonations established during the present work. The miospore zones will be discussed in detail in a separate paper.

As mentioned above, *Auroraspora* complexs

* Paper read at Seventh International Palynological Congress Brisbane, Australia, 28th August—3rd September, 1988.

have been established during the present investigation. These are in ascending stratigraphical order as follows :

1. *Auroraspora pseudocrista* complex.
2. *Auroraspora solisorta* complex.
3. *Auroraspora commutata* complex.

Each complex, characterised by particular forms possessing distinctive morphological features, is discussed below.

1. *Auroraspora pseudocrista* Complex In this complex large distinctive forms such as *A. pseudocrista* Ahmed 1980 and *A. torquata* Higgs 1975 have been observed. These species range throughout the sequence and occur in the lowermost samples studied (Java Formation). *A. pseudocrista* ranges from samples US11A to US6D, whilst *A. torquata* has been found occuring from samples US11D to NY95A (see fig. 1). A comparison of both species lends some support to the view that *A. pseudocrista* is morphologically related to *A. torquata*. However, their relationship is indicated by a question mark because the two species have quite different size ranges (see Ahmed 1980, p. 236). This complex is distinguished by the species possessing large folds on the pseudosaccus and/or the inner body. Also at this horizon forms having a size less than 51 µm have not been encountered. Finally it is important to emphasize that this assemblage has only been recognized in the *Streelispora catinata—Ancyrospora neograndispinosa* (CN) assemblage zone and at highers these species are accompanied by other species of *Auroraspora*.

2. *Auroraspora solisorta* Complex. The second group of *Auroraspora* species makes its stratigraphical debut at base of the *Synorisporites flexuosus—Auroraspora varia* (FV) miospora zone. Five miospore species have been recorded in this complex. The species occurring within this horizon are illustrated in fig. 1.

A small species having its pseudosaccus slightly larger than its inner body e.g. *A. pallida* (Naumova) Ahmed and another miospore species possessing an extremely thin pseudosaccus e.g. *A solisorta* Hoffmeister, Staplin and Malloy have deen recorded from the Upper Canadaway Formation (US10A) up to the top of the sequence (US7). *A. varia* (Navmova) Ahmed also bears a thin walled pseudosaccus and is recorded from the Canadaway to Cattaraugus Formation (US80A to Ny95A).

Another species, *A. submirabilis* (Luber) Ahmed 1978 originally described from the Soviet Union which possesses a finely infrapunctate, probably corroded pseudosaccus. This species has been recorded from the Upper Canadaway to Cattaraugus Formation(US10A to US6H). At a slightly higher level, US4B, Chadakoin Formation, one specimen of the Canadian species *A. micromanifesta* (Hacquebard) Richardson 1960 has been recorded, while another specimen of identical form has been founded occurring still higher in the sequence, at US6H.

In all of these forms of the complex the pseudosaccus is finely and simply folded. The size of the species in this assemblage ranges from 29µm to 100µm.

3. *Auroraspora commutata* Complex. This complex begins in the upper part of the FV zone and within the Dexterville Member. It is characterised by species of the genus *Auroraspora* which possesses a characteristic pattern of folding. The incoming of such distinctively folded and wrinkled forms warrants the recognition of this complex.

It appear that these forms are genuine morphological variations of *A. commutata* (Naumova) Ahmed 1980. *A. commutata* is the first species to appear at the base of this FV assemblage showing radial folds. This has been recorded from the Chadakoin (Dexterville and Ellicott Members) Formation. Some larger specimens corresponding to *A. commutata* var. *major* (Kedo) Ahmed 1978 have also been encountered.

It is believed that *A. callosa* (Kedo) Ahmed 1980 bears possibly close morphological relationship to *A solisorta*. The two miospore are almost identical morphologically, however *A. callosa* possesses a compressionally folded body whilst *A. solisorta* has an unfolded body. *A. callosa* has been recorded from the Chadakoin Formation (US4F to US8C).

At this stratigraphical interval the incoming of *A. poljessica* (Kedo) Streel in Baker *et al.* is rather interesting. This species shows minute and closely packed folds and wrinkles all over the pseudosaccus. Because of its comprehensive folds, it is considered premature to attempt to attribute morphologically such a distinctive form to any of the species exhibited and described in this work. The form has been recorded from the Chadakoin and Cattaraugus Formation (US4F to NY95C).

At the base of the *Vallatisporites vallatus* var, *hystricosus—Retispora lepidophyta* (HL) miospore zone, species possessing radial and project:ng folds have frequently been observed. The restricted vertical range of these forms is worthly of special mention. These miospores are confined to the Chadakoin Formation. The miospore forms which make their first appearance at this horizon are *A. papillara* (Kedo) Ahmed 1980, *A.* cf. *papillara* (Kedo) Ahmed 1978, *A. prostata* Ahmed 1980, *A. prostata* var. *prostata* Ahmed 1980. The incoming of these forms together with their vertical range is shown in fig. 1.

At a slightly higher stratigraphical level a miospore with well defined radial folds, *A. versabilis* (Kedo) Turnau was recorded from the Chadakoin and Cattaraugus Formations (NY96C to US6A).

It is important to note that intensively folded rather damaged miospores have frequently been found occurring in clusters. These are miospores of *A. varia* var. *multifaria* Ahmed 1980. This form has been recorded from the Chadakoin and Cattaraugus Formations (NY96C). The author regards this variety to be gradational form of *A. varia*.

Fig. 1 indicates the morphological variations of the genus *Auroraspora*, encountered in the samples investigated and arranged stratigraphically together in relation to the three miospore zones. Due to lack of space not all samples could be illustrated in particular column. For a complete list of samples arranged stratigraphically, the readers are referred to Ahmed 1980, p. 229, fig. 2.

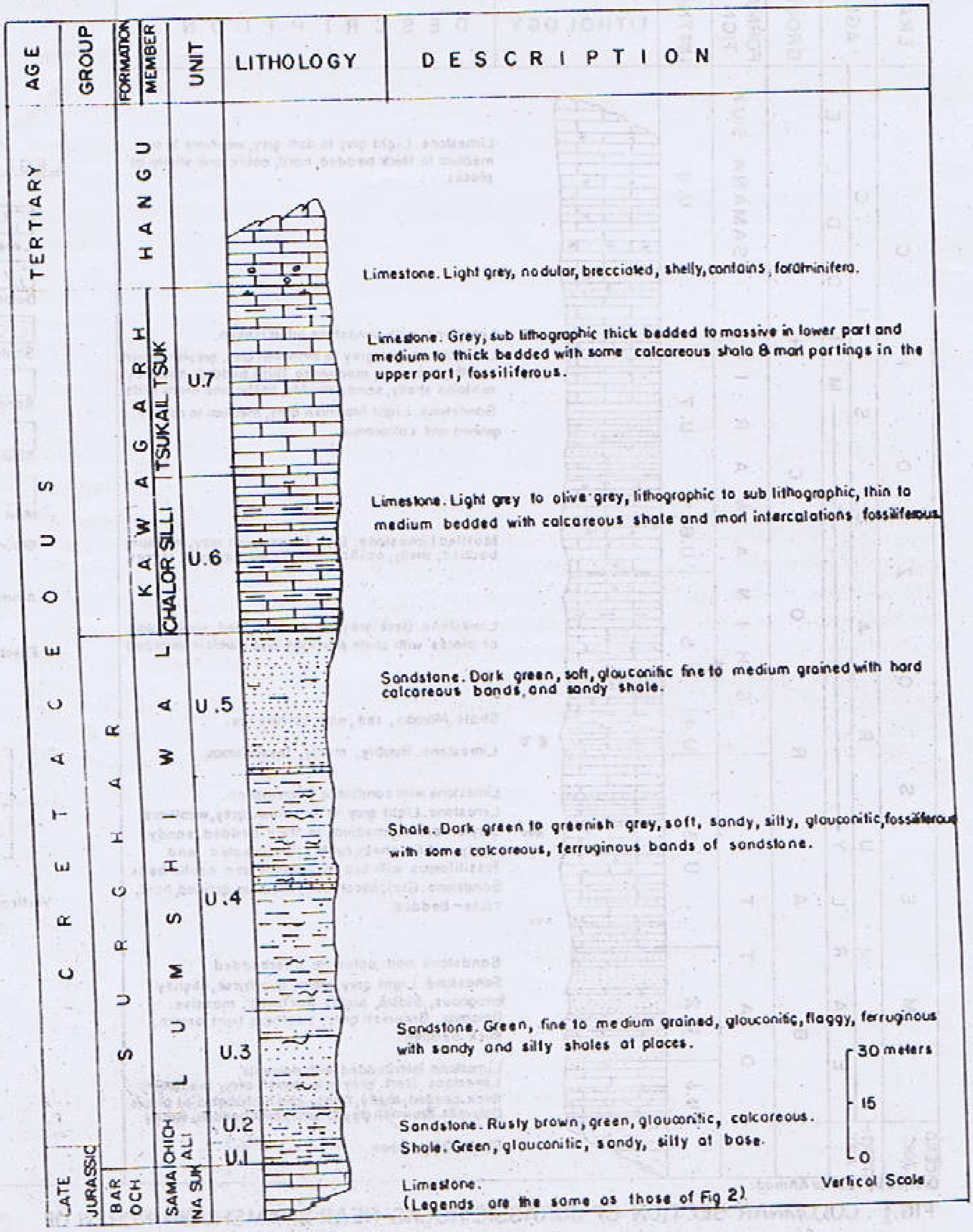

FIG. 2. COLUMNAR SECTION OF CRETACEOUS ROCKS IN EAST OF KHADIMAKH.

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PRELIMINARY SLOPE STABILITY STUDIES ALONG THE KOHALA—MUZAFFARABAD ROAD, AZAD KASHMIR

BY

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Abstract : *Geotechnical studies of a stretch of about thirty kilometers of a problematic road between Kohala and Muzaffarabad in Azad Kashmir, were carried out to identify areas of stable, unstable and potentially unstable zones. Most of the slope failures, at present, seem to be occuring in overburden due to drainage problems. The occasional outcrops of the Murree Sandstone and the Hazara Formation are problematic due to extensive fracturing within them. Most economical and feasible remedial measures are suggested to overcome the failure problems.*

INTRODUCTION

The Murree—Kohala—Muzaffarabad Road (Fig. 1) is the main route of transportation between Azad Kashmir and Pakistan. The road was constructed through difficult sub-humid and semi-arid mountainous terrain which is characterized by weathered and highly fractured rocks with extensive overburden and scree slopes. A number of huge slides occur along this road from time to time and block this important route for hours and sometimes for days. The major part of the road follows the steeply incised valley of the Jhelum River.

In recent years, the role of geomorphological and geotechnical investigations prior to road construction, has gained significant importance (Jones *et al* 1983). Since this road was constructed a long time ago when sophisticated engineering techniques were not developed for analyzing the slopes as well as their geotechnical solution of the instability problem, the landslides in the area are very frequent.

The area of study along the road is a mountainous terrain of sedimentary rocks exposing the Murree Formation (mainly sandstones and clays) and the Hazara Formation, (mainly slates) alongwith some alluvial deposits along the Jhelum River. Since the major part of the road exists in alluvium or scree accumulation on the slopes, the instability of the road is posed by circular slump failures. The present study categorizes various zones (as stable. unstable and potentially unstable) along the road, presents modes and causes of failure and suggests most economical and feasible remedial measures.

GEOLOGY

The Murree Formation covers about 80% of the mapped area and is separated from the Hazara Formation by the Main Boundary Thrust (MBT). The presence of well developed bedding and oblique cleavage in these rocks breaks it in flat pieces thus contributing to formation of scree slopes. In the axial planes of the folds, considerable shearing is exhibited.

The strength of the Hazara Formation varies considerably along and across the bedding. The Murree Formation is represented by coarse to medium grained massive and hard purplish sandstones with subordinate mudstones and claystones. The sandstones are well jointed in which calcite veins are common, the shales are splintery and thinly bedded, The Murree Formation is highly disturbed because of its location in the Hazara—Kashmir Syntaxis (Fig. 2) and the Main Boundary Thrust. The trend of the rocks, therefore, changes from place to place. However, the general strike is in the north west direction with dips varying from 45 to 75 degrees to west. Joints are widespread and filled with calcite and clay. The Murree Formation is folded into broad anticlines and synclines.

The Murree Formation, due to shales and fractured sandstones, presents most of the engineering problems in the area because of :

(i) Presence of high percentage of clay and shale and shear zones in them.

(ii) High tectonic stresses due to major structural elements i.e., syntaxis and thrust fault.

(iii) Poor drainage in shales giving rise to pore water pressures.

The Quaternary deposits are present along the Jhelum River and some of its tributaries in the form of terraces of which Barsala and Shahdara are the biggest (Fig 2). They consist of, mainly pebbles and cobbles of different sizes embedded in silty and sandy matrix. Generally cobbles are medium in size (8 cm to 23 cm) whereas boulders range from 92 to 120 cms. The thickness of deposits varies from place to place due to irregular topography. Both consolidated and unconsolidated alluvial deposits are present in the area.

Except for very steep slopes, all others are covered by angular weathering product that has been rolled down under the action of gravity. Due to relative steepness and rock uniformity, slopes of the Hazara Formation are less deeply burried under scree accumulation, whereas the Murree Formation is intermixed with deeply weathered shales. The tops of both the formations are covered by thin soil layer. These scree accumulation on the slopes are the youngest deposits.

GENERAL SLOPE CONDITIONS

The existing slopes in the area of study exhibit different stability condition in different rock types and formations. The Hazara Formation as compared to Murree Formation makes steep slopes or cliffs i.e. near Chattar Domel (479370) and opposite to Dulai Camp (515260), the under cut escarpment slopes make very steep angles.

The contact of the Hazara Formation with the Murree Formation, wherever exposed, is marked by break in the valley slope, below which Murree Formation makes gentle rock or debris slopes. The slaty rocks are differentially weathered and eroded. The depressions mark pre-existant argillaceous, while ridges are of calcareous slates.

The outcrops of the Murree Formation have been deeply dissected by the Jhelum River and its hundreds of well devoloped tributaries. Regionally the outcrops of the Murree Formation manifest dip slopes. The formation is rapidly undergoing denudation through mass wasting and differential erosion, owing to a weak unit. The outcrop is commonly burried under thick masses and stream laid alluvium.

The hard, resistant rock (sandstone) makes ridges, while soft rocks (shales, siltstones etc.) have been eroded to leave deep depressions or hollows. The slopes on Murrees are gentle with few escarpments at places, particularly in massive sandstones. The major part of the slopes along the road is covered with alluvium, where slump failures are very frequent; these failures range from a few meters to one kilometer (Kohala slide). Most of the slides are on upslope side, with a combination of number of small circular failures, whereas at places, the down slope failures have also been observed. The successive sliding in Murrees at certain places has rendered the rock material to almost huge masses of soil on the slopes, which undergo debris flow, having saturated in rainy reasons. High rate of percolation, demonstrated by the development of sinkholes on certain slopes and bad drainage is also the contributing factor towards instability of the said slopes. The gentle or naturally well drained steep slopes in alluvium or screes, because of thick vegetation, are quite stable.

Slumping in the slopes of the Hazara Formation is not common because of its favourable engineering behaviour and the geologic setting in the field.

The plane failures in the project area are very few on account of few outcrops along the entire strip of road. In addition, the basic conditions for the plane failures are rarely fulfilled. The orientation of discontinuities is unfavourable for such failures. The outcrops of Murree sandstone, being massive, do not provide release surfaces and failure planes for such phenomenon.

The undulating and rough joint surfaces are the caracteristics of the area which also diminish the chances of such failures. Some discontinuities at places are oriented so as to form wedges, but these are unlikely to fail on account of higher friction values, owing to surface roughness.

Toppling and rockfall are of minor importance in the area, because very few examples are found.

SLOPE STABILITY ANALYSIS

The entire project area was thoroughly investigated to know the stability conditions prevailing and their variation throughout the area. In order to discriminate the stability number in different portions of the road, the entire road was divided into various zones of stability on the basis of different stability criteria. Keeping in view the geotechical character of the slope material and the other field conditions, three types of zones are marked on Figs 2 & 3, and are described as under :

1. Stable Zones
2. Unstable Zones
3. Potentially unstable Zones

1. STABLE ZONES

Stable zones were declared having gone through detailed geotechical assessment in the field, based on various engineering geological and other field conditions The stability numbers of the said zones were understood to be substantially higher than the number at the equilibrium.

The total mapped area comprised of 22 stable zones along the road. These zones are represented by the symbol "Z" and marked as "S" and have the following numbers :

Z_1, Z_3, Z_5, Z_7, Z_6, Z_{11}, Z_{13}, Z_{15}, Z_{12}, Z_{21}, Z_{23}, Z_{25}, Z_{26}, Z_{31}, Z_{33}, Z_{35}, Z_{27}, Z_{38}, Z_{40}, and Z_{42}.

It has been noticed that all above stable zones possess almost the same set of stability conditions except in a few cases. Most of the areas of the mentioned zones exist in over burden whereas rock outcrops of Murrees and at places Hazara Formation are also present. The slopes are stable because of the following :

1. The slopes are relatively gentle
2. Slope height is generally small

3. Almost all the slopes are thickly vegetated, percolation through slope material is nominal and the slopes are being drained through surface run-off.

4. The surface drainage is naturally controlled, and consequently the problem of infilteration, pore-pressure and eventual reduction of shear strength is automatically minimized.

5. The deposits are well cemented and compacted, thus offering high shear resistance.

6. Sirike of the rock outcrops at most of the places is at righ angle to the road allignment which is the most favourable orintation for the stability of slope.

7. Beds dip away from the road.

8. Discontinuities, other than bedding planes daylighting on slopes have rarely been observed.

9. Discontinuities are rarely oriented so as to form wedges and the line of intersection of the wedges are dipping away from the slope or the shearing strength along these lines are found to be higher because of their roughness, undulation etc.

10. Massive or thickly bedded rocks do not provide release surface for the rock mass to slide through plane failure in the form of slabs.

The areas falling under these stable zones have not been considered for detailed studies. Unstable and potentially unstable areas were undertaken for detailed field studies supplemented by laboratory investigations. For the evaluation of index and strength properties of the materials occuring at different zones, representative samples were taken, preserved and transported to the laboratory.

Three samples from each zone (top centre and bottom) were taken so that the engineering behaviour of the entire slope material may be depicted as precisely as possible. The samples are numbered as Z_{s1}, Zs_2 and Zs_3; where symbol Z represents the particulars zone from which the sample was taken and suffixes S_1, S_2, S_3 represent locations of samples from bottom to top respectively.

The sampling detail is given in table 1.

TABLE 1

Zone Number	Location	Sample Number
Z6	495E 375N	Z6S1, Z6S2, Z6S3
Z12	512E 331N	Z12S1, Z12S2, Z12S3
Z14	510E 324N	Z14S1, Z14S2, Z14S3
Z18	514E 305N	Z18S1, Z18S2, Z18S3
Z20	513E 2°5N	Z20S1, Z20S2, Z20S3
Z22	507E 269N	Z22S1, Z22S2, Z22S3
Z34	539E 100N	Z34S1, Z34S2, Z34S3
Z39	530E 094N	Z39S1, Z39S2, Z39S3
Z41	532E 112N	Z41S1, Z41S2, Z41S3

In the engineering laboratary, the selective samples collected from the field were put to various tests listed below:

1. Natural moisture content
2. Particle size distribution
   (a) Sieve analysis
   (b) Hydrometer analysis
3. Direct shear test
4. Atterberg's limits
5. Specific gravity test
6. Compaction test for moisture density relation.

Direct shear and Atterberg's limits tests were carried out on the samples after separating gravels. The test results of various soil samples are presented in the form of "Summary of Test Result", (table-2).

2. UNSTABLE ZONES

The slopes which are invariably active in rainy season or throughout the year are termed as unstable and marked on Fig. 2 & 3. These are numbered as Z_{12}, Z_{16}, Z_{20}, Z_{22}, Z_{39}, and Z_{41}. These areas were found active during the field work.

The different causes of slumping in these areas are summarised as below :

1. Steep slopes with greater heights in overburden slopes is responsible for such large scale failures in the said zones.

2. Water entering through tension cracks present behind the upper edge of the slopes acts as a triggering factor. producing pore pressure and decreasing shear strength enormously.

3. The slid material of the upper slope adds weight to lower slope, thus increasing the driving moment and resuring into slide.

1

4. Presence of loose slid material at the slopes which increases percolation.

5. Presence of clay, which facillitates sliding having saturated on account of slipery minerals in it.

6. Lower values of cohesion and friction as is evident from laboratory results.

7. In saturated condition, moisture content is very close to its liquid limits, hence the material starts flowing during rainy season.

8. Small vegetation cover.
9. Bad surface drainage.

3. POTENTIALLY UNSTABLE ZONES

These are slopes, possessing stability number slightly above equilibrum, and likely to fail on account of little disturbance in equilibrium. The safety of these slopes is slightly over one.

The field and laboratory investigations revealed that there are sixteen potentially unstable zones which are marked on Fig. 2 & 3 and numbered as Z_2, Z_4, Z_6, Z_8. Z_{10}, Z_{14}, Z_{16}, Z_{18}, Z_{24}. Z_{26}, Z_{28}, Z_{30}, Z_{32}, Z_{34}, and Z_{36}.

Most of these areas exist in rock outcrops while others are in overburden slopes. These slopes are declared as potentially unstable because of the following :

1. The rock outcrops are highly jointed and orientation of joints forms wedges which are fulfilling basic condition of the failures i.e., the line of intersection is daylighting on the slope, but the friction value is higher due to surface roughness. As soon as the φ value decreases due to weathering or pore pressure, the wedges slide down, as it is obvious from previous examples.

2. Numerous irregular and rectangular blocks have resulted because of extensive jointing in the Murree sandstone and Hazara Formation. These blocks are likely to topple or roll down when detached from the rest of the mass as it happens from time to time.

3. At some places, the rocks are moderately to highly jointed and slopes at the moment appear to be stable owing to tight or infilled joints. The continuous penetration of rain water washes the infilled material, thus leading to destablize the rock masses.

4. The under cutting of river at certain places on the down slopes is going to disturb the stability and needs to be controlled in time.

5. Slopes in the overburden are likely to undergo slumping because of the bad surface drainage, high rate of infilteration, and soil erosion, particularlv at the toes, and breakage of the retaining structures.
6. The low value of C and ϕ of the slope material is also an indicator of the instability.

DISCUSSION AND CONCLUSION

The geotechnical study of the area revealed that most of the problematic slopes are covered by overburden and are failing through slumping mechanism. Surface erosion and lack of drainage control of the area contribute towards circular or slump failures and debris flows,

Presence of gravels, cobbles and boulders at the surface retard run-off, thus increasing the percolation into loose overburden on the slopes. The clay content in the slope material also affects the subsurface dıainage, creates pore pressure and consequently diminishes the resisting moment of the sliding mass.

