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ENGINEERING GEOLOGICAL STUDIES AT THE DHOK PATHAN DAM SITE, DISTRICT ATTOCK, PAKISTAN

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Abstract : *Tests carried out ou three proposed allignments for construction of dam suggest the use of clay/shale as good core and blanket material on site marked as 'AA'. Sandstones may offer some problems of seepage because of their high permeabilities and nature of jointing but they can be overcome by effective grouting.*

INTRODUCTION

Investigations were carried out on three proposed sites for potential off-channel storage from Terbela reservoir. These sites are situated on the Soan River, a tributary of Indus, near the Village Dhok Pathan, about 120 kilometers southwest of Rawalpindi on topographic sheet No. 48 C/8 of the Survey of the survey of Pakistan at coordinates 33°8′ N Latitude and 72° 21′ E Longitude.

Preliminary investigations were initiated as early as 1955 when a feasibility report was prepared by the Dam Investigation Circle. No subsurface exploration was carried out then. In 1960, a reconnaissance report was prepared by M/S Hazara alongwith geological mapping of the three proposed dam axes, power plant and a part of reservoir area. Investigations for construction of dam were reactivated in 1971 by the Directorate of Planning and Investigation of Water and Power Development Authority (WAPDA) Pakistan when a number of bore holes were drilled for subsurface evaluation.

The present studies were carried out for about three months when detailed geological mapping and testing of clay/shale and sandstones present in the area were carried out.

Geology

The area lies in low lying central Potwar with regular and spacious interfluves and low relief having semi-arid conditions. Gulleys incised in shales are frequent due to differential weathering.

Rocks exposed in the area belong to the Siwalik Group represented by the Dhok Pathan and Nagri Formations. Since the dam site is situated in the least disturbed area, the original structural features have little or no influence on the stability of the proposed structure.

The rocks present are shallow water continental deposits and consists of sandstones, clays, shales and occasional gravel beds which are not continuous. These rocks vary in lithology, texture, strength, cementing material, fracturing and degree of weathering resulting in variable engineering characteristics.

The geology and engineering characteristics of the three proposed sites i.e. AA′, BB′ CC′ (Fig. 2) have been discussed in the present study for their mutual comparison and suitability. The physiography of the area is characerized by the flat alluvial filled valleys and depressions and the relief is primarily controlled by the variable resistant nature of rocks and partly by structural features. A general description of the rocks exposed is given under :—

Sandstone. Light to dark grey and medium fine to medium coarse grained sandstones are exposed. Both the types are loosely cemented with argillaceous materials (Krynine, 1937). Hardness or strength of these sandstones varies according to type and amount of cementing material. Generally the coarse grained sandstone is weaker than medium or fine grained sandstone. Most of the sandstone beds, however, are fairly weak and friable. About 20% of sandstones are in the form of hard ribs which are fine grained and very well cemented and are resistant to immersion and erosion. The rest of the sandstones are usually cross bedded, poorly graded and show poor stratifications. At places, pebbly sandstone is present but has small lateral extent (a few feet). Soft sand pockets and clay lumps are present near the contact with shales.

Feldspar and quartz are the major constituents with calcite as cementing material (Abbassi et al., 1983). Muscovite, Biotite Amphibole, Sericite and Magnetite are present as accessory materials.

The sandstone is traversed by two sets of near vertical joints with spacing ranging from ten inches to four feet. Some joints are persis tant and can be traced laterally for about hundred feet (Fookes, 1966).

The average cnbe compressive strength of seven sandstone samples at one of the sites is 1322 P.S.I.

Shales (clay/shales). The shales are orange red to dark reddish brown, splintery, arenaceous and do not show lamination. A general term 'shale' is being used here for this material which is otherwise more like clay, claystone and siltstone. The gradation analysis reveals its texture as 'silty clay' which is quite hard and indurated and shows dessication cracks wherever the clay fraction is appreciable.

Shear zones varying from a fraction of an inch to about one foot are found near the contacts of sandstones indicating the loss of strength due to folding (Fookes, 1965, 1966).

The compressive strength of these clays/shales in dry condition is fairly good but decreases considerably in wet conditions (Morgenstern and Eigenbrod, 1974). The average unconfined strength of fifteen samples in remoulded state at maximum dry density and optimum moisture content is about 32 P.S.I. and the average angle of internal friction is 25 degrees with cohesion as 15.5 P.S.I. Thick exposures of 'clays' with low permeability ($K=3.9\times10^{-6}$ cm/sec.) are present in the area and can be used for core and blanket in the dam.

Gravels. Two types of gravels i.e. coarse and fine are present. Coarse gravels contain 66% sand, 4% silt and 5% clay. In the fine gravel beds, the matrix is clayey and silty at lower levels which decreases upwards where it becomes sandy. These gravels can serve the purpose of filter zones in the proposed dam.

Thin seams (upto 10″) of bentonite clay occur in association with shales at the right bank. These seams of bentonite will have to be excavated and back fiilled before the construction of dam.

Terrace deposits are present along the Soan River and other small streams in the area. Gradation analysis carried out on these deposits reveal an average content of 82% sand, 11% silt and 7% clay. In the valley section, the thickness of overburden and alluvium varies from 0-130 feet suggesting rejuvenation.

PROPOSED ALLIGNMENTS

Three dam axes (AA′, BB′, CC′) on figure 2 have been considered, keeping in view the topography and geological conditions at each site.

Allignment AA′

This is located 3000 feet upstream from the bridge on Soan River. The only bore hole (150 feet deep) drilled reveals the 12 feet thick overburden above the foundation rocks which are composed of alternate sandstones and shales (sandstones being predominant). At the right bank of this site are the sandstones of Nagri Formation with very gentle dips and are moderately strong. At places, hard ribs of well cemented sandstone are present. At the left abutment, there is a thin veneer of sandy alluvium above the alternate sandstones and shales. A small localized normal fault is present which will not be a threat to stability of the dam.

Allignment BB′

At this site, thickly bedded sandstone striking N 64° E normal to the allignment and dipping 15° S (towards the river) is exposed making a dip slope. The sandstone is soft to medium hard and occasionally friable. At places, soft sand pockets and clay lumps are present. A minor bentonite layer is also present. A minor bentonite layer is also present. Four bore holes drilled for subsurface investi- reveal the intercalation of shale and sandstone gationbeds for a total thickness of 200′ suggesting a simple geologieal structure at this site.

Allignment CC′

This axis is located about 800′ downstream from the Rawalpindi-Talagang Road bridge. The rocks on the right bank consist of sandstone with few shale beds. The sandstones are similar to the ones at site BB′. Away from the river along the axis CC′, the dip becomes steep while the strike remains constant. The sandstone is thickly bedded and jointed, the joints being filled with silty clay. A total of eight bore holes, one on each abutment and six in valley section were drilled which reveal that the over burden is underlain by alternate beds of sandstone and shales. The core recovery is good (varying from 75-100%) suggesting that at depth the joints are closed.

The right bank is composed of thick sandstone dipping towards the river making a gradual dip slope, whereas the left bank is composed of alternate sandstone and shale beds. The clay/shale layers are vulnerable to slumping on saturation. The previous nature of the river bed will require a thorough blanketing for a long distance and an upstream cut-off will be needed. The ground water observations in the existing wells indicate a rise of water table away from the river suggesting that ground water is feeding the stream.

Quarry areas A and B (Fig, 2) were investigated for construction materials. Some engineering charaeteristics of materials from these two sites are given in Table 2. The results show that both the areas will yield suitable materials for construction.

General Engineering Geological Properties

The average values for tests on clay/shale are given as :—

Specific Gravity	=	2.722
Liquid Limit	=	29.67%
Plastic Limit	=	19.81%
Plasticity Index	=	9.86

Maximum dry Density = 116.5 P.C,F.

Optimum Moisture Content = 12.93%

Unconfined Compressive Strength = 31.69 P.C.I.

Cohesion = 15.5 P.S.I.

Angle of Internal Friction = 25°

Table-III gives the results of grain size analysis of various samples from the three alignments.

In the light of the above tests and results, an attempt was made to discuss and compare the feasibility of each allignment or axis.

All the clay/shale samples were classified accordtng to U.S. Bureau of Soil Triangular Classification on the basis of various gradations present. It is worth mentioning here that most of the soil samples fall in the textural class of 'clay'; though some of these were generally called 'shale' in the field.

The result of two samples from quary area 'A' (samples 16 and 20) show textural class as 'silty clay' and 'silty loam' and 'clay'. Percentage of sand in all these quarry area samples is less than 10% and their graphs show well graded distribution. This higher silt content in samples 13, 16 and 20 may be because of improper crushing of samples.

The average Liquid Limit, Plastic Limit and Plasticity Index (Table-IV) are 30%, 14% and 11% respectively, while the samples from quarry areas give a value of 18 for their Plasticity Index. Moreover, bands of sandy silt are present particularly in quary area 'A'; so a thorough investiaation is needed before recommending this material for the core of the dam.

Permeability tests on remoulded clay/shale samples gave an average value of 3.15×10^{-6} cm/sec. which is low enough for use in core as well as blanket. Although the permeability of foundation sandstone (1.7×10^{-3} cm/sec.) is high, yet proper grouting will prove effective.

This shear tests gave an average value of Angle of Internal Friction as 25° and cohesion as 15 P.S.I. Twenty one samples were tested for their unconfined compressive strength and the average value was found to be 32 P.S.I. Slightly higher value of Angle of Internal Friction may be due to hard lumps in some samples. Under compression mostly the samples failed in plastic or semi plastic manner. Only samples 28A, 30 and 32 failed in semi-brittle form. In rest of the samples the shear plane made an angle of 60-70 degree with the horizontal axis.

The sandstones were tested in field as well as laboratory. The average compressive strength of sandstone was found to be 1600 P.S..I. which is higher than the average laboratory value (1322 P.S.I.).

Similarly, the compressive strength of 6 inch cube samples is 18% higher than the strength of core samples (1120 P.S.I.) with length to diameter ratio as more than two.

The average water absorption of sandstone (0.8%) and permeability (1.7×10^{-3} cm/sec) alongwith jointing indicate that this is a porous medium and may create problems of seepage. However, proper grouting may improve the conditions.

CONCLUSIONS AND SUGGESTIONS

On the basis of field observations and laboratory work, the following conclusions and recommendations are made :—

1. The valley section along the three proposed allignments in covered with varying depth of alluvium. It consists mostly of sand, silt, clay with traces of gravel.

2. The visual study of the rock and the structure of the area indicates that the rocks of the foundation are the same as that of the abutments. Moreover, the bore hole logs show alternation of shale and sandstone in the foundation.

3. The water brings a lot of sediments especially during the flood season, so silting will be a major problem after the construction of the dam.

4. The exposed nature of sandstone and the drilling records indicate that the joints are not tight. Considerable loss of water during the water pressure test further justify above statement. It is anticipated that the grouting treatment would be required in the foundation and the abutments of the dam.

5. Positive cut-off under the embankment and upstream blanket in the reservoir will be necessary as the nature of the river bed alluvium is quite previous. More elaborate laboratoro and insitu tests will be required to determine the characteristics of the overburden in order to evolve a suitable and economical remedial measure against seepage through the previous overburden in the valley section.

6. Engineering geological testing of the foundation core sample reveals that the bearing capacity of this rock is sufficient to withstand the super imposed load of the proposed embankment type of structure.

7. Keeping all the criteria for the selection of dam in broad valleys, the site AA′ should be preferred to the other two sites namely BB′ and CC′. Topography, structure and engineering geological properties at all the thcee proposed sites are the same. Valley width is minimum at site AA′ so the construction at this site will be economical. Minor faulted nature of left abutment of AA′ axis needs careful investigations and it is anticipated that proper grouting of th fault plane can improve the situation,

8. In order of merit, site BB′ is second. At site CC′, a dam 140 feet high as proposed by WAPDA cannot be built because the left abutment of this site is only 130 feet high above the mean river level. Moreover, the valley is very broad along this allignment which will make the construction of the dam uneconomical.

9. Within the surveyed area of the reservoir, there is no topographic weakness.

10. The Dhok Pathan Dam project is an off-channel storage reservoir. As such, it would also involve a complicated conveyance system. The dam site and other appertenant structures do not seem to pose any serious problem and it is anticipated that overall feasibility of the project would mostly depend upon the technical and economical viability of the conveyance system. It is, therefore, suggested that economic and technical feasiability of the conveyance system should be preferred in further investigations.

11. The above conclusions are based on very limited amount of surface exploration and laboratory investigations. Much more detailed surface and subsurface exploration together with adits, shafts and laboratory and insitu tests will be needed, for dejailed feasibility studies.

TABLE I

Location	Quarry area "A"		Quary area "B"	
Sample No.	16	20	13	14
Grain Size Analysis				
Sand %	10	9	6	10
Silt %	54	73	78	45
Clay %	36	18	16	45
Atterberg Limits				
Liquid Limit %	29	24	29	37
Plastic Limit %	20	18	27	18
Electricity Indix	9	6	2	19
Compaction (Havard Miniture)				
Max. dry density P.C.F.	119	118	116	119
Optimum moisture content %	13	13	12	14
Direct Shear Test				
Cohesion P.S.I.	15	14	14	13
* degree	25	24	23	20
Unconfined Compression Test				
** P.S.I.	32	30	25	29
Permeability Test				
*** x 10^{-6} cm./sec	2.5	2.4	1.15	1.86

* Angle of Internal Friction
** Unconfined Compressive Strength
*** Coefficient of Permeability

TABLE II

Sample No.	Location	Sand %	Silt %	Clay %	Textural class
21-A	Left Abt. CC′ axis	17	43	40	Clay
21-C	—do—	34	43	23	Clay loam
21-D	—do—	23	40	37	Clay
22-A	Left Abt. AA′ axis	36	27	36	Clay
22-B	—do—	14	44	42	Clay
22-C	—do—	10	38	52	Clay
22-D	—do—	15	59	26	Silty clay loam
28-A	Right Abt. CC′ axis	55	29	16	Sandy loam
28-B	—do—	21	46	33	Clay
28-C	—do—	16	40	44	Clay
28-D	—do—	7	53	40	Silty clay
29	Left Abt. BB′ axis	3	61	36	Silty clay
30	—do—	36	46	18	Loam
31	—do—	18	32	50	Clay
32	—do—	23	40	37	Clay
13	Quarry area "B"	6	78	16	Silty loam
16	Quarry area "A"	10	54	36	Silty clay
20	Quarry area "A"	9	73	18	Silty loam
14	Quarry area ,'B"	10	45	45	Clay
23-A	Khorian Ledge	20	47	33	Clay
23-B	Khorian Ledge	7	58	35	Silty clay
44	Soan Sand	82	11	7	Sand+Traces of silt and clay.
40	Gravel bed (G.R. 8340.4287)	25 + Gravel 66%	4	5	Sandy Gravel with traces of Clay and Salt.

TABLE III

Sample No.	Location	L,L. %	P.L. %	P.I.
21-A	Left Abt. CC′ axis	20.50	20.26	16.24
21-C	—do—	23.41	19.11	4.30
21-D	—do—	32.31	21.96	10.35
22-A	Left Abt. AA′ axis	21.79	17.97	3.82
22-B	—do—	41.20	22.01	19.19
22-C	—do—	42.10	19.26	20.84
22-D	Left Abt. AA′ anix	25.42	18.16	7.26
28-A	Right Abt. CC′ anix	32.54	20.14	12.40
28-B	—do—	25.15	17.62	7.53
28-C	—do—	38.58	21.58	17.18
28-D	—do—	26.81	19.41	7.40
29	Left Abt. BB′ anix	25.40	17.21	9.19
30	—do—	21.86	19.97	1.89
31	—do—	32.25	21.70	10.55
32	—do—	32.00	21.12	10.88
13	Quarry area "B"	38.48	27.19	11.29
16	Quarry area "A"	38.83	20.13	18.70
20	Quarry area "A"	34.48	18.01	16.47
23-A	Khorian Ledge	25.80	18.84	6.96
23-B	—do—	23.60	16.99	6.61
14	Quarry area "B"	37.50	16.96	19.54

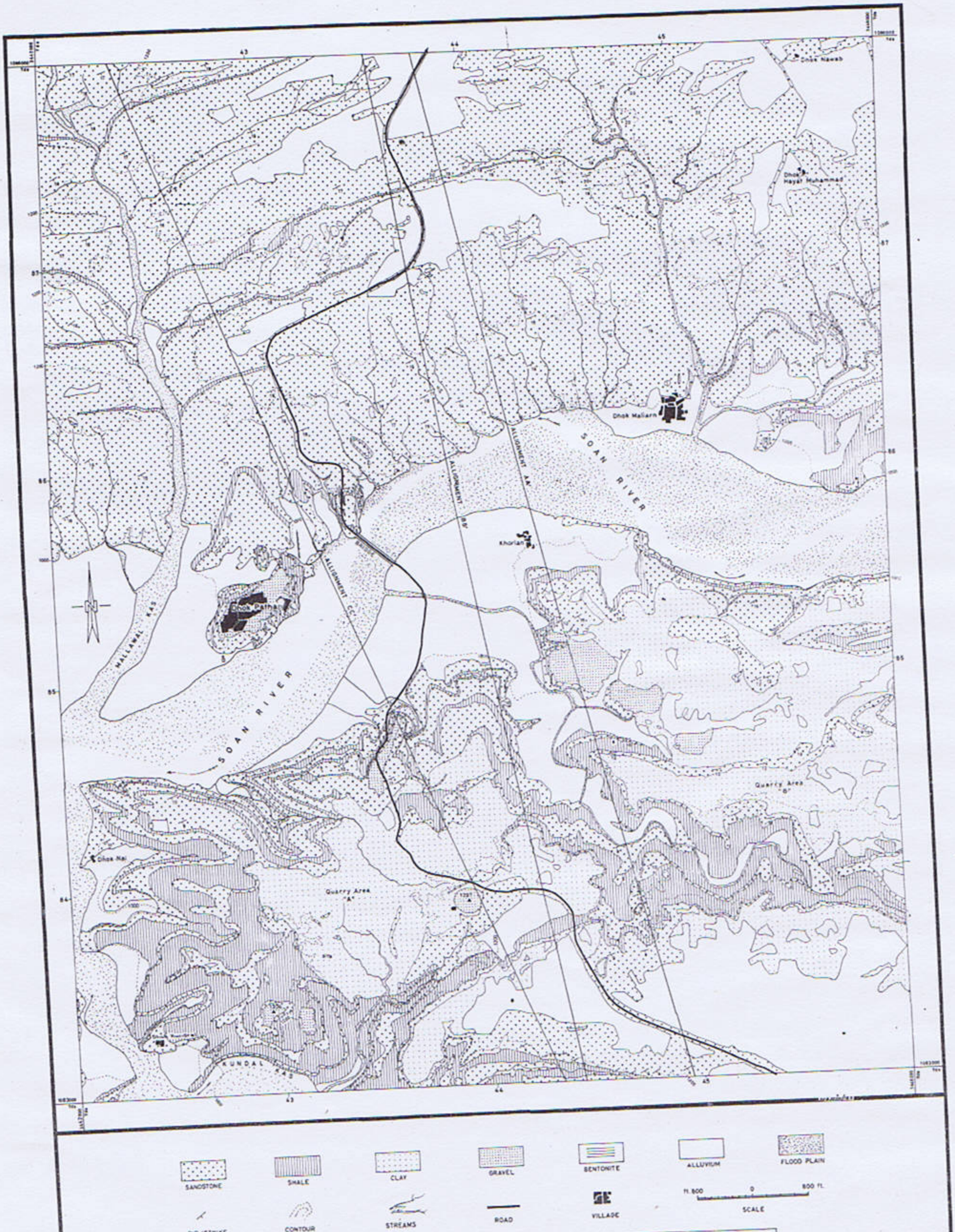

FIG. 2 DETAILED GEOLOGICAL MAP OF DHOK PATHAN DAM SITE AREA

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GEOLOGY AND ENGINEERING CHARACTERISTICS OF MATERIALS FROM BORROW AREAS OF THE KHANPUR DAM HAZARA, PAKISTAN

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Abstract : *Geological mapping at different scales revealed complicated structure. Samples from borrow areas for impervious materials suggest good engineering characteristics for use in dam. Fracture frequency, orientation and solution channels seem responsible for seepage around the spillway. The strength of limestones was found to be greatly affected by the degree of weathering.*

INTRODUCTION

Khanpur Dam, an earth and rock fill structure, is built on Haro River, about 30 miles north-west of Rawalpindi and Islamabad (Fig. 1). Initially, it was planned to construct 137 feet high dam to create a reservoir of 5,900 acre feet for irrigation purposes, but subsequently due to demand of industrial and domestic water for Islamabad and heavy complexes at Taxila, it was decided to increase the height of the dam upto 164 feet for a reservoir of 1,06,000 acre feet. Tne dam has an impervious fill on upstream side, a random rock-fill on downstream side and a pervious filter in between the two fills. The saddle embankments of earth fill material are also constructed. Five tunnels of different lengths planned were for irrigation and water supply etc.

The area around the dam site was investigated by WAPDA and M/S Associated Consulting Engineers at various times. About 30 sq. miles area was geologically mapped in 1963-64 (Malik, 1964). Later on, about 25 sq. miles area was mapped (Ahmad, 1972) at 1:10,000 scale for regional geology, 1 inch=50 feet for Abutments, 1 inch=200 feet for layout of the dam and appertenances, and 1 inch=10 feet to 200 feet for five tunnel allignments.

A number of tests were carried out on soils and rocks from four borrow areas alongwith the tests on insitu shales aggregates and rock cores from bore holes for their suitability and use in different parts of the dam.

Geology

The precence of a number of terraces along the Haro River indicates that the river is cutting its already deposited alluviam due to rejuvenation. Old Khanpur village (now under reservoir) was situated on a big terrace composed of cemented pebbles and boulders, while the alluviam plain associated with this contained a lot of clay and silt which was used in the dam. Three distinct terraces can be observed along the course of the river suggesting three episodes of uplift and down-cutting. Drilling carried out for investigation of the dam revealed the bed rock at a depth of 200 feet from the river bed suggesting that the river had filled its own valley for at least upto 363 feet (the height of top terrace from river bed being 163 feet). This suggests that the bed rock (Shale) at the site has experienced different loading-unloading, reloading conditions during the geological past.

The rocks exposed in the area are generally limestones, sandstones and shales from Jurassic to Eocene age. The succession is very well developed representing different lithologies of shallow to deep sea water, except an unconformity between Cretaceous and Palaeocene which is marked by a laterite bed. The stratigraphic position is as :—

Lower Eocene	Margala Hill Limestone
Upper Paleocene	Patala Formation. / Lockhart Limestone
———Unconformity———	Laterite
Upper Cretaceous	Kawagarh Formation
Lower Cretaceous	Lumshiwal Formation
Upper Jurassic	Samanasuk Limestone

Samanasuk Limestone. This is the oldest unit in the area and consists of massive and thickly bedded limestone with dolomitic patches. The weathered surface is dark yellow to brown. It is easily recognisable due to its oolitic and arenaceous nature. Two to three sets of joints are prominent at places but otherwise this limestone is randomly fractured and shows some persistent joints with large apeture.

Cores tested for unconfined compressive strength give a range of 10,000 P.S.I. in the laboratory.

Lumshiwal Formation. The only arenaceous unit present in the area, is distinct rusty brown colour sandstone. It is massive, hard to hammer and thickly bedded. At places, it is moderately jointed resulting in huge blocks. The precence of limonite, hematite and glauconite are responsible for its peculiar and easily identifiable colour from distance. It has granular texture and uniform grain size indicating high degree of sorting. The degree of weathering is enormous and has a great affect on its strength. The unconfined compressive strength of fresh rock is about 12,500 P.S.I. while weathered samples give a maximum strength of 5,000 P.S.I.

Kawagarh Formation. This comprises of very fine grained pure limestone which is thickly bedded with some random fractures and solution cavities at places. These cavities posed some problems of grouting and seepage etc. The strength of this limestone in laboratory varies from 9,000-15,000 P-S.I.

Lockhart Limestone. This is the most extensive and widespread formation in the area and is present in the form of either massive or nodular nature and at places is shaly limestone or intercalation of shale and marl. Tne elongated nodulas about 6 to 24 inches in size appear to be embedded in argillaceous partings. Massive limestone is fine to medium grained and thickly bedded. Generally within the nodular limestone band of massive limestone (about 10 feet thick) are interspread. However, this limestone is generally modular at the base and becomes massive upwards. It is extensively jointed and the joints are filled with claycy, ferruginous and decomposed calcareous materials. The massive limestone is very similar to Kawagarh Limestone except the presence of larger framinifera. The strength of this limestone (massive limestone only) varies from 12,000—16,000 P.S.I.).

Patala Formation. It consists of bhaki coloured shale and marl. It is soft, laminar, plastic and shows slaking tendency on exposure to weather. Iron contents in it show fairly oxidizing conditions at the time of deposition. A large number of engineering geological tests were carried out for its use in construction of the dam and the results are discussed in later pages.

Margala Hill Limestone. This is light grey to grey, pure to marly limestone full of fossils which are bigger in size than those of the Lockhart Limestone. The contact between this limestone and the underlying shale is transitional. At places it is nodular with shaly partings in between the nodules. The strength varies from 1,000 to 14,000 P.S.I.

The area lies at the western flank of the Hazara-Kashmir Syntaxial Bend bend and, therefore, has developed a very complicated structure (Gansser, 1964; Wadia 1975). The overall pattern of the outcrops is such that the western part seems to have moved towards north relative to the eastern part. Laterite is present only in the north and north-eastern parts and is missing in the rest of the area due to various tectonic forces which had been prevailing at different times. Most of the folds are of cross-folding type indicating two directions of forces normal to each other. There are a number of minor and six major faults. Most of the major faults are longitudinal interformational type, which are not active (Kazmi, 1979). All the lithologies are fractureed ; the degree of fracturing and spacing varying according to their lithology, grain size and bed thickness. Generally, greater spacing of fractures is attributed to greater thickness of beds (Ladeira and Price, 1981) which seems true here, although, some thick beds are fairly fractured especially near minor or major faults. Open fractures are common in massive limestones which are further widened by solution weathering (Hobbs, 1967). The joints are (NE/SW) orientated i.e. parallel to the general strike of outcrops.

The rocks on the left abutment have a general trend parallel to the river and dip away from the valley. These are repetitions of massive limestone, nodular limestone, argillaceous limestone and shales. Solution cavities in this area were thoroughly grouted. The average permeability of the rocks on the left abutment was determined as 2.5 gallons/m/feet.

On the right abutment the succession is as follows :—

Massive limestone	25 ft.
Nodular limestone	195 ft.
Variegated limestone	165 ft.
Shale	200 ft.

The dam along this abutment is lying across massive limestone, argillaceous limestone and nodular limestone. The average permeability is 2.8 gallons/m/ft. at 112 P.S.I. which is higher than left abutment. Seepage problems around and under the spillway are due to extensive fractures and their orientation.

The overburden in the valley is not uniform (gravel, sand and silt of variable percentages) and is highly permeable. The permeability being 0.005 cusecs/ft^2 laterally and 0.00013 to 0.0002 cusecs/ft^2 vertically. The overburden is mostly underlain by shale in the valley at a depth of about 200 feet. It is believed that the river is flowing along the axis of an anticline, which is proved by the fact that synclines exist on both sides of the valley. The possibility of a major fault along the crest of the fold has not been proved. Anyway, if there is a fault along the crest of the anticline, it will be a threat to the stability of the structure.

Seepage, as anticipated, is a major problem due to permeable nature of foundation and abutments. Blanket of clay on upstream side river bed and abutments was provided alongwith a peripheral grout curtain. About 15,566,00,000 cubic feet of impervious material alongwith 90,00,000 cubic feet of excavated limestone was used. All the construction materials were available within the economic haulage distance except courser sand for filter which was transported from Lawrencepur.

Four different borrow areas named A,B,C and D of impervious material wese used. A number of tests were carried out on samples from these borrow areas. Only the average results from each borrow area are being presented here in tabular and graphical from (Figs. 2-5).

Standard international procedures (ISRM, 1981 ; Hoek and Brown, 1980 ; Hawkes and Mellor, 1970 ; British Standard, 1975) were used for testing of soil, shale and limestones for their engineering characteristics such as :—

Grain Size Analysis, Atterberg Limits, Specific Gravity, Unconfined Compression Test, Permeability Test, Direct Shear Test, Triaxial Compression Test, (Soils) Soundness Test and Unconfined Compression Test on Limestones and Chemical Tests of Soils and Rocks.

CONCLUSIONS

The grading cruves of samples A, B, C, D and shale from borrow area A, B, C and D have shown that materials are silty clayey, with higher percentage of silt as compared to the clay and sand, The precence of sand is very low percentage as compared to silt and clay makes the borrow materials impervious and higher amount of silt present in the materials gives the higher degree of resistance against any movement.

The soil possesses low plasticity, high strength and higher angle of friction makes the materials suitable for the construction of the Dam.

ANALYTICAL RESULTS

1. Grain Size Analysis :—

Borrow Area	*A*	*B*	*C*	*D*	*Shale*
Sand	5.00%	4.50%	5.30%	11.90%	1.00%
Silt	77.00%	74.00%	77.70%	71.00%	84.00%
Clay	18.00%	21.50%	17.00%	18.00%	15.00%

2. Atterberg Limits :—

Description	*A*	*B*	*C*	*D*	*Shale*
Liquid Limit	29.50%	35.00%	21.20%	30.50%	
Plastic Limit	21.55%	21.72%	25.40%	21.60%	
Shrinkage Limit	17.95%	23.55%	15.50%	21.55%	
Shrinkage Ratio	1.74%	1.55%	1.94%	1.76%	
Volumatic Shrinkage	22.15%	16.17%	25.78%	11.90%	
Specific Gravity	2.52%	2.44%	2.77%	2.70	

3. Un-confined Compression Strength of Soil Samples :—

	A	*B*	*C*	*D*	
Mixed unconfined compression strength	38.4 PSI at 2.6% strain	17.80 PSI at 3%	24.50 PSI at 3%	37.40 PSI at 3,5%	9.75 PSI at 4% strain

4. Direct Shear Test (Strain Controlled Quick Test)

Description	*A*	*B*	*C*	*D*	*Shale*
Cohesion	6.0 PSI	6.2 PSI	7.0 PSI	7.0 PSI	6.2 PSI
Angle of internal Friction	34°	33°	35°	39°	33°

5. Triaxial Test of Soil Samples :—

Description	*A*	*B*	*C*	*D*	*Shale*
Cohesion	11.5 PSI	6.5 PSI	8.0 PSI	10.0 PSI	0
Angle of Internal cohesion	27°	24°	32°	28°	25°

	A	*B*	*C*	*D*	*Shale*
6. Specific Gravity Test	2.733	1.732	2.737	2.737	2.691
7. Organic Content Test	11.008%	10.406%	10.863	10.864	11.180%

8. Permeabilıty Test (Constant Head Method)

Sample A = 6.5×10^{-6} cm/sec.

Sample B = 8.4×10^{-6} cm/sec.

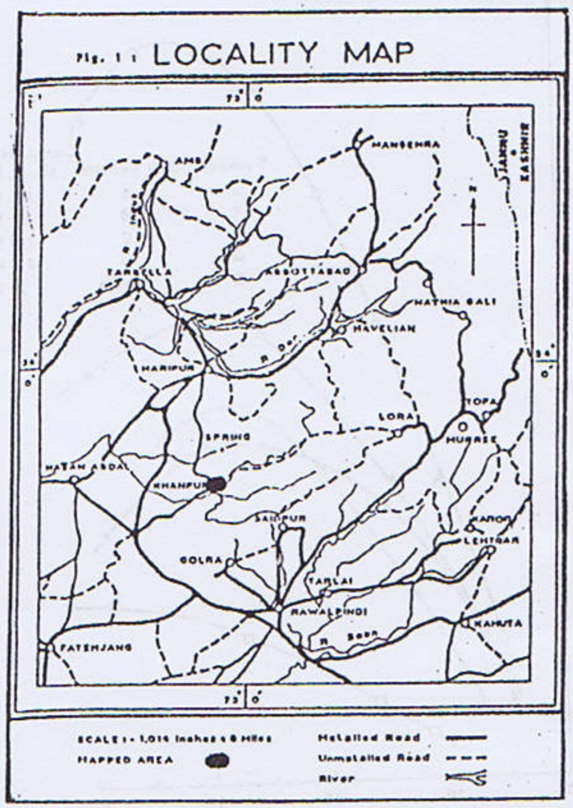


Fig. 1 : LOCALITY MAP

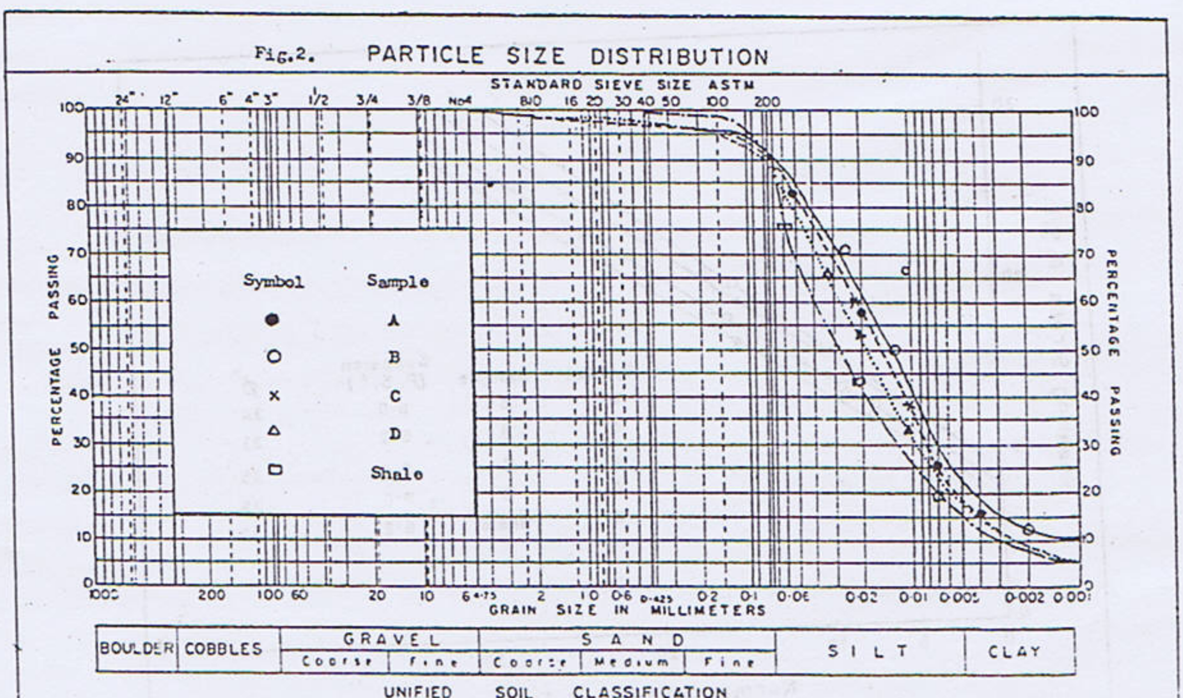


Fig.2. PARTICLE SIZE DISTRIBUTION

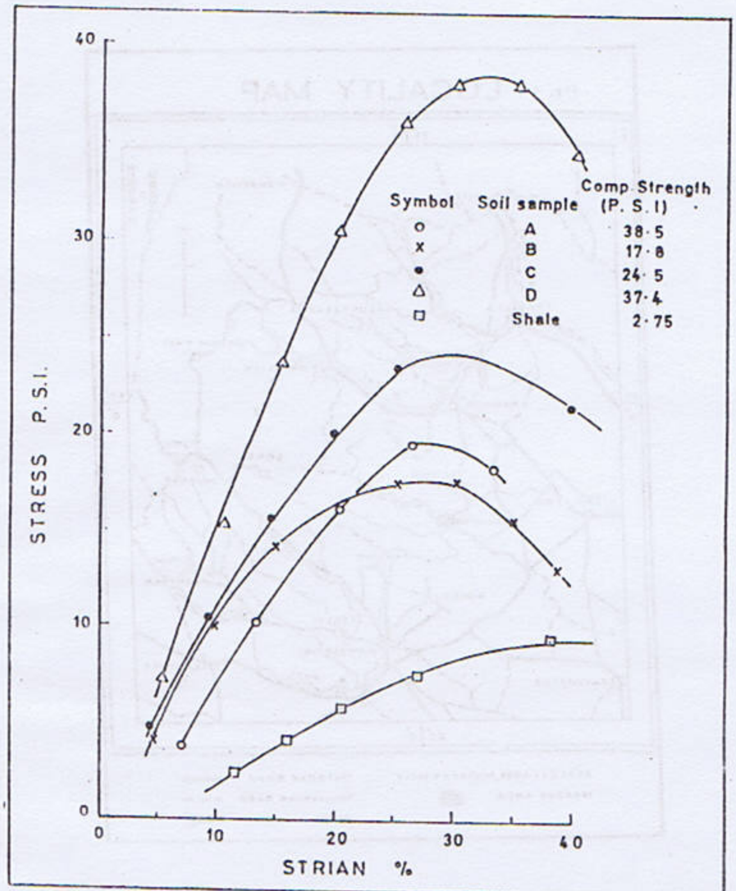


Fig. 3. Unconfined compressive strength of Soil samples A, B, C, D and Shale.

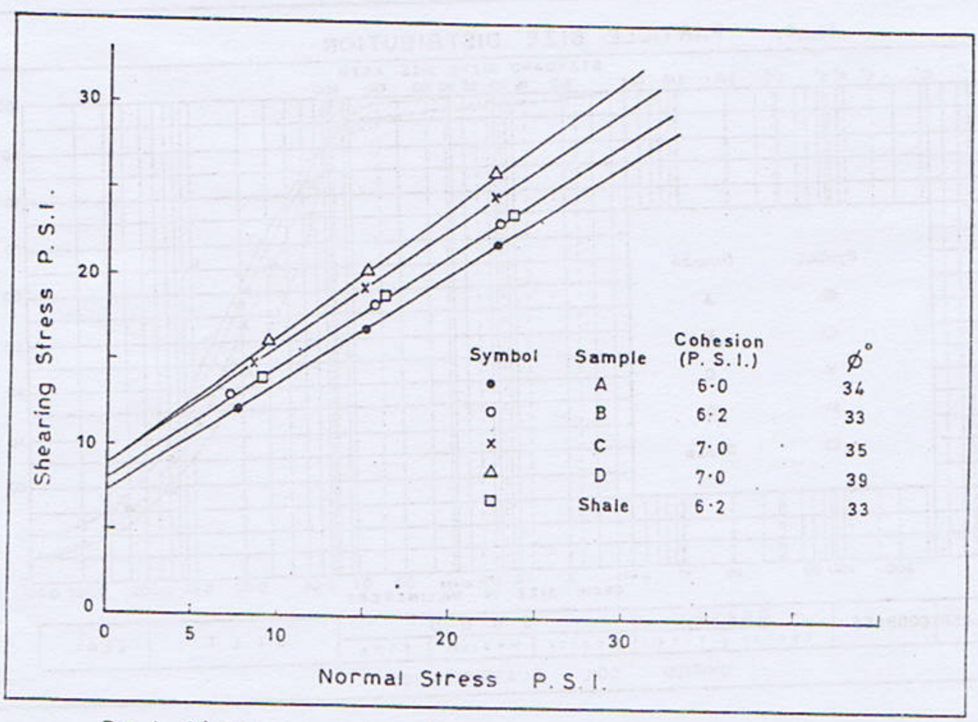
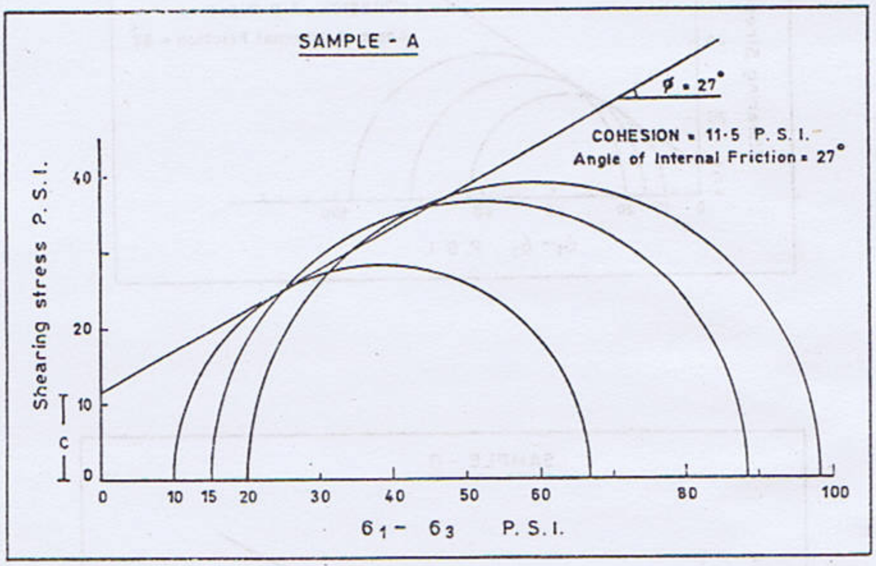


Fig. 4. Direct shear strength test of Soil samples A, B, C, D and shales.