Most of the unstable slopes are active only in rainy season, which otherwise are stable. Mainly, the upslope failures are more frequent, because the excavation of road in the valley slope has rendered the slope unstable, on account of removing the load from the toe (Hoek and Bray 1981), thus reducing the resisting moment. The down slope failures are rare and are because of erosive action of river i.e. near Rara, where the road sinking is due to t he erosion of the softer material from the toe. The presence of the Murree Formation (weak and liable to extensive weathering and erosion) all along the road is also found to be the basic reason of large scale landslips. The slopes in outcrops particularly of sandstones and Hazara Formation are less problematic.

Keeping in view the economy, sensitivity of the road and the geologic condition of the area, following remedial measures are considered as an apprnpriate solution to the problem ;

1. Surface drainage has to be controlled at the earliest, particolarly in the unstable and potentially unstable zones by diverting the drainage away from the slopes.
2. Plantation and grassing should be made in order to retard seepage and prevent surface erosion. Grassing Is more important as it has rapid growth and covers the slopes in a very short period.
3. Retainigg walls are desirable at all the sites of slumping in scree and alluvial deposits along the road.
4. Relief walls should be installed at the slope of Kohala slide, so that the pore pressure may be avoided during the rainy season.
5. Comparing the sensitivity of the road and the cost, piling may also be considered as a remedial measure for the Kohala landslide.

TABLE 2
Summary of Test Results

LOCATION	SAMPLE	M.C. % IN DRY season	M.C. % IN RAINY season	PARTICLE SIZE DISTRIBUTION CLAY .005 mm in %	SILT 0.074 mm in %	SAND 4.76 mm in %	GRAVEL 76.0 mm in %	ATTERBERG LIMITS L.L.	P.L.	P.I.	SHEAR BOX C PSI	Φ DEG	COMPACTION TEST TYPE	MAX. DRY DENSITY gm/cm²	OPT M.C.	SP GRAVITY
495 E	$Z_{6}-S_{1}$	4.59	17.27										Silty Clay			
375 N	$Z_{6}-S_{2}$	4.80	17.47										"			
	$Z_{6}-S_{3}$	4.90	17.02										"			
512 E	$Z_{12}-S_{1}$	10.52	34.92	22	233	11	44				2.2	9.5	"			2.61
331 N	$Z_{12}-S_{2}$	10.11	35.29	23	22.5	10.9	44				2.4	9.00	"			
	$Z_{12}-S_{3}$	10.91	34.71	21	21	11.5	45				2.1	8.99	"			
510 E	$Z_{14}-S_{1}$	3.63	14.77	13	18	17	52				1.5	10.0	Sandy Silty	2.171	7.65	2.65
324 N	$Z_{14}-S_{2}$	3.85	14.99	11	16.5	17.5	54						Clay			
	$Z_{14}-S_{3}$	3.15	14.45	12	17	16.9	51				1.4	10.3	"			
514 E	$Z_{18}-S_{1}$	4.36		16	21	12	51						Sandy Clay	2.153	11.3	2.64
305 N	$Z_{18}-S_{2}$	4.65		14	20.5	11.8	50				1.6	9.8				
	$Z_{18}-S_{3}$	4.10		15	21	11.02	49						"			
513 E	$Z_{20}-S_{1}$	9.60	21.60	37	16	9.63	37.37				3.2	9.5	Clay			
285 N	$Z_{20}-S_{2}$	9.25	21.88	35	16.24	10	40						"			2.67
	$Z_{20}-S_{3}$	9.95	21.28	35	15.02	9.45	39				3.0	9.2	"			
507 E	$Z_{22}-S_{1}$	9.65	11.30	22.5	13.5	21	43	35	25	10	2.0	9.0	Sandy	1.981	11.25	
269 N	$Z_{22}-S_{2}$	9.90	11.65	23	12.9	20.08	42.50	34	24	10			Clay			
	$Z_{22}-S_{3}$	9.30	11.05	21.95	12.02	21.5	41	33.50	22	11.50			"			
539 E	$Z_{34}-S_{1}$	5.63	21.2	18	18	21.50	41	20	12.73	7.27			Sandy			
100 N	$Z_{34}-S_{2}$	5.80	20.80	17.5	18	22	42	21	12.75	8.25	1.2	10.0	Silty Clay			
	$Z_{34}-S_{3}$	5.40	21.30	18.90	17.5	22.1	43	19.5	13	6.5			"			
538 E	$Z_{39}-S_{1}$	4.70		19	13	20	48	29	20.5	5.40			"	2.098	11.60	
094 N	$Z_{39}-S_{2}$	5.00		18.75	11.99	19	46.25	28.5	19	19.5	1.5	9.5	"			
	$Z_{39}-S_{3}$	4.40		18.60	12.02	18	47	27	19	8			"			
532 E	$Z_{41}-S_{1}$	4.28		8.5	18.5	15	58	25	18	7	1.0	11.0	Sandy			
112 N	$Z_{41}-S_{2}$	4.00		9.0	17.75	14.06	57.65	21.50	18.25	6.25			Clay			
	$Z_{41}-S_{3}$	4.01		8.3	17.08	14.90	56	23	17.75	5.25			"			2.66

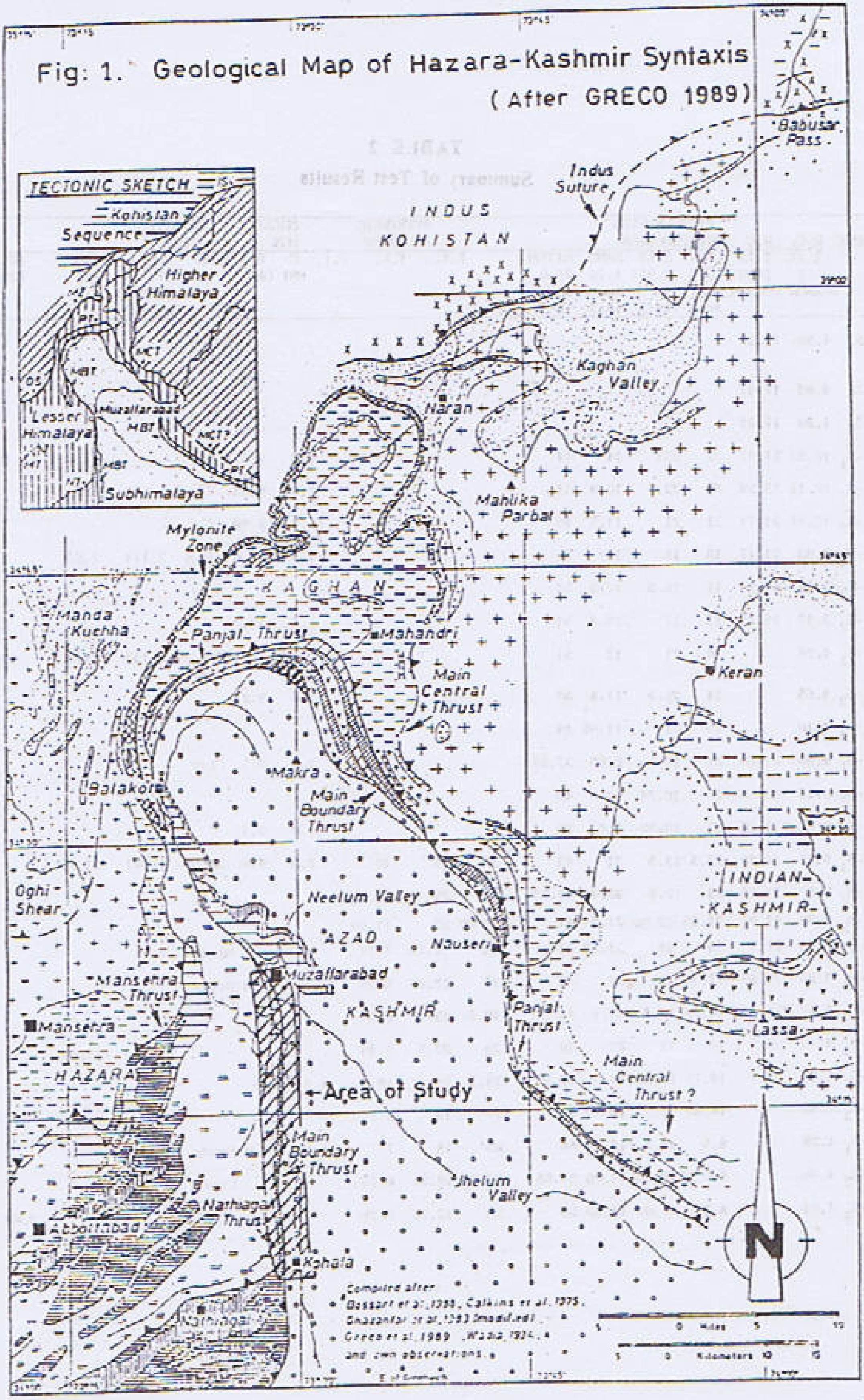

Fig: 1. Geological Map of Hazara-Kashmir Syntaxis (After GRECO 1989)

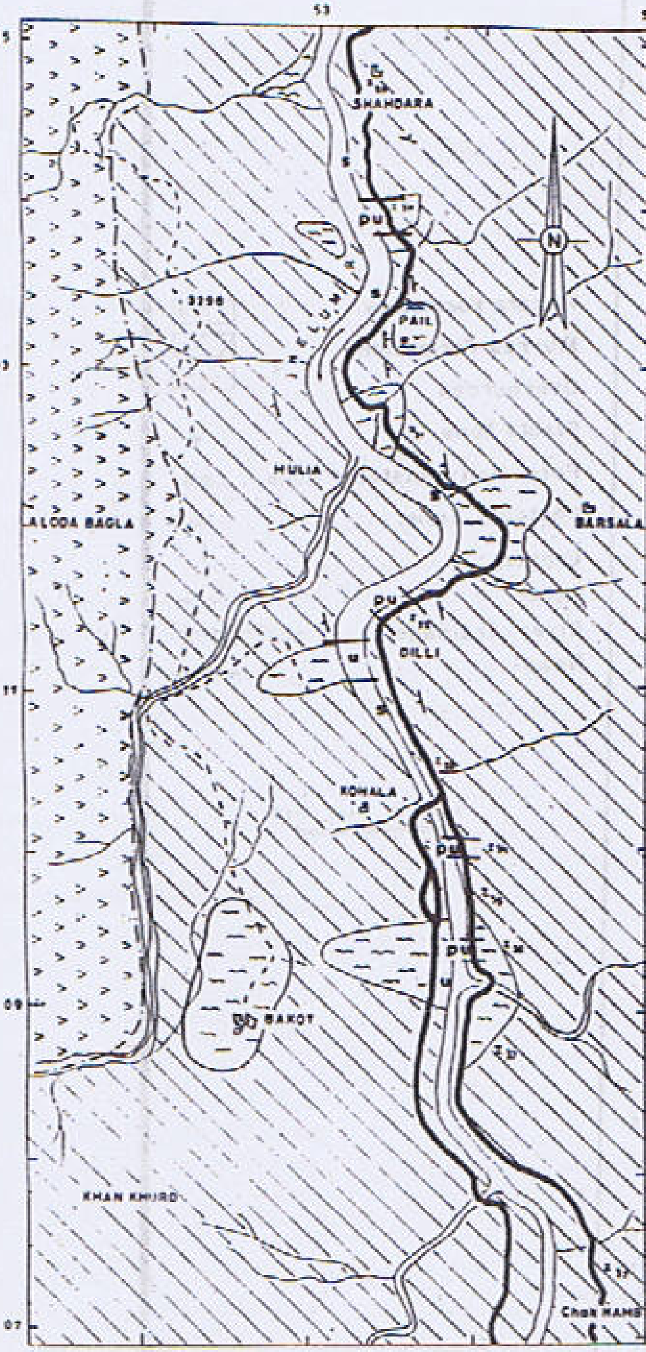

FIG. 2

GEOLOGICAL MAP OF MUZAFFARABAD AREA

SHAHDARA TO KOHALA-CHAK NAMB

Hazara Formation
Murree Formation
Overburden
Stable Zone s
Potentially unstable Zone pu
Unstable Zone u
Contact
Fault
River
Road / track
Locality

1040 0 2080 ft

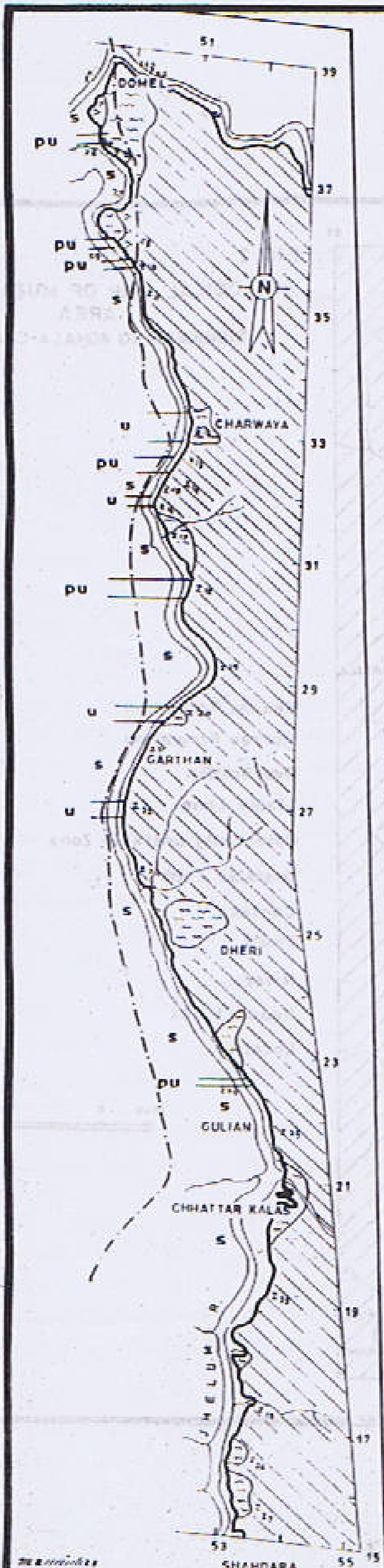

FIG. 3

GEOLOGICAL MAP OF MUZAFFARABAD AREA DOMEL TO SHAHDARA

Hazara Formation
Murree Formation
Overburden
Stable Zone — s
Potentially unstable Zone — pu
Unstable Zone — u
Contact
Fault
River-drainage
Road

2080 0 feet 4160

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GEOPHYSICAL STUDY IN LAHOR-SERAI AREA OF LEAD-ZINC ORE

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Abstract : *Gravity and magnetic survey carried out in Lahor-Serai area of Besham for the search of lead-zinc deposit shows that structurally controlled lithologic complexity deteriorates the quality of signal. Similar nature of signal over the ore and other lithologies causes a major confusion in isolation and identification. Swarm of pegmatites and structural complexities are responsible for the obliteration of ore and geophysical experimentation.*

INTRODUCTION

The Lahor-Serai area of Besham spreading over 1,48,500 square meters contains small exposures of lead-zinc ore at northern and southern ends. The intervening area mostly covered by overburden is characterised by rough terrain and steep slopes. Structurally, as it has undergone several phases of deformation (Fletcher 1985), the complexity so emerged is probably the major hurdle in unravelling the distribution of the ore within the area. The complexity is represented by the repetition of rock units, isoclinal folds in pegmatites (new in the form of pods and lenses), concentric intrafolial fold, series of open monoclines, thrust with imbricated behaviour, extensional faults, amphibolites intrusions along the thrust planes. The different lithologies exposed in the area have been grouped into three formations by Fletcher (1985) ; quartzite formation, sulphide formation, and the pelite formation. The ore (combined Pb-Zn content is upto 11.4%) zone which is about 2 meters thick is characterised by sulphide minerals (sphalerite, galena, pyrrhotite, and pyrite), and generally is associated with the basal part of the sulphide formation (about 16 meters thick) which overlies the pelitic formation and is underlain by the quartzite formation (about 8 meters thick). This is a common observation that the pegmatitic bodies found in the area are the certain sites of deformation of the ore zone.

GEOPHYSICAL APPROACH

The intensity of the geophysical signal generated on any prospective zone in the surface geophysical survey is dependent upon the contrast in physical properties (like density, susceptibility, electrical conductivity etc.) between the ore and the host medium, the mineral assemblage, geometry, the probable thickness and depth of occurrence of the ore deposit, the nature of the host rocks, structure system, and the oxidation / leaching effects. The intensity of signal related to the ore is usually low because of the reason that the ore deposit makes small volume fraction of the rock. The signal becomes further complicated due to the interference of other factors Sometimes the accumulative noise is so high that the recognition of signal becomes very difficult. This seems to be the probable situation in our case as the structural complications have effected greatly the lithologic sequence.

GENERALISED MODEL

Taking into account the above explanation, the following simple generalizations about the distribution of the ore within the study area can be made.

1. The ore is exposed at the northern and southern ends, while the intervening 400 meters is mostly covered by overburden. Continuity of the ore from one end to the other as defined by Fletcher (1985) may be in the form of a sheet, or structurally controlled patches.

2. The ore zone is about 2 meters thick with a halo of upto 6 meters, i e. Pb-Zn is also expected to occur in the overlying sulphide-rich feldspathic granulites and the underlying layered calcsilicate quartzite.

3. Isolated pods of sulphide-rich feldspathic granulite occasionally occur at the contact between Quartzite formation and the carbonates, giving some indication of the occurrence or ore.

4. The thickness of the succession overlying the Pb-Zn massive sulphide is about 21 meters.

5. The mineral-assemblage of the ore includes sphalerite, galena, pyrrhotite, pyrite with subordinate chalcopyrite.

This is an oversimplified picture which in reality has been distorted largely by different deformational phases. Probably this is the reason that three holes (DH_2, DH_3 and DH_4) out of four drilled in the area did not encounter any ore. The drill hole DH_1 which proved successful showed repetition of the rock units. Adit and a cross-cut proposed by Fletchr also failed, probably because of structural complications.

DATA ACQUISITION AND PROCESSING

In this difficult area the use of gravity and magnetic methods is an unlikely approach, however, the existing contrasts in density and susceptibility, and limitations of available facilities allowed to test the methodology. For the acquisition of gravity and magnetic data the area was covered densely by a rectangular grid, and the observations were made on grid nodes at an interval of 15 meters. The data were reduced to the Base established at B-3 by applying conventional corrections. For calculating gravity anomalies the surface density was used 2.6 gm/cc.

GRAVITY

The Bouguer anomaly map with contour interval of 0.1 mgal (Fig. 1) has been prepared with surface density 2.6 gm/cc. This shows maximum (4.5 mgals) and minimum (−0.5 mgal) values in the north-west and south-eastern zones respectively. The Bouguer anomaly decreases generally towards the south east with varied gradients. The most prominent features that can be observed in the folded nature of a bench of contours particularly to the south of Line 21. These almost east-west oriented contours show sharp gravity decrease towards south. Between Lines 14 to 11 there are four prominent gravity lows which are aligned in such a way that they appear parallel to the (east-west) axis of the topographic ridge. To the north of Line 21, there is a distribution of elongated (N-S) gravity lows and highs. Two gravity noses are also developed, which run north-west respectively. The former seems to be connected with the north-south directed axis of the strong gravity low. Between Lines 1 to 4 the east-west oriented bunch of contours shows a sharp gradient towards south. The steep gradients are believed to be the indication of faults which probably run north-south and east-west. A major north-south oriented fault seems to be linking line mark F in the north line mark B in the south. The north-east oriented off shoot of this fault is also observed starting from the central area. There are two east-west running faults ; first, coinciding safely with line-3 and the second with line-13. If geological assumption of amphibolite is taken into consideration, the existence of amphibolite bodies along north-south marked faults would narrate these faults the thrusts with western block as the hanging wall, and east-west running faults then may be the normal faults. The existence of normal faults on the margins of the topographic ridge suggests that topographic feature could be a result of the horst structure. In the area of this structural feature positive anomalies (the axis of which coincides with line-7) are separated from negative anomalies (the axis is oriented WNW-ESE) by swinging contours due to the presence of carbonate and pegmatite intrusive bodies on southern and northern sides, respectively. The negative and positive anomalies in the northern half of the area could be attributed similarly to quartzite/pegmatite and sulfide formation under the overburden.

Fig. 2 represents the residual gravity map of the area. It shows a wide distribution of both positive and negative anomalies. These anomalies with a magnitude of less than 0.7 mgal are generally elongated in shape. Comparison of the residual map with the surface lithology indicates that the negative anomalies are associated not only with the sites of lead-zinc ore but also with pegmatites and quartzites. Whereas the positive anomalies unlikely are found uncorrelated with lithology. This state of affairs has caused a difficulty in identifying promising zones solely on the basis of gravity, thus, magnetic response was supposed to be considered as the constraint for identification.

MAGNETIC

As can be observed from total intensity magnetic map (Fig. 3) the concentration of strong magnetic anomalies is predominantly confined to the southern half of the area. The control portion which is mostly covered by overburden shows low magnetic relief and suggests that this part is magnetically quite as compared to its surroundings. A similar situation exists on the lead-zinc exposures magnetic effect generally varies from -500 to $+500$ gammas.

The strong magnetic anomalies are commonly produced due to an enrichment of ferromagnetic materials in the rocks. In the present case, magnetite and/or pyrrhotite could be considered responsible for the strong magnetic anomalies. The mineral pyrrhotite depending upon the sulphide content may also behave as a diamagnetic mineral. As exact data on its composition from within the study area is lacking, its contribution towards the magnetics is not fully understood. However, the low magnetic relief on exposed lead zine ore of which pyrrhotite is one of the constituent suggests that it may not be acting as a ferromag. etic mineral. Thus, magnetite is the sole agent of magnetic anomalies, and occurs especially in carbonates with varied concentration. This indirectly implies that magnetic source which has been determined by various methods lies in carbonates at an approximated depth of 10 to 20 meters. The occurrence of sources at these depths, even bearing the structural complications, is substantiated by the stratigraphic sucession of Fletcher.

Since the positive anomalies have appeared in conjunction with negative anomalies, the sporadic source seams to be dipole in character. Overlooking the influence of remanence and considering normal magnetisation of causative bodies the analysis of the anomalies in terms of susceptibility, magnetite content, depth and dipning dipoles are given in Table-I. The depth estimates have been obtained using different approaches (Babu *et al.*, 1986 : Peters, 1949) and Half-width rule, whereas the dips, susceptibility, and magnetite content of the anomalous bodies are calculated on the basis of a technique given by Babu *et al* (1986). The susceptibility varies from 0.03 to 0.01 egs. and correspondingly magnetite centent varies from 4 to 12%.