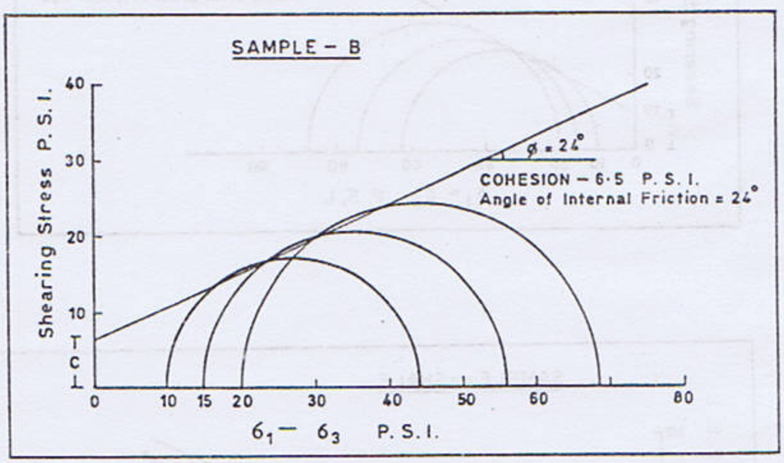
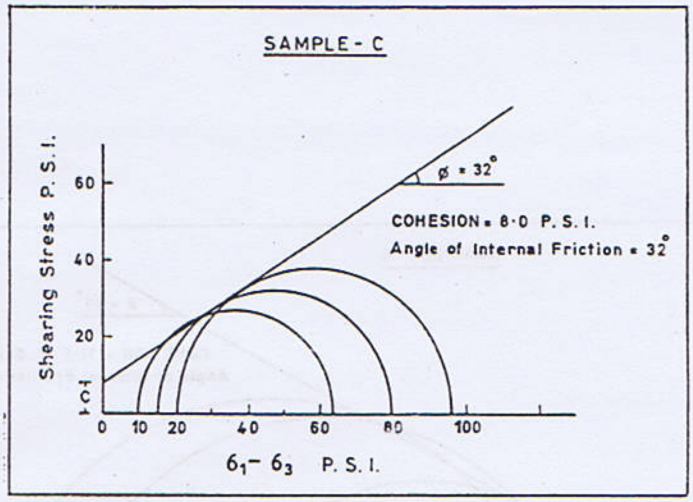
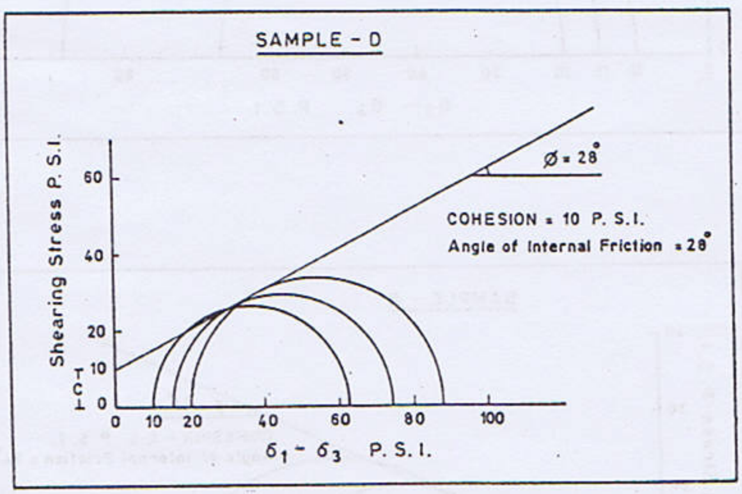


Fig.5(a) Triaxial Tests on Soil Samples A and B.





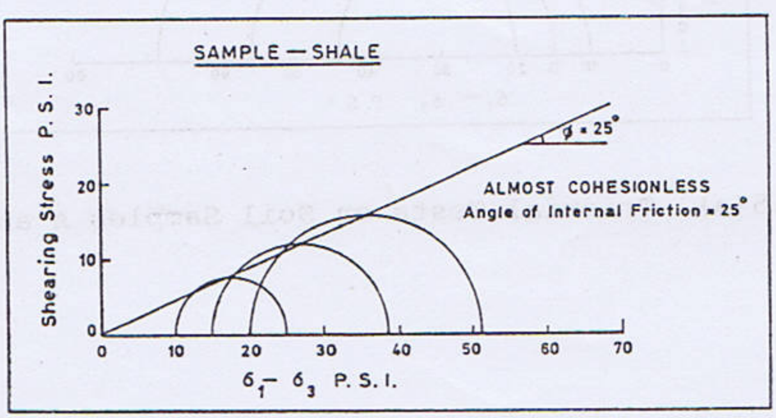


Fig.5(b) Triaxial Tests on Soil Sample C,D & Shale.

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The authors are grateful to authorities of Planning and Investigation Cell of WAPDA for their valuable help in the field and laboratories. We are also thankful to Mr. Riaz Ahmad, M.Sc. student for carrying out field work and producing excellent geological maps.

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Geol. Bull. Punjab Univ., 1991, 26, 21-28

HYDROLOGICAL INVESTIGATIONS IN RELATION TO GEOLOGY OF THE KALABAGH DAM AREA, PAKISTAN

BY

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Abstract : *Ground water studies carried out for the project area reveal that major source of recharge is precipitation, whereas part of the area is being recharged through the river in its vicinity. The piezometric level curves do not exactly coincide with the hydrograph curve of the River Indus. The lag in time is due to fracture frequency and fracture permeability. The anomaly in ground water contours is due to the impermeable gouge material along the fault, which may be removed under tremendous pressures when the reservoir is filled resulting in enormous seapage.*

INTRODUCTION

The area is located in the western extremity of the Salt Range, about 13 miles northwest of Kalabagh Town (Figure 1), which is bound by Potwar in the northwest, Salt Range in the south and Sarghar Range in the west. The proposed damsite is located just below the confluence of the Indus and Soan Rivers. The damsite is one of the last downstream locations from the Tarbela Dam for constructing dam on Indus before it enters the Punjab plain. The Indus River at the site carries an average annual run off of about 101 million acre feet.

The area is characterized by cold winters and hot summers, semi arid and arid climatic conditions and has low relief (absolute relief 337 feet). Extreme temperature conditions prevail ranging from 116°F to 124°F in summer and 40° to 72°F in winter. In the Monsoon months (July-August) ,there is some precipitation while the other months of the year are nearly dry. The mean annual precipitation is 10 to 12 inches.

At the site, the rocks exposed belong to the Dhok Pathan Formation of the Siwalik Group. This formation is typically represented by monotonous cyclic alternations of sandstone and clay beds. The sandstone is commonly grey, light grey or greenish grey and is friable with hard ribs moderately cemented and cross bedded. The clay is reddish brown or dull-red with minor intercalations of siltstones. Conglomerates in the form of lenses and layers is an essential character of the upper part of the formation. This formation has transitional contact with the underlying Nagri Formation. The beds dip very gently (3° — 5°) upstream. The sequence exposed at the site is as :—

1. River channel and Nala deposits.
2. Terrace deposits.
3. Dhok Pathan Formation.

1. River Channel Deposits

These are 80-110 feet thick fresh hard gravels, cobbles and boulders with silty sand (gravels have been derived from igneous, metamorphic and sedimentary rocks).

2. Terrace Deposits

These deposits vary in thickness from 20 to

70 feet and consist of gravels overlain with silt and sand of low insitu density. Two terrace levels occur in the area. A lower terrace at a level of about 800 feet on both sides of the river and a higher terrace level at about 900 on the right bank (Kalabagh Project Report, 1975). The presence of these terraces shows the two stages of erosion and down cutting upto the bed rock (182 m) below the river bed indicating stress relief or unloading of the River Indus at the site.

The water table elevation is about 18 m from the ground surface of terraces with seasonal fluctuation of 1-3 m. The higher water table elevation (18 m) as compared to the mean river elevation (200m) is responsible for recharge to the river. Some water, however, remains within buried channels or wherever shallow water table occurs (perched water table) due to lenses of claystone, the sandstones and gravels act as aquifers which sometimes show slight artesian conditions only near the river.

3. Dhok Pathan Formation

This formation (Middle Miocene) is typically represented by monotonous cyclic alternations of sandstone, claystone and siltstone bed with occasional lenses of gravels. The sandstone is commonly grey to light grey and occasionally brownish grey. The clay is orange, brown, dull-red or reddish brown. The silt intercalations are of yellowish brown colour.

The sandstones vary in thickness from a few feet to about 200 feet. They are weak and friable with occasional harder ribs and are composed of angular to sub-angular quartz and feldspar grains with varying amount of calcium carbonate as cementing materials. (Abbassi et al., 1983).

At the site thirteen sandstone beds and claystone/siltstone interbedding beds have been identified with a total thickness of 1300 feet.

Joints

In the area, the fractures are mainly systematic fractures found in sandstones are (1) Shear Joints and (2) Tension Joints. Shear joints are inclined to the direction of maximum principal stress and occur in conjugate sets intersecting along the line of intermediate principal stress. Tension joints are vertical or very near vertical and the lack of any evidence of movement along or parallel to these joints faces indicates that they are the result of tensile stresses acting perpendicular to joint planes. Some random and irregular joints also occu but are not very frequent. Some sheet joints nearly horizontal and parallel or sub-parallel to topography are also observed and are the result of escape of stored stresses due to erosion or unloading (Lajtai, 1977). Initially, an attempt was made to classify these fractures genetically but subsequently, an overall estimation of their number and their orientation was found appropriate for the statistical data required for joint frequency, stereonet presentation and relationship of their orientation with the movement of ground water (either from aquifer to the river or vice versa),

The following three prominent sets of joints have been observed and recocded on the basis of their geometry,

1. Near vertical joints
2. Diagonal joints dipping in opposite directions.
3. Low angle joints.

The near vertical joints in sandstone seem to be the governing factors in formation of cliff in different sandstone beds. These are regarded as master joints and the configuration of geomorphological features in the area is mainly controlled by the pattern of these joints.

The direction of movement of ground water (Fig. 2) seems to be affected by the orientation of a prominent set of joints. A detailed study, however, of continuity of joints and their interconnection with each other alongwith their filling material can further establish such relationship (Fookes, 1966).

HYDROLOGY

The River Indus after emerging from the gorge at Tarbela, flows for about 32 miles in an open and braided channel and enters the Attock Gorge through which it flows for about 90 miles in a narrowed confined channel and finally enters the Punjab Plains near Kalabagh, the Project area Kalabagh Report, 1975).

The Kabul River is the major tributary of Indus in the region which originates from the Hindukush Range in Afghanistan and contributes about 1/3rd of the annual runn-off of Indus at Attock.

The drainage area of the Indus River and its tributaries above the project are is 110,500 square miles (Kalabagh Report, 1975).

The mean annual precipitation of the area is 12 to 15 inches. Extreme conditions of temperature are noticed (116 to 124°F in the month of June and 40 to 72°F in the month of January).

The ultimate source of recharge to the ground water reservoir is precipitation. The recharge occurs due to direct percolation from nalas during rainfall and seepage from the river.

The major part of run off of Indus River consists of glacier melt and snow melt which also previde base flow of the river. The mean daily flows varied from 9000 causes (as lowest in 1975) to a maximum of 10,25,000 in 1/29.

Ground Water Hydrology

The ground water conditions only at the right bank of Indus River at the project area were studied which included the preparation of contour map (Fig. 2) the movement and fluctuation of ground water has been interpreted in the same-manner as suggested (Stallman, 1956, Todd, 1965).

The area is covered by a large number of bore holes and adits in connection with subsurface geological investigations for the proposed Kalabagh Dam. Data from piezometric levels of 29th January, 1984 was used for the preparation of ground water contour map.

The topography of the area is uneven and the area is truncated by many nalas and tributaries which also effect the ground water conditions (Verruijt, 1/70). The gradient of water table varies in different parts of the project area (indicated by varying spacing of contours in Fig. 2) and can be somewhat attributed to the general dip direction of a prevailing joint set.

Any major discontinuity (i.e., fault) may effect the gradient of ground water as is the case in Kharjwan Nala (Fig. 2) where a normal fault runs across the Nala. In the vicinity of bore holes KCR 521, KCR 522 KCR 523 on the left bank of Kharjwan Nala (Fig. 2) the gradient is very high. This abnormality is attributed to the Kharjwan Fault.

Mostly the terrace deposits are unconsolidated and granuler and capable of storing and transmitting large amount of water (Childs i.e., 1950). Main source of recharge is precipitation and the infiltration through over burden is influenced by its thickness that varies from place to place. Permeability tests were carried out in the alluvium and terraces during drilling of bore holes for investigation purposes. Tests on sany gravels show that 75% of results are between $1x10^{-3}$ to $1x10^{-4}$ cm/sec. and 7% result are between $1x10^{-2}$ to $1x10^{-1}$ cm/sec.

The ground water contour map (Fig. 2)

shows that almost througout the year, the river is recharged from the surrounding aquifers. The piezometric level remains higher than that of the river. However, there are some bore holes such as KCR 117 (Fig. 2) which recharge the river and sometimes are recharged by the river (hydrograph No. 2). This is attributed to high flood season.

The ground water fluctuasions in the area are shown by hydrographs No. 1·5 (Fig. 3-7) are related with the rainfall data although it is not an accurate indicator of groundwater level changes. Rainfall is maximum in the month of July, August and September which corresponds with hydrographs (Fig. 4 i.e. Hydrograph 2). The peaks of hydrograph No. 2 show a seasonal pattern of fluctuation i.e. the piezometric levels are maximum in the season of maximum rainfall.

A few bore holes as KCR 311, KCR 228, KCR 502 being very close to the river, are recharged by it. The piezometric levels of these holes is influenced by the river flow and is always found to be lower than that of the river (as shown in Fig. 6 i.e. hydrograph No. 4), although the piezometric level curves do not exactly coincide with the curve of the river (hydrograph No. 4). The lag in time being due to fracture frequency and fracture permeability.

Hydrography No. 5 Fig. 7 shows that some part of the area is not influenced by the river level. Piezometric levels of KCR 303, KCR 362 and KCR 366 are much higher than the river level and throughout the year it shows minor fluctuations which are due to precipitation.

SUGGESTIONS

The main fault encountered at the site is the Kharjwan Fault with a displacement of about 90 feet, which is easily traceable at the left bank of Kharjwan Nala. Gouge material found along the fault plane is clayey and sliding along the fault plane is excepted. The ground water contour map shows that permeability is low due to clayey george matetial alone the fault plane (indicated by very close contours in the vicinity of the fault plane). When the reservoir is filled tremendous water pressure may remove the gouge increasing the seepage although fault plane.

The catchment area of Soan river is overlain by Siwaliks and Murree Formation (increasing the load of Soan river). Check dams are recommended to reduce silting in the tributaries and streams joining the Soan River.

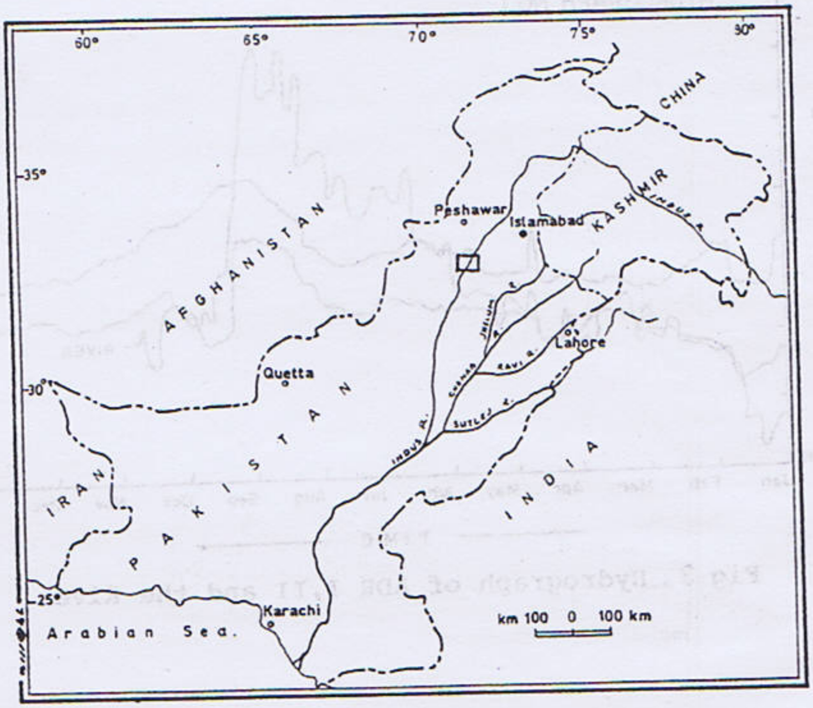

Fig.1. Location map.

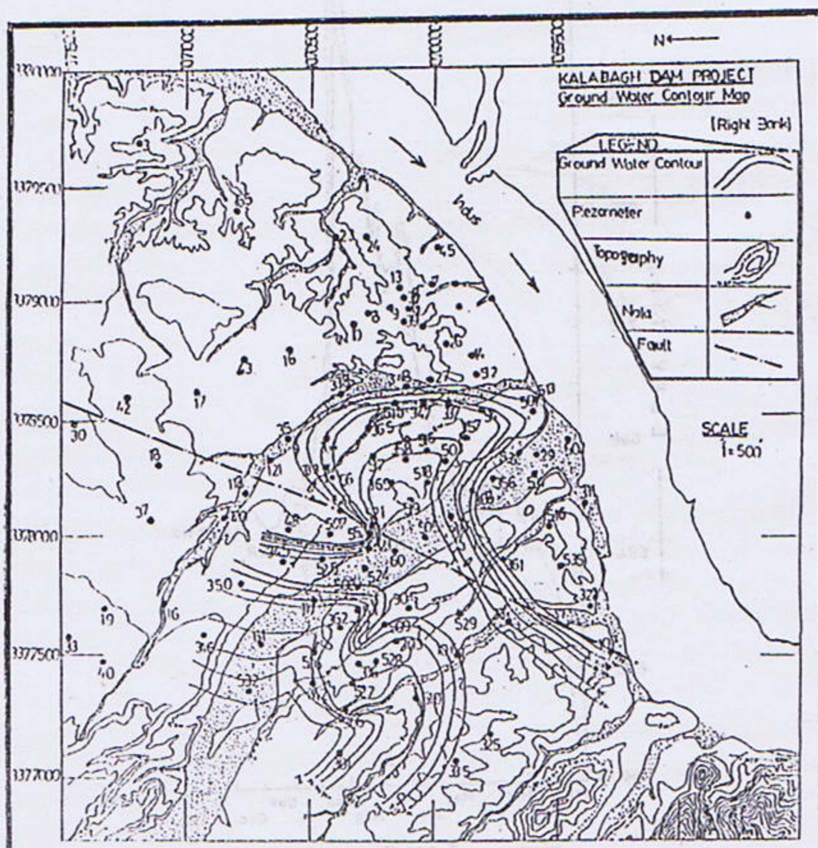

Fig.2. Groundwater contour map.

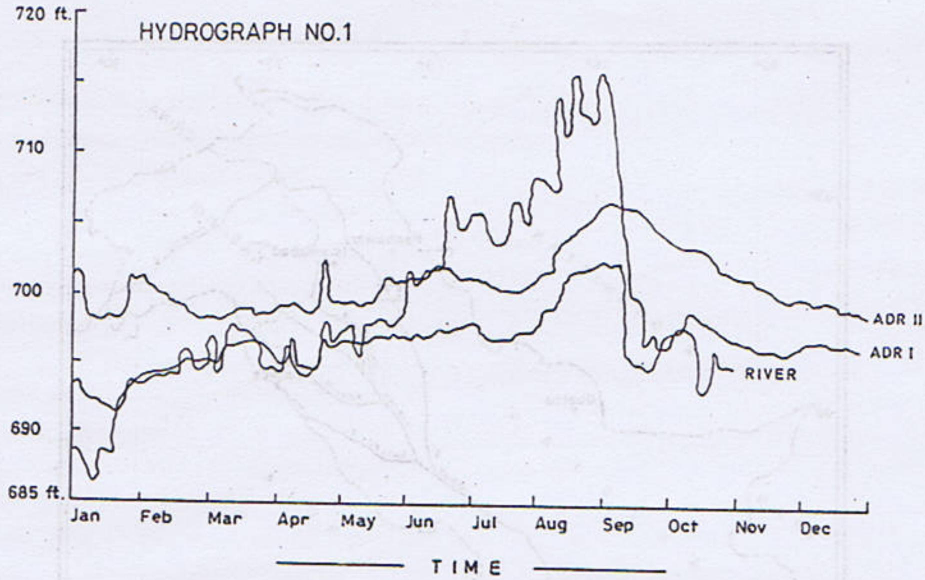

Fig.3. Hydrograph of ADR I,II and the River.

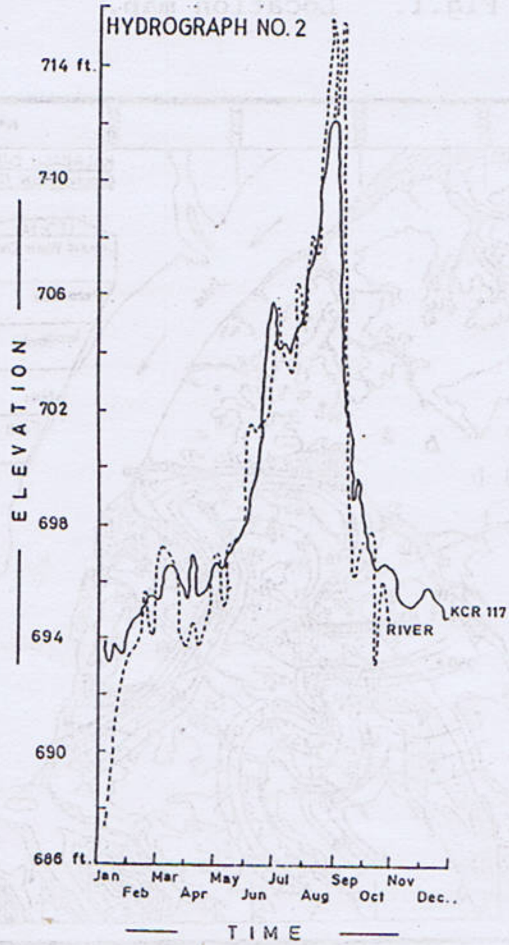

Fig.4. Hydrograph of KCR 117 and the River.