The magnetic picture suggests that the strong anomalies are related with sulphide formation and low magnetic response corresponds with quartzite and pegmatite. The overburden mav also be playing a role of anomaly attenuator. On the basis of this correlation it appears that the area south of line-12 and the area north of line-30 are predominantly occupied by sulphide formation (carbonate and sulphide-rich feldspathic granulite). On line-B between lines 21 to 29 the existence of strong anomaly also represents the same lithology.

DISCUSSION AND CONCLUSION

Since the area lies just south of MMT and has undergone multiphase deformation, the lithostructural complexities are quite obvious. The gravity and magnetic results point out these complications and suggest that Fletcher's stratiform model (1985) was a basic deviation from reality. The structurally controlled rapid variation of lithology within short distance, and extensive magnetic activity in the area divert the attention to the model of Chowdhry *et al* (1983), that the lead-zinc minsralisation could be in the form of skarn and/or hydrothermal veins The failure of previously drilled holes DH2, DH33, and DH4 to varied depth, based on stratiform model, and associated with positive gravity and magnetic signal in this study, gives a clue of obliteration of the Fletcher model. The hole DH-1 which showed repeated strata and consequently twice encountering of the ore at different shallow depths, and the other surficial showing of the ore in the northern boundary of the area are modestly related with gravity and magnetic lows. When this observation was typified and used as a pilot message in the area it also faced the consequence of invalidation. Conclusively, it appears that the mineralisation in the area has a random distribution and possibly follows Chowdhry *et al* (1983) model and needs extensive multifold geophysical work for the detection of probable sites.

TABLE 1

Cross-Section	Magnetic Amplitude in Gammas	Suscepti-bility K × 10⁶	Volume % of Magnitute	Average depth (Meters)	Magnetically determined Dip	Geological Dip
A-A′	5200	31,200	10.4%	11	46°NE	40°NE
B-B′	5500	33,000	11%	11	66°SE	55°SW
E-E′	3500	21,000	7%	16	48°NE	50°NE
G-G′	3500	21,000	7%	—	—	—
H-H′	—	—	—	10	40°NE	Overburden
I-I′	—	—	—	10	55°NE	Overburden
L-L′	2500	15,000	5%	7	27°NE	32°NW
P-P′	4200	25,000	8.4%	—	—	—
Q-Q′	—	—	—	15	40°NE	45°SE

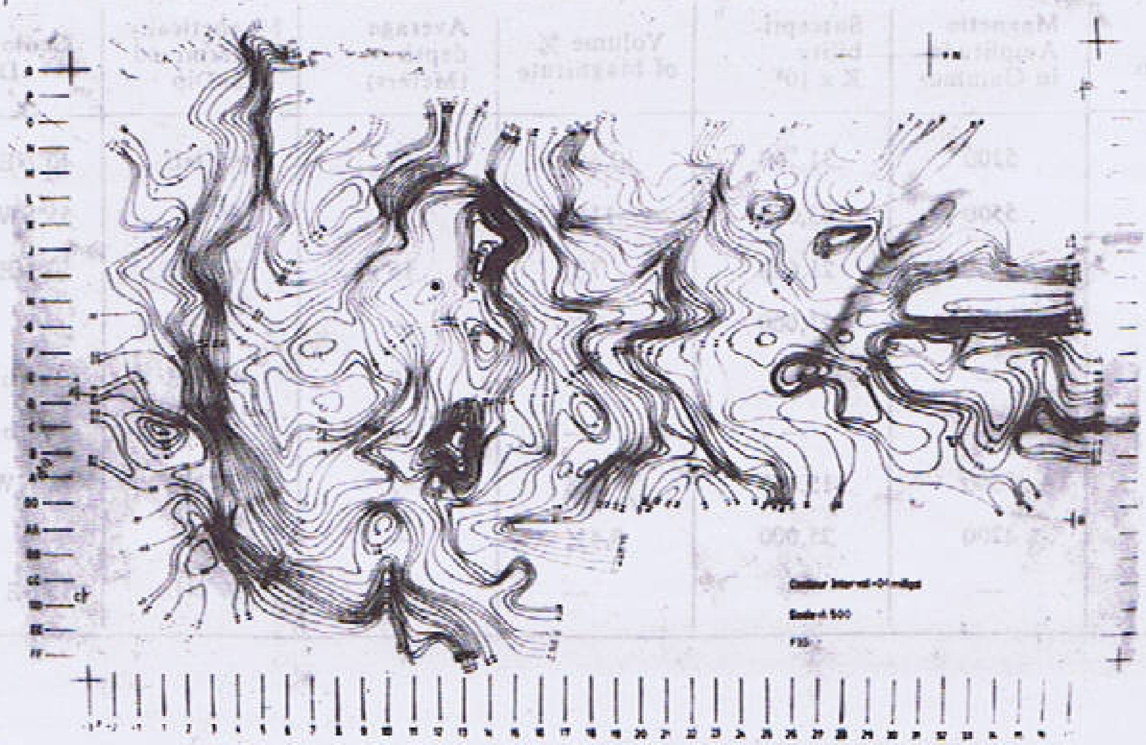

FIG.1. BOUGUER ANOMALY MAP OF LAHOR-SERAI AREA, BESHAM.

FIG.2. RESIDUAL GRAVITY MAP OF LAHOR-SERAI AREA, BESHAM.

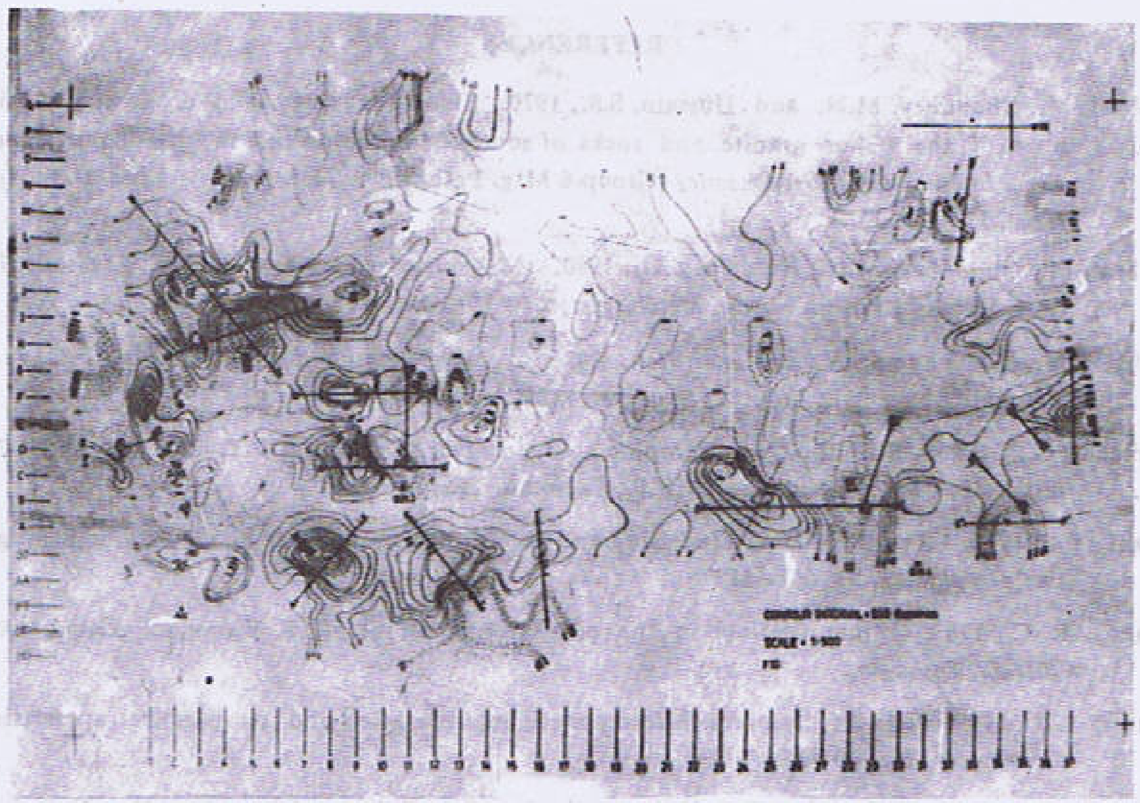

FIG. 3. TOTAL INTENSITY ANOMALY MAP OF LAHOR SERAI AREA, BESHAM.

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VARIATION OF POISSON'S RATIO ACROSS VARIED LITHOLOGY – A CRUSTAL STUDY

BY

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Abstract : *Poisson's ratio being a function of Vp and Vs is exceptionally low in quartz and high in hydrous minerals, and fluctuates significantly over varied mineral assemblages. This behaviour of the Poisson's ratio provides an invaluable control in the seismic study of lateral lithological variations. Model array of the Lewisian Units Seismic Traverse in the Lewisian Metamorphic Complex of NW Britain shows significant change in the Poisson's ratio across varied lithology, and suggests hydrated nature of the lower crust. Study of Poisson's ratio in Pakistan would reveal convincing evidence to provide crustal model.*

INTRODUCTION

Since the aim of many seismic surveys is to definne the physical state of materials deep in the earth, the more variables that can be defined the more tightly the physical state can be constrained. A system as complex as the earth, which requires for its description a whole series of variables (such as the composition, rock texture, pores and cracks, the nature of saturating fluids), poses difficulty for any analysis based solely on one parameter, namely the compressional or P-wave velocity—Vp. Of course, P-wave have contributed greatly in defining the earth, particularly the crust, and are still the major source of information. This is due to the reason that most artificial sources generate more compressional energy than shear energy and the compressional energy or P-waves give rise to readily detected first arrivals.

However, a wide range of Vp in one rock type of Vp over laps in different mineral assemblages (Christensen and Fountain, 1975) suggest that for a detailed analysis of lithology or physical state of materials further constraining parameters are required. Thus, the share or S-waves generated alongwith P-waves by mode conversion (White and Stephen 1980) in most of the seismic experiments, are commonly used as an extra control. Since the nature and characteristics of S-waves are different from those of P-waves, the effect of different mineral assemblages or physical situations will be different in both cases. For example, an increase in the quartz content of a rock will decrease Vp but increase Vs (Christensen and Fountain 1975). Both velocities decrease in a porous medium but the saturation of pores and cracks with water or gas will effect Vp and Vs differently

(O'Connel and Budiansky, 1974, Tokoz *et al.*, 1976, Nur and Simmons, 1969).

A third constraint, derived from the combination of Vp and Vs, is the Poisson's ratio

$$\alpha = \frac{0.5\ R-1}{R-1} \qquad R = (Vp/Vs)^2$$

which is also used for lithological studies. In the majority of rocks and rock forming minerals it ranges from 0.19 to 0.40. However, quartz is an exception, with $\alpha = 0.08$, it concentatian in a rock produces a significant drop in Poisson's ratio (Christensen and Fountain 1975). The value of Poisson's ratio is also affected by physical changes in rocks, like geometry of cracks and their saturation.

Poisson's ratio in Lewisian rocks

To test association between Poisson's ratio and lithology, example of the basement crystalline rocks of the Lewisian metamorphic complex (NW Scotland) is taken into consideration. The significance of these rocks can be realised from the equivalence established geologically and geophysically, between different rock units and the crustal layers (Smith and Bott 1975; Bamford *et al.*, 1978, Bowes 1978, Hall and Simmons 1979; Hall and Al-Haddad 1979). The complex is divided into three main belts (Peach *et al*, 1907) ; The northern and southern belts predominantly of quartz-feldspathic gneisses (Laxford assemblages) are separated tectonically by the central belt of pyroxene granulites and retrogressed equivalents (Scourie assemblage, amphibolished assemblage + Inver assemblage), and the boundary between northern and central belts (Fig. 1) referred to as the Ben Stack Line contains consentration of pegmatites and granites (Bowes 1978).

Smith and Bott (1975) analysed refraction data of North Atlantic Seismic Project (NASP) and correlated the observed upper and middle crustal P-wave velocities of 6.1 km/s and 6.5 km/s with the Laxford assemblage and Scourie assemblage of the complex, respectively. Bamford *et al* (1978) gave further support to that view, based on the interpretation of the Lithospheric Seismic Profile in Britain (LISPB), and proposed a three layer model for the crust. Hall and Simmons (1979), and Hall and Al-Hadded (1979) subsequently confirmed these results.

The P-wave velocity distribution limited to 3 km depth in the northern and central belts, obtained by the ray-tracing technique (Cerveny *et al* (1974) applied on the data of Lewisian Units Seismic Traverse (LUST), is presented in Fig. 2. The corresponding S-wave velocity distribution obtained with the same scheme is also shown in Fig. 3. The most noticeable feature of these illustrations is that the major structure of both velocities is almost similar. Laterally, the Scourie assemblage of the central belt reflects higher velocities than those reflected by the Laxford assemblage (northern belt). In retrogressed rocks of the central belt, the velocities decrease progressively (Vp more than Vs) and reach a minimum over granites and pegmatites.

The Poisson's ratio distribution shown in Fig. 4, obtained by cambining these velocity models, gives a resolved association between lithology and physical parameter. The northern and central belts are clearly differentiated by subhorizontal and vertical contour patterns, respectively. An anomalous low is produced over granites and pegmatites. It is interesting to note that Poisson's ratio decreases laterally in the central belt, and vertically in the northern belt. The lateral decreas: can be related with dominant effect of changes in the reconstituted mineralogy due to retrogression, and vertical decrease with the closure of cracks the volume concentration of which decreases with depth due to overburden pressure (Toksoz *et al* 1976).

Since the vertical gradient at 2 km depth becomes minor, it can reasonably be supposed that the effect of cracks at a depth of 2 km is minimal. Therefore, the Poisson's ratio observed at that depth may be free from cracks effect and is more representative of the rock composition. In scouric assemblage, apparently Poisson's ratio is 0.27, and this estimate would certainly be an underestimate, because the value is taken for roughly 5 km range at the boundary (maximum ray penetration) between sampled and unsampled regions. An increase in the accuracy of this figure would require an extrapolation into the unsampled region. In retrogressed rocks Poisson's ratio varies fastly (northwards) from 02.7 to 0.235 with an average value 0.25. Over granites and pegmatites it is 0.235, whereas in quartz-feldspathic gneisses increases slightly to 0.24. This variation in Poisson's ratio corresponding to laterally varied lithology suggests that may be used as a diagnostic tool—a third control in seismic experiments.

In retrogressed rocks, pyroxene is replaced by amphiboles (Sutton and Watson 1962, Beach 1974). Since Poisson's ratio for amphibole ($\alpha=0.29$) is much higher than that of pyroxene ($\alpha=0.21$), the progressive increase in the amphibole/pyroxene ratio due to retrogression should demostrate a corresponding increase in (Christensen and Fountain 1975). But the observation in retrogressed zone is opposite. The possible explanation for the decrease of Poisson's ratio is the effect of another strong variable, which most probably is the quartz whose exceptionally low Poisson's ratso ($\alpha=0.08$) and increased amounts has served to mask the effect of replacement of pyroxene by amphiboles. The anomalously low Poisson's ratio over granites and pegmatites is also the result of high proportion of quartz in these rocks. This suggests that the quartz plays a critical role in rocks as well as in analysing Poisson's ratio data.

CRUSTAL STUDY

The estimated Poisson's ratios for quartz-feldspathic gneisses ($\alpha=0.24$) and pyroxene-granulites (Scourie assemblage, $\alpha=0.27$) are applicable to the upper and middle crust, since an equivalence has been established between these rocks and the crustal layers (Smith and Bott 1975 ; Bamford *et al.*, 1977; Hall and Simmons 1979 ; Bowes 1978 ; Assumpcao and Bamford 1978). The significance of these results is judged with reference to other works, particularly of Assumpcao and Bamford (1978). and Hall and Simmons (1979). Assumpcao and Bamford, (1978) using LISPB data, have shown a range of Poisson's ratio ($\alpha=0.25$ to 0.26) with an average $a=0.245$, for the upper crust, which correlates very reasonably with our estimation ($\alpha=0.240$). For the middle crust, our estimate ($\alpha=0.27$) is much higher than the LISPB result=0 246. However, the laboratory determination of Hall and Simmons (1979) shows a correlatable Poisson's ratio for pyroxene granulites ($\alpha=0.27$-0.29) and amphibolites (basic material in garnet granulite facies). It seems that the hydration of exposed pyroxene-granulites due to retrogression is the source of the higher Poisson's ratio, and if this situation exists in the middle/lower crust then the lower estimates of Poisson's ratio in LISPB would require a preferred mineral orientation to generate a necessary anisotropy. Since the LISPB line is roughly perpendicular to the general strike of the major structures and perpendicular to the LUST line, and if mineral lineation is along the strike then the shear wave velocity sampled in LISPB would be higher than that in LUST (Hall and Simmons 1979), thus would yield lower Poisson's ratio in LISPB.

CONCLUSIONS

1. Poisson'c ratio responds appreciably to lithological variotion.
2. Poisson's ratio may be used as a third constraint on seismic interpretations.
3. Poisson's ratio suggests hydration and anisotropy in the middle/lower crust.
4. Such study needs to be carried out in Pakistan to understand the nature of crust.

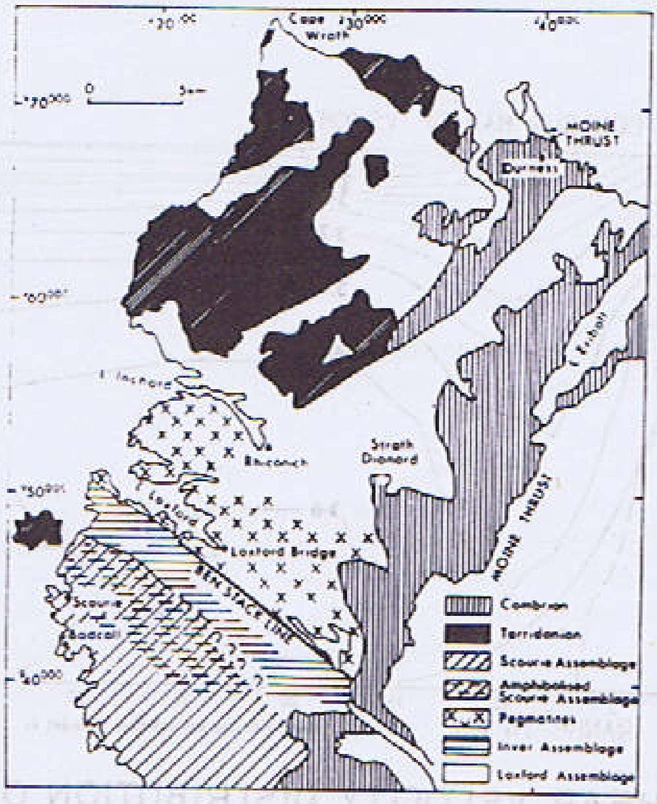

FIG. 1. INDEX MAP OF LEWISIAN METAMORPHIC COMPLEX

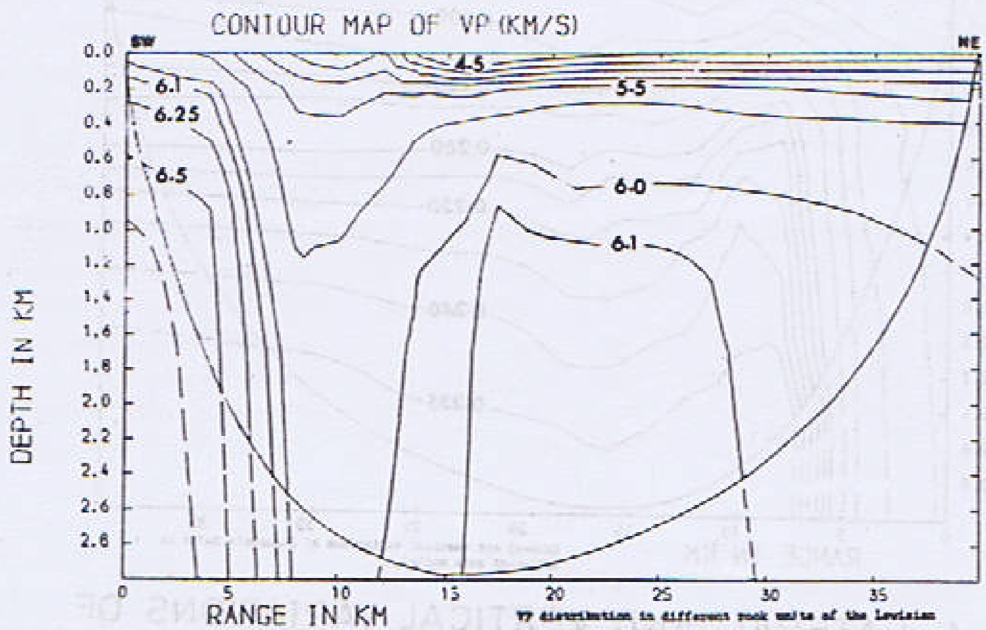

FIG.2. VP DISTRIBUTION IN DIFFERENT ROCK UNITS OF LEWISIAN

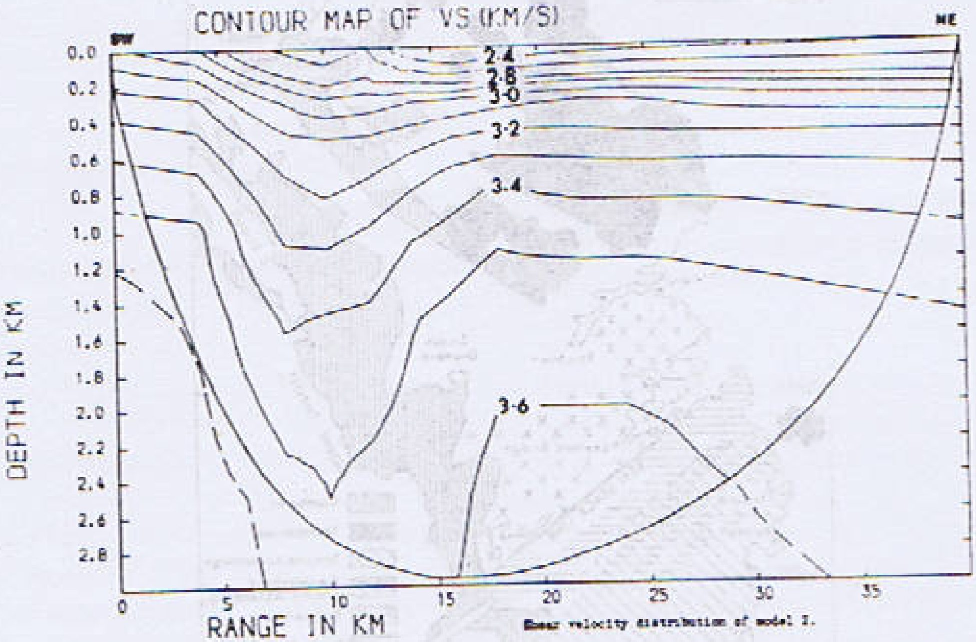

FIG. 3. SHEAR VELOCITY DISTRIBUTION OF MODEL 2.

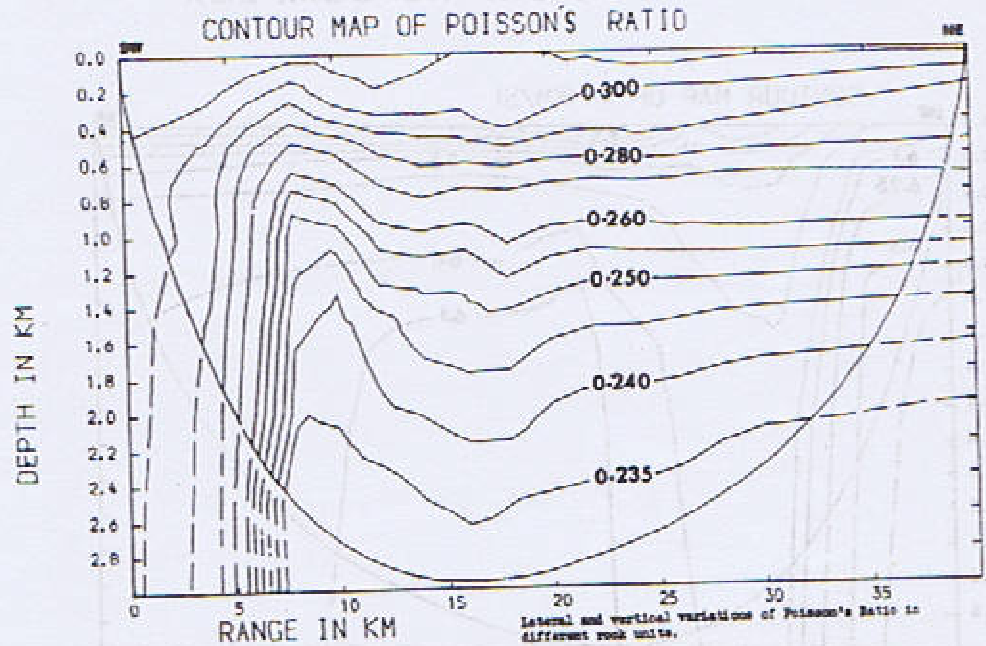

FIG. 4. LATERAL AND VERTICAL VARIATIONS OF POISSON'S RATIO IN DIFFERENT ROCK UNITS

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AN APPRAISAL OF THE GEOLOGY OF THE HAZARA ARC, NORTHERN PAKISTAN

BY

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The Hazara Arc is a NE-SW trending crescent-shaped epicontinental troughw hich is situated along the northern border of the Potwar Basin (Fig. 1). It forms part of the northern-most extremity of the sedimentary succession along the northwestern margin of the Indian Plate and is a result of continent to continent collision (Indian Plate versus Eurasian Plate).

The town Balakot which is a gatewav to the Kaghan Valley of the Higher Himalayas, is situated at the northern pointed tip of the crescent-shaped Hazara Arc, while the western end of the Hazara Arc is broadly truncated by the Grand Trunk Road (Rawalpindi-Peshawar Highway).

The Hazara Arc originated as a geosynclinal sedimentary depression during the Precambrian time as is evidenced by the deposition of the Precambrian Turbidite Facies (HAZARA FORMATION), whereas it remained as a shallow subsiding trough with paleogeographic vicissitudes throughout its remaining geological history except it relatively deepened during the Upper Cretaceous (Butt, 1988, 1989).

The Hazara Arc forms part of the western limb of the Hazara-Kashmir Syntaxis (Fig. 2). The closely situated geological segment of Azad Kashmir from the towns Balakot to Muzaffarabad appears to form an integral part of the Hazara Arc. This interpretation gains support on the basis of the following criteria :—

1. The structural configuration of the Hazara Arc and the presence of dislocated lobe-shaped geological segment of Azad Kashmir between the towns Balakot and Muzaffarabad in its immediate neighbourhood.

   The dislocated junction between the geological segment of Azad Kashmir and the main Hazara Arc can be visualised as a result of structural complexities caused by the Nathiagali Thrust merging further into the Main Boundary Thrust.

2. The extension of the stratigraphic units of the Hazara Arc into the neighbouring geology of Azad Kashmir.

3. The location of the town Balakot at the northern tip of the Hazara Arc.

Our interpretaion, based upon the structural setting, stratigraphic framework and the geographical location appears most convincing for the definition of the geographical extent of the Hazara Arc.

The changing outline of the Hazara Arc from Precambrian to Miocene sedimentation within its northern and southern borders (Panjal Thrust to the north and Murree Thrust or Main Boundary Thrust to the south) has been demonstrated here by a series of idealised paleogeographic maps (Figs a-g).

Major geological events which occurred in the Hazara Arc can be summarized as follows :

1. A major Paleozoic stratigraphic gap crossing over to the Triassic.

2. Cretaceous—Tertiary unconformity (Maastrichtian—Danian interval) marked by the residual deposits, namely, laterite or ferruginous pisolite.

3. Marked southward depositional shift towards the adjoining Potwar Basin during the Middle Eocene when the Kuldana Formation was laid down.

4. A major depositional break from Upper Eocene to the Oligocene marking an end to the maximum stratigraphic and structural evolution of the Hazara Arc.

5. Creation of the Hazara Arc as a hinterland to the adjoining actively subsiding Potwar Basin during the Miocene. This structural framework brought prominence to the Miocene sedimentation (Murree Formation) to the actively subsiding Potwar Basin, while the Murree Formation formed only a southernmost bordering belt of the Hazara Arc.

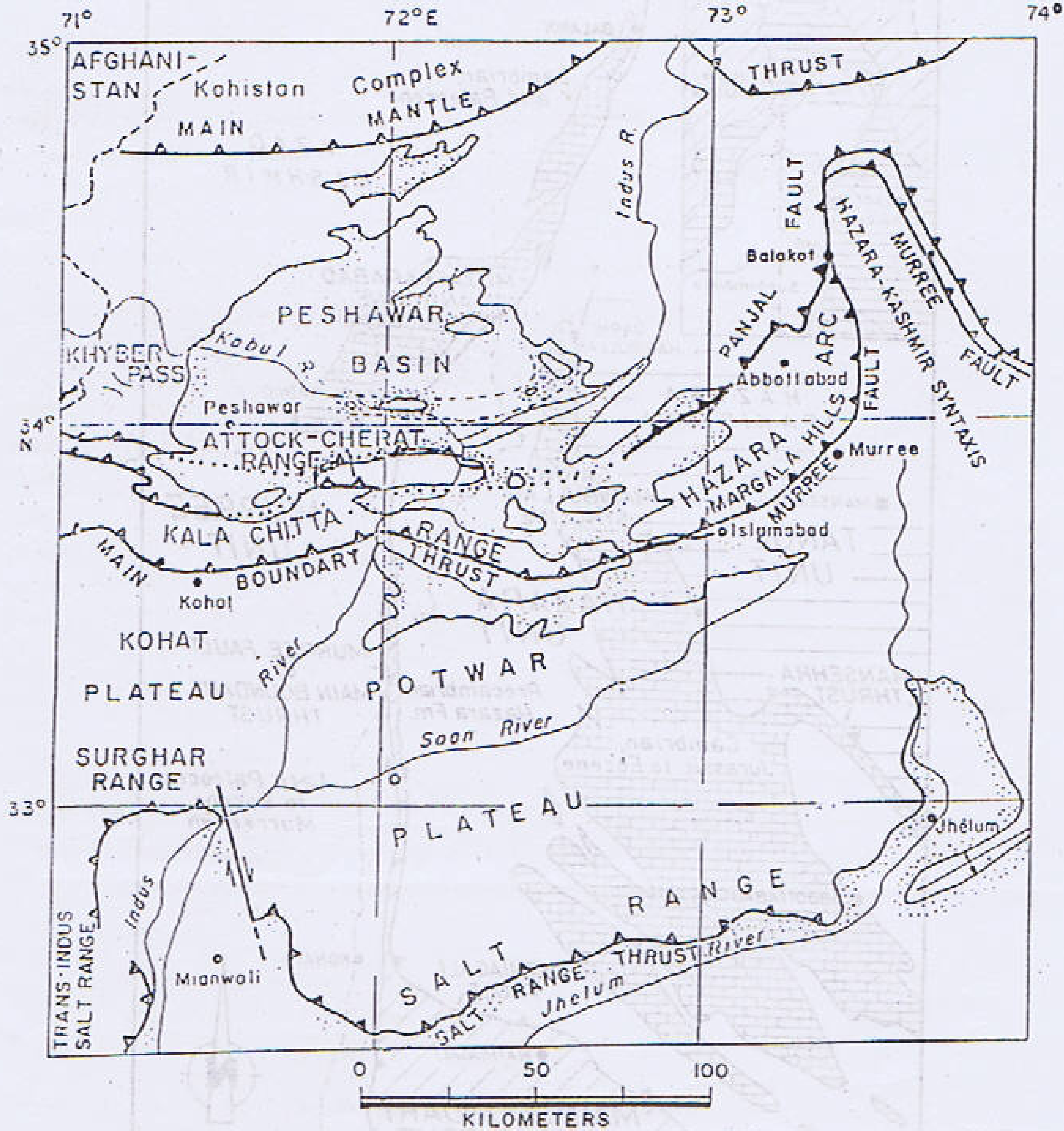


Fig. 1. Location map of the Hazara Arc northern Pakistan.
(After Yeats and Hussain - 1987)

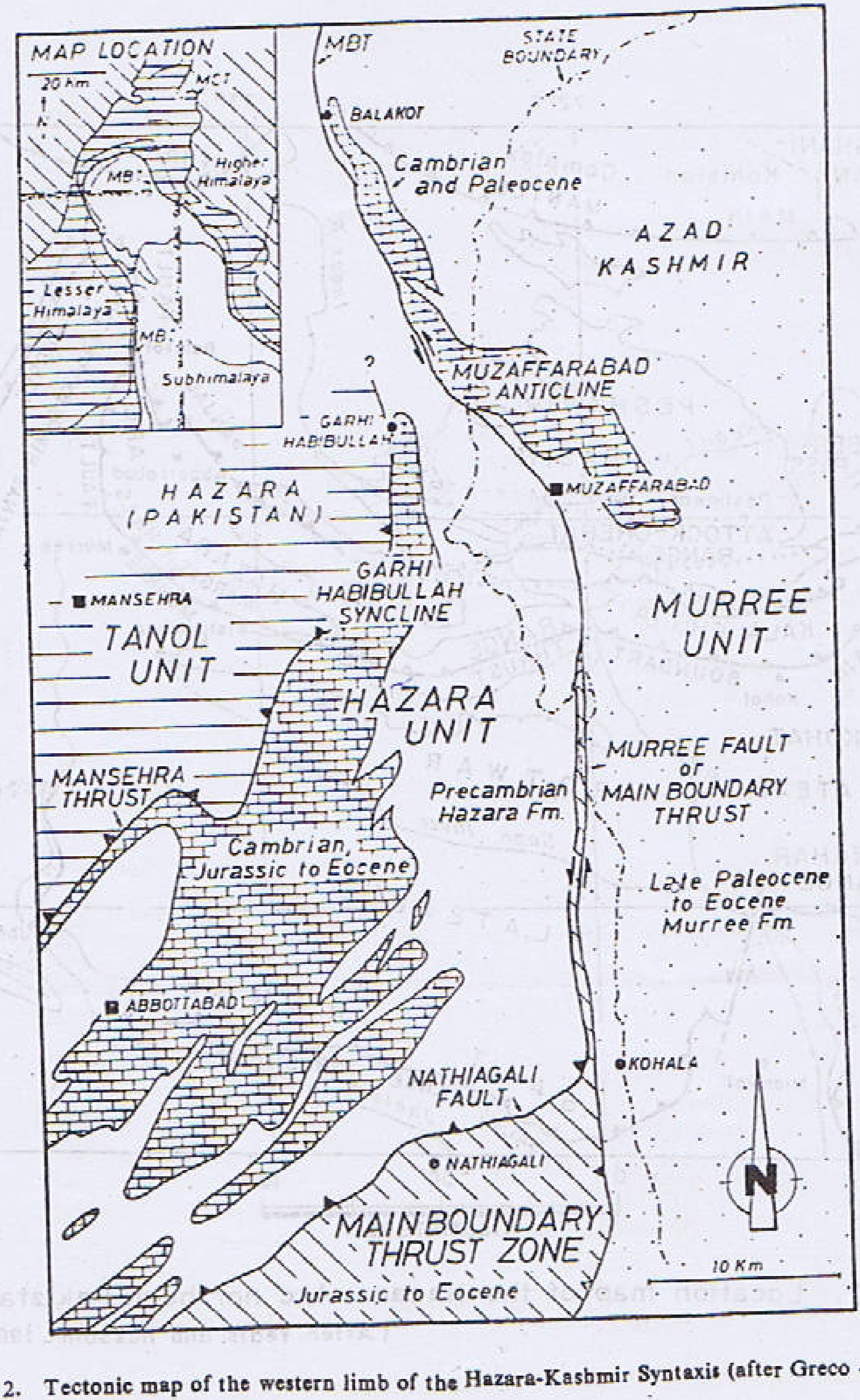


Fig. 2. Tectonic map of the western limb of the Hazara-Kashmir Syntaxis (after Greco - 1989).

DIAGRAMMATIC ILLUSTRATION OF THE PALEOGRAPHIC SETTING OF THE HAZARARC DURING GEOLOGICAL TIMES. HACHED AREA REPRESENTS DEPOTCENTRE.

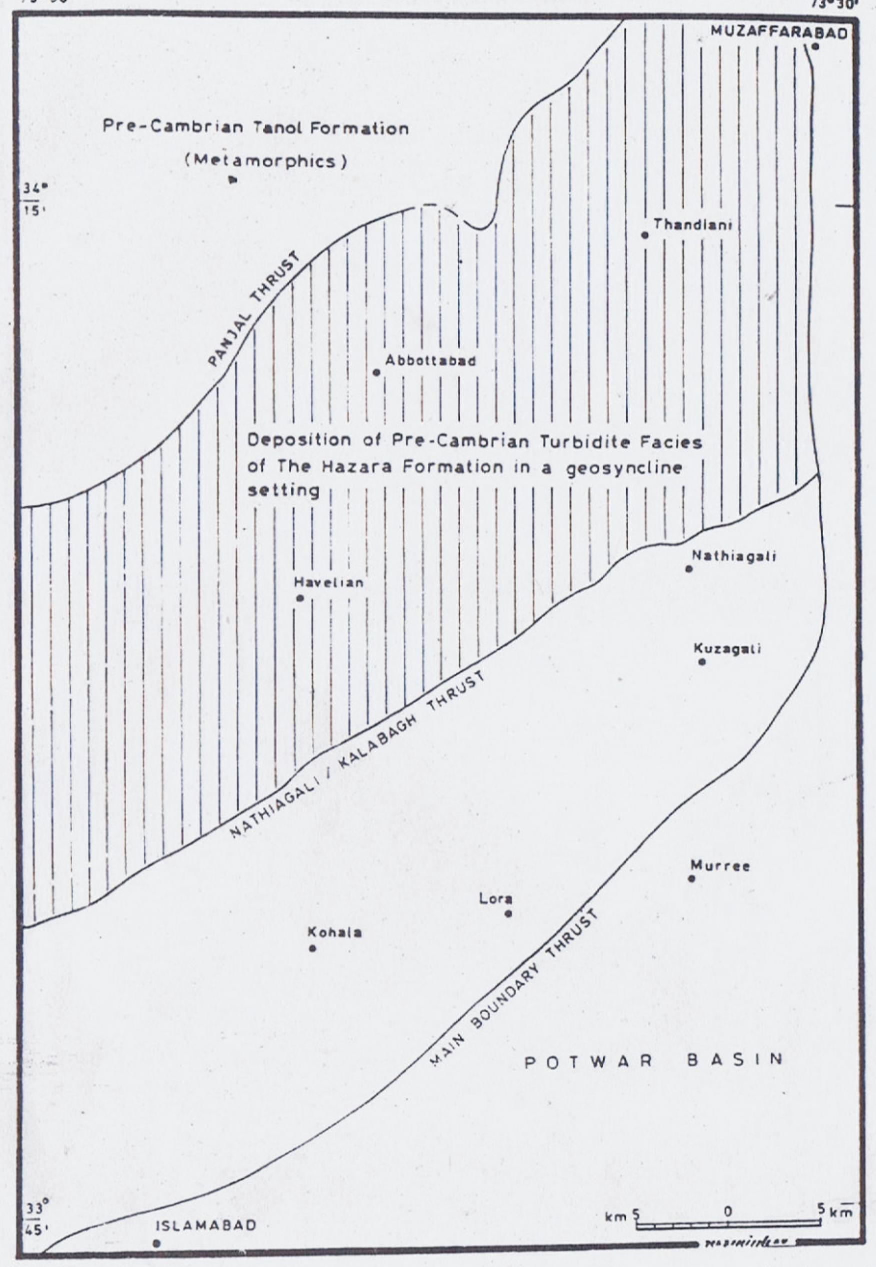


Fig. a. Idealised paleogeographic pattern of the Hazara Arc during the PreCambrian