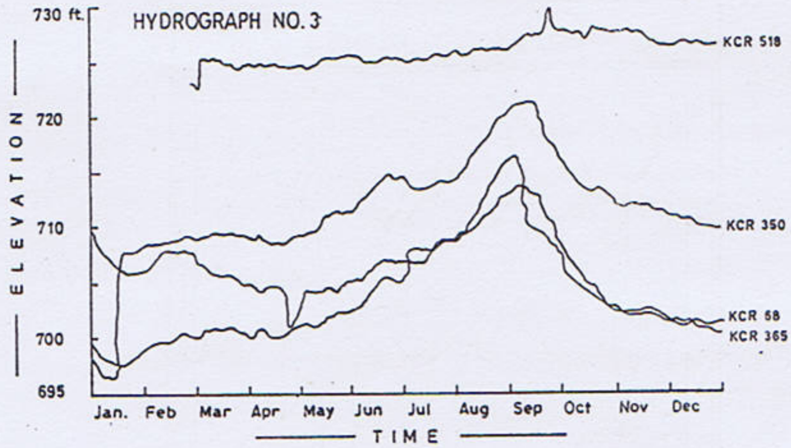

Fig.5. Hydrograph of KCR 68, 350, 365 and 518.

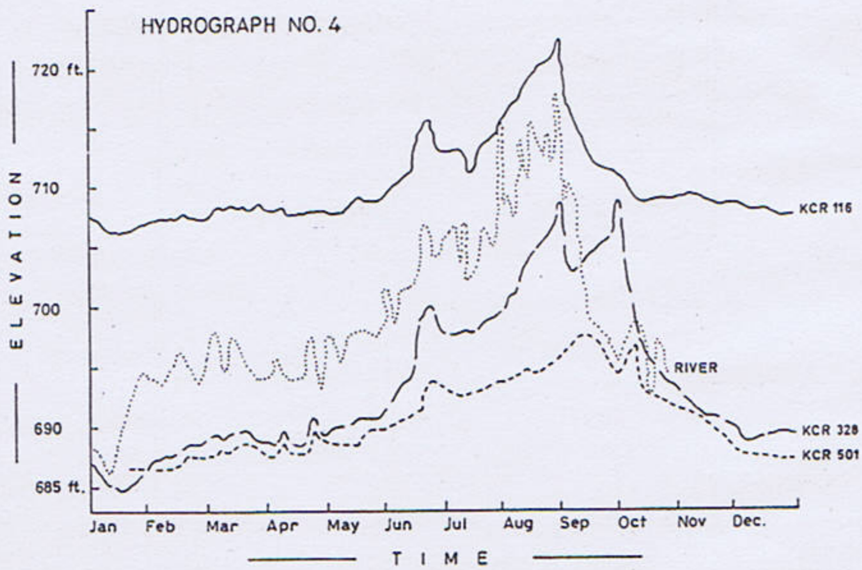

Fig.6. Hydrograph of KCR 116, 328, 501 and the River.

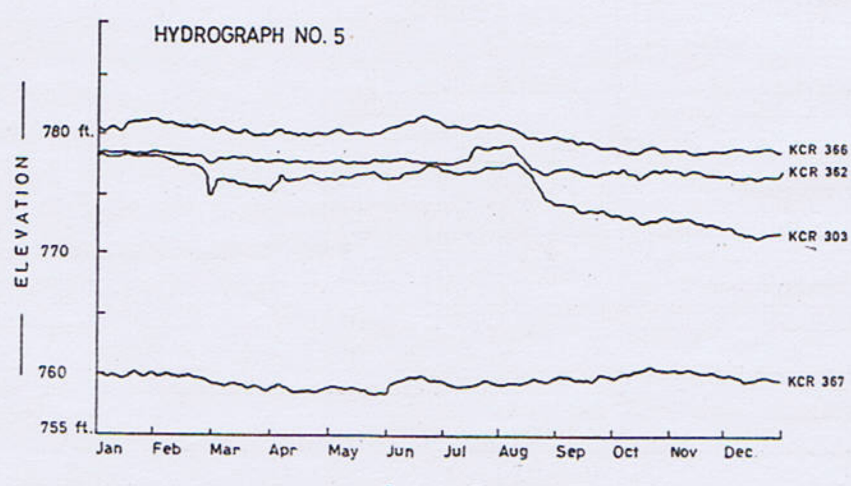

Fig.7. Hydrograph of KCR 303, 362, 366 and 367.

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Geol. Bull. Pnnjab Univ., 1991, 26, 29-36

PALYNOTAXONOMICAL INVESTIGATIONS ON A DEVONIAN MIOSPORE GENUS *ANCYROSPORA* RICHARDSON EMEND. RICHARDSON, 1962

BY

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Abstract : *Four miospore of the genus Ancyrospora Richardson 1960 emend. Richardson 1962 have been identified from the Upper Devovian sediments of western New York State and northern Pennsylvania U.S.A. Two species are described for the first time. One new combination is established. The lithology of succession investigated is mainly composed of shale, siltstone. Sixty four samples from four formations namely the Java, Canadaway, Chadakoin and Cattaraugus, have revealed frequent assemblages of this taxon. In some horizons these are profusely represented.*

INTRODUCTION

During the present biostratigraphic palynological studies of an area extending over 4000 Km² in western New York State and northern Pennsylvania, U.S.A. the genus *Ancyrospora* proved to be of particular interest and importance. The present paper was not an *ad hoc* investigation of *Ancyrospora* alone, but this genus, as a part of a complete palynological study (Ahmed, 1978), selected for present publication in view of its special interest and importance. This paper, therefore, provides a systematic description of moispores of the genus *Ancyrospora* recorded from 64 samples which range in age from Upper Frasnian to upper Famennian.

The palynological floras of marine and non-marine sediments of this area contain a diversity of trilete spores, together with an acritarch component that is relatively inconspicuous qualitatively and quantitativly.

Based on qualitative changes in the spore assemblages it is of interest to note that the Upper Devonian miospore assemblages that have been reported from western Europe, North America and North Africa are found to have a uniform composition.

The species *Ancyrospora multifurcata* comb. nov. is regarded to be an important element of the Frasnian-Famennian deposits in Northern and Southern hemisphers ; however the Australian sediments are devoid of this taxon.

In the area under investigation a miospore form *Ancyrospora ancyrea* var. *ancyrea* has not been found occuring in the younger Cattaraugus Formation while a miospore *Ancyrospora acadensis* sp. nov. makes it first appearance in the middle part of the Canadaway Formation. Two distinctive miospore species i.e. *Ancyrospora multifurcata* comb. nov. have infrequently been observed in all four the formations (Fig. 1). The latter species has been studied in abundance in some of the horizons during the present investigation.

SYSTEMATIC DESCRIPTION
INCERTAE SEDIS

Genus *Ancyrospora* Richardson emend. Richardson, 1962.

Type species : *A. grandispinosa* Richardson 1960.

Diagnosis : See Richarson 1962, p. 175.

Remarks : Urban (1969) provided an adequate appreciation of morphology of the genus *Ancyrospora* by studying two species under SEM. He observed that processes are formed by the fusion of "elongated bars of netlike inner exoexine". However, these results are additional informations of the exinal layers which are useful at specific level but not to modify the genus. Generic diagnosis given by Richardson (1962) is quite comprehensive and still remains the basic circumscription of this taxon, hence followed in the present work.

Ancyrospora acadensis sp. nov.
Plate 1, Figs. 1-6

Derivation of name : Acadia, old name of the eastern part of North America.

Holotype : Plate 1, Figs. 1-2, US6E 299 1125055.

Type Locality : Pope Hollow Section, along boundary between Carroll and South Valley Townships, Jamestown quadrangle, New York State, U.S.A.

Occurrence : Present in all four of the formations investigated.

Diagnosis : Amb subcircular to roughly hexagonal ; exoexine completely appressed to the intexine. Distal and equatorial margins bear spines with a constriction near the top ; spines are usually terminated by multifurcate terminations. Laesurae discernible, simple or masked by folds.

Description : Miospores radial trilete ; amb irregular due to the distribution or conical bases of appendages but in general organization subtriangular to roughly hexagonal. Exine two layered ; the intexine laevigate, with a distinct or indistinct margin and the exoexine which is closely appressed to it and extends equatorially to form a narrow flange or pseudoflange. Distal and equatorial hemispheres ornamented by processes 8-28μ m long, 4-12μ m broad at the base, slightly curved occasionally straight with a constriction near the top. Each process consists of a broad-based spine with moderate to sharply tapering sides terminated by a narrow, slightly expanded, solid, bi, tri- or multifurcate termination (Fig. 2b ; Pl. 1, Fig. 2). Trilete mark distinct, sometimes obscured by thick nature of exoexine ; laesurae straight extending 3/4 to the full spore radious. Folds occur along the tetrad mark which extend to the radius of the spore.

Size range : 38-71μ m, mean 61μ m (70 specimens measured).

Comparison : *Ancyrospora densispinosa* Bharadwaj & Venkatachala, (1971) described from the Upper Devonian of Kentucky, appears comparable to this species, but it lacks constriction and multifurcate terminations to the processes.

Ancyrospora ancyrea (Eisenack) Richardson var. *ancyrea* Richardson, 1962.
Plate 1, Fig. 7

1925 Type G2 Lang p. 257, pl. 1, Figs. 16-17.

1944 *Triletes ancyrea* Eisenack p. 110 (part), pl. 2, Fig. 2 ; pl. 1, Figs. 7-8.

1962 *Ancyrospora ancyrea* (Eisenack) Richardson var. *ancyrea* Richardson, 1962.

1966 *Ancyrospora* sp. cf. *A. ancyrea* (Eisenack) Richardson ; De Jersy p. 20, pl. 8, Figs. 9-12.

Occurrence : Present in all four of the formations studied.

Diagnosis : See Richardson 1962, p. 177.

Size range : Exoexine 61-153μ m, mean 102μ m ; intexine 48-79μ m, mean 61μ m (30 specimens measured). Spine length 10-35μ m, basal width 7-10μ m.

Remarks : The specimens from New York State and Pennsylvania, although corroded, appear to be similar to specimeas of *A. ancyrea* var. *ancyrea* from the Orcadian Basin, Scotland.

Ancyrospora multifurcata (Winslow) comb. nov.

Plate 1, Fig. 8, Plate 2, Figs. 1-4

1962 *Dicrospora multifurcata* Winslow in part Mortimer & Chaloner p. 53, pl. 12, Figs. 8 & 8b ; Pl. 13, Figs. 1 & 6, 7-9.

1962 *Dicrospora multifurcata* var. *impensa* Winslow, p. 54, pl. 12, Figs. 7, 7a.

1970 *Ancyrospora capillata* Dolby & Neves, p. 639, pl. 2, Figs. 7-10.

Occurrence : Present in all four of the formations studied.

Description : Miospores radial, trilete ; amb subcircular, subtriangular but normally irregular because of the distribution of wide bases to the spines. Proximo-distal compression rare, oblique and lateral views frequent. Broken specimens common. Exine two layered ; exoexine completely covers the thick walled subcircular to irregular laevigate body, attached proximally and distally. Ornamented by spines, 21 to 51μm in length, some of these gradually taper towards the top while others nearly cylindrical with wide conical to bulbous bases. Spines as wide as 23μ m at the base to 2.5μ m near top. Number of spines vary from 9 to 23 on the equatorial and distal surfaces ; nearly half the total are mounted distally. At the top spines are multifurcate comprising 2 to 9 hook like spinules, 2.6 to 10.2μ m in individual length while the total diameter of terminal processes are laterally extended, expanded and reflexed. Trilete mark indistinct due to the dark and dense nature of intexine.

Size range : Exoexine 83.8-153μ m, mean 105μ m, intexine 51—89.3μ m mean 70μ m (55 specimens measured).

Remarks and comparison : *Ancyrospora multifurcata* is identical to both *Dicrospora multifurcata* Winslow (1962) and *D. multifurcata* var. *impensa* Winslow (1962) except for size, which is regarded as insufficient justification to differentiate these two forms. Winslow (loc. cit.) gave a size range of 100—200μ m in the diagnosis of *D. multifurcata* and 240-300μ m for *D. multifurcata* var. *impensa*. The second basis for differentiation which she mentioned is the presence of both bi - and multifurcate appendages on *D. mullifurcata* var. *impensa* but only multifurcate spines on the parent species. It has been observed during the present investigation that both kinds of appendages are present on a single specimen, so there is no reason for varietal separation.

Mortimer & Chaloner (1967) justify keeping all the species of *Dicrospora* within the morphographic circumscription of *Hystricosporites* McGregor. However, it is felt that the spores described here have characteristics typical of *Ancyrospora*. Winslow (1962) did not mention the presence of inner body in her specimens but it is obvious from the figures that some of the specimens posses intexine.

It is further suggested that Dolby & Neves spores labelled *Ancyrospora ? capillata* are certainly identical to the present form. The species name *capillata* has been discarded because Winslow's specific epithet has priority.

Grandispinosa multiapicalis Chi & Hill (1978) is probably identical to *A. multifurcata.*

Ancyrospora neograndispinosa sp. nov.

1988 *Ancyrospora sp.* McGregor & McCutcheon p. 1352, pl. 2, fig. 21.

Plate 2, Figs. 5-6

Derivation of name : A species of *Ancyrospora* similar to *A. grandispinosa.*

Holotype : Plate 2, Fig. 5, US8D 355 1130327·

Type locality : One mile south of Hamlet town, New York State ; Ellicott Member of Chadakoin Formation.

Occurrence : Frequent in the Java and Canadaway Formations, rare in the Chadakoin and Cattararaugus Formations.

Diagnosis : Miospores two layered, comprising a well-defined inner body completely covered by thin exoexine ; the latter is ornamented by well-developed appendages including gently tapering spines and cones which frequently bifurcata at their terminations ; exoexine irregular in outline ; laesurae frequently masked by folds.

Description : Miospores radial trilete ; amb irregular, occasionally subtriangular with straight to convex sides and rounded apices. Exine double layered ; the intexine subcircular, thick, laevigate and the exoexine which is closely appressed to it and extends equatorially to form a flange or pseudoflange. The width of the exoexine from intexine equal to subequal, in a few cases more at angles than at interradial areas. Exoexine thin, finely infrapunctate, ornamented equatorially and distally by hollow cones and spines, the former 5-15μ m long and 3-10μ m wide at bases, spines vary in length from 10-35μ m and in basal width from 5-10μm. Elements taper gently throughout their length, some are parallel sided while a few taper for only 1/2 of their length to a slender neck, terminated by bifurcata tips. Number of spines along equator 6-17. The appendages on the distal surface are coalesced at their bases ; spines normally stout rarely curved. Trilete mark distinct ; laesurae indiscernible to perceptible, folds on the suturae run beyond the body but do not reach to the equator of the spore.

Size range : 87-130μ m, mean 109μ m, intexine 56-80μ m, mean 68μ m (30 specimens measured).

Comparison : Ancyrospora grandispinosa Richardson (1960) stands closest morphologically but differs however, in possessing spines with wide conical bases. The Scottish form lacks conical processes and it is also considerably larger (174-276μ m). *A. confluenca* Tiwari and Schaarschmidt (1975) described from the Middle Devonian of the Prum Syncline, Eifel(Germany), is closely similar but differs from *A. neograndispinosa* in not having well defined spines. McGregor & McCutcheon (1988) illustrated a specimen which is closely similar to *A. neograndispinosa* sp. nov. but comparison is not possible as it was not described.

EXPLANATION OF PLATES

All figures are from unretouched negatives and prints. Magnifications are X500, unless stated otherwise. Transmitted light photographs were taken with Zeiss Photomicroscope under bright-field illumination. Ilford Pan-F film was used.

Scanning electron micrographs, indicated by the letters SEM, were taken with Cambridge Stereoscan scanning electron microscope, using Kodak Tri-X film.

The numbers, written near each slide number, are the microscope co-ordinates.

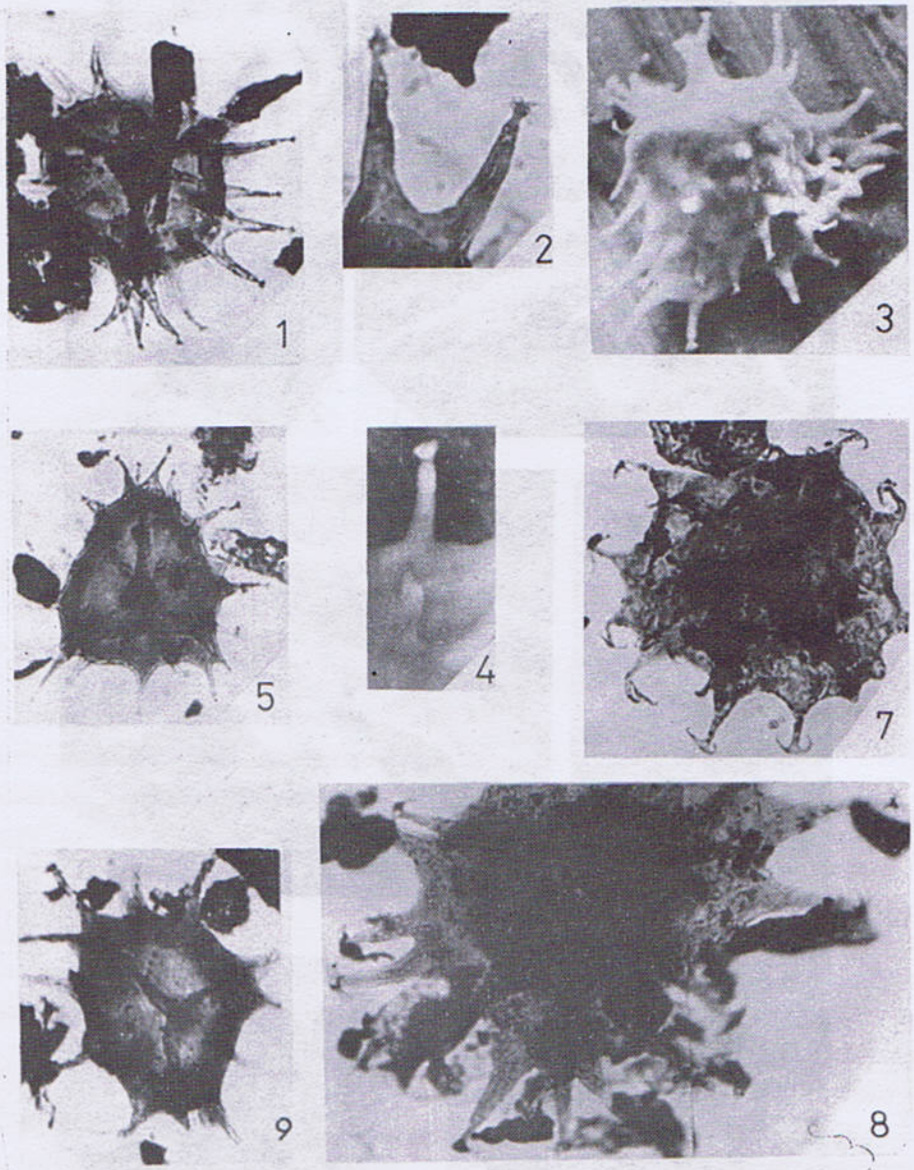
CONCLUSIONS

The palynological floras of marine and non-marine sediments of western New York State and northern Pennsylvania contain a diversity of trilete spores together with an acritarch component that is relatively inconspicuous qualitatively and quantitatively.

A strikingly close similarity has been observed between the microfloras studied during the present investigations and those reported previously from the upper Devonian of other parts of the world. Detailed correlation of these Famennian deposits with those from North America, North Africa, Western Europe and Australia shows that *Vallatisporites vallatas* var. *hystricosus* (Winslow) clayton *et al.* and *Retispora lepidophyta* (Kedo) Playford appear in the same horizon in Famennian (approximately at the base of Fa2d) in the area investigated as in other sequence so far described from northern and southern hemispheres. Inter-regional correlation based on miospore assemblages has indicated that the Dexterville Member is equivalent to the Evieux beds ; whilst the Ellicott Member and overlying Cattaraugus Formation are probably Coeval stratigraphically to the Comblain-Au-Pont beds of Belgium. In terms of Belgian substages, the age of range from F3 to Fa2d (upper Frasnian to middle Famennian in terms of standard European stages). In term of North American nomenclature, the series range in age from upper Senecan to Chautauquan.

McGregor and McCutcheon (1988) reported a spore assemblage from the Carrow Formation of the Piskahegan Group, south western New Brunswick, eastern Canada. In this paper they illustrated 46 spore types. The Carrow Formation was considered to be an Early Carboniferous, However, they recorded spores including *Retispora lepidophyta* (Kedo) Playford *Vallatisporite pusillites* (Kedo) Dolby and Neves 1970, Sensu late=*Cirratriradites hystricosus* Winslow 1962, *Ancyrospora multifurcata* (Winslow) Comb. nov. and *A. sp.* which is similar to *A. neograndispinora* sp. nov. from the Carrow Formation McGregor and McCutcheon 1988) concluded that this formation is late Devonian (Famennian) rather than Early Carboniferous.