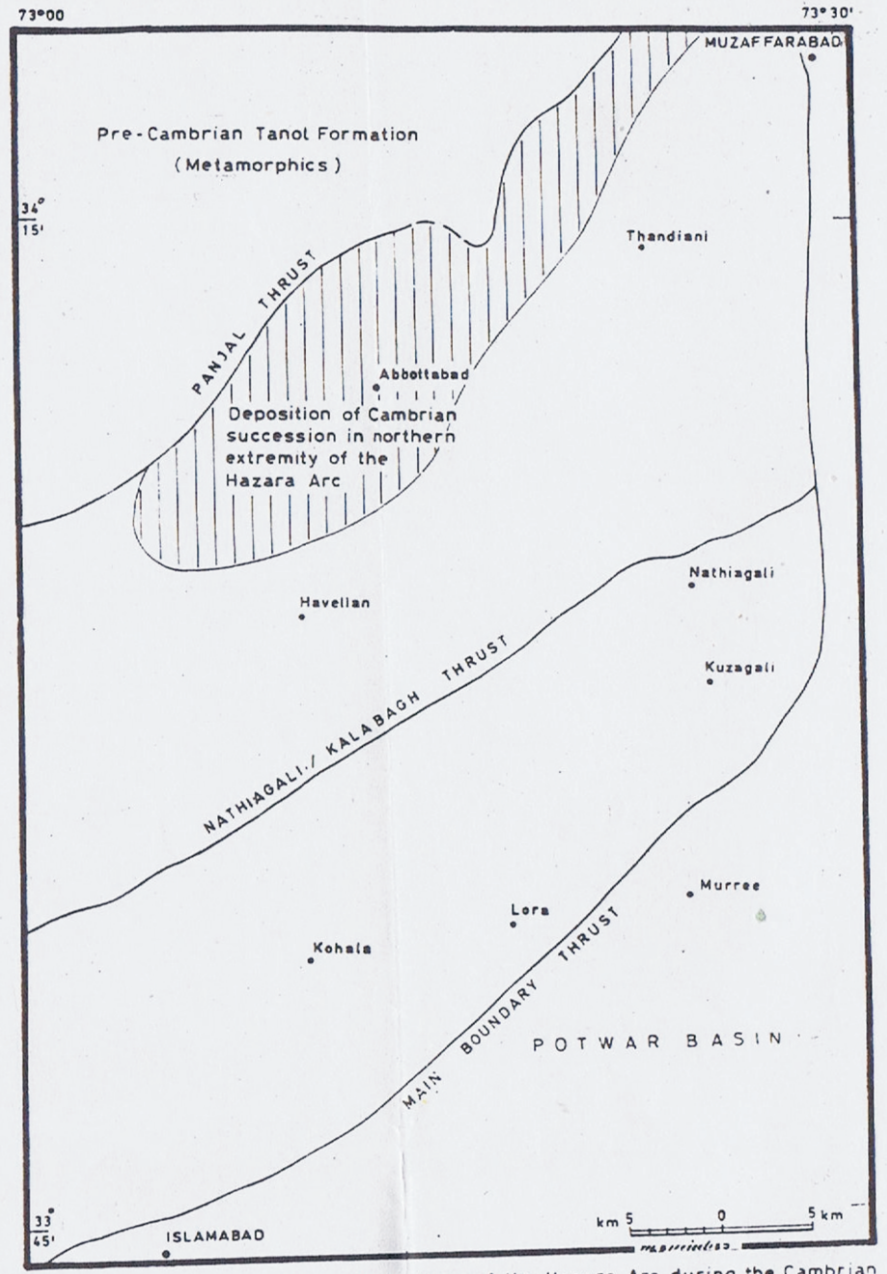
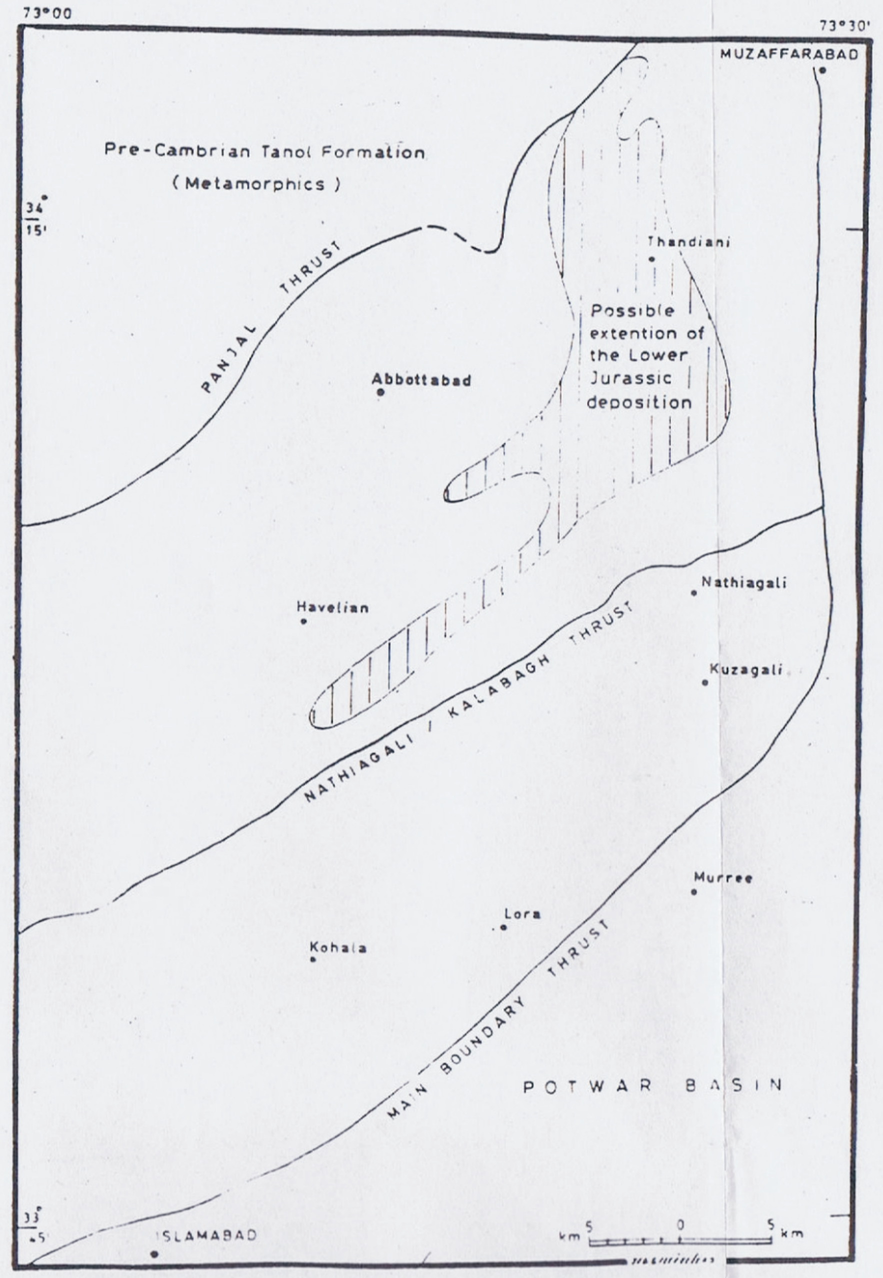
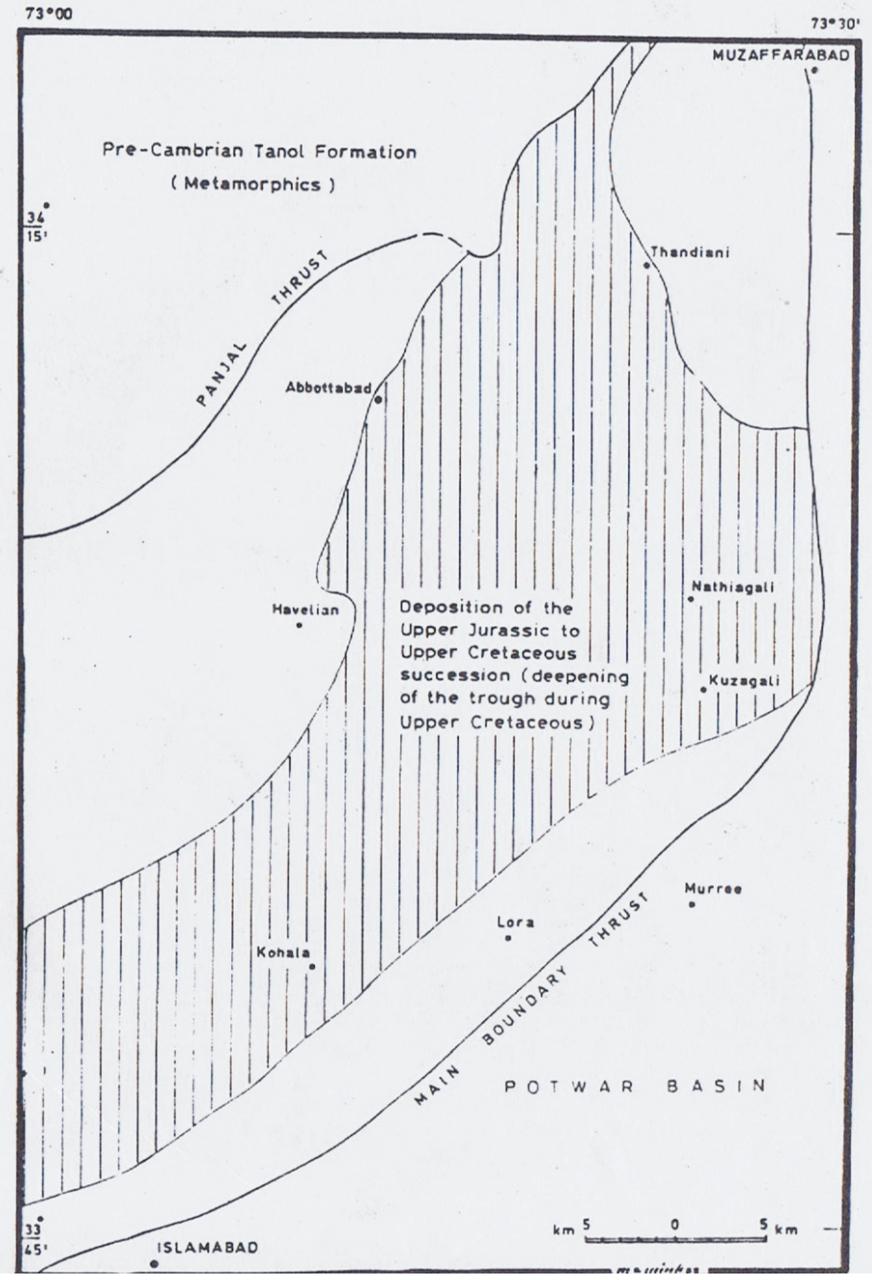


Fig. b. Idealised paleogeographic pattern of the Hazara Arc during the Cambrian





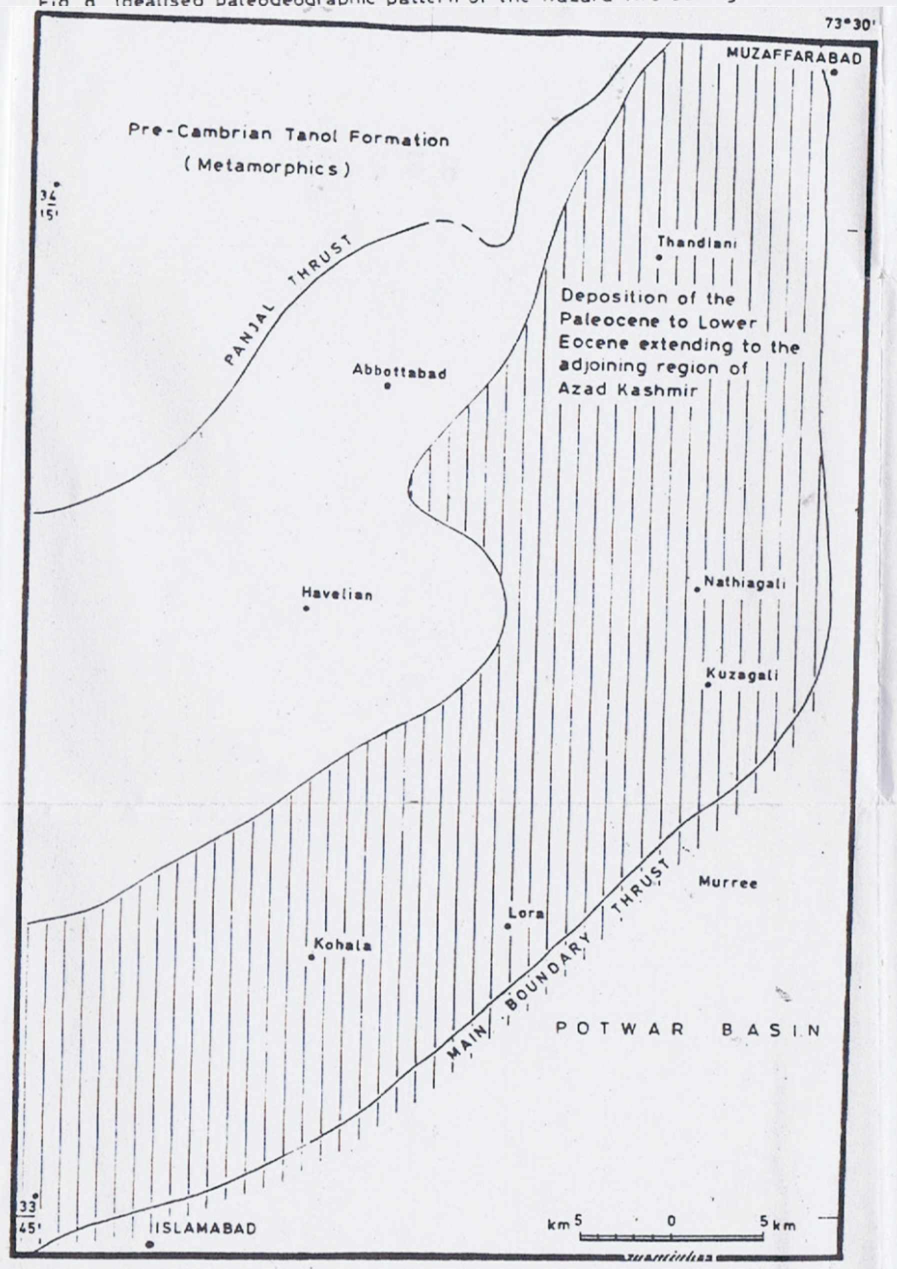


Fig. e. Idealised paleogeographic pattern of the Hazara Arc during the Paleocene to Lower Eocene time

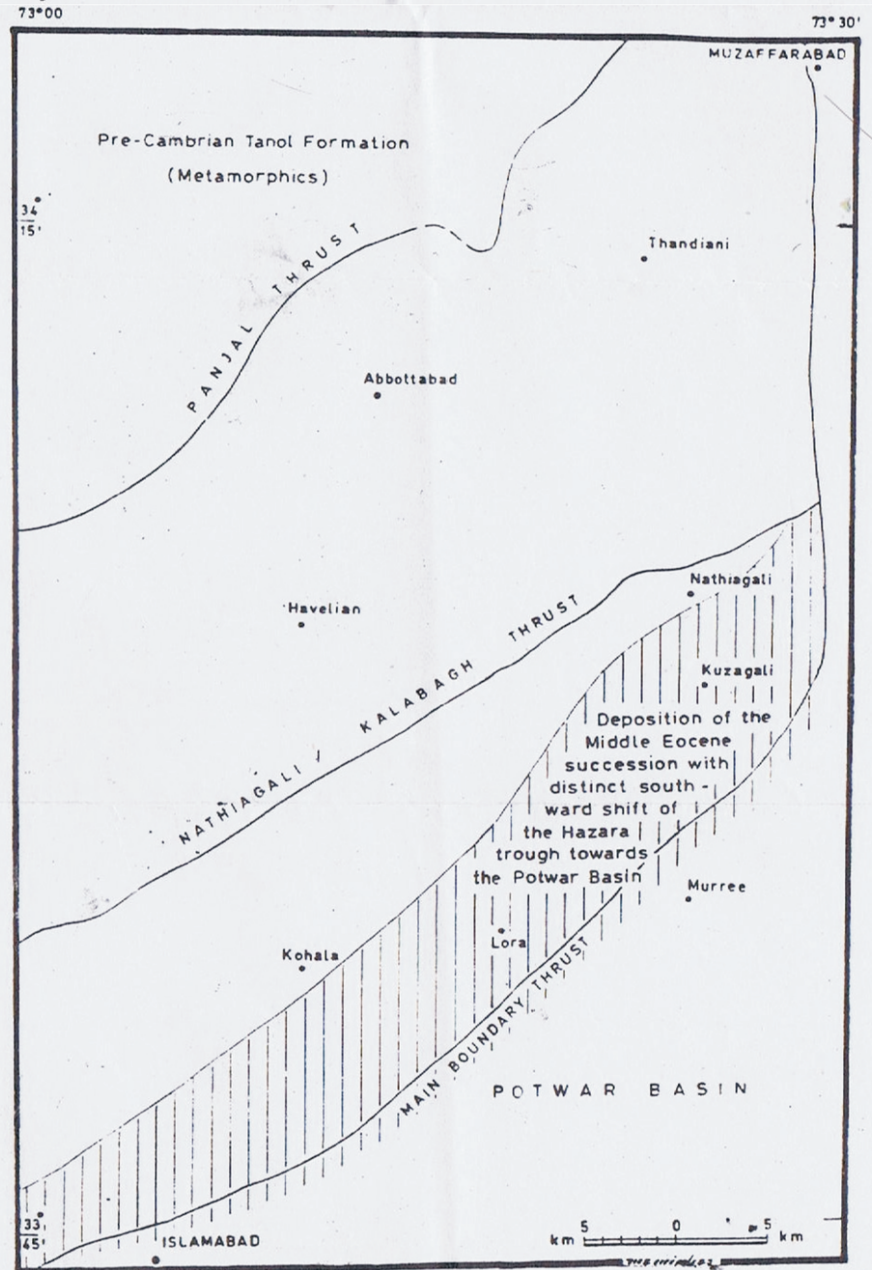


Fig. f. Idealised paleogeographic pattern of the Hazara Arc during the Middle Eocene time

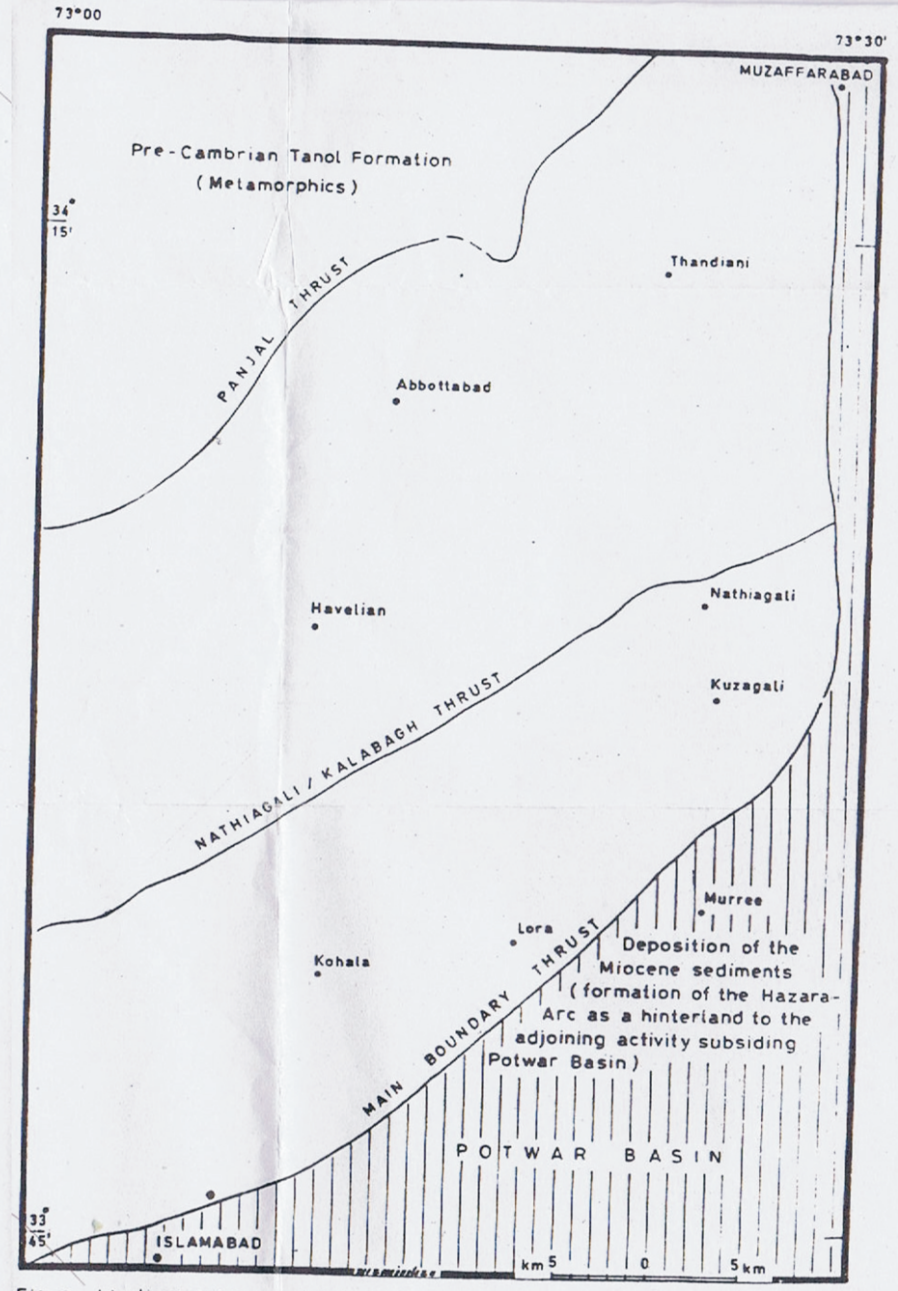


Fig. g. Idealised paleogeographic pattern of the Hazara Arc during the Miocene time

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OCCURRANCE OF THE LOWER JURASSIC AMMONOID GENUS *BOULEICERAS* FROM THE SURGHAR RANGE WITH A REVISED NOMENCLATURE OF THE MESOZOIC ROCKS OF THE SALT RANGE AND TRANS INDUS RANGES (UPPER INDUS BASIN)

BY

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Abstract : *Lower Jurassic ammonoid genus* Bouleiceras *is recorded for the first time from the Surghar Range (Trans Indus Salt Range) and its importance in regional and interregional correlation of Lower Jurassic rocks is emphastzed. A major marine transgression occured in the Early Toarcian (late Early Jurassic) covering most areas of Indus Basin with important regressive phases during Bajocian, Early-Middle Callovian.*

A revised nomenclature of the Mesozoic rocks of the Salt Range and Trans Indus Range is presented and the Shinawari Formation is redefined. A new Baroch Group is proposed for Datta, Shinawari and Samana Suk formations of Early to Middle Jurassic age. As rocks of thie group are disconformably overlain by the Chichali Formation, the name Surghar Group (Gee, 1980) is proposed to be restricted only to Chichali and Lunshiwal formations of Late Jurassic to Early Cretaceous age. Two new members, namely, Doya and Vanjari for the lower mixed clastic-carbonate unit and for an upper flaggy to massive dolomite unit of Kingriali Formation respectively, are proposed. These two members are not only recognizable in the Surghar Range but can be recognized in parts of western Salt Range over the upper massive sandstone unit (Landa Member) of the Tredian Formation.

INTRODUCTION

Mesozoic nomenclature of the Upper Indus Basin which includes the presently described section of Landu Nala in the Surghar Range (Trans Indus Salt Range) has been issued by the Stratigraphic Committee of Pakistan (Fatmi, 1973) and is widely accepted both in national and international publications. Fatmi, (1977) introduced the Shinawari Formation, a mixed clastic-carbonate unit in between the continental Datta Formation and shallow water marine carbonate Samana Suk Formation. All these formations were dated as Lower to Middle Jurassic but the Shinawari Formation in the Surghar Range was not previously defined.

The Shinawari Formation in southern section of the Trans Indus Ranges (Sheikh Budin Hills) were previously refered by Fatmi and Cheema(1971) as "Wazir Wal Member" (95 meters thick) of the Datta Formation and these authors recorded the Lower Toarcian *Bouleiceras* fauna from the Khisor Marwat Ranges, This formation is also well developed in the Surghar Range (Fig. 1) and shows a strong similarity to Sheikh Budin Hills. The lower brown-grey limestone unit of the Shinawari Formation containing *Bouleiceras* and other mollusca has been noted to extend in parts of the western Salt Range. Gee (1980) included Jurassic and Early Cretaceous rocks of the Salt Range into one Surghar Group. The present authors feel that extending the group name across a major Middle Jurassic disconformity (post Middle Callovian) in the Surghar Range is not justified. The Surghar Group is, therefore, recommended for Late Jurassic Chichali and Early Cretaceous Lumahiwal Formations which are well recognized in the escarpment face of the Surghar Range by its green (Chichali Formation) and dirty white color (Lumshiwal Formation) below the Paleocene Hangu Formation. (Makarwal coal Stage).

A new Baroch Group name is, therefore, proposed here for the Lower-Middle Jurassic sequence of the area which represents a transgressive-regressive cycle. The Landu Nala (Fig. 1) in the Surghar Range is designated as the type section while Sheikh Budin Hills (Wazirwal Section) to the south as principal reference section of the group. The name Baroch is well known in old literature and was previously used by Gee for Jurassic of this region. Its status from a formation (placed already in synonymy of Samana Suk due to priority of nomenclature) is raised here to Group. The Baroch group is well exposed in Baroch Nala, Landu Nala, Datta Nala, Chichali Pass forming the lower half of the Surghar Range escarpment face and steep slopes.

The three Triassic formations, namely, the Mianwali, Tredian and Kirgriali were grouped by Gee (1980) in the Musa Khel Group which needs to be defined and approved by the Stratigraphic Committee of Pakistan as rocks of these group are also well exposed at the base of the Surghar Range, north and north west of Qamar Mushani. The two members of Middle Triassic Tredian Formation, namely, Landa (mixed fine and coarse clastic) and Khatkiara (a coarse clastic) members of Danilchick and Shah (1976) are accepted and redefined from the Landu Nala Section. The Upper Triassic Kingriali Formation transitionally overlying the Middle Triassic Tredian Formation is excellently exposed with its upper and lower contacts in Landu Nala and adjoining Narmia Section of Surghar Range.

The authors believe that the Kingriali Formation is also divisible into two members (Fig. 1). A lower transitional member (Doya Member) is a mixed sandstone, dolomite and dolomitic limestone with *Spiriferina*, gastropods and echinoids and an Upper Vanjari Dolomite Member (both massive coarser dolomite and flaggy dolomicrite) which is sharply and disconformably overlain by the basal reddish silty shale of the Datta Formation. These two members are widely recognized in the Surghar Range (excellently exposed in Landu Nala) and western Salt Range (excellent fresh exposures are in Zaluch Nala near the mining road). The names of the two members of the Kingriali Formation are also taken from the villages of this name located at the base of the Surghar Range in the Makheriwal-Narmia area which are proposed here as type ectionss of these members.

This paper is intended to define the limits of the Shinawari Formation in the Surghar Range and to record for the first time the Lower Toarcian genus *Bouleiceras* (Pl. 1) from the basal carbonate unit of Shinwari Formation above the Datta Formation. This marks the first Jurassic marine transgression in Surghar Range with sea connections to others parts of the Upper and Lower Indus Basin. *Bouleiceras* is recorded by Davies and Gardezi (1965) from Hazara and by Fatmi (1972, 1975) from Kala Chitta, Kohat Tribal Belt and recently (1989) in the type area of Shinawari in Kohat district. *Bouleiceras* is also reported from various Jurassic sections of Baluchistan. In Baluchistan (Lower Indus Basis) in addition, Pre-Toarcian deeper marine sections are also present while in Upper Indus Basin this level is represented by continental or near shore deltaic clastic beds of the Datta Formation.

STRATIGRAPHIC SUMMARY

The Mesozoic rocks show major intra and inter system disconformities, a variety of environments, transgressive and regressive depositional (both marine and continental) cycles and, in turn, are disconformably over and underlain by rocks of Tertiary and Paleozoic ages. Most of the Mesozoic nomenclature of this area is already well established and approved by the Stratigraphic Committee of Pakistan excepting the two proposed new members, the Vanjari and the Doya of the Kingriali Formation and new Baroch Group for the Lower-Middle Jurrasic formations of Upper Indus Basin. The Surghar Group of Gee (1980) which included the three formations of Baroch Group is proposed to be restricted to the Chichali and Lumshiwal Formations of Late Jurassic to Early Cretaceous age as there is a major unconformity separating rocks of these two groups. The Musa Khel Group of Gee (1980) is accepted with its three formations.

The nomenclature scheme proposed here is based on our current studies of Landu Nala(Haj Zardad Shah Coal Mines area) in the Surghar Range and is summarized below .

Surghar Group

- Lumshiwal Formation
- Chichali Formation

Early Cretaceous to Late Jurassic

Shallow marine transgressive (lower part) and regressive (upper part) clastic sequence.

UNCONFORMITY

Baroch Group

- Samana Suk Formation
- Shinawari Formation
- Datta Formation

Middle (Middle Callovian) to Early Jurassic.

Continental clastic (lower part) to mixed repeated marine and continental carbonate+clastic (middle part) and shallow marine (upper part) transgressive and regressive sequence.

UNCONFORMITY

Musa Khel Group

- Kingriali Formation
  - Vanjari member
  - Doya member
- Tredian Formation
  - Lunda member
  - Khatkiara member
- Mianwali Formation
  - Narmia member
  - Mittiwali member
  - Kathwai member

Triassic

A transgressive marine carbonate-clastic sequence (lower part) followed by a regressive cycle of fine and coarse clastic deltaic in the middle part with a tidal and intertidal flats in the upper part.

PARACONFORMITY

Zaluch Group

Permian

A transgressive and regressive marine cycle of carbonate dominant-clastic sequence.

STRATIGRAPHIC ANALYSIS OF SHINAWARI FORMATION AND OTHER ROCKS OF BAROCH GROUP

The name Shinawari Formation was introduced from the Shinawari Village, Samana Range, Kohat district. It is 164 meters thick in the Surghar Range (Landu Nala Section) as contrasted to over 300 meters in the type area of the Samana Range, 95 meters in Sheikh Budin Hills and considerably reduced to 15 meters and less in Kala Chitta and Hazara. In all these areas the basal brown limestone unit has yielded *Bouleiceras* and other mollusca which are indicative of a major marine transgression in the Lower Toarcian (upper part of Lower Jurassic).

In all these sections excepting the type area where the Shinawari Formation is thick and is in a shallow marine clastic-carbonate facies, the basal limestone unit is remarkably overlain by deep red or maroon shale (3 to 4 meters) which serve as an important marker horizon particularly in the Samana Range (Shinawari), Hazara, Kala Chitta and Trans Indus Ranges. The succession following the maroon shale is a return of regressive sequence of variegated clastic beds of sandstone, siltstone and shale with carbonaceous bands in Surghar Range and gradually the succession becomes transgressive again with inter beds of calcareous sandstone, non calcareous sandstone, marl, shale and shallow water limestone (both sandy and shelly). The upper boundary of the Shinawari Formation with the Samana Suk Formation is placed with the last disappearance of sandstone beds (Fig. 2).

The overlying Samana Suk Formation is less than 60 meters in the Surgher Range (Landu Nala) and consists of medium to thick bedded grey, light grey, grey brown limestone with thin marly interelationss. The limestone is biosparitic, biooolitic, bio-micritic and some times sandy. The top most 2 to 3 meters of limestone below the unconformable contact with the Chichali Formation weathers brown in Datta-Punnu-Lunda Mine sections of Surghar Range and contain Middle Callovian ammonites and brachiopods like *Reineckcia* spp. *Obtusicostites* sp. *Hubertoceras* sp. *Rhynchonella nobilis* etc. These Middle Callovian beds, however, are truncated laterally towards north east in the Chichali Pass due to the Chichali overstep and unconformity. This Chichali/Samana Suk contact strongly suggest a Pre-Chichali regression and uplift which coincide with an important inter Jurassic unconformity recognized in most areas of the Indus Basin. Mroc recently (1989) *Obtusicostites* sp. and *Rhynchonella no'ilis* were found in the top bed of the Samana Suk Limestone in Khadimakh section of western Kohat.

The Samana Suk boundary is diachronous and that in the north and north western areas of the Upper Indus Basin carbonate facies were deposited, while in the Trans Indus Ranges and the Salt Range near shore clastic deposits were formed due to nearness of the Indo-Pak Plate margin in the lower part of Middle Jurassic. The Early Toarcian marine transgression is, however, recognized in all these areas due to the presence of *Bouleioeras* and other allied ammonoid genera (e.g. *Protogrammoceras*).

Fatmi et al (1987) described an interesting Mesozoic sequence in Lalumi area of the western Salt Range where the "ghost" outcrops of lower part of the Chichali Formation (as Chichali, Samana Suk and even Shinawari Eormation are missing in many areas of Western Salt Range such as Nammal-Chiddru by the Paleocene overstep on older rocks) disconformably overlying the basal brown limestone unit of Shinawari Formation (unlike that of Sunghar Range) and in turn, is disconformably overlain with lateritic bed by carbonaceous shale and sandy marly fossiliferous beds of Hangu Formation of Early

Paleocene age. It is also from this Lalumi area Fatmi (1987) described an overstepping relationship of Datta formation over the Triassic from Upper Kingriali (as in Surghar Range) to Lower Kingriali, Tredicn and Mianwali Formations in sections close to Chiddru High (i.e. Sarai, Lalumi, Chotu wala) in parts of western Salt Range.

In the Salt Range and Trans Indus Ranges, the pre-Toarcian Jurassic rocks (Datta Formation) are in a continental clastic facies and after a major Early Toarcian marine transgression, there is a strong indication in Pakistan that Bajocian regression occured which is suggested by the variegated clastic beds over the Toarcian marine carbonate units in the western Salt Range and Trans Indus Ranges and a Late Bajocian uplift in the Axial Belt region of Baluchistan where Lower-Middle Bajocian carbonate rocks are disconformably overlain by clastic rocks (Sembar Formation) of Late Jurassic to Early Cretaceous age. From Baluchistan there is another evidence of post Lower Callovian regression and uplift (Mazar Drik Formation) which in the Trans Indus and the SargharRanges is reflected by lenticular presence of Middle Callovian horizon and its absence in other areas of Kala Chitta and Hazara.

BOULEICERAS AND ITS IMTORTANCE IN CORRELATION

The discovery of *Bouleiceras* in the Surghar Range completes a picture of its distribution in all the marine sections of the Lower Toarcian (Lower Jurassic) in Pakistan (Indus Basin) right from Karachi (Gadani area) across the Axial Belt of Baluchistan to north (Fig. 1). It further provides proof of a major marine transgression during Early Toarcian throughout Pakistan, though the sections in Axial Belt region of Baluchistan, Waziristan and part of Kohat have a deeper marine Pre-Toarcian Jurassic requence.

The *Bouleiceras* cf. *niticens* Thevenin (Pl. 1) from Landu Nala. Surghar Range is rather weakly ribbed smooth fragment of a large phragmocone of 185 mm showing a very typical *Bouleiceras* suture and tricarinate bisulcate venter. It has an evolate shell with a sub rectangular higher than broad whorl section.

The dimension are :—

Diameter	Whorl height	Whorl breadth	Umbilical diameter
185 mm	74.0 (40)	54.0 (29)	64.0 (35)

The Surghar Range form is comparable to a large phragmocone fragment figured by Davies and Gardezi (1965) as *B.* cf. *niticens* (identified by M.K. Howarth) from Hazaea It also compares well with some large evolute smooth fragments described by Arkell (1952) from Saudi Arabia and Thevenin (1908, fig 11, pl. 2) from Madagascar. It may also be compared to a large phragmocone figured by Fatmi and Cheema (1972, pl. 2, figs. 3,4) as *Bouleiceras* sp. indet. from Sheikh Budin Hills.

Bouleiceras with its associated fauna like *Protogrammaceras* has proved of great importance in dating the marine Lower Toarcian rocks of Pakistan. Hillebrandt (1973) even recognized a Kala Chitta special *Bouleiceras chakdallensis* Fatmi from Chile, South America.

Bouleiceras is reported (Fig. 3) from Lower Toarcian of Spain, Ethopia, Saudi Arabia (Arkell, 1952) Chile (Hillebrandt, 1973) and thus constitute an important short lived genus for world wide correlation of Lower Toarcian rocks. In Pakistan it is commonly recognized from most of the marine Lower Jurassic sections. It is, however not yet known from the Kioto limestone sequence of Himalaya (Kashmir), though its distribution has been proved in parts of the southern Himalaya Jurassic sequence of Hazara which is correlative with parts of the Kioto Limestone of the Indian Himalayas.

ACKNOWLEDGEMENTS

The authors are grateful to Mr. Waheeduddin, former Director-General, GSP for his permission to carry out research on the Mesozoic rocks of Pakistan and to Mr. A.H. Kazmi, also former Director-General, GSP for his friendly persuation and invitation to bring this new information on *BOUEICERAS* from the Surghar Range and the proposed revised Mesozoic nomenclature on record. Fatmi among authors, wishes to record that every work in Geology which he has written, he owes to his mother's encouragement and blessing who died on 7th March, 1987 (God may rest her soul in peace).

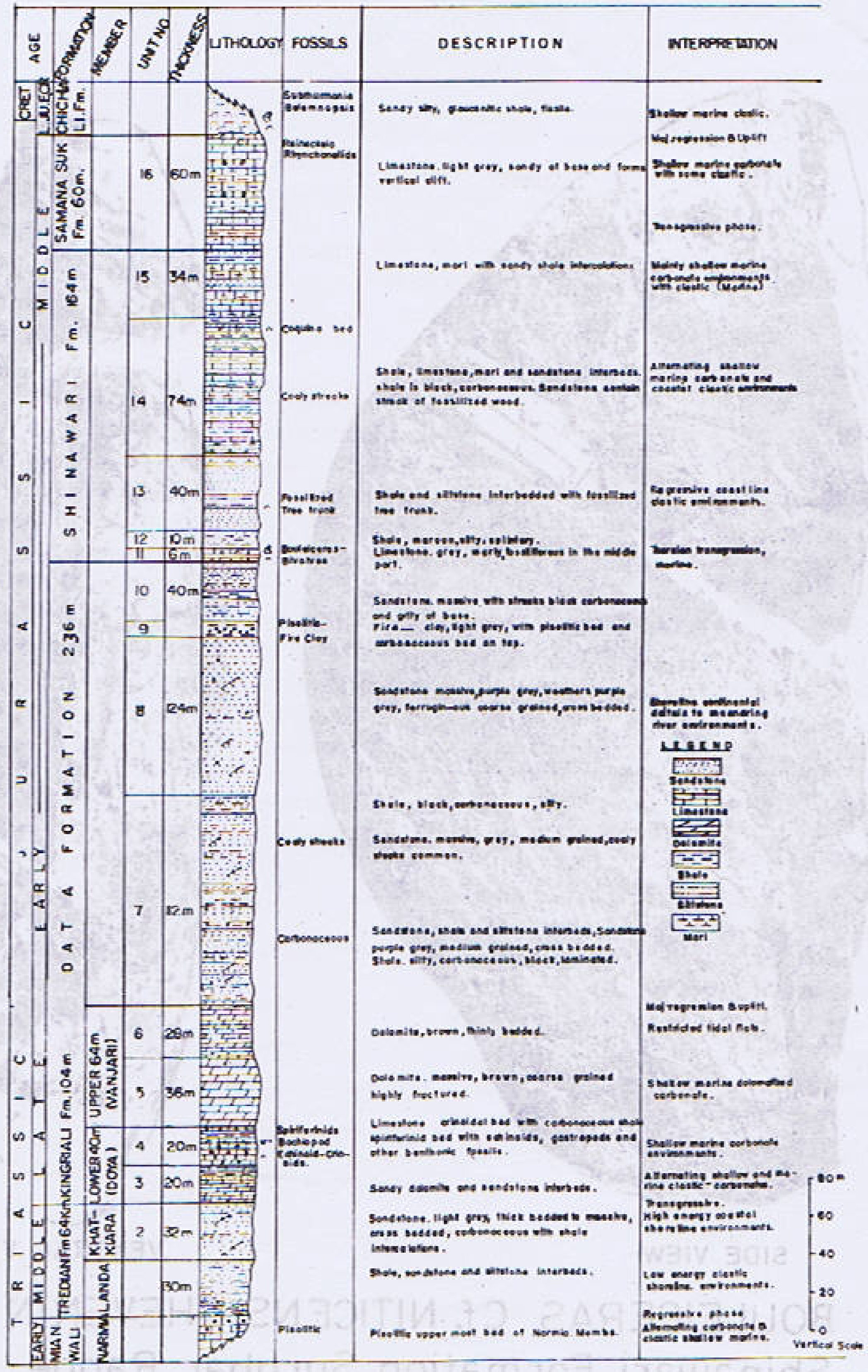

FIG.1. COLUMNAR SECTION OF TRIASSIC & JURASSIC ROCKS AT LANDU NALA, SURGHAR RANGE, TRANS INDUS RANGES (38 P/I, LONG: 71° 12 08 N, LAT: 32° 58 17 TO 32 58 25 E).

PLATE 1

SIDE VIEW

VENTRAL VIEW

BOULEICERAS Cf. NITICENS THEVENIN
Shinawari Formation Surghar Range.

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STRATIGRAPHY OF THE SHINAWARI AND DATTA FORMATIONS FROM THE SHINAWARI AREA (WESTERN SAMANA RANGE), KOHAT DISTRICT, PAKISTAN

BY

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Abstract : *Stratigraphy of Shinawari Formation is described from the type area of Shinawari on the basis of newly described* Bouleiceras *bed and the overlying maroon shale. Both these units show as key horizens indicating a Lower Toarcian transgression in most areas of Kohat-Potwar Province of the Upper Indus Basin and provide a facies basis of interegional correlation. The clastic shallow water marine sequence below the* Bouleiceras *beds is placed in the Datta Formation. The Datta Formation in the Samana Range shows a facies change from the type area of Datta in the Surghar Range where the formation is mainly continental. In western Kohat (Samana Range) it is a shore-line to shallow marine sequence as is represented by the frequent carbonate beds with the molluscan and brachiopod fauna and clastics. The two Datta facies are comparable to the Lower Cretaceous Lumshiwal facies which show similar environmental change from continental in the south to marine in the north west of the Trans Indus Ranges.*

INTRODUCTION

Stratigraphic studies of the Mesozoic rocks particularly that of the Shinawari Formation were carried out in Shinawari, Darsamand and Khadimakh areas of the Kohat District (38K) during March, 1989. The primaryobjective was to redefine the Shinawari Formation—a middle unit of the Baroch Group from the type area of Shinawari and to establish its relationship with the underlying Datta Formation and the overlying Samana Suk Formation of Jurassic age in the Samana Range. These studies were made as a GSP project "Stratigraphic and Sedimentologic Studies of the Mesozoic Rocks of Pakistan". Two sections were measured in detail, one is Shinawari for Jurassic rocks and the other in Khadimakh for mainly Cretaceous to Late Jurassic rocks. Only one section was studied north of Darsamand (38 K/11). The presence of diagnostic fossils from top beds of the Samana Suk Formation confirm the upper age limit as Middle Callovian.

The Shinawari Formation is redefined from the type area of Shinawari is western Samana Range where the underlying rocks are proposed to be included in the Datta Formation. A marked facies change of the Datta Formation is noted which is comparable to the Lumshiwal facies changes in the Kohat-Potwar Province. A new name below the Shinawari Formation is avoided and the rocks in spite of marked facies changes are included in the Datta Formation. The Datta Formation in the Samana Range is shallow marine mixed clastics (sandstone) and carbonates (both ltmestones and dolomites).

The area lies between Hangu and Thal and is bounded by the Tribal territory on the north, Kohat-Thal highway on the south. Thal is also connected with Kohat by the narrow gauge railway line (Fig. 1). The localities of Shinawari, Darsamand and Khadimakh are apprachable through a new set of mettled link roads connecting the main Kohat-Thal highway.

PREVIOUS WORK

Detailed stratigraphic studies of Khadimakh, Thal and Darsamand areas were carried out by Fatmi and Khan (1966) and later by Fatmi (1972) who provided the detailed information on the stratigraphy and fauna of the Jurassic and Cretaceous rocks of western Kohat. A summary of previous work is creditable in the pioneer works of Wynne (1879), Griesbach (1891), Davies (1930) and Spath (1930). Fatmi (1972), however, did not recognize the Datta Formation as a separate unit and placed it in his Shinawari Formation and the presence of dolomite at lower level.

In this report the Shinawari limits are well defined on the basis of ammonite fauna and maroon shale beds in the lower part and the last sandy unit is limestone sequence in the upper part. The overlying Samana Suk Formation is mainly a limestone sequence while the Shinawari Formation is a mixed clastic and limestone sequence. The Datta Formation is saparately defined for the first time from the Samana Range below the Shinawari Formation as a mixed clastic and carbonate sequence defining in environment to the mainly classic and carbonate sequence defining in environment to the mainly clastic rock beds of the type area in the Surghar Range below the Shinawari Formation (Fatmi et al, 1990, this volume).

STRATIGRAPHY

Rocks of Jurassic and Cretaceous Systems are widely exposed in the Samana Range and its western and eastern extensive range falling in Kohat Trible Belt. The Lower-Middle Jurassic rocks and mainly represented by limestone, shale and sandstone with subordinate dolomitic rocks and mainly marine clastics in the lower part followed by a mixed marine carbonate and clastics in the upper part. The Upper Cretaceous is mainly marine carbonates (limestone and marl). In the Kohat-Potwar Province, considerable variation in the Early Cretaceous sediments (Lumshiwal Formation) is noted. The Neocomian sequence of this area (Chichali Formation) is marine and is represented by sandstone and shale which are highly glauconitic, partly phosphatic and locally pyritic. Some sections have yielded ammonites.

The names of the formations are adopted from the Stratigraphic Code of Pakistan (Fatmi, 1972, 1977) except the Datta Formation which is being introduced for the first time in this area. The nomenclature scheme is based on recent investigations in Shinawari, Khadimakh and Darsamand areas of western Kohat and is summarized as below and in Figures 1 and 2. The names Baroch and Surghar Groups are adopted by Gee and modified by Fatmi et al (1990, this volume).

Hangu Formation	Paleocene
.... UNCONFORMITY	
Kawagarh Formation	Cretaceous
Tsukail Tsuk Member	
Chalor Silli Member	
.... UNCONFORMITY	
SURGHAR GROUP	
Lumshiwal Formation	Early Cretaceous
Chichali Formation	Late Jurassic to Early Cretaceous.
.... UNCONFORMITY	
BAROCH GROUP	
Samana Suk Formation	Middle Jurassic
Shinawari Formation	Early to Middle Jurassic.
Datta Formation	Early Jurassic
.... THRUSTED CONTACT	
Olive green shale	Tertiary (?)

STRATIGRAPHIC ANALYSIS

Baroch Group

The name "Baroch Group" was proposed for the rocks of Early-Middle Jurassic (Datta, Shinawari and Samana Suk Formations) by Fatmi et al. (1987) and now published in this volume. The rocks of this Group are widely exposed in Sheikh Budin Hills, Khisor and Surghar Ranges, western Salt Range, western Kohat, Kala Chitta and Hazara areas (Fig. 3). This Group is disconformably overlain by the Chichali Formation of the Surghar Group, while its lower contact is faulted with olive green shale of Tertiary age in the Shinawari section but is disconformable with the Triassic unit in other areas of Pakistan.

Datta Formation

The formation shows a marked facies changes from its type area of Surghar Range and consists of quartzose, dolomite and limestone suggesting a shallow marine shore-line environment. The formation is divisible into three units (Fig. 2). The lower unit is carbonate dominated consisting of limestone interbedded with dolomite. The limestone is dark grey to yellowish grey, medium to thick bedded, shelly, flaggy and laminated at places. The dolomite is brownish grey to pink, medium to thick bedded and sandy. Some beds are bioturbated and shelly. The middle unit is mixed clastics and carbonate, consisting of sandstone with dolomite interbeds. The sandstone is light grey to white, soft, massive, mottled, quartzose, slightly ferruginous, friable and highly fractured. The dolomite is brownish grey, whethers light brown and thick bedded. The upper unit consists of limestone with sandstone intercalations. The limestone is brownish grey to brown, weathers greyish brown, medium to thick bedded, bioturbated, rubbly, shelly and fossiliferous, It is sandy in the lower, oolitic in the middle and marly in the upper parts. Two dark red, oolitic, shelly and ferruginous iron beds are also present. The sandstone is grey, hard, medium grained, calcareous and cross-bedded.

The thickness of the Datta Formation is 272 meters in Shinawari section near Shamshudin Village, north of Shinawari (the base is faulted). This formation can be correlated with the lower part of oldest "Samana bed" of Davies (1930) in Kohat, "Red beds" and nart of "Kioto Limestone" of Middlemiss (1986) in Kala Chitta and lower part of "Malra Formation" of Davies and Gardezi (1965) in Hazara. In the Shinawari section, this formation is over-thrusted on (?) Tertiary shale. The upper contact with Shinawari Formation is gradational marked by a change from sandy beds to a rubbly grey limestone and marls with abundant molluscan fauna indicating the Lower Toarcian *Bouleiceras* genus. These limestone beds with the overlying characteristic maroon shale are regarded as the basal Shinaawari. The Datta Formation in Shinawari area is a mixed clastic shallow water carbonate including intertidal flat deposits suggesting a shallow water shore-line environment. It differs from Surghar Range type area in brief less clastic and more shallow water, limestone and dolomite. No diagnotic fauna was seen. The age is considered Early Jurassic mainly Pre-Toarcian.