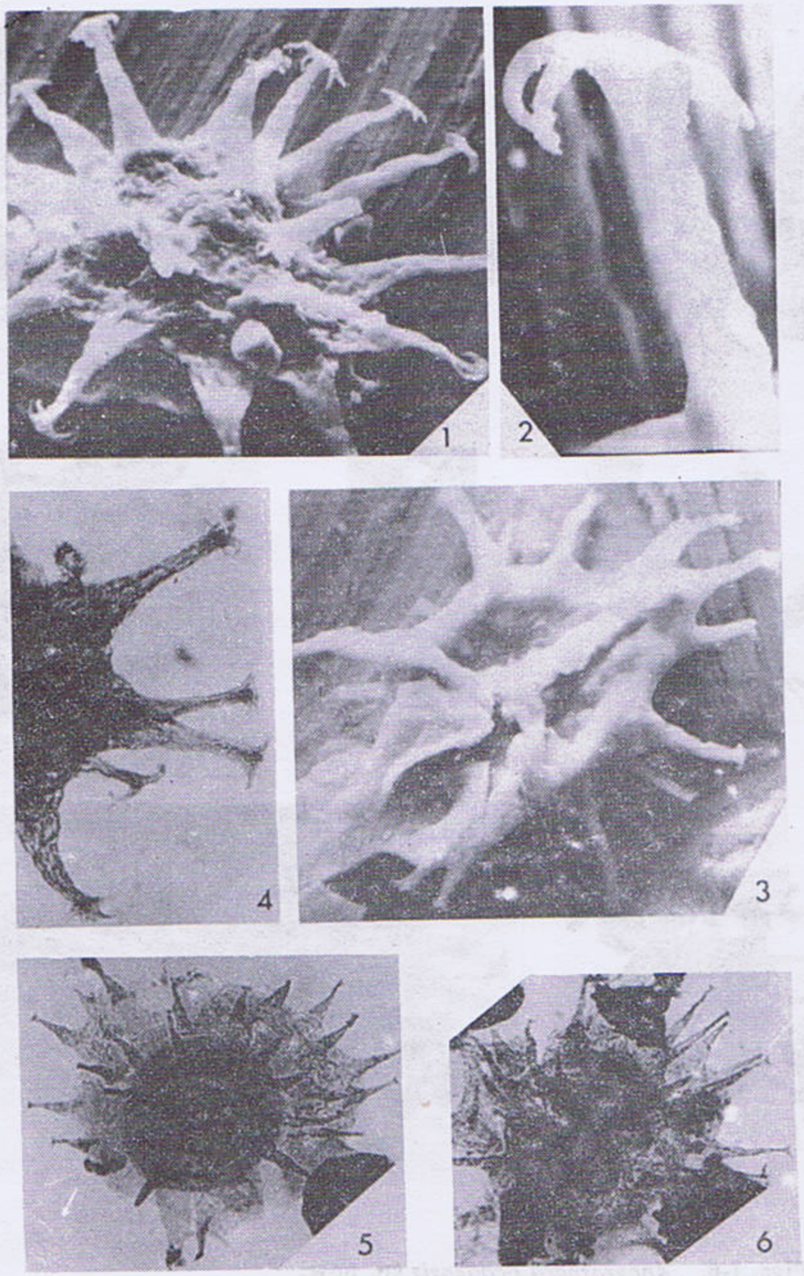
PLATE 1



Figs. 1-6. *Ancyrospora acadensis* sp. now.

1. Holotype, US6E 299 1125554. Cattaraugus Fm.
2. Detail of 1, X1000.
3. Distal surface, US6E, SEM X580. Cattaraugus Fm.
4. Detail of 3, X1170.
5. US6E 302 1089619. Cattaraugus Fm.
6. Proximal focus, US6E 302 119865. Cattaraugus Fm.
7. *Ancyrospora ancyrea* var. *ancyrea* Richardson. US12L 132 1131421, South Wales Shale Member.
8. *Ancyrospora multifurcata* (Winslow) comb. nov. US6E 301 1164558· Cattaraugus Fm.

PLATE 2



Figs. 1-4. *Ancyrospora multifurcata* (Winslow) comb. nov.

1. Distal surface, SEM, X560. Cattaraugus Fm.
2. Detail of 1, SEM, X2500. Cattaraugus Fm.
3. Proximal surface, SEM, X1100. Cattaraugus Fm.
4. NY95AII 1209742. Cattaraugus Fm.

Figs. 5-6. *Ancyrospora neograndispinosa* sp. nov.

5. Holotype, US8D 355 1130327. Ellicctt Member.
6. US6E 1118356. Cattaraugus Fm.

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GEOCHEMICAL/HYDROLOGICAL PARAMETERS REGARDING MAJOR SOLUBLE CONSTITUENTS OF SOILS, SURFACE AND GROUND WATER FROM KHANSPUR-DEWAL AREA, DISTRICT ABBOTABAD, PAKISTAN

BY

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Abstract : *Geological evaluation of the soils of Khanspur-Dewal area, District Abbotabad is carried out by the chemical analysis of their saturation extracts for major soluble ions and other related chemical properties of eight soil samples collected randomly from the area. Major ionic concentrations and other geochemical parameters are related to the prevailing geologic conditions in the area and the soils are categorised as non-sodic, non-saline in nature. The assesment of the hydrochemistry of the area is made by the chemical analysis of thirty water samples from the streams and springs of the area. The resulting data is interpreted by various graphical techniques. The analytical data show that the surface and sub-surface water of the area has no chemical hazard for irrigation and domestic uses and all the analytical parameters lie within the safe limits of delineated water quality standards.*

INTRODUCTION

Khanspur-Dewal area (District Abbotabad) lies in the foothills of Himalayas. Rugged mountains with steep slopes and deeply incised valleys are present in the area. The average elevation of the area is about 2000 feet. The area lies between the longitude 73°, 15′ to 73°, 30′ east and between latitude 33°, 55′ to 34°, 10′ north.

Tectonically, the area is a small part of Hazara-Kashmir Syntaxis. It is the northernmost extremity of the sedimentary succession along the north west margin of the Indian Plate.

The rocks exposed in the area range from Early Jurassic to Early Miocene in age. The lithology is mainly limestone, dolomite, sandstone and shale with minor amounts of marl, mudstone, siltstone, and clay intercalations.

The soils found in the area are mainly of three types with regard to their position. Soil on the hill tops, soil deposits on the slopes and soils on terraces.

Cultivation is carried out on terraces where spring water is available and is generally timed with rains. It is practised on limited scale due to lack of flat land. Step farming is commonly visible in the area. Cultivated lands widen towards Dewal and fruit trees such as of apple, walnut and appricot etc. are also found in plenty in this area and are a major source of income for the local community.

METHODOLOGY

In order to know the geochemical behaviour of the soils of the area, eight soil samples were taken from different locations of the area (indicated by grid reference of topo sheet No. 43 F/8, against each sample in table No. 1) and the chemical analysis of the saturated soil extract was carried out in same way as for water analysis.

For the study of the hydrochemical charecteristics of water, thirty water samples from the two main streams of the area, their tributaries and the springs, were collected. The location of each sample is indicated by the grid reference on the table No. 2. The cations Ca^{++} & Mg^{++} and anions CO_3^{--}, HCO_3^- and Cl^- were determined by the standard titrimetric methods. While Na^+ and K^+ were determined by the flamephotometric method. SO_4^{--} was determined by an estimated method of difference of total cations and determined anions.

Ranges of analytical parameters of soils

The analytical data of soil is shown in table No. 1. The electrical conductivity of soil extracts varies from 0.45 to 2.80 milli mho/cm. pH from 7.0 to 7.6 and SAR values range from 0.20 to 0.95. The range of SAR values of soil extracts is indicated by the bar 1 in bar graph of Fig. 8.

Concentrations of cations and anions are presented both in ppm and m. eq/l units in table No. 1 and their ranges of concentrations are indicated by bar graphs in Figs. 1 to 8. It is visible from the bar graphs that Ca^{++} is the most abundant cation among the soluble constituents of the soil, while K^+ is the least in concentration. The order of abundance of cations is as $Ca^{++} > Mg^{++} > Na^+ > K^+$. Among the anions, SO_4^{--} is the most abundant and order of abundance is $SO_4^{--} > HCO_3^- > Cl^- > CO_3^{--}$. The concentration of the SO_4^{--} is the most variable among the soil samples and it ranges from complete absence to 56.5 epm. It is the indicative of strong affinity of soil to its parent materials.

Ranges of Hydrochemical Parameters of Water

Chemical analysis of thirty water samples from two main streams namely Kalaban Kas, Lahur Kas, their tributaries and the springs at different locations in the area is listed in table No. 2. The ionic concentrations are presented both in ppm and m. eq/litre. The ranges of concentrations of Ca^{++}, Mg^{++}, Na^+, K^+, HCO_3^-, Cl^-, SO_4^-. total dissolved solids and SAR values are represented by bar graphs in figs. 1 to 8. It is obvious that among the cations Ca^{++} and Mg^{++} have more concentrations while Na^+ and K^+ are in lesser amounts.

Among the anions HCO_3^- is dominant and second abundant anion is Cl^- and order of abundance varies in surface & subsurface waters, as second abundant anion in the stream water is Cl^- and that of spring water is SO_4^-. Furthermore, the range of concentration of the SO_4^{--} ion is wide, as it varies from complete absence to maximum of all the ions and that of HCO_3^- is short and it is present in about equivalent amounts in all the three categories of water. It can be visualised with the first glance at the bar graphs shown in Figs. 4 to 6.

DISCUSSIONS

Evaluation of Geochemistry of soil

Apart from the major ionic concentrations in the soil extracts, three parameters are vital for deciding the geochemical behaviour of the soil. Those are electrical conductivity, pH and sodium adsorption ratios. The ranges of these parameters as indicated above, show that the soils of the area lie in the non-sodic, non saline category. Considering the soil composition as a whole, the soils of the area contain greater amounts of Ca^{++}, HCO_3^- and scattered abundance of SO_4^{--}. These concentrations owe to the prevailing geological conditions in the area, that is vast exposures of limestone and occasional occurances of gypseferous shales i.e. Kuldana Formation (Latif, 1970).

Hydrochemical Evaluation of Water

Total dissolved solids in surface water range from 70 to 204 ppm, bar No. 2 & 3 in Fig. 8, while in spring water from 140 to 364 ppm, bar No. 4 in Fig. 8 T.D.S values both for surface and subsurface water indicate that these are fresh water according to the classification based on T.D.S concentrations by Davis & De-Wiest 1966.

It is revealed from the glance of the concentration ranges bar graphs Figs. 1 to 3 that Ca^{++} and Mg^{++} have more concentrations in the three categories of water while Na^{+} and K^{+} are in lesser amounts. This relates to the geology of the area that is the dominance of limestone and dolomitic lithology in the area. Similarly among the anions, HCO_3^- is dominant and second abundant anion in the stream water is Cl^- and that of springs is SO_4^{--}. The presence of HCO_3^- owes to carbonate rocks and carbonate cementing materials of sandstone and SO_4^{--} to the gypseferous shales of Kuldana formation as springs mostly originate in these shale.

Electrical conductivity, pH and S.A.R values of all the three categories of water are within the safe limits prescribed for agricultural and domestic use.

Arithmatic averages of major ionic concentration of the three types of water are represented by Stiff Pattrens, based on the equivalents per million in Fig. 9. The comparison of the charecteristic shapes of these patterns indicate that these waters originate from the similar geologic conditions.

Trilinear plotting of the ionic concentrations of thirty water samples as three constituents i.e. Ca^{++}, Mg^{++} and alkali metals and of three anions constituents i.e. SO_4^{--}, Cl^- HEO_3^- and those contributing to alkalinity is shown in Fig. 10. All the samples from both the streams and springs (except a single sample) plot in the upper half of the diamond shaped field i.e. they have secondary salinity and their chemical properties are dominated by the alkaline earth metals and weak acids. A single sample plot in the lower half indicating that its chemical properties are dominated by alkali metals and weak acids.

T A B L E

RESULTS OF CHEMICAL AN

Sample	G.R	S.P	E.C	pH		Ca++		Mg++		Na+
			m.mho/cm		ppm	m.eq/l	ppm	m.eq/l	ppm	m.eq/l
S1	513990	43.00	1.36	7.60	380.00	9.50	72.00	1.50	25.30	1.10
S2	495004	45.00	0.60	7.60	140.00	3.50	36.00	0.75	14.00	0.61
S3	494971	47.00	0.35	7.60	80.00	2.00	0.00	0.00	21.60	0.94
S4	539989	40.00	0.65	7.10	180.00	4.50	24.00	0.50	19.10	0.83
S5	500983	35.00	0.45	7.20	80.00	2.00	24.00	0.50	26.70	1.16
S6	478971	40.00	1.05	7.00	120.00	3.00	156.00	3.25	12.90	0.56
S7	534972	37.00	2.80	7.00	840.00	21.00	204.00	4.25	17.90	0.78
S8	544979	40.00	0.72	7.30	200.00	5.00	36.00	0.75	11.50	0.50
AVERAGES		40.88	1.00	7.30	252.50	6.31	69.00	1.44	18.63	0.81

T A B L E

RESULTS OF CHEMICAL

Sample	G.R	PH	EC	TDS		Ca++		Mg++		Na+
			m.mho/c	ppm	ppm	m.eq/l	ppm	m.eq/l	ppm	m.eq/l
						K	A	L	A	B A
K1	465972	8.1	255.00	163.20	24.00	1.20	14.40	1.20	2.99	0.13
K2	471975	8.2	270.00	172.80	30.00	1.50	12.00	1.00	3.45	0.15
K3	477972	8.0	240.00	153.60	28.00	1.40	10.80	0.90	2.70	0.09
K4	474966	8.1	245.00	156.80	26.00	1.30	12.00	1.00	2.53	0.11
K5	487969	8.2	220.00	140.80	30.00	1.50	6.00	0.50	2.68	0.16
K6	499970	8.2	270.00	172.80	36.00	1.80	8.40	0.70	3.22	0.14
K7	508970	7.9	260.00	166.40	20.00	1.00	16.80	1.40	2.70	0.11
K8	517973	8.1	140.00	89.60	20.00	1.00	3.60	0.30	2.53	0.11
K9	522985	8.2	265.00	169.60	26.00	1.30	14.40	1.20	2.76	0.12
K10	524996	8.2	250.00	100.00	24.00	1.70	14.40	1.20	2.76	0.12
K11	525004	8.1	210.00	134.40	28.00	1.40	6.00	0.50	3.22	0.14
K12	512979	8.0	240.00	153.60	32.00	1.60	7.20	0.60	3.22	0.14
								L	A H	U
L1	461005	7.9	250.00	160.00	26.00	1.30	12.00	1.00	2.53	0.11
L2	466000	7.1	160.00	102.40	28.00	1.40	1.20	0.10	1.84	0.08
L3	471004	8.0	150.00	96.00	18.00	0.90	6.00	0.50	2.07	0.09
L4	473996	8.1	250.00	160.00	32.00	1.60	12.00	1.60	3.68	0.16
L5	481997	7.9	110.00	70.40	16.00	0.80	2.40	0.20	2.07	0.09
L6	497003	8.1	230.00	147.20	32.00	1.60	6.00	0.50	3.45	0.15
L7	507005	8.0	320.00	204.80	32.00	1.60	18.00	1.50	2.07	0.09
L8	511996	8.3	215.00	176.00	20.00	1.00	19.20	1.60	2.76	0.12
L9	515002	7.9	160.00	102.00	20.00	1.00	16.80	1.40	2.76	0.12
L10	522007	8.1	280.00	179.20	44.00	2.20	3.60	0.30	5.98	0.26
								S	P	R
S1	500984	8.4	270.00	172.80	16.00	0.80	18.00	1.50	8.28	0.36
S2	522971	8.3	570.00	364.80	30.00	1.50	45.60	3.80	8.05	0.35
S3	513998	8.2	280.00	179.20	30.00	1.50	12.10	1.10	3.45	0.15
S4	533989	8.3	220.00	140.80	20.00	1.00	12.00	1.00	3.22	0.14
S5	525977	8.2	215.00	137.60	24.00	1.20	7.20	0.60	7.13	0.31
S6	525963	8.0	260.00	166.40	30.00	1.50	10.80	0.90	3.68	0.16
S7	508996	8.4	320.00	204.80	10.00	0.50	15.60	1.30	27.60	1.20
S8	535016	8.3	220.00	140.80	16.00	0.80	10.80	0.90	8.97	0.39

No. 1.

A L Y S I S O F S O I L S

K^+		HCO_3^-		Cl^-		SO_4^{--}		TDS	SAR
ppm	m.eq/l	ppm	m.eq/l	ppm	m.eq/l	ppm	m.eq/l	ppm	
5.20	0.13	152.50	2.50	53.25	1.50	460.80	9.60	1143.85	0.44
1.40	0.04	122.00	2.00	35.50	1.00	144.00	3.00	491.53	0.38
2.20	0.06	122.00	2.00	53.25	1.50	0.00	0.00	276.87	0.94
4.80	0.12	122.00	2.00	71.00	2.00	120.00	2.50	536.09	0.50
4.20	0.11	152.00	2.50	71.00	2.00	0.00	0.00	353.68	0.95
1.80	0.05	122.00	2.00	71.00	2.00	312.00	6.50	797.88	0.26
10.00	0.25	152.50	2.50	35.00	1.00	1272.00	26.50	2521.94	0.20
3.80	0.10	152.50	2.50	71.00	2.00	129.00	2.70	600.00	0.28
4.18	0.10	137.19	2.25	57.63	1.63	304.73	6.35	840.23	0.49

No. 2.

A N A L Y S I S O F W A T E R

K^+		TC		HCO_3^-		Cl^-		SO_4^{--}		SAR
ppm	m.eq/l	ppm	m.eq/l	ppm	m.eq/l	ppm	m.eq/l	ppm	m.eq/l	
N		K	A	S						
0.39	0.01	41.78	2.55	97.60	1.60	14.20	0.40	26.40	0.55	0.12
0.78	0.02	46.23	2.70	103.70	1.70	14.20	0.40	28.80	0.60	0.13
0.39	0.01	41.26	2.40	85.40	1.40	17.75	0.50	24.00	0.50	0.08
0.78	8.00	41.31	2.45	79.30	1.30	21.30	0.60	26.40	0.55	0.10
0.39	0.01	40.07	2.20	79.30	1.30	14.20	0.40	24.00	0.50	0.16
0.78	0.02	48.40	2.70	91.50	1.50	35.50	1.00	9.60	0.20	0.13
1.56	0.04	41.12	2.60	79.30	1.30	67.65	1.90	0.00	0.00	0.11
0.39	0.01	26.15	1.40	48.80	0.80	39.05	1.10	0.00	0.00	0.14
0.39	0.01	43.55	2.65	97.60	1.60	28.40	0.80	12.00	0.25	0.11
0.78	0.02	51.94	2.50	91.50	1.50	17.75	0.50	24.00	0.50	0.10
0.39	0.01	37.61	2.10	85.40	1.40	17.75	0.50	9.60	0.20	0.14
0.39	0.01	42.81	2.40	103.70	1.70	28.40	0.80	0.00	0.00	0.13
R		K	A	S						
0.78	0.02	41.31	2.50	85.40	1.40	21.30	0.60	24.00	0.50	0.10
0.78	0.02	31.82	1.60	33.20	1.20	10.65	0.30	4.80	0.10	0.09
0.78	0.02	26.85	1.50	61.00	1.00	14.20	0.40	4.80	0.10	0.11
0.39	0.01	48.07	2.77	109.80	1.80	14.20	0.40	14.40	0.30	0.14
0.78	0.02	21.25	1.10	48.80	0.80	35.50	1.00	9.60	0.20	0.13
0.78	0.02	42.23	2.30	79.30	1.30	46.15	1.30	0.00	0.00	0.15
0.39	0.01	52.46	3.20	97.60	1.60	14.20	0.40	57.60	1.20	0.07
0.39	0.01	42.35	2.75	128.10	2.10	17.75	0.50	7.20	0.15	0.12
1.17	0.03	40.73	1.60	67.10	1.60	17.75	0.50	0.00	0.00	0.11
0.78	0.02	54.36	2.80	79.30	1.30	31.95	0.90	28.80	0.60	0.23
I	N	G	S							
0.78	0.02	43.06	2.70	97.60	1.60	31.95	0.90	0.00	0.00	0.34
1.56	0.04	85.21	5.70	115.90	1.90	17.75	0.50	158.40	3.30	0.22
0.78	0.02	46.33	2.80	73.20	1.30	14.20	0.40	57.60	0.20	0.13
0.78	0.02	36.00	2.20	103.70	1.70	14.20	0.40	4.80	0.10	0.14
0.39	0.01	38.74	2.15	85.40	1.40	24.85	0.70	2.40	0.05	0.33
0.39	0.01	44.87	2.60	91.50	1.50	21.20	0.60	2.40	0.05	0.15
3.58	0.09	56.78	3.20	134.20	2.20	17.75	0.50	24.00	0.50	1.26
0.39	0.01	36.16	2.20	91.50	1.50	21.30	0.60	4.80	0.10	0.42

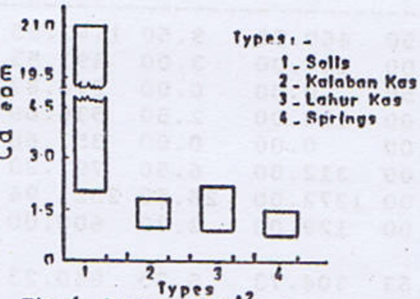

Fig. 1 _ Range of Ca^{+2} conc.

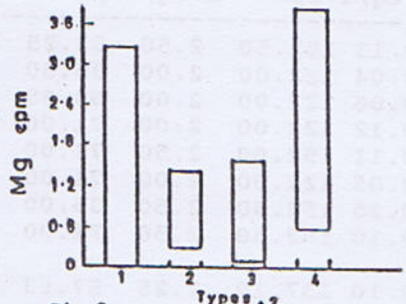

Fig. 2_ Range of Mg^{+2} conc.

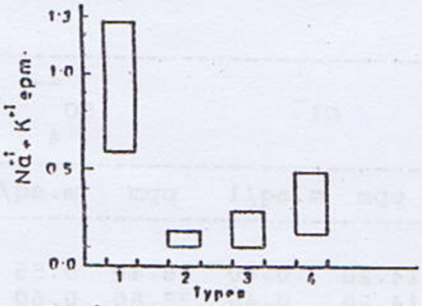

Fig:3 _Range of K+Na conc.

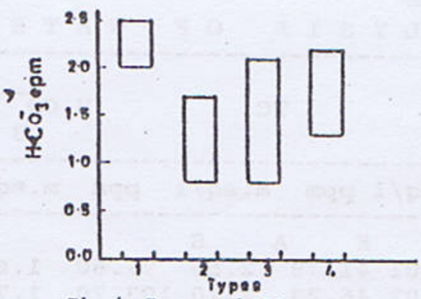

Fig. 4. Range of HCo_3 conc.

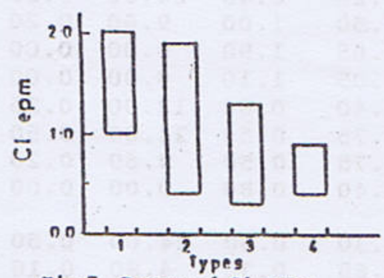

Fig. 5_ Range of Cl conc.

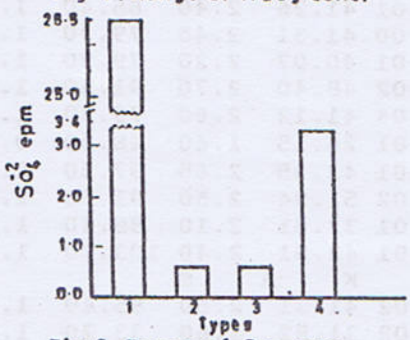

Fig. 6. Range of So_4 conc.

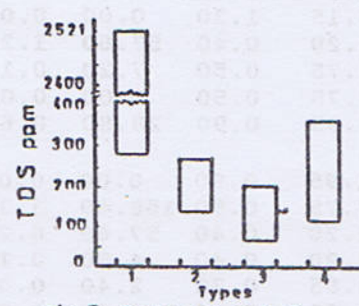

Fig. 7. Range of T.D.S.

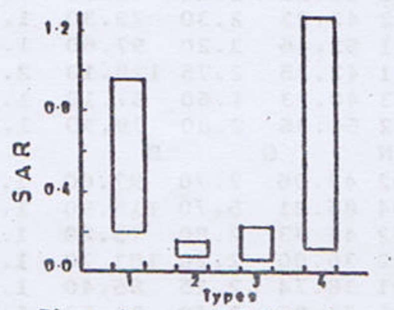

Fig. 8_ Range of SAR values

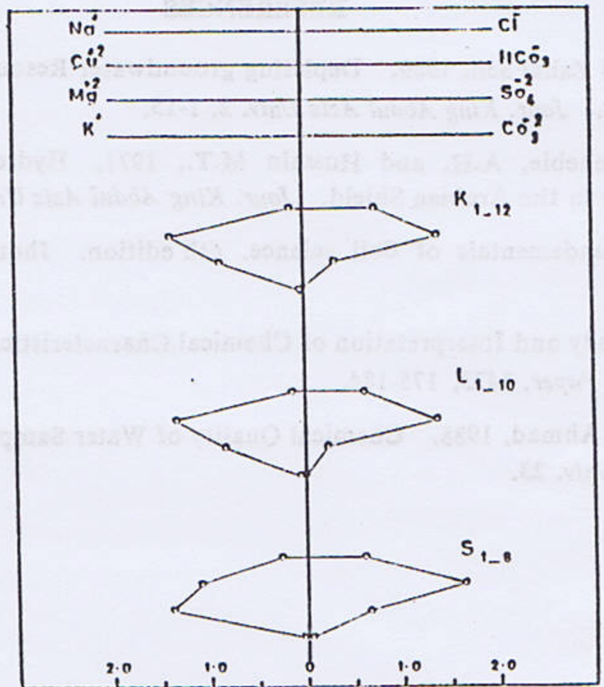

Fig 9 . Water analysis (Arithmatic Averages of the three types) represented by stiff patterns based on equivalents per million, of 30 water samples from Khanspur - Dewal area, Abbottabad.

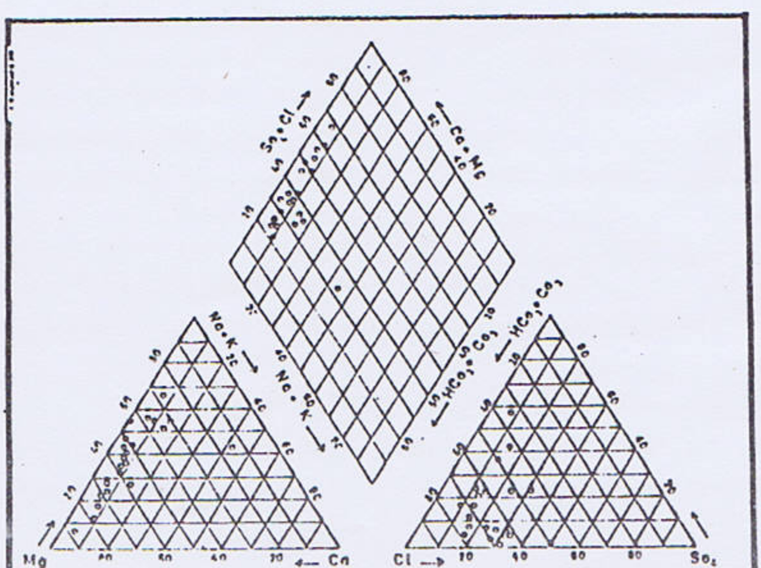

Fig. 10 . Analysis of water samples from Khanspur - Dewal area, represented by Trilinear Diagram .

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HYDROLOGICAL INVESTIGATIONS AT THE LEFT BANK OF KALABAGH DAM SITE WITE SPECIAL REFERENCE TO THE VARIATIONS OF GROUND WATER CONDITIONS OF VARIOUS SANDSTONE BEDS OF THE SIWALIK GROUP

BY

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Abstract : *Artesian conditions have been found in sancstone beds of the Siwalik Group which will result in high pore water pressures. Mostly the seepage occurs at the contacts of sandstone and claystone beds. The direction of ground water movement is from north-east to south-west. Generally, the ground water recharges the river with the exception of a few bore holes which recharge the river and sometimes are recharged by the river. The piezometric levels do not exactly coincide with the hydrographs due ta variable permeability.*

INTRODUCTION

The location of the area and its geological setting have already been given in another paper of these auothors in this issue of the bulletin. This paper highlights the hydrological investigations of the left bank of the Kalabagh Damsite.

Ground Water Hydrology

Ground water conditions at the left bank of Indus River at the project area were studied which included the preparation of ground water contour maps (Fig. 3, 4 & 5), movement and fluctuations of ground water were interpreted after taking into account Stallman (1956) and Todd (1965).

The area is covered by a large number of bore holes and adits in connection with subsurface geological investigations for the proposed Kalabagh Dam. Data from piezometric levels of 1936 in beds number 7, 8 and 9 on the left bank only were used for the preparation of ground water contour maps.

Indus and Soan rivers and Sanhi nala are potential influent sources for charging ground water. Variation in the elevations of the streams, dewatering of exploratory adits and seasonal wet and dry spells are found to influences the water table. In order to measure the ground water pressures stand pipe piezometers have been installed in most of the exploratory holes drilled after 1983. Daily and weekly measurement records of piezometers and river levels have been used for ground water contourigg and hydrographs.

A bed wise ground water contour maps (Figs. 3, 4 & 5) of the left bank are prepared according to the piezometric levels of December, 1986. These map do not cover the entire left bank area since some of the readings were not available or some piezometers were damaged.

The topography of the area is uneven and is truncated by nalas and tributaries affecting the ground water conditions. The gradient of water table varies in different parts of the area indicated by varing spacing of contours (Figs. 3, 4, 5).

Ground water contour map of Bed No. 7

Sandstone bed No. 7 varies in thickness from 110 to 130 feet with a discontinuous clay bed (-7a) which is 5 to 10 feet thick and is ronghly in the middle of bed No. 7. The bed is fully exposed in the Sanhi Nala and dips down 3° to 5° north-west. Along Soan river the bed is below water and outcrops about 2000 feet downstream of Soan bridge. The bed is 180 to 200 feet below bed level of the Indus channel in the damsite area and is exposed along the left bank of Indus about 1000 feet down stream of Pir Pihai villege.

A total of 44 piezometers were installed in Bed No. 7 till December, 1986 including three piezometers of post-feasibility period.

Nineteen instrument have been damaged and three piezometers have no readings on 18th December, 1986.

Ground water contour map of Bed No. 7 is prepared with the help of piezometric data on 18th December, 1986 of bore hole Nos. KCL-228, KCL-257, KCL-266, KCL-267, KCL-280, KCL-282, KCL-286, KCL-288, KCL-610, KCL-614, KCL-617, KCL-618, KCL-619, KCL-620, KCL-621, KCL-622, KCL-626. KCL-808, KCL-810, KCL-256 and KCL-272.

As the values of the contours decrease towards south-west, so the direction of ground water flow is also south-west. It is observed from the map that Bed No. 7 is fed by the Indus and Soan rivers as it is exposed to these rivers. Moreover, Sanhi Nala recharges Bed No. 7.

Most of the contours are well spaced showing high permeability. Whils the contours in the centre are of close spacing indicatiug high gradient, the value of the contours decreases towards centre i.e., gradient is towards bore hole No. KCL-257. This abnormality is due to the dewatering of ADL-4 which effects the ground water levels of piezometers installed in bore hole Nos. KCL-617, KCL-618, KCL-26, KCL-280, KCL-257, KCL-282, KCL-619, KCL-626, KCL-266, and KCL-257.

Ground water contour map of Bed No. 8

Sandstone Bed No. 8 is about 45 to 50 feet thick and is exposed on the surface beyond Bed No. 7 further upstream in Sanhi Nala.

Nine piezometers were installed in this bed in bore holes on the left bank, out of which 8 piezometers are in operative condition. These piezometers are located in the area of power house and its tailrace channel.

Ground water contour map of Bed No. 8 is prepared with the help of ground water elevation on 18th December, 1986 for bore hole Nos. KCL-95, KCL-279, KCL-606, KCL-608, KKL-609, KCL-805, KCL-806 and KCL-808(1).

As the values of she contours decrease south-west so the direction of the ground water flow is from north-east to south-west. The large spacing between the contours indicate low gradient and high permeability of the sandstone Bed No. 8. Bed No. 8 is exposed upstream of the Sanhi Nala, so this bed is most probably recharged by rain and Sanhi Nala.

Daily record of piezometers plotted graphically for the year 1986 indicates that there is no influence of river on water table of Bed No. 8.

Ground water contour map of Bed No. 9

Sandstone Bed No. 9 is about 90 feet thick and is exposed in the Sanhi No. 8. This bed will form foundation for replacement work of power unit. A total of 8 piezometers were installed in this bed, out of which 6 were in working condition in the month of December, 1986. At the location of KCL-625, KCL-801 and KCL-802, ground elevations are lower than the piezometeric levels and the piezometers are in flowing conditions. Water levels in these piezometers are measured by fixing extension pipes above ground surface.

Ground water contour map of Bed No. 9 is made with the help of bore holes KCL-808. KCL-601, KCL-604 and KCL-605. The values of contours decrease towards south-west, so the direction of ground water flow is from north-east to south-west. From the piezometeric measurements, Bed No. 9 appears to be recharged by rain or Sanhi Nala and is not effected by the river.

GROUD WATER CONDITIONS AND MOVEMENTS

Ground water occurs in permeable geologic formations known as aquifers i.e. the formations having structure that permit appreciabls water to move through them in ordinary field conditions. A ground water basin is the physiographic unit containg one large aquifer or several connected and interrelated aquifers. In the area there exists a very long range of unconsolidated material, partly brought down from the Himalayas and left at the edge of plains. These are Siwalik hills between 2,000 to 4,000 feet in height and contain large amount of water transported materials, said to deposited by geological river called siwalik which originated from Assam. In the area the Siwalik beds are overlain by a bed of Soan boulders which can be seen only at terraces.

Ground water at the Dam site is accumulated or flowing as a result of infiltration from surface resources such as rainfall, nalas or river or artificial discharge such as pumping in the adits. Mostly the under ground units are unconsolidated and granular. So, it can store a large amount of water. Main source of recharge in the project area is precipitation.

The nalas and tributaries in the project area are seasonal and flow only during the period of rainfall. Nala have high gradient towards the river. Most of the water directly flows to the river. However, a part of the nalas, runoff is infiltered to the sub-surface units and become a part of ground water. Again the ground water depending upon the hydraulic gradient, may recharge the river. The underground units are consolidated as well as unconsolidated. The infiltration of water from the ground surface is highly influenced by the permeability and thickness of the overburden lying in the area. The overburden is composed of gravels, sand and silt. The gravels range in diameter from fraction of an inch to cobble size. The total thickness of the overburden varies from place to place).

Permeability tests are carried out to determine the capacity of soil to transmit water through it. Its results are helpful in the studying of ground water problems. The permeability test were performed in the alluvium and terraces during drilling the holes either by constant or falling head methods on land or by rising head method in water holes. The tests performed on sandy gravels show that 75% test results are between $1x10^{-3}$ to $1x10^{-4}$ cm/sec and 7% tests results are between $1x10^{-2}$ to $1z10^{-1}$ cm/sec. Higher permeability values of the overburden make the infiltration of water easier and faster.

The permeability of the sandstone was measured in the field by packer tests in the drilled holes. They were performed under pressures generally applied in three increasing and two decreasing stages. The tests show permeabilities upto 5 lugeons for about 80% of the tests and 5 to 10 lugeons for 13% tests while higher values were observed for the remaining 7% of the tests.

The groundwater contour maps show that almost throughout the year, the river is recharged from the surrounding aquifers. The piezometric level remains higher than that of river showing that ground water is moving towards the river.

River flow and ground water

At the site, the River Indus is effluent i.e., ground water flows towards the river. During rainy season the piezometeric levels rise up and the river flow increases (Figs. 6-13). The piezometric levels of different bore holes in Bed No. 7 is influenced by the river flow and always found to be lower than that of the river. An increase in the flow increases the piezometric levels of a few bore holes. There are some bore holes such as KCL-621 which sometimes recharge the river and at times, get recharged by the river depending upon the river level. Piezometric levels of some bore holes are much higher (throughout the year) than the river level and they show minor fluctuation which is due to precipitation.

CONCLUSIONS

From the ground water contour maps and hydrographs, it is concluded that :—

1. The direction of ground water movement on left bank is from north-east to south-west, almost parallel to the river flow.
2. Artesian conditions occur in Bed Nos. 7, 8 and 9. Artesian head in Bed No. 9 is 15 feet higher than in Bed No. 7.
3. High pore pressures are expected due to artesian conditions.
4. The seepage water emerges, generally, at the bottom of each sandstone bed and the intermediate claystone/siltstone bed acts as barrier between the two sandstone beds. Therefore, most of the seepage occurs at contacts of sandstone and claystone.
5. From hydrographs it is clear that ground water level becomes maximum dnring rainy season.

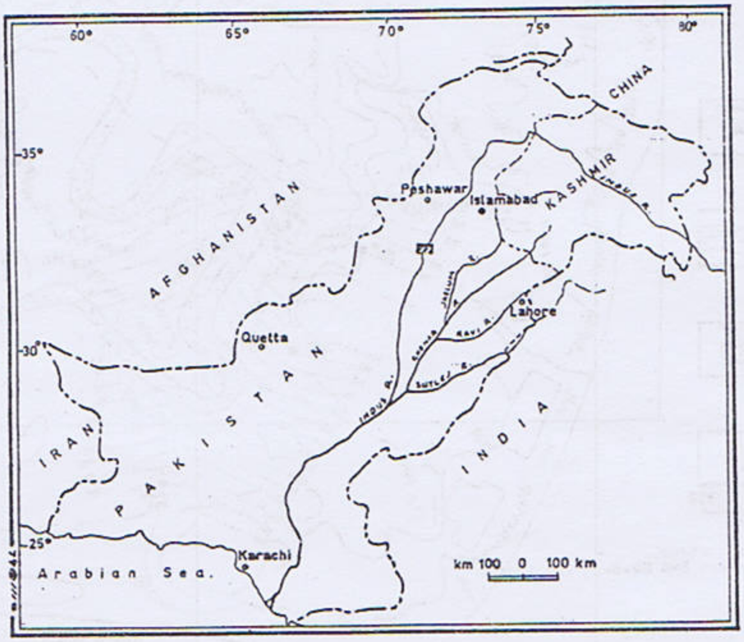

Fig.1. ▨ Location map.

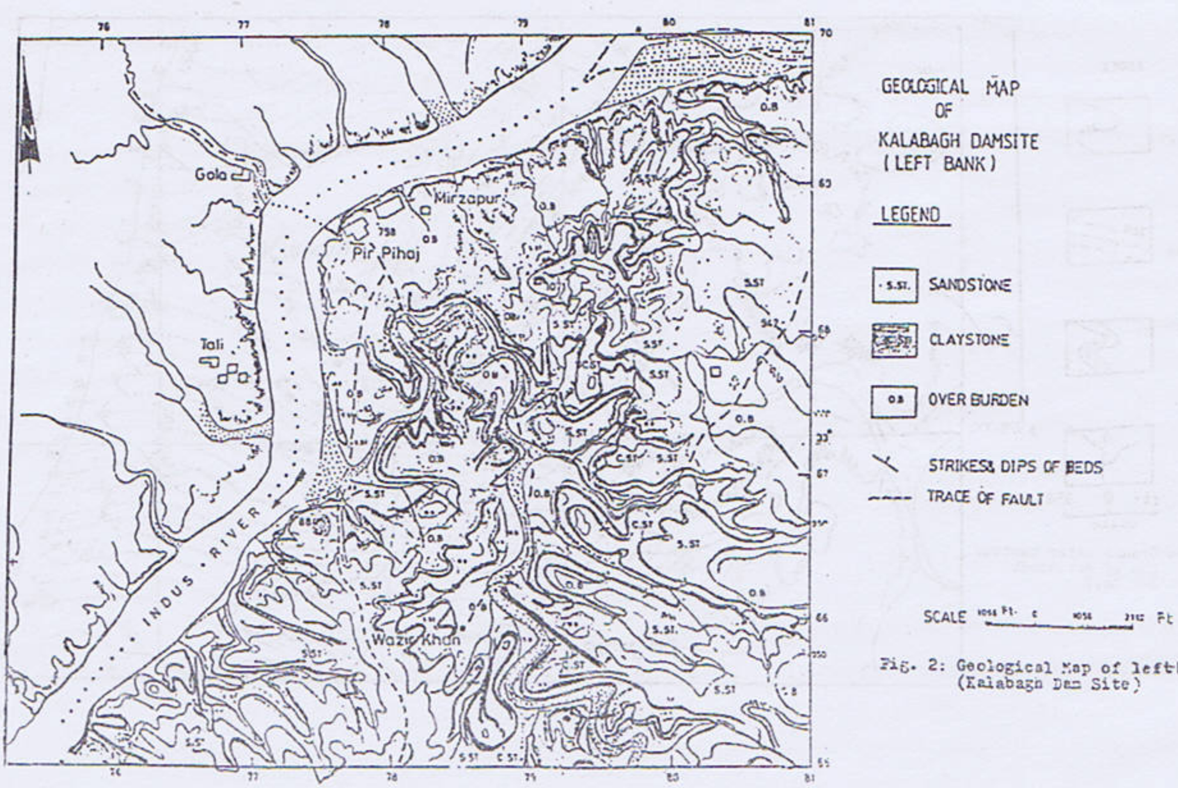

Fig. 2: Geological Map of leftbank (Kalabagh Dam Site)

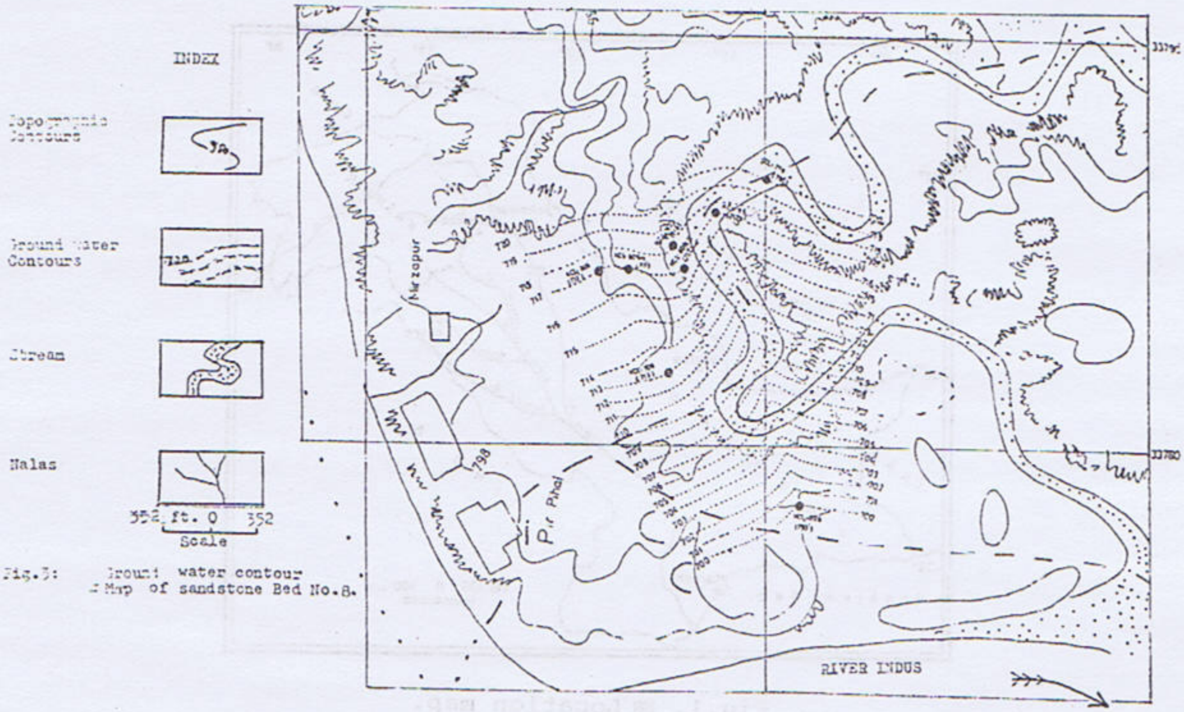

Fig.3: Ground water contour Map of sandstone Bed No.8.