Shinawari Formation

The Shinawari Formation as defined here in the type area includes the basal *Bouleiceras* limestone and marly beds and the distinct maroon shale unit which are recognized in all the areas of Trans Indus Ranges, Kala Chitta and Hazara. The formation consists of limestone, shale and sandstone (Fig. 2). The limestone is grey to brownish grey, whethers brown, marly, thin to thick bedded, medium textured, lithographic, micritic, muddy and contains occasional sandy, oolitic, flaggy, platy and shelly beds. It is mottled, oolitic, bioturbated and biosparitic. The shale is red, maroon, greenish grey to dark grey, splintery, calcareous and non-calcareous. The most characterislic feature as mentionable as the base is the presence of ammonite (*Bouleiceras*) bearing rubbly, marly limestone and nodular marl below a distintion maroon shale horizon which have already been recognized in Shaikh Budin Hills, Khisor, Surghar, Kala Chitta Ranges and other areas of northern Pakistan (Fig. 4). The sandstone is light grey, brown, medium to coarse grained, flaggy and calcareous.

It is 360 meters thick in the Shinawari area (type locality). This formation is correlative to the "Lowest Samana beds" of Davies (1930) in Kohat, "Lower part of Kioto Limestone" of Cotter (1933) in Kala Chitta, "Upper part of Maira formation" of Davies and Gardezi (1965) in Hazara, "Upper part of Datta Formation" (Fatmi, 1968, 1972) and "Wazir Wal Member of the Datta Formation" of Fatmi and Cheema (1972) in Sheikh Budin Hills and Khisor Range. The formation has a transitional contact with the underlying the Datta Formation and overlying the Samana Suk Formation. *Bouleiceras*, brachiopods (*Terebratula* and *Speriferina*) have been collected from the lower part (rubbly, marly limestone below maroon shale horizon) which indicate us Early Jurassic (Tourcian) age but upper part of the formation may extend into Middle Jurassic as no diagnostic fossils in the upper part were noted.

Samana Suk Formation

The formation consists of limestone with subordinate marl and thin shale intercalations. The limeston is grey to dark grey, weathers brownish grey, medium to thick bedded, massive, hard and crystalline, mircitic, dense in bedded. Oolitic and shelly limestone beds occur at frequent intervals within the formation.

The formation is 187 meters thick in Shinawari section (Fatmi and Khan, 1972). During this field programme, it has been partly measured (more than 87 meters). This area is also type area of the Samana Suk Formation. In the adjoining areas of Khadimakh the top beds yield *Obtusicostites* sp. and large size *Rhynchonella nobilis*. From Fort Lockhart section (Fatmi, 1972) *Belemnopsis grantana* sp. is recorded from the upper part of the formation. The lower contact is transitional with the Shinawari Formation while the upper contact with Chichali Formation is unconformable marked by pitted ; grooved, ferruginous, unevenly whethered surface (Khadimakh section). The presence of shelly fragments (brachiopods, Mollusca), belemnites (in upper part) and *Obtusicostites* (ammonite at the contact with the Chichali Formation indicate the top age limit as Middle Callovian and of the formation as Middle Jurassic.

Surghar Group

The Surghar Group in this area includes the Chichali and Lumshiwal which are dated as Late Jurassic to Early Cretaceous. The group disconformably overlies the Samana Suk Formation and is disconformably overlain by the Kawagarh Formation of Late Cretaceous.

Chichali Formation

The formation consists of rusty brown to dark green, massive, soft, friable, ferruginous, silty sandstone with sandy shales. It is measured Khadimakh section where it could be subdivided into two units.

Upper Unit (9 m.)	Sandstone, dark rusty brown to dark green, massive, ferruginous, glauconitic, calcareous, nodular, fossiliferous with belemnite and Berriasian and Valanginian ammonoids.

Lower Unit (6 m.)	Shale, green to dark green, highly glauconitic, bedded, sandy, silty at base with belemnites and ammonites.

In the Darsamand and For Lockhart areas following three units in the Chichati Formation were reconfirmed.

Upper Unit	Green to reddish brown, massive, glauconitic and ferruginous at the top with sandy shale at places.
Middle Unit	Sandstone, rusty brown, massive, glauconitic, silty and fossiliferou (ammonites, belemnites).
Lower Unit	Sandstone and sandy shale, dark green, soft, glauconitic with abundant belemnites.

The thickness of the formation in the Khadimakh section is 15 meters but in Darsamand and Fort Lockhart areas, it is more than 30 meters (not measured). The upper unit in Khadimakh section could not be separated from the overlying Lumshiwal Formatjon which is greenish grey, glauconitic, sandy shale with occasional belemnites (*Hibolithes*). The lower contact with the Samana Suk Formation is unconformable. The contact with the Lumshiwal Formation is not well seen (covered with scree) in Fort Lockhart Road Section but it is transitional. In the Samana Range the upper member is distinguished from the overlying Lumshiwal Formation because of change of colour from green glauconitic to non glauconitic light grey, white, ferruginous, quartzose, flaggy sandstone which forms the base of the Lumshiwal Formation. The age is Late Jurassic to Neocomian.

Lumshiwal Formation

The formation consists of sandstone, sandy and silty shale with hard, calcareous, glauconitic sandstone bands. The sandstone is dark green to greenish grey, weathers brownish grey, glauconitic, soft to medium hard. medium bedded and ferruginous. In the Khadimakh section the formation can be poorly subdivided into three units.

Upper Unit (40 m.)	Sandstone, dark green to greenish grey, weathers brown, soft, glauconitic, slightly ferruginous, massive, silty, fine to medium grained and fossiliferous with hard calcareous sandstone and sandy shale.
Middle Unit (66 m.)	Shale, dark green to greenish grey, soft, sandy silty, glauconitic with some calcareous, ferruginous bands containing fossils, partly covered with scree.
Lower Unit (27 m.)	Sandstone and sandy shale. Green to dark green, weathers brown, flaggy, fine to medium grained, massive, glauconitic, ferruginous, silty with belemnites and sandy, silty shale.

Thickness of the formation is 133 meters in the Khadimakh section. In Fort Lockhart (Samana Section) the lower unit is quartzose, flaggy sandstone of light colour (Fatmi, 1972). In the Khadimakh section the rusty ferruginous sandstone is overlain by massive, greenish, grey glauconitic, sandy shale (Fig. 3). The upper unit of the Chichali Formation appears to pass without any distinct lithologic a change into overlying unit of the Lumshiwal Formation. Hence the contact is transitional. Its upper contact with the Kawagarh Formation is unconformable (Fatmi and Khan, 1966). Belemnites are distributed throughout the formation but are more common in the calcareous sandy bands. Fatmi and Khan (1966) have reported a rich fauna consisting of mainly ammonites

(*Douvillericeras, Oxytropidoceras, Lyelliceras*), echinoids, brachiopods, pelecypods, gastropods, and belemnites from the top gritty calcareous bed. The age is considered to be Late Cretaceous (post Valanginian to Middle Albiar).

Kawagarh Formation

The formation is typically a lithographic to sub-lithographic limestone which is thick bedded in the upper part and thin bedded with calcareous shale and nodular marl in the lower part and is mainly open sea pelagic limestone. It is divisible into the Chalor Silli and Tsukail Suk Members (Fatmi and Khan, 1966).

Chalor Silli Member

It consists of light grey, olive grey, thin to medium bedded, flaggy, lithographic to sub-lithographic with subordinate calcareous shale and nodular marl intercalations with smaller foraminifers. It is 45 meters thick in Khadimakh section.

Tsukail Tsuk Member

It consists of grey to light brownish grey, slightly olive grey, sublithographic, thick bedded to massive in the lower part and medium to thick bedded with some thin calcareous shale and marl partings in the upper part. It is rich in smaller foraminifers. The thickness is 49 meters in the Khadimakh section.

The Kawagarh Formation is 120 meters thick in the Darsamand section (Fatmi and Khan, 1966) and 94 meters in the Khadimakh sections. The formation has disconformable contacts with the overlying Hangu Formation of Paleocene age and the underlying Lumshiwal Formation of Early Cretaceous age. Smaller forminifers are commonly distributed throughout the formation. Fatmi (1968, 1972) has also recorded some collignoceratid ammonoids from the basal part of the formation. On the basis of fauna the age is considered as Late Cretaceous.

CONCLUSIONS

Some of the important conclusions are summarized below :—

1. The Datta Formation shows a facies change in western Kohat and includes marine and more shallow water facties rocks of sandstone dolomite, limestone, oolites, ferruginous beds. The micritic dolomites suggest, development of supra sidal flats with repetition of regressive and transgressive marine deposits.

2. The Shinawari Formation shows establishent of a shallow marine environment with occasional influx of sand from source area.

3. The Samana Suk Formation is of a shallow water marine deposits with hardly any influx of sand from source area. The upper beds of the Samana Suk Formation suggest a more regressive at the close of Middle Jurassic (Middle Callovian).

4. The post Middle Callovian regression was followed by a shallow marine transgression in Late Jurassic as rocks of Late Jurassic and Early Cretaceous ore highly glauconitic sandstone and sandy shale. A Middle Albian regression occurs at the top of Lumshiwal Formation marked a major unconformity between Early and Late Cretaceous.

5. The Late Cretaceous transgression was more open marine with development of pelagic carbonates.

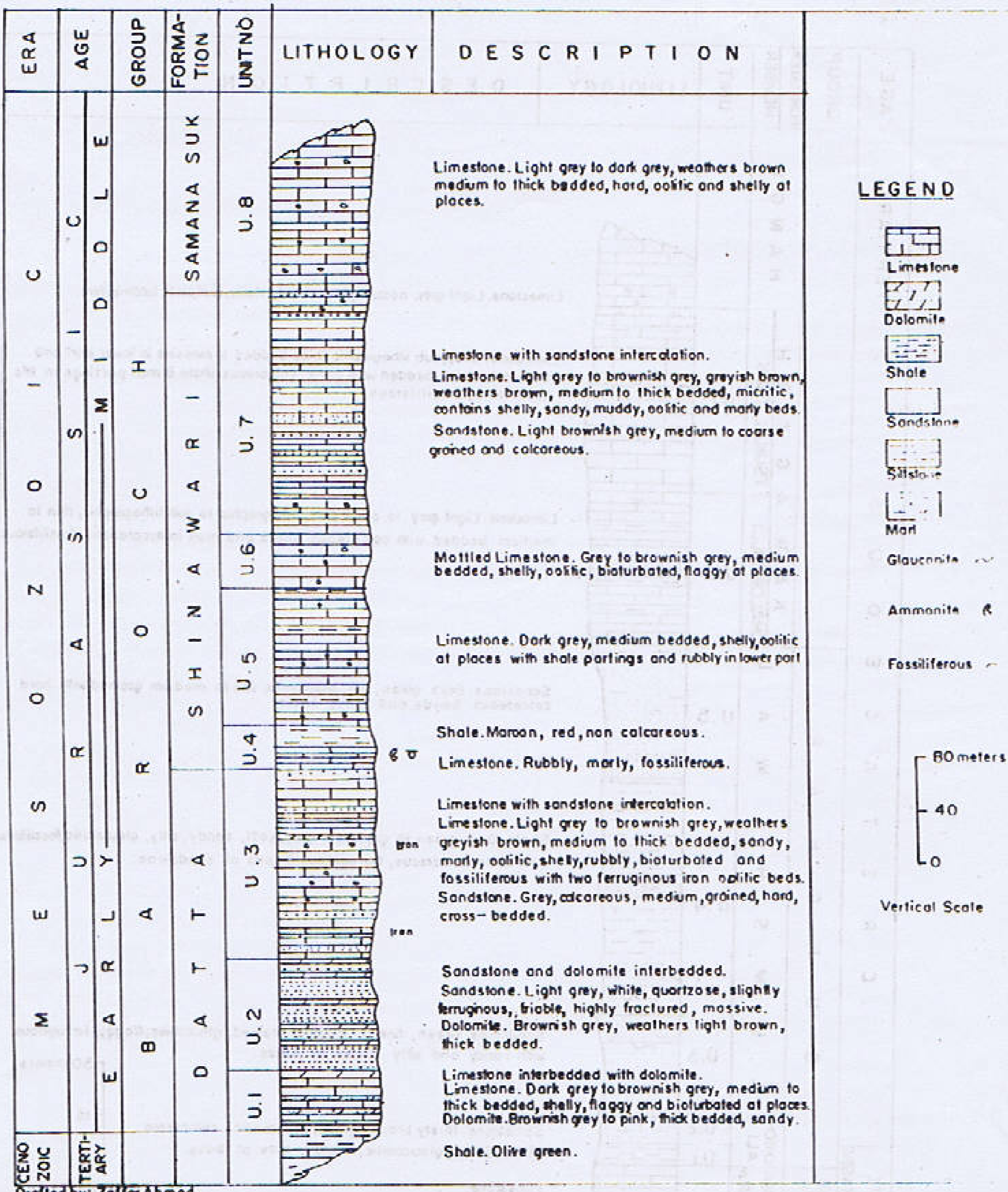

FIG.1. COLUMNAR SECTION OF JURASSIC ROCKS NEAR SHAMSHUDIN, NORTH OF SHINAWARI (38 F/14).

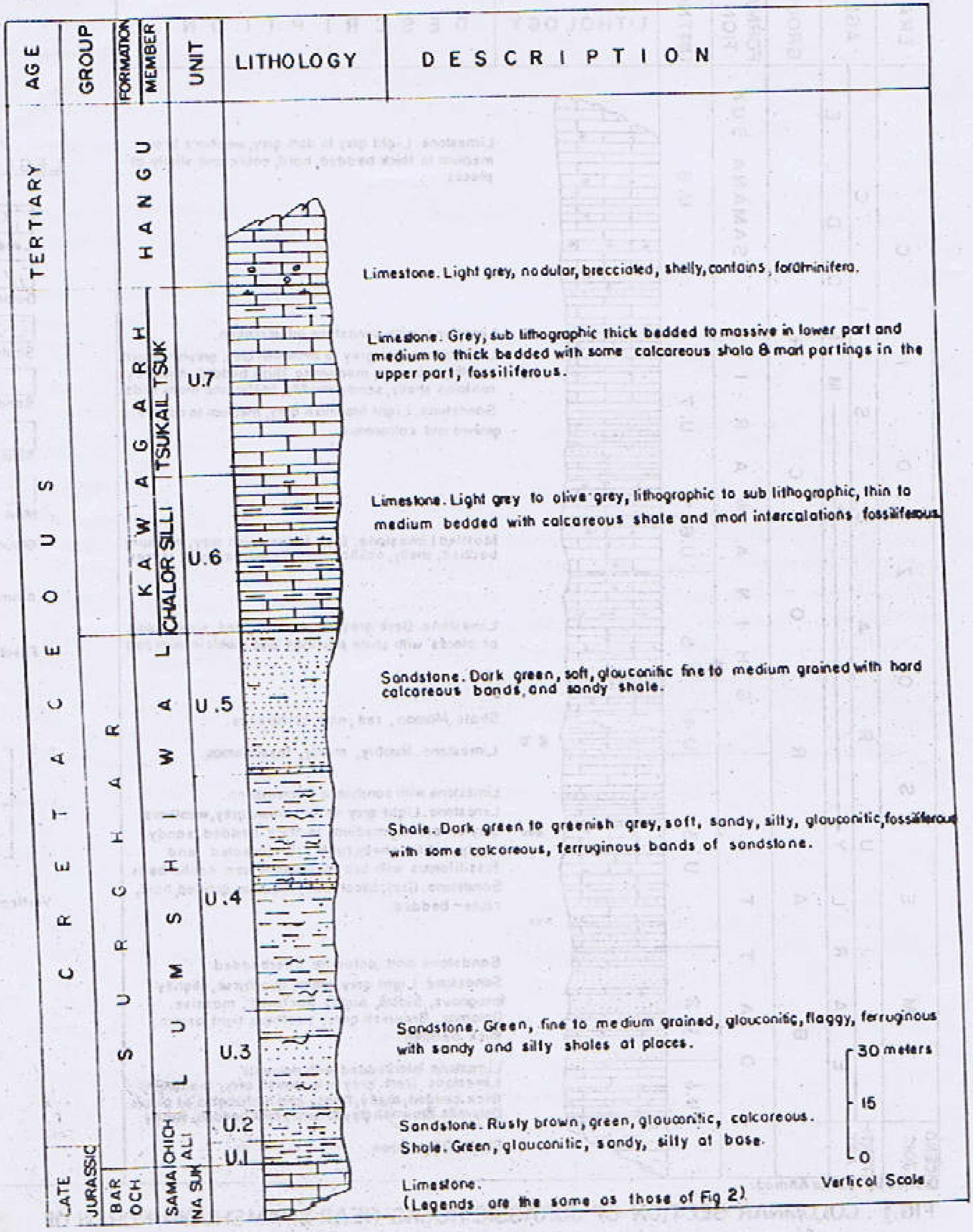

FIG.2. COLUMNAR SECTION OF CRETACEOUS ROCKS IN EAST OF KHADIMAKH.

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ECONOMIC EVALUATION OF THE GRANITES AS DECORATIVE STONES OF THE NEELUM VALLEY, AZAD KASHMIR

BY

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Abstract : *The granites exposed in different parts of Neelum valley Azad Kashmir have been investigated to evaluate their mechanical properties to use them as decorative stones. The mechanical properties like compressive strength, shear strength, soundness, porosity, water absorption, slack durability and degree of polish of the granites, show compatable values to the recommended ASTM range of values with few exceptions.*

An economic evaluation of different granities as decorative stones on the basis of above parameters, in addition to reserve estimation, accessibility of labour and geographical control, have been discussed.

INTRODUCTION

The occurrance and uses of decorative stones are well known in the territory of Azad Kashmir since last many centuries to present era. The potential areas of granites as decoratives stones are at different localities in theNeelum Valley except for the granites of Keran area. Scientific development of quarries have not been made so far due to the lack of geotechnical know how and commercial reasons. The rocks studied in the present investigations represent varieties of granites which differ in colour, texture, structure and overall look at surface exposures. During economic evaluation, due consideration has been given to the accessibility of the sites of reserves, geographical control of the locality, available manpower in the area and the amount of reserves in addition to the engineering geological characteristics of the rocks mentioned above. The calculation of reserves is made on the basis of rocks exposed and can be obtained by open quarry mining. The total reserves also include the possible workable depth of the rocks below the surface through an open quarry process. Decorative stones of the Neelum Valley, Azad Kashmir are randomly quarried at present and proper consideration is not given to demand consumption ratio. Hence, during evaluation such factors have been given due consideration. The present investigation was undertaken to explore the quality and reserves of decorative stones.

During evaluation of the decorative stones due consideration was given to the distance of localities from Muzaffarabad city which has the facilities of transport through road ways to other parts of the country to process and export. The access to the localities, quarrying activities, availability of labour and demand of the decorative stones have been taken into consideration and given in Table-I.

TABLE-I
Trend of Infrastructure, Labour Charges and Demand

S. No.	Locality and type of rock	Distance from M. abad	Access to Locality	No. of quarries	Labour charges	Demand
1.	Jura granite (Jg.)	45 Km	Paved road	3	Not high	High
2.	Islampura granite (Ig)	52 Km	3.5 km unpaved	2	Moderate	High
3.	Samari granite (Sg)	58 Km	11 km unpaved	—	Low	Moderate
4.	Attmuqam granite (Ag)	60 Km	Paved road	5	Low	High

ENGINEERING GEOLOGICAL PROPERTIES

The determination of compressive strength, shear strength, soundness and porosity of the rock samples from various localities of the present study is expected to help in the classification of the decorative stones and their proper economic exploitation. Although geologigal investigations and mapping of the areas have been done by various geologists from time to time, no detailed work on decorative stones has been done so far.

COMPRESSIVE STRENGTH

The comparison of the data for unconfined compressive strength of decorative stones with allowable data of the US Bureau of standards reveals, that the higher values for granites of Jura exceed the upper limit of the recommended values (Fig. 1). Most probaly this increase is due to siliceous cement. Likewise, some of the samples from granite beds of Chilians which show a maximum of 38987 psi compressive strength may be attributed to their origin and higher degree of recrystallization in tightly folded structures. The other beds of granites exposed in this locality do not show much higher compressive strength value, but have fairly higher values (15560-42000 psi). It appears that tectonic conditions and tight folding in this part of the locality has affected the compressive strength in general. The reserves of material is fairly high (562781×10^3 million tons) and can be exploited as decorative stones. Hence, it appears reasonable to consider that the building stones of the area under study are of fairly high quality with respect to their compressive strength However, some of the granite samples of Islampura and Atthmuqam localities show their comprersive strength to be less than the lower limit of the recommended values but such beds are few and identifiable in the field on the basis of their appearance. It is, therefore, possible to separate the better quality and the poor quality decorative stone during exploitation.

SHEAR STRENGTH

The rock samples from Jura, Islampura and Atthmuqam are mainly siliceous rocks which show great variation in shear strength values but they are within the recommended range of ASTM values. The variation in the values of tne granites are probably due to mineralogical composition and the microcracks at the boundaries of the grains. The rock samples from Samari show better average of shear strength value as compared to Atthmuqam. The change in the values are due to microfractures present and the argillaceous nature of the rocks. The decorative stones from Islampura are highly fissnred and some grains are also crushed which decrease the durability and its strength. (Fig. 2).

GRADING, ABRASION AND SLACK DURABILITY

To find out the behaviour of rocks as crushed stone, the granites from Jura, Islampura, Samari and Atthmuqam have been crushed separately. It was Jaw type small unit crusher and small pieces of rock sizes ranging from 12×14 cm to 15×20 cm were used for crushing. The product produced in one short was mechanically analysed to see the crushing behaviour of rocks. 70% of the crushed samples, all granites were retained on sieve no. 4. All granites show excellent aggregate grading while crushing. (Table-II).

TABLE-II

Abrosion, Slake Durobility Index and Aggregate Groding

Samples	Abrassion %	Slake durability Index (S cycle) %	Retained on Sieve-4 after crushing %
Jura Granite	15	99.8	> 75
Islampura Granite	18	99.5	> 75
Samari Granite	20	98.6	> 75
Atthmuqam Granite	14	99.6	70

Abrasion and slake durability values are also high and within the limit of ASTM Specification.

WATER ABSORPTION

To find water absorption and the behaviour of rocks, $2 \times 2 \times 2$ inches (125 cm) oven dried granite samples were tested using ASTM C-170, (1986) method. The values ranging from 0.22 to 9%. The difference in the values is due to structural weaknesses like microporosity produced by tectonic deformation and the amount of clay present in the rocks (Table-III).

POROSITY

The total porosity of the granites are mostly within the recommended limits of 10% of ASTM. However, there are some beds in Samari and Atthmuqam localities which show higher values, but they can be identified with the help of textural characteristics and argillaceous composition (Table-III). The granite beds from Samari show higher percentage of total porosity and can be used as decorative stones in arid regions, because of their higher compressive strength to withstand civil engineering construction works. Alternatively, the granites of Atthmuqam which show higher porosity can be utilized in the manufacture of handicrafts and decoration pieces.

TABLE-III

Water Absorption, Porosity and Degree of Polish of different granites in Neelum valley

Type of Rock	Water Absorption %	Porosity %	Degree of Polish
Jura Granite	0.22 – 0.54	5	Excellent
Islampura Granite	2.04 – 3.00	10	Good
Samari Granite	0.90 – 8.00	15	Good
Atthmuqam Granite	2.00 – 9.00	12	Good

DEGREE OF POLISHING

The degree of polishing of the rock reflects the shine that rock can take-after passing through various processes of polish. This property was achieved by passing the rock sample generally, through cutting, sizing and grinding with specially made abrassives. After polishing, the surface of the rock shows possible colours and becomes eminent. Commercially, the degree of polish is very important. The minerals present in the rock give prominency of the shade present in a rock· In the area under study, most prominent decorative stones are granites, which take good to excellent polish and reflect the texture and structure of the rocks. The degree of polish is a matter of choice of the users which varies from person to person and hence, the demand for these rocks is very high. The present effort is aimed at giving a scientific approach in classifying the rocks as decorative stones of varying grades, according to their mechanical and physical properties.

The degree of polish in the rocks of the areas under study, varies from Jura to Atthmuqam due to textural and structural differences. The excellent polish was observed in Jura Granite and good polish was found in Islampura and Atthmuqam Granites. (Table-III).

TABLE-IV

Reserves and preferable uses of the building stones of different granites

Rock Type	Reserves in Million Tons	Possible Uses
Jura Granite	5019418×10^3	Decorative stones
Islampura Granite	874×10^3	Decorative and Building stones
Samari Granite	5467×10^3	Decorative and wall stone
Atthmuqam Granite	34873×10^3	Decorative and wall eston

RESERVES

The present estimation of the reserves is for the granites of the Neelum valley Azad Kashmir. It appears that, one day full attention will be directed to possibilities of using the building decorative stones particularly in localities where abundant supply is available. In view of this, it will not be prudent to ignore decorative stones of the area when the country is passing through an industrial revolution and there is urgent need to have good quality stones. In this connection private companies can be encouraged to explore the possibilities of using decorative stones and their possible reserves in Azad Kashmir.

The aim of the reserve calculation during the present work is to show all the reserves of available decorative stones in the Neelum valley Azad Kashmir, and their possible proper utilization and exploitation on a rational basis.

The demand of the granites as decorative stone in the country and abroad is very high. Presently the rocks are being used as wall stones in the area. If the development and marketing of these rocks is done on scientific grounds, it would prove to be a good source of foreign exchange for the country. Very little of the exposed rocks have been quarried so far. The bulk reserve of the granites estimated from Jura is 5019518000 million tons. The grey variety is about 1346000 million tons.

The grey banded variety is about 23876000 million tons. The estimated reserves from Islampura are about 874000 million tons. The bulk reserves calculated from the main granite quarries of Samari, range in colour from grey to white and are not presently in operation. The estimated reserves are about 5467000 million tons. The bulk reserves estimated from two quarries of Atthmuqam area are about 34873000 million tons. The reserves of greenish grey, brown and white granites estimated to be 2345000, 567000 and 2168000 million tons respectively. These rocks could be exported as decorative stones if quarring and dressing of the rocks be done on a scientific ground. Presently there is no arrangement for dressing of the rocks at the quarry sites. They are transported away to Islamabad or the Rawalpindi for the purpose of dressing and to be put in the market. If dressing provision for the rock is made at the quarry site saving can be made, due to availability of labour at low cost and so more earnings can be achieved. The extra transportation changes for the waste material can be minimized. Mechanized mining and dressing of the material at site would further increase production and thus exportation of the material abroad will be facilitated. Presently, in public sector these rocks are being used in the construction of boundary walls, which is not rational use of the rocks. The exploitation of the reserves in various parts of the Neelum valley would facilitate development work programme of Azad Kashmir, shall provide job opportunities both for the locals and the skilled unemployed manpower. It would prove a good source of earning Foreign Exchange for the country with the condition that mining methods and techniques are also improved to avoid wastage of the rocks and improved working and safety conditious of the workers.

MINING TECHNIQUES

Mining techniques in use are old and unscientific due to lack of practical and scientific information. The explosives mainly used are gilatinous, scismic semi gilatinous, powdered, wabocord, detonators etc. The above mentioned explosives produce shock waves which travels with very high velocity and disturb the bonding between particles and also break the internal structures resulting small and large cracks on the surface of the rocks. The rocks with discontinuities more than 20 per meter are not suitable raw materials for decorative stones.

During mining safety measures such as ohm meter, leakage testers, lightening detectors, short firing cables, and climpers should be used to reduce the wastage and risk assessment. Such purpose can be achieved provided that the training facilities and a blasting services division are established.

CONCLUSIONS

1. The reserves of good quality granites for decorative stones are huge and transport charges would not be very high due to easy approach to the sites, cheap labour and proximity with the city of Muzaffarabad.

2. The granitic rocks having a compressive strength greater than 20,000 psi from Jura and other lacalities can be used for important buildings and external surfacing in addition to their use in special engineering works.

3. The soundness values of granites under study are within recommended limits with few exceptions. Hence the effacts of weathering would be very low and the rocks can be used for civil engineering works in varied types of climatic controls.

4. The change in textural and mineralogical characteristics of the granites due to recrystallization, diagenesis and the effects of tectonism appear to affect the engineering properties of the granitic rocks of different localities under study.

5. The granites with discontinuities more than 20 per meter are not suitable raw material decorative stones.

6. The degree of recrystallization and diagenesis appears to have affected the porosity of the granitic rocks.

7. The exploitation of the granites for decorative stone can be done by open quarry mining and the waste material can be used for filling purposes. The exploitation of these granites can be economical.

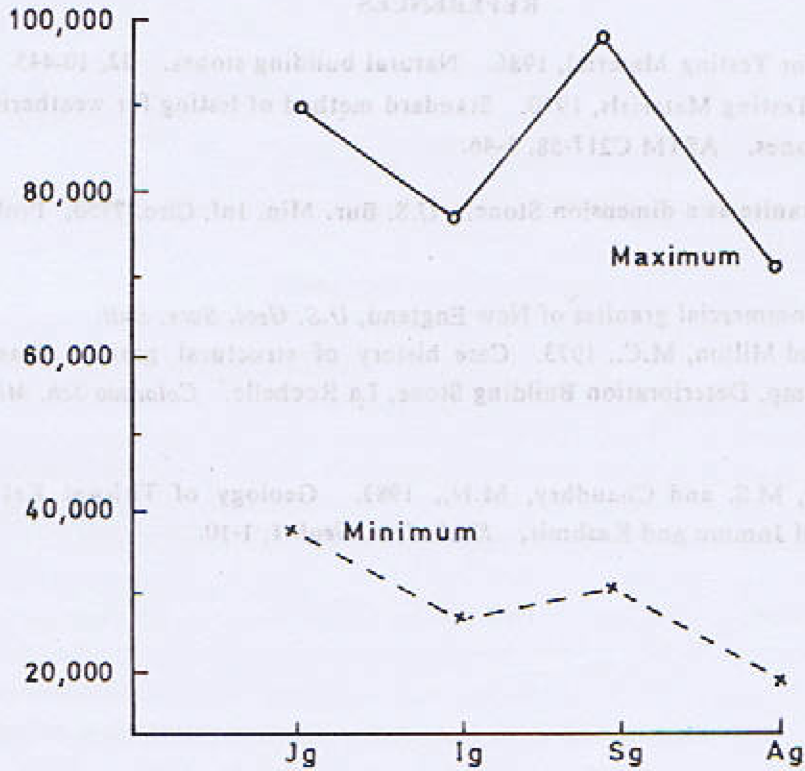

Fig:1_Maximum and minimum shear strength of granites from Neelum Valley.

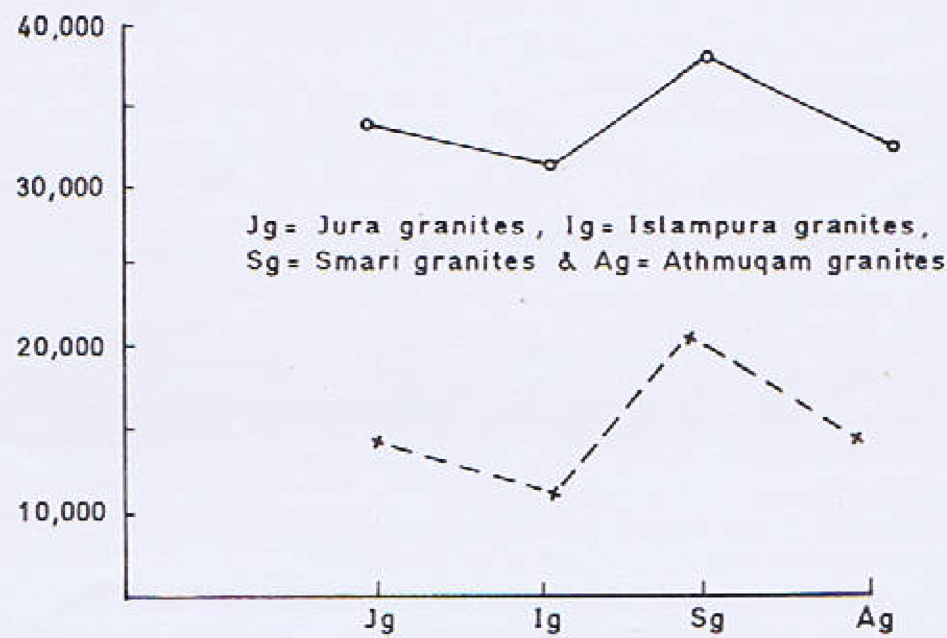

Fig: 2_Maximum and minimum unconfined compressive strength of granites from Neelum Valley.

was marked by consulting the Topo sheets No. 38P/14, 43D/5, P/5 and O/8 of Survey of Pakistan. Brunton compass was used to record the dip and strike readings of these deposits and outcrops were measured by measuring tape. Field study also included the lithology and stratigraphic sequences of deposits located at Kutti Chopri, Katha, Nala Rikhi, Mouza Bazar and Musa Khel.

Grading : Raw (unwashed) and washed sand samples belonging to various deposits were sieved on 10 to 120 Tyler screens, in order to find out the suitability for glass melting, regarding their grain size. 100 grams of every sample were weighed out separately and said screens were applied one by one. The relative amounts of the sand samples retained on and passed through the given mesh sizes were accurately weighed and carefully recorded in tables with numbers S.S. 1 to S.S. 5. These tables also show the retained % and commulative % of various specimens.

Washing treatment : Simple water washing, being the most economical, was chaosen to upgrade the sand. Consequently, 700 grams of every sample were added to clean stainless steel bath containing one litre of water, thoroughly siirred for sufficient time and allowed to settle down. Water containing impurities was decanted off carefully so that no grain of sand would escape out along with it. Stirring with fresh water and decanting off the same was continued until the lastly decanted water was clear and colourless. Such processed sand samples were procured, dried at 200°C, graded and analysed chemically.

GEOLOGY OF THE DEPOSITS

The preliminary geological study of the deposits under investigations was executed by one of the authors at related sites. It revealed that these belong to the Datta Formation of lower Jurassic age, and are of continental origin and associated with siltstone, sandstone, limestone, calcareous dolomite and gypsiferous clay.

The geological aspects of the studied deposits are briefly and separately discussed as under :—

1. Nala Rikhi deposit (SS-3) is located on the western side of Mianwali-Talagang Road near the Rikhi Village and is exposed at third furlong in the Rikhi Gorge (Topo sheet No. 38P/14 ; Long : 71°46'45" ; Lat : 32°42'14"). It is lying at foot hills and is easily approached for transportation by trucks. The eastern portion of this deposit is comprising two beds of silica sand (arbitrarily marked as A and B) which have been separated by four feet thick bed of sandstone. The western portion is medium grained, yellow to reddish in colour and hence not suitable for glass melting due to high percentage of iron as impurity.

   A. Its exposure is 30 × 100 feet and consists of medium grained greyish white sand. Its detailed study was done in the laboratory.

   B. It is 15 × 100 feet thick, consisting of relatively fine grained silica sand and associated with clay materials.

2. Musa Khel deposit lies on the eastern side of Mianwali-Tallagang Road at eighth mile. One bed is 20 to 30 ft. thick, striking north-south and dipping 65°. (Grid Ref. 877282 ; Topo sheet No. 38P/14). Silica sand present here is white in colour, medium grained and having quartz nodules to some extent. However, the weathered surface exhibits dull red to greyish black colour. The bed of sand, showing excessive jointion, is associated with pockets of yellow coloured and compact siltstone.

3. The Mauza Bazar deposit is located at 1½ miles NE of Musa Khel-Sakesar Road (Long : 70°49'37" ; Lat : 32,36,'14" ; Topo sheet No. 38P/14). It is approximately 60 feet thick striking N68° and dipping 50 NE. It it one of the largest deposits in the area (50×100 feet). The sand is medium to fine grained and off white to light yellow and dark yellow to reddish brown colour. The same deposit might be anticipated to prove a good source of glass sand in future,

4. Katha Surgal deposit is 20×30 feet thick and consists of white to greyish white colour silica sand. It is easily approachable through jeep tracks and suitable for open mining (Grid Ref. 508147 Topo Sheet No. 43O/6).

5. Kutti Chopri deposit is about 100 feet thick. In runs west of Chopri to east of Kutti Village, Distt. Mianwali. It has total length ranging upto two miles, dipping 20°–30° and is cut by small Nalas which facilitate the study of exposure. It co-ordinates at E 3443480, N 1064760 (Topo sheet No. 43P/5 and 43O/8). Recently it has been taken up by PUNJMIN and is being mined mechanically on sufficiently large scale. The silica sand, present here, has been roughly estimated amounting to 22 million tons.

CHEMICAL ANALYSIS

As first step, raw sand samples selected after coning and quartering, were ground to fine powder and analysed. International standard methods for chemical analysis of glass sands were followed for this purpose. SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O and K_2O were determined quantitatively by applying the well recognized gravimeteric, calorimetric and flame photometric techniques. Secondly, the water washed and graded samples of the sands under study were again analysed as above. The results thus obtained have been recorded in table No. 6 and table No. 7 respectively. Comparison of these tables clearly refers to the improvements in the percentage of SiO_2 and Fe_2O_3 from the view point of a glass melter. There is also general decreasing trend in quantities of Al_2O_3 and CaO after washing the sands except SS - 5 (only in case of Al_2O_3 content).

GLASS MELTING

A glass batch based upon typical container glass composition was mixed thoroughly by including the appropriate amounts of raw materials. Washed and graded sand marked as SS-5 was added as silica sand portion of the the batch. Table No. 9 gives the raw material-wise composition of this batch. It was melted in crucible type glass melting pot in gas fired furnace, at 144°C for about two hours. The occasional observations of the melt indicated that molten glass was free from seeds etc. Then temp eraturewas slowly lowered to 124°C and maintained for further two hours, in order to refine the moltin mass by dissolving the occluded gases. Contents of the melting pot were cooled on natural cooling rate upto room temperature. The obtained glass was keenly inspected which was colourless and free of stones, cords, bubbles, straie and other defects.

RESULTS AND DISCUSSION

The concerned section of ASTM (1961) implies that useful fraction of good quality glass sand, meeting all other standard specifications between – 10 and + 100 should exceed 94% by weight when graded after washing treatment. It is obvious from table No. 1 to 5 that the said fractions in case of SS-1, SS-2, SS-3, SS-4 and SS-5, are 90.20, 96.28, 94.05, 92.58 and 99.59 respectively. This data ranks SS-2, SS-3 and SS-5 upto the standard as regards the parameter under consideration.

SS-4 almost approaches near the specified percentage, while SS-1 drops itself below the specifications. However, this might be exploited for silica containing products other than glass such as ceramic industry.

According to BS specifications regarding chemical composition, SiO_2 content for fine grade optical glass, for high grade domestic and decorative glassware and general colourless glasses including containers must be 99.5% and 98.5% respectively. Table No. 7 giving chemical analysis results of washed sand samples shows that all the sand samples except SS-4 qualify the related specifications in general. The same table also indicates the improving trend with respect to SiO_5 content after washing all of the sand samples and mostly same is the case regarding Fe_2O_3 cnntent. Table No. 8 records the % improvement in iron content for every specimen.

It is again notable with reference to the above table that there is common decreasing tendency (except SS-5) in both Al_2O_3 and Fe_2O_3 after washing treatment which leads us to the fact that most of the iron present is in the form of feruginous clay. BSS demand 0.008%, 0.013% and 0.03% Fe_2O_3 in washed and graded glass sands as maximum permitted limits for manufacturing fine grade optical glass, high grade domestic glassware and decorative glassware and general colourless glass (including containers) respectively. From this point of view SS-5, SS-4 and SS-2 accurately meet the requirements for the decorative colourless type. While SS-3 and SS-1 are with slightly higher Fe_2O_3 content.

CONCLUSIONS

The collective and comprehensive visualization of all the aspects like SiO_2 and Fe_2O_3 content, grain size, washing and grading, as described and discussed above, infers that the varieties of glass sands represented by SS-2 (Katha area, Khushab) and SS-5 (Musa Khel) are both commercially and technically feasible for manufacturing general colourless glasses. On the other hand SS-3 (Nala Rikhi Area) is suitable for producing coloured glassware and the remaining SS-1 (Kutti chopri Area) and SS-4 (Mauza Bazar) may find utilizations in ceramic industry.

TABLE 1

Grading of Glass Sand of Kutti Chopri (SS-1)

Mesh No.	Sieve aperture in microns μ	Raw Sand Percentage retained	Raw Sand Cummulative Percentage	Washed Sand Percentage retained	Washed Sand Cummulative percentage
10	2000	—	—	—	—
20	841	1.88098	1.88089	2.0454	2.0454
30	595	4.92112	6.8021	3.54082	3.58622
40	420	233.26677	30.06887	17.81482	23.81482
50	297	26.05986	56.12873	26.02366	19.4247
80	177	28.15041	84.27914	32.8869	82.3116
100	149	6.46383	90.74297	7.90868	90.22028
120	125	5.21009	95.95055	6.65056	96.87084
—120	—	3.2432	99.19626	2.5856	99.45644

TABLE 2

Grading of Glass Sand of Katha Area, Khushab (SS-2)

Mesh No.	Sieve aperture in microne μ	Raw Sand Percentage retained	Raw Sand Cummulative percentage	Washed Sand Percentage retained	Washed Sand Cummulative percentage
10	2000	—	—	—	—
20	841	0.30478	0.30478	1.18498	1.18498
30	595	0.80216	1.10694	4.33142	5.5164
40	420	1.8252	2.93214	17.39424	22.91064
50	297	15.67682	18.60896	26.29558	49.20622
80	177	66.28134	84.8903	43.18363	92.3899
100	149	7.62526	92.5156	3.89682	96.28672
120	125	3.87472	96.39028	2.43302	98.71974
—120	—	3.15192	99.5422	1.26302	99.98276

TABLE 3

Grading of Nala Rikhi Glass Sands (SS-3)

Mesh No.	Sieve aperture in microns μ	Raw Sand Percentage retained	Raw Sand Cummulative percentage	Washed Sand Percentage retained	Washed Sand Cummulative percentage
10	2000	0.19848	0.19848	—	—
20	841	3.46368	3.66216	2.21266	2.21266
30	595	12.4476	16.10976	3.26660	9.4481
40	420	41.02758	57.42582	38.44602	47.89412
50	297	19.28848	76.42582	24.71526	72.60938
80	177	11.04126	87.46708	16.95626	89.56564
100	149	3.05788	90.52496	4.4894	94.05504
120	125	2.67814	93.2021	3.1523	97.20734
—120	—	20.34558	99.54848	.19714	99.17374

TABLE 4

Grading of Mauza Bazar Glass Sand (SS-4)

Mesh No.	Sieve aperture in microns µ	Raw Sand		Washed Sand	
		Percentage retained	Cummulative percentage	Percentaga ratained	Cummulative percentage
10	2000	—	—	—	—
20	841	0.23436	0.23437	0.12996	0.12996
30	595	0.87566	1.11002	0.45188	0.58184
40	420	2.10472	3.21474	1.54322	2.12506
50	297	24.2722	27.48694	22.9688	25.09386
80	177	59.51732	87.00426	61.4651	86.65896
100	149	5.00562	91.00988	6.03036	92.58932
120	125	3.199	95.20888	3.96914	96.55846
—120	—	3.42084	98.[illegible]2972	2.52646	99.08492

TABLE 5

Grading of Glass Sand of Musa Khel (SS-5)

Mesh No.	Sieve aperture in microns	Raw Sand		Washed Sand	
		Percentage retained	Cummulative percentage	Percentage retained	Cummulative percentage
10	2000	0.28774	0.28774	0.3014	0.3014
20	841	5.60318	5.89092	5.84276	6.14416
30	595	23.60794	27.45889	22.01768	28.16184
40	420	46.36794	75.8668	51.09468	79.25652
50	297	12.81534	88.68214	13.7831	93.03962
80	177	6.44994	95.13208	5.87404	98.91456
100	149	1.27134	96.40342	0.67972	99.59428
120	123	1.20486	97.60828	0.32998	99.99676
—120	—	1.55294	99.16122	0.0725	99.99676

TABLE 6

Chemical Analysis, Results of Raw Hand Samples

Sr. No.	%L/I	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Total
SS-2	0.22	99.09	0.30	0.07	0.10	0.02	NIL	NIL	99.98
SS-2	0.28	98.87	9.39	0.05	0.59	Trace	0.02	NIL	100.00
SS-3	0.46	97.87	1.32	0.06	0.28	,,	NIL	,,	99.99
SS-4	0.63	96.02	1.50	0.04	0.89	,,	0.16	0.76	100.00
SS-5	0.68	97.24	0.78	0.05	0.75	,,	NIL	NIL	100.00

TABLE 7
Chemical Analysis Results of Washed and Graded Sand Samples

No. %	%L/I	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2G	Total
SS-1	0.21	99.61	0,04	0.04	NIL	0.10	NIL	NIL	100.00
SS-2	0.15	99.42	0.33	0.03	0.05	Traces	0.02	,,	100.00
SS-3	0.32	98.97	0.45	0.04	0.21	,,	NIL	,,	99.99
SS-4	0.61	96.38	1.26	0.03	0.82	0.05	0.15	0.70	100.00
SS-5	0.10	98.70	0.86	0.02	0.07	0.04	0.07	0.03	99.89

TABLE 8
Improvement in Silica Sand Sample with respect to Iron Content

Sample No.	% of Fe_2O_3 in unwashed Sand	% of Fe_2O_3 in washed and graded Sand	% Production of Fe_2O_3
SS-1	0.07	0.04	42.85
SS-2	0.05	0.03	40.00
SS-3	0.06	0.04	33.33
SS-4	0.04	0.03	25.00
SS-5	0.5	0.02	60.00

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