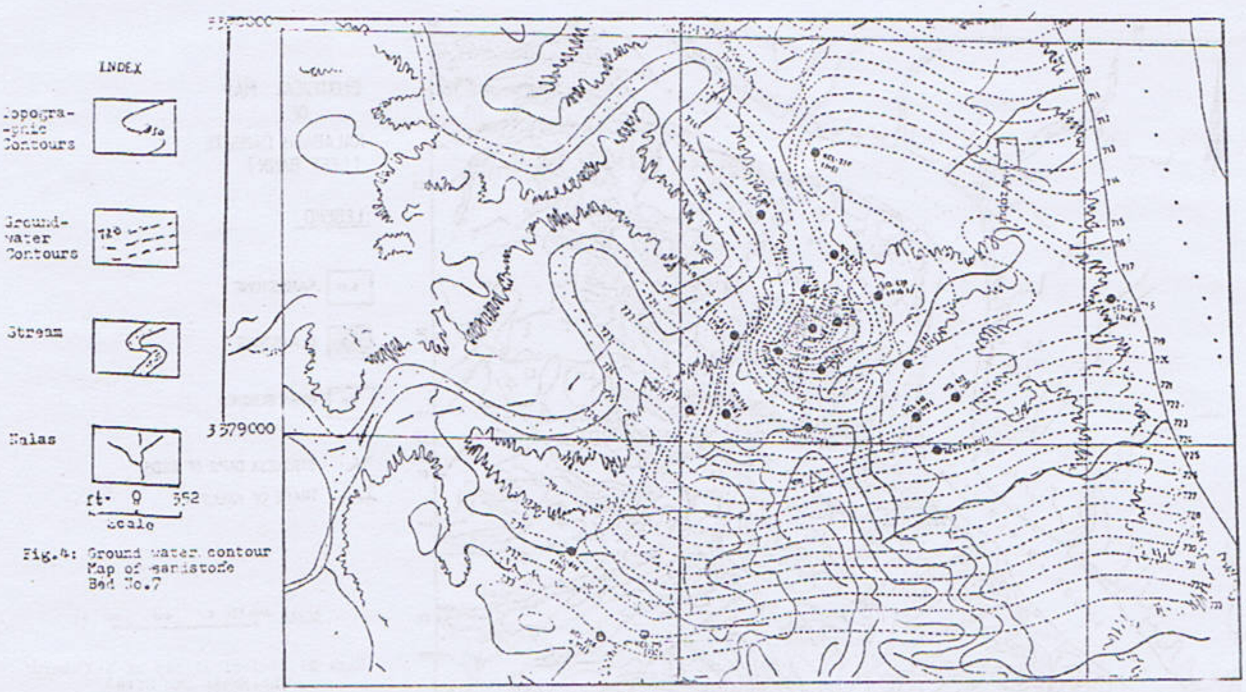

Fig.4: Ground water contour Map of sandstone Bed No.7

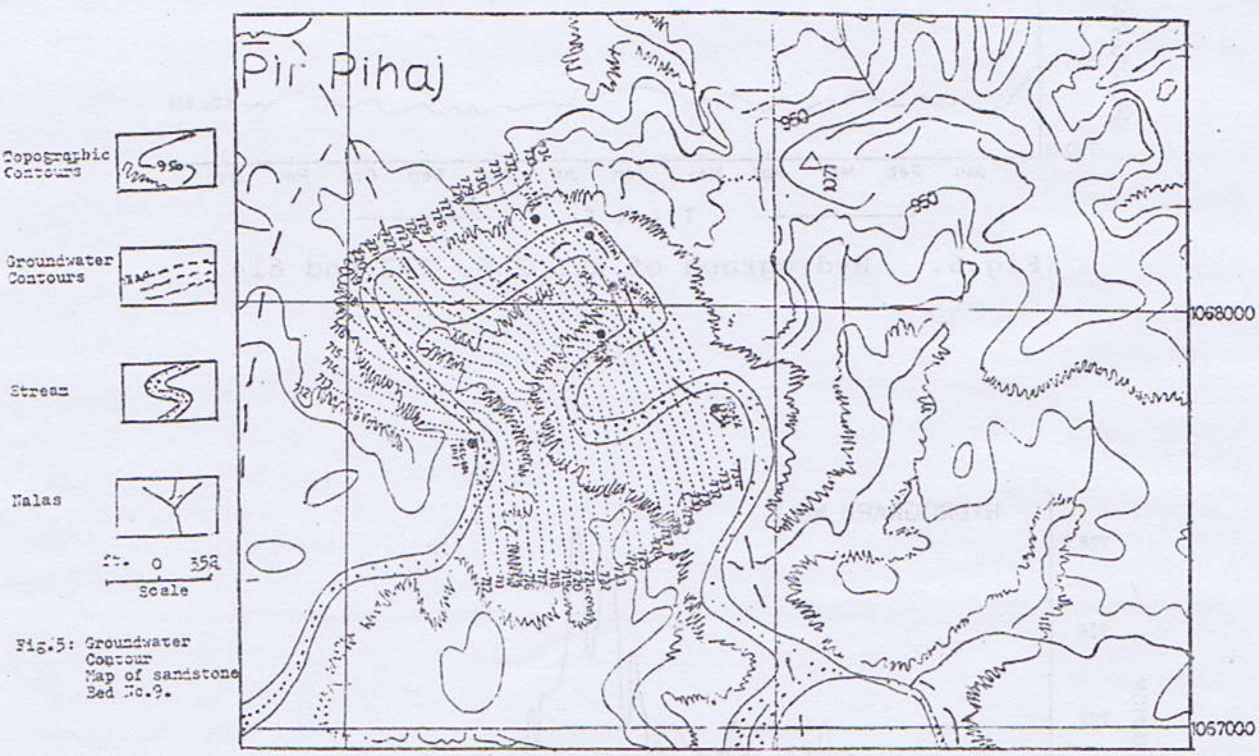

Fig.5: Groundwater Contour Map of sandstone Bed No.9.

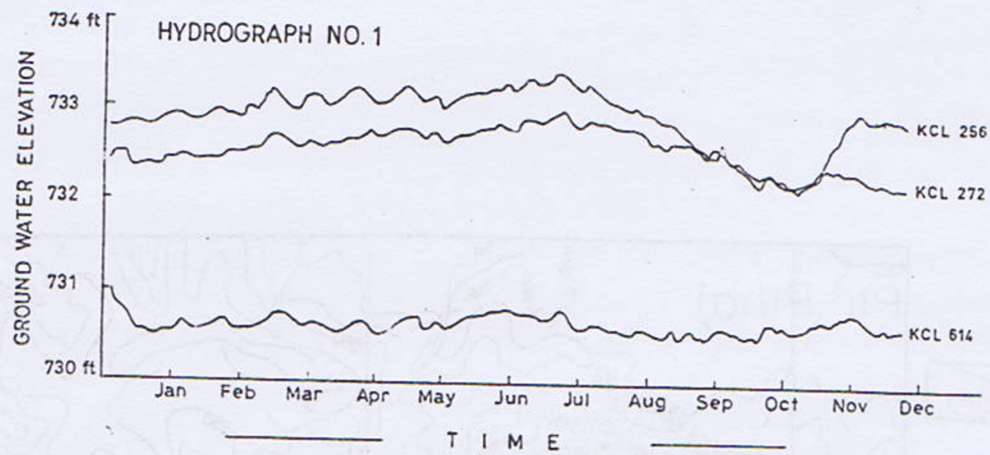

Fig.6. Hydrograph of KCL 256, 272 and 614.

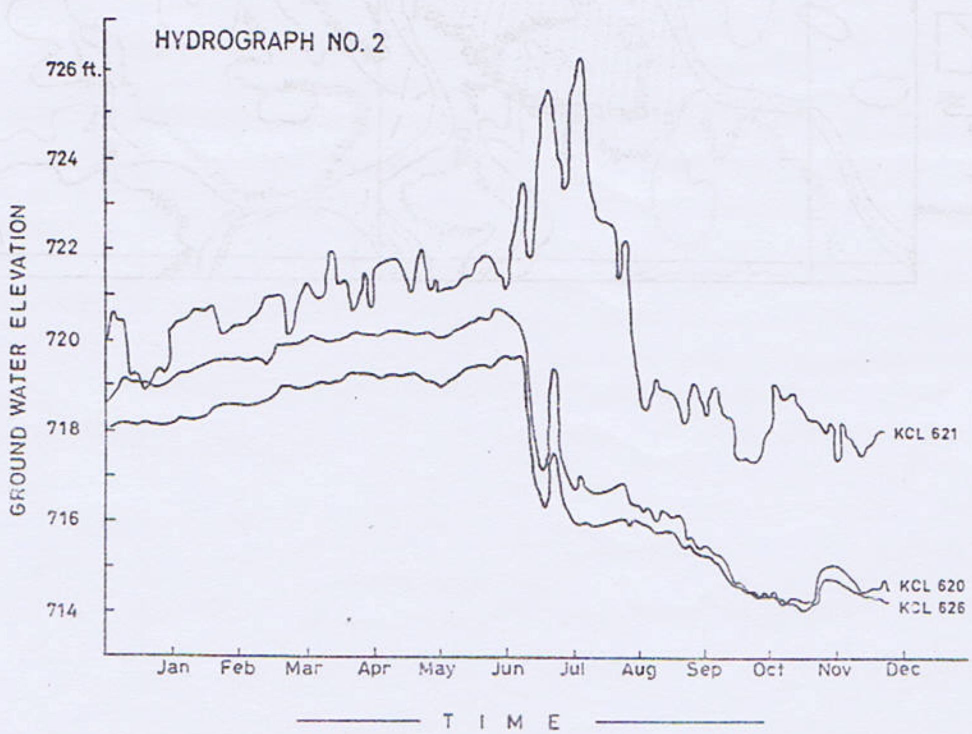

Fig.7. Hydrograph of KCL 620, 621 and 626.

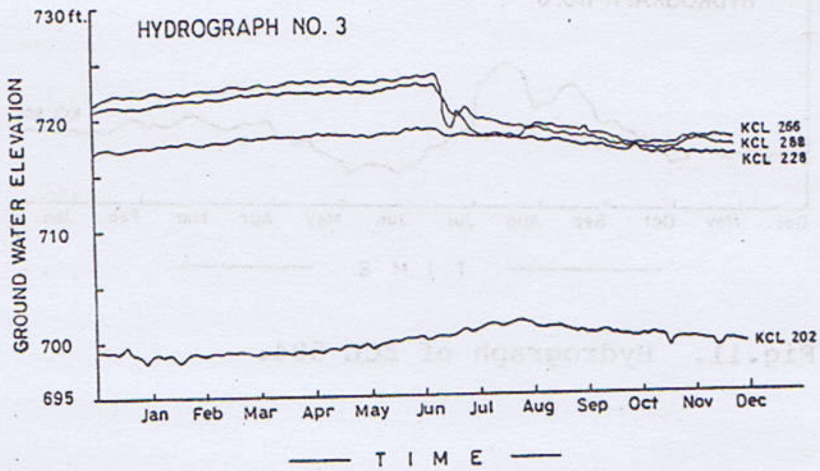

Fig.8. Hydrograph of KCL 202, 228, 266 and 288.

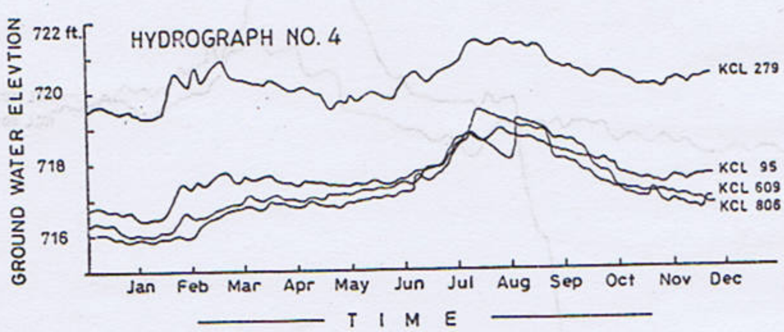

Fig.9. Hydrograph of KCL 95, 279, 609 and 806.

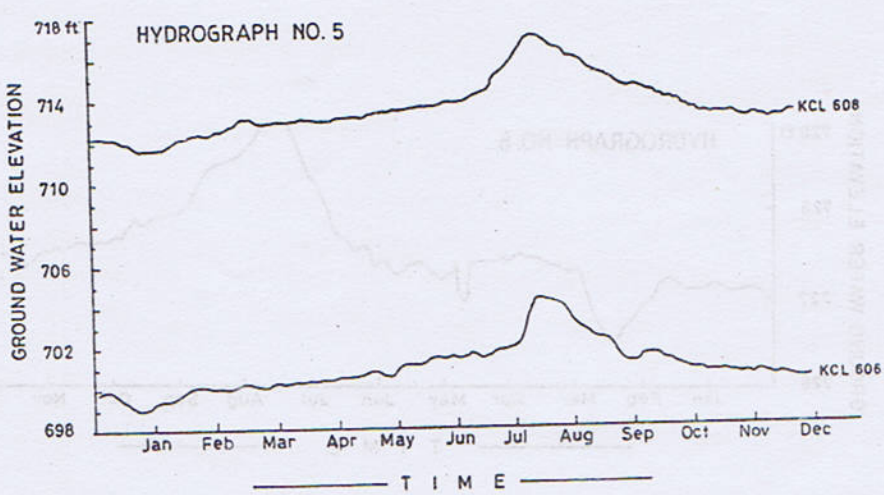

Fig.10. Hydrograph of KCL 606 and 608.

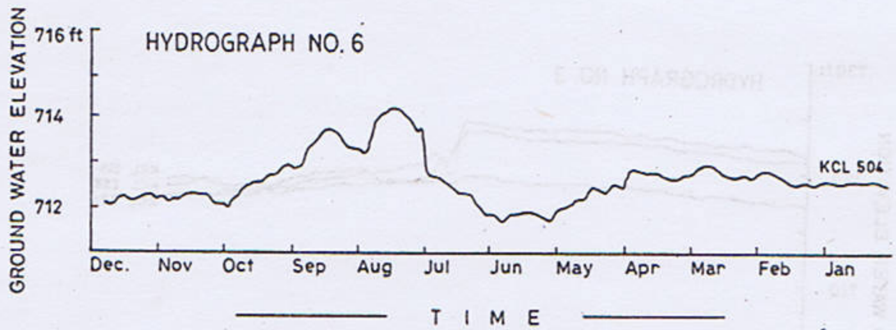

Fig.11. Hydrograph of KCL 504.

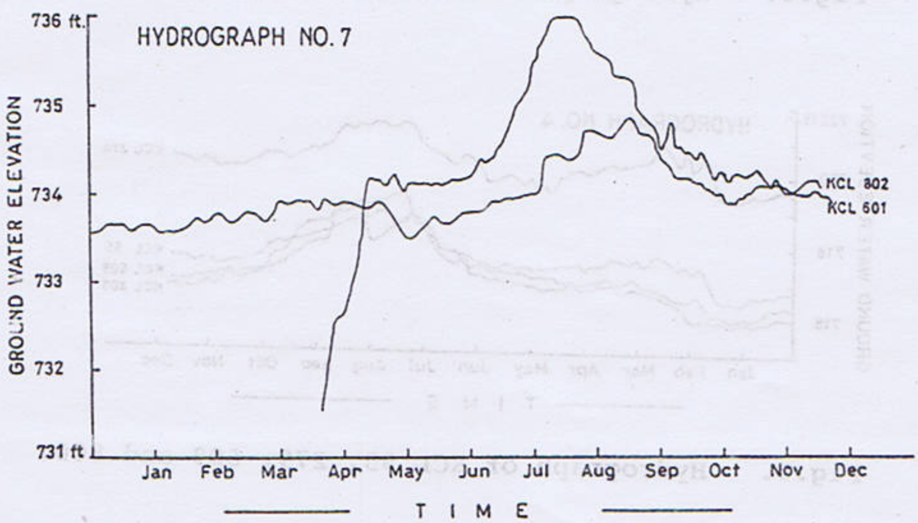

Fig.12. Hydrograph of KCL 601 and 802.

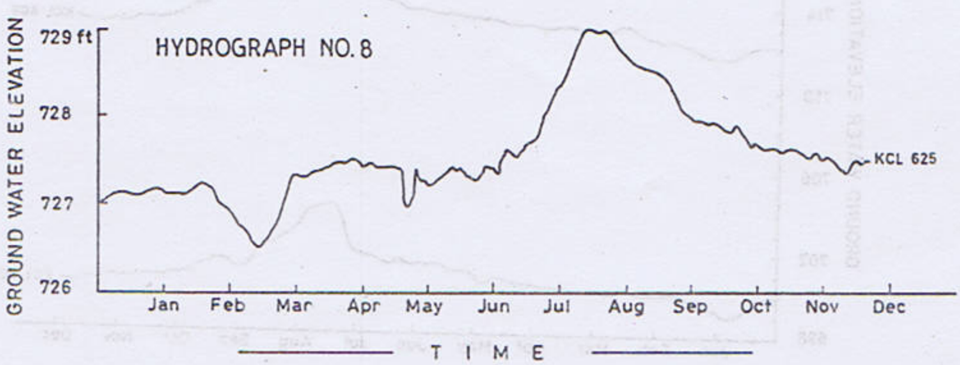

Fig.13. Hydrograph of KCL 625.

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STRATIGRAPHIC ANALYSIS OF THE MESOZOIC ROCKS OF CENTRAL BALOCHISTAN, PAKISTAN

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Abstract : *Stratigraphic revision of the Mesozoic rocks exposed in the Axial Belt of the Central Balochistan has been made on the basis of lithology and the ammonitic fauna. The Ferozabad Group comprising the Shirinab, Malikhore and Anjira Formations of Triassic to Middle Jurassic in age is followed by the Chiltan Limestone of Middle Jurassic age. The Mona Jhal Group consists of the Sembar, Goru, Parh and Mughal Kot Formations of Late Jurassic to Cretaceous in age.*

Harpoceratids of Upper Pliensbachian (Early Jurassic) age have been collected from the Shirinab Formation (Shahr Haji area). Bouleiceras, Nejdida, Protogrammoceras, Fuciniceras, Grammoceras, Dumorlieceras, Polyplectus *and* Phymatoceras *of Toarcian age have been recorded from the Anjira Formation, while* Phylloceras, Neolissoceras, Olcostephanus *and* Duvalia *of Valanginian oge have additionally been picked up from the Sembar Formation.*

INTRODUCTION

The first detailed stratigraphic subdivision of the Central Balochistan was established by Vredenburg (1909). Hunting Survey Corporation (1961) introduced the Shirinab Formation and Chiltan Limestone for the Jurassic and Parh Group/Parh Series for the Cretaceous strata. Fatmi (1977) used the nomenclature of Hunting Survey Corporation (1961). However, he subdivided the Shirinab Formation into three members, namely, Spingwar, Loralai and Anjira (formational ranks of Williams, 1959). In this paper, the stratigraphy of the area is redefined and the status of the Anjira Member is raised to formation due to its distinct lithology and fauna.

Stratigraphic studies of the Mesozoic rocks were carried out to establish lithostratigraphic units and their contact relationship in the Axial Belt of the Central Balochistan. The fossils reported from the Ferozabad and Mona Jhal Groups have been identified by A.N. Fatmi. The Central Balochistan covers the area from Anjira to Gwal. This work is based on detailed stratigraphic section measurements and collection of fossils from the Kalat, Johan, Quetta and Sanjawi areas in the Axial Belt. The new fossil horizons from the Shirinab, Anjira and Sembar Formations lead us to fix the age and to correlate the formations within Balochistan and those deposited during that time in the Upper Indus Basin. The stratigraphic sequence established by us is summarized as below :

LATE JURASSIC-CRETACEOUS	Thickness in metres
Mona Jhal Group	
Mughal Kot Formation	0–36m
Parh Limestone	75–288m
Goru Formation	80–369m
Sembar Formation	12–178m
——Disconformity——	

TRIASSIC-MIDDLE JURASSIC	
Chiltan Limestone	260 (Lower Part)
Ferozabad Group	
Anjira Formation	135–225m
Malikhora Formation	145m
Shirinab Formation	>230–1000m
(Base not exposed)	

STRATIGRAHY

Two new groups, Ferozabad and Mona Jhal, have already been introduced in the area (Anwar et al., 1991). The Chiltan Limestone is taken as a separate unit because of its prominent development of massive limestone forming cliffs in the area. The names of the Shirinab Formation and Chiltan Limestone of Hunting Survey Corporation (1961) have been accepted as the same but the lower and middle parts of the Chiltan Limestone is renamed as the Malikhore and Anjira Formation due to its lithology and fauna.

Triassic-Middle Jurassic

Ferozabad Group. This group includes the following three formations in ascending order:

3.	Anjira Formation	Early to Middle Jurassic
2.	Malikhore Formation.	Early Jurassic
3.	Shirinab Formation.	Triassic to Early Jurassic

Shirinab Formation. The formation consists of limestone interbedded with shale and marl. In the Kalat section (Fig. 1), the limestone is light grey to dark grey, weathers brownish grey, medium to thick bedded, mottled, micritic to biomicritic, sublithographic, hard and fossiliferous. It is marly, argillaceous, flaggy, platy, silty and crinoidal at places. It contains pelletic and oolitic beds at different levels with coquina beds and some dolomitized beds in the lower part. The shale is buff, greenish grey to brown, calcareous and fissile. The marl is greenish grey, nodular and hard. The shale and marl are minor in the lower part and dominant in the upper part. In the Gurruk-Ziarat section (Fig. 2), the limestone is brownish grey, weathers brown, thick bedded, biosparitic, mottled and fossiliferous. The shale is buff, maroon, greenish grey and fissile.

The formation is measured in the Kalat (>1000m) and Gurruk-Ziarat (>230m) sections. The base of the formation is not exposed. Its upper contact with the Malikhore Formation is transitional. No Permian outcrop has been located by us as reported by Vredenburg (1909) and Hunting Survey Corporation (1961) in the Central Balochistan. The authors have collected Spiriferinids, Terebratulids and Harpoceratids of Upper Pliensbachian (Early Jurassic) age from the Shahr Haji area. The fauna was also collected from the Gurruk-Ziarat section (Fig. 2) that include *Rhynchonella* sp., *Terebratula* sp., *Spiriferina* sp., and bryozoans. The age of the formation is considered to be Early Jurassic but it may extend into the Triassic. The Shirinab Formation is a stratigraphic facies equivalent of the Kharrari Formation in the Southern Balochistan and of Wulgai Formation and the lower part of the Spingwar Formation in the Northern Balochistan.

Malikhore Formation. The formation mainly consists of limestone with minor shale as partings (Fig. 2). The limestone is light grey to brownish grey, weathers palish brown, thick bedded to massive, sugary textured, hard, fractured, and crystalline. It is sparitic, shelly, mottled, oolitic and contains scantly chert nodules. The formation is highly resistant and forms cliffs and high ridges.

The formation is only measured in the Gurruk-Ziarat section (145m). Its contacts with the underlying Shirinab Formation and the overlying Anjira Formation are transitional. Only some poorly preserved molluscan fossils have been reported at different levels. An Early Jurassic age is considered on the basis of its stratigraphic position between the Shirinab Formation of (?) Triassic to Early Jurassic and the Anjira Formation of Toarcian (Early Jurassic) age. The formation is a facies equivalent of uppar part of the Spingwar Formation in the Northern Balochistan.

Anjira Formation. The formation consists of limestone with interbeds of marl and subordinate shale. The limestone is grey to dark grey, weathers brownish grey, thin to thick bedded, biosparitic, marly and highly fossiliferous. It is also argillaceous, oolitic, pelletal and shelly at places. It contains chert nodules and forms ridges. The marl is grey, greenish grey, soft, nodular and fossiliferous. The shale is dark grey to greenish grey and calcareous.

The formation is measured in the Gurruk-Ziarat (135m) and Baleli (225m) sectlons. Its contact with the underlying Malikhore Formation is transitional whereas its upper contact with the Chiltan Limestone is conformable. The fossils collected from the Gurruk-Ziarat section (Fig. 2) include *Rhynchonella* sp., *Terebratula* sp., *Spiriferina* sp., (F-3), Bryzoans (F-3 & 4), *Bouleiceras* sp., *Nejdia* sp. and *Protogrammoceras* sp. (F-5). In addition to this, *Fuciniceras* sp. (F-7), *Rhynchonella* F-8), *Grammoceras. Dumorlieceras menaghini* (F-9), *Polyplectus*, *Grammocera* (F-10) and *Phymatoceras* sp. (F-11) have also been picked up from the Baleli section (Fig. 3). An Early Jurassic (Toarcian) age is considered on the basis of fossils. The stratigraphic position of this formation is similar to that of the Loralai formation in the Northern Balochistan and these both are time or facies equivalent. It is also correlated with the Shinawari Formation of Upper Indus Basin.

Chiltan Limestone. The Chiltan Limestone is divisible into the lower and the upper parts. The lower part consists of grey to dark grey, micritic, bedded and lithographic limestone while the upper part is composed of dark grey to black, thick bedded to massive and biosparitic limestone with some dolomitized beds. However, in the Kalat area only lower part is developed and is mainly consisted of limestone. It is grey to dark grey. brownish gray, weathering dark brownish gray, fine grained, thin to thick bedded, flaggy, flaky, argillaceous, sublithographic to lithographic and fossiliferous with oolitic, shelly and bioturbated beds. Chert is present both along bedding planes and in nodular from in the Gurruk-Ziarat section. In the Moro Gorge and Lak Pass-Ziarat sections the upper part consists of massive to thick bedded limestone. It is dark grey to black, weathers dark grey to brown, oolitic, pelletal and crinoidal with hardly any shale and marl intercalations.

The Chiltan Limestone is developed only in the Central Balochistan. Its lower part is measured in the Gurruk-Ziarat (260m) section. Its contains with the underlying Anjira Formation is conformable and with the overlying Sembar Formation is sharp and disconformable measured by a change in lithology but it is faulted in the Kalat area. The Chiltan Limestone has yielded poorly preserved vary rare fossils. Its age is Middle Jurrassic mainly on the basis of its stratigraphic position by overlying the Anjira Formation of Toarcian age. It is correlative with the Takatu Limestone of the Sulaiman Limestone Group of the Lower Indus Basin and with the Samana Suk Formation of the Upper Indus Basin.

Late Jurassic-Cretaceous

Mona Jhal Group. This group includes the following four formations in ascending order :

4. Mughal Kot Formation.
3. Parh Limestone.
2. Goru Formation.
1. Sembar Formation.

This group replaces the Parh Group or Parh Seriesof Hunting Survey Corporation (1961) and is developed throughout Baluchistan except Mughal Kot Formation which is missing in Kalat and Quetta areas.

Sembar Formation. The formation mainly consiste of shale. It is yellowish green to dark green, weathers light green to brown, glauconitic, silty, fissile to blocky, ferruginous, calcareous and flaky in the Kalat section. In the Moro Gorge section, the formation is sandy and non-calcareous with glauconitic sandstone beds and laterite at the base. In the Surrkh Kattai section, the lower part of the formation contains shale and sandstone interbeds.

The formation is measured in the Kalat (178m), Gurruk-Ziarat (80m), Moro Gorge (37m), Murree-Brewery (12m) and Srakhezai (174m) sections. The contact with the underlying Chiltan Limestone is disconformable and sharp whereas in the Kalat section, it is faulted. Its contact with the overlying Goru Formation is transitional in the Central Balochlstan.

Laevaptychus from the Gurruk-Ziarat section and some *Belemnopsis* and *Hibolithes* (F-6 & 12) from the Gurruk-Ziarat and Moro gorge sections have been reported from the lower part. Phylloceratids are also recorded a few meters above the base near Purduzai village. The fauna recorded from the Surrkh Kattai section includes *Phylloceras* sp., *Neolissoceras* sp., *Olcostephanus* sp., *Duvalia* sp. and *Hibolithes*. The age is considered to be Late Jurassic to Early Cretaceous on the faunal basis. The formation is correlated with the Chichali Formation of the Upper Indus Basin.

Goru Formation. The formation consists of interbeds of marl, shale and limestone. In the Kalat, Moro Gorge and Srakhezaai sections the marl is greenish gray, greenish brown to dark grey, weathers light green to polish grey, nodular, blocky and fossiliferous. In the Moro Gorge section, it is maroon, purplish grey and soft. The shale is purple and green, calcareous, flaky, fissile, splintery and fossiliferous. The limestone is grey, greenish grey, purple, weathers brown, thin bedded, marly and occasionally argillaceous. In the Murree-Brewery section, the limestone is light gray to yellowish grey, pihkish brown, thin bedded, micritic, marly, pelagic and fossiliferous. It is cherty in the upper part. The shale/marl is purple to red, pink, calcareous and silty. Pencil shaped weathering is common.

The formation is measured to be 369m thick in the Kalat section, 80m in Moro Gorge section, 92m in the Murree-Brewery section and 272m in the Srakhezai section. The lower contact of the formation with the Sembar Formation is transitional in all section. The upper contact with the Parh Limestone is transitional throughout Central Balochistan and is placed at the last marl/shale interbed with limestone.

The formation contains pelagic foraminifers and, at places, occasional belemnites. Fritz and Khan (1967) described the foraminifers from Banga Nala in Quetta region. Its age is considered Early Cretaceous but map extend to basal Late Cretaceous. The formation is correlated with the Lumshiwal Formation of Shaikh Budin Hills, Surghar Range and Western Kohat. Marly limestone and abundant pelagic fauna suggest relatively deep water shelf or slope environment. The fine argillaceous sediments are more common in lower Goru lithology but the upper Goru gets more clear water carbonates argillaceous material (deep water deposits).

Parh Limestone. The formation mainly consists of limestone. It is light gray, white to creamy, purple, pink to grayish brown, weathers brownish gray to dirty white, thin to medium bedded sublithographic to porcellaneous, occasionally platy and at places thick bedded and argillaceous. It is thin bedded in the lower and upper parts and medium to thick bedded in the middle part. At places, the formation is cherty with minor calcareous shale in the lower and upper parts. The porcellaneous nature, concoidal fracture and persistence ridges of Parh Limestone are the distinctive characters that differ it from other limestone units.

The formation is widely distributed in the Axial Belt. Its thickness is 288m in the Moro Gorge section, 75m in the Murree-Brewery section and 202m in the Srakhezai section. The lower contact of the formation with the Goru Formation is transitional. The upper contact with the Mughal Kot Formation/Moro Formatiou is conformable and sharp. It is Moro Gorge section it is conformably overlain by the Moro Formation. However, when Tertiary formotions overlie the Parh Limestone, the contact is always unconformable. In the Murrer-Brewery section, it is conformable with Orbitoides limestone of Upper Masstrichtian age. In the Kalat area, it has a faulted contact with the Spintangi Limestone (Middle Eocene). Its age is considered to be Late Cretaceous on the basis of forminifers reported by Gigon (1962). It is correlated with the Kawagarh Formation of the Western Kohat. The sediments of Parh Limestone were probably formed in the prograding deep water carbonate shelf conditions.

Mughal Kot Formation. The formation mainly consists of greenish gray to yellowish gray, nodular marl with some calcareous, silty shale in the upper part. A thick pisolitic laterite unit (about 2.5 m) is developed at the top (Fig. 8).

The thickness of the formation is 36m thick in the Srakhezai section. The fomation is missing around the Kalat and Quetta area. The lower contact with Parh limestone is conformable whereas its upper contact in unconformable with the Sanjawi Limestone of Paleocene-Eocene age. The formation contains Cretaceous foraminifers. The age is considered to be Late Cretaceous on the basis of *Orbitoides* described by Williams (1959) and Marks (1962) from the Rahi Nala (Sulaiman Range).

CONCLUSIONS

The present investigations summarize the following important conclusions related to the stratigraphy and ages of the Mesozoic rocks in the Central Balochistan.

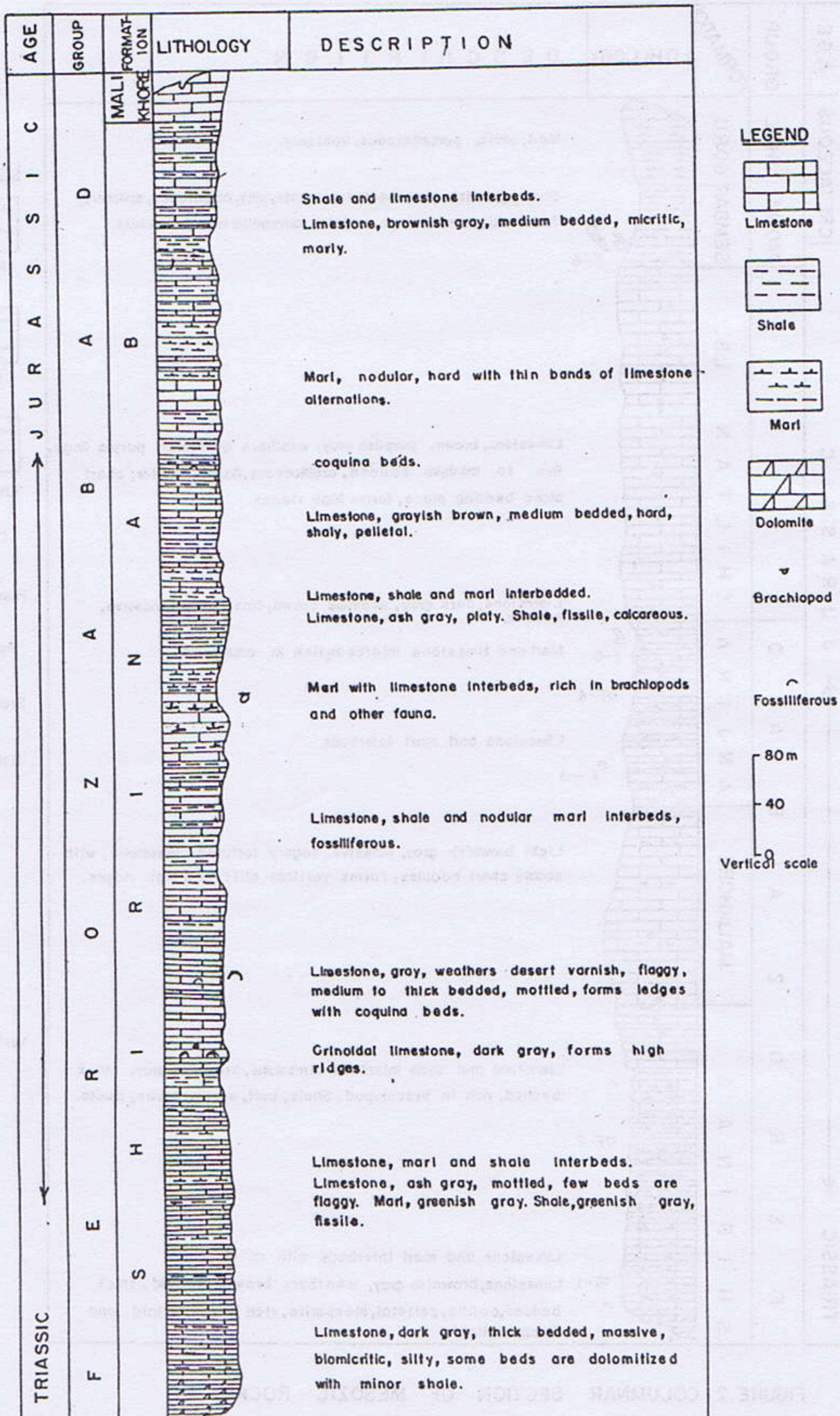
1. The Shirinab Formation of Hunting Survey Corporation (1961) appears to be a facies equivalent of the Kharrari Formation in the south and of the Spingwar Formation in the north.

2. There are no Permian fossils as reported by Vredenburg (1909) and Hunting Survey Corporation (1961) from the Sar Jangal and Shahr Haji in the Kalat-Surab areas respectively.

3. The presence of *Fuciniceras* (Lower Toarcian), *Bouleiceras* and *Phymatoceras* (Upper Toarcian) in the Anjira Formation indicates Toarcian (Early Jurassic) age.

4. The Anjira Formation is a stratigraphic equivalent of the Loralai Formation of the Northern Balochistan and they do not overlie each other because Toarcian fossils have been collected from the lower part of both these formations.

5. The Anjira Formation is correlated with the Shinawari Formation of the Shaikh Budin Hills, Surghar Range and Western Kohat (Samana Range) on the basis of *Bouleiceras*.



Drafted by:- Zafar Ahmad.

FIGURE.1 .COLUMNAR SECTION OF SHIRINAB FORMATION WEST OF KALAT.

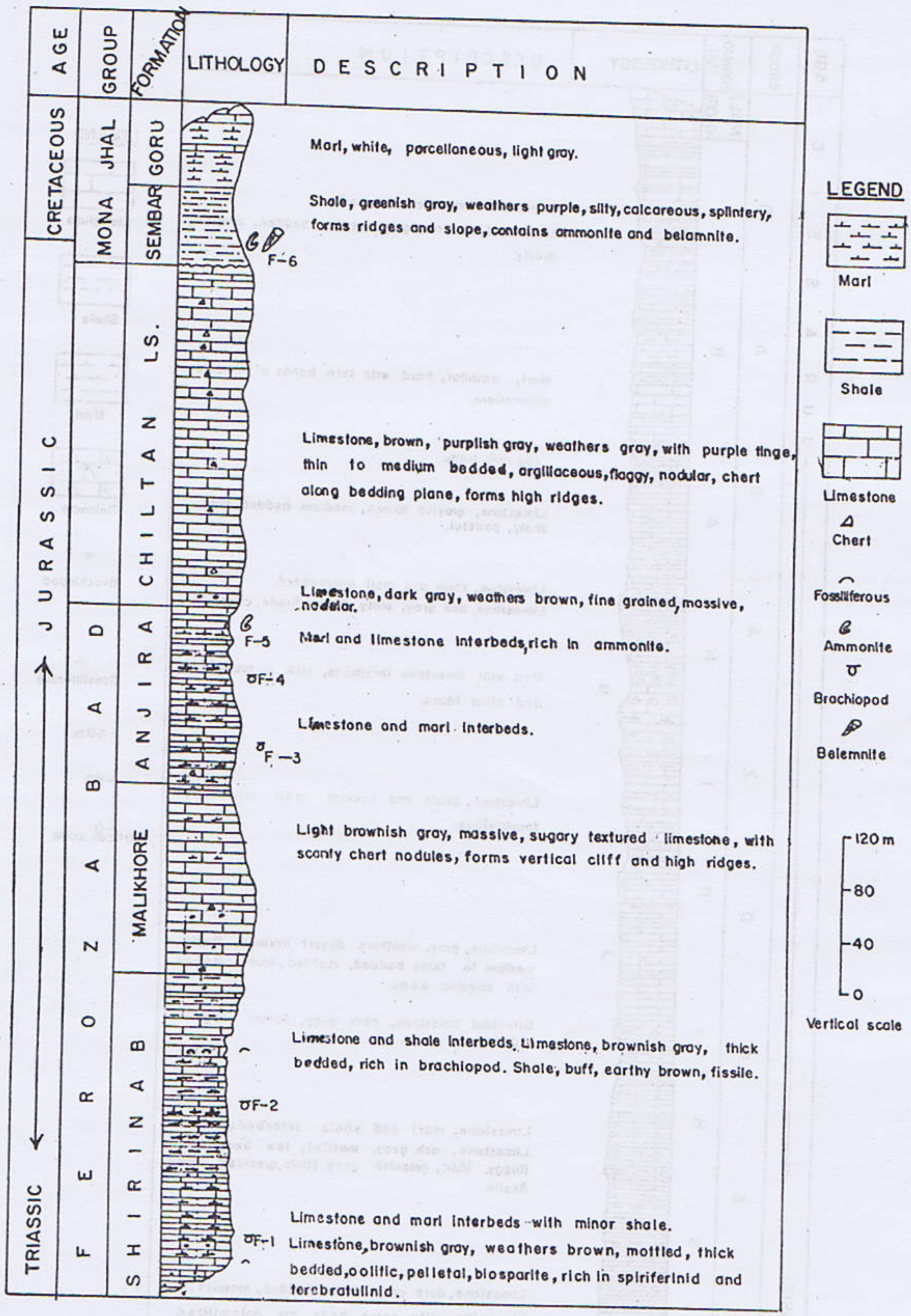


FIGURE. 2. COLUMNAR SECTION OF MESOZIC ROCKS IN GURRUK— ZIARAT, NORTH WEST OF KALAT.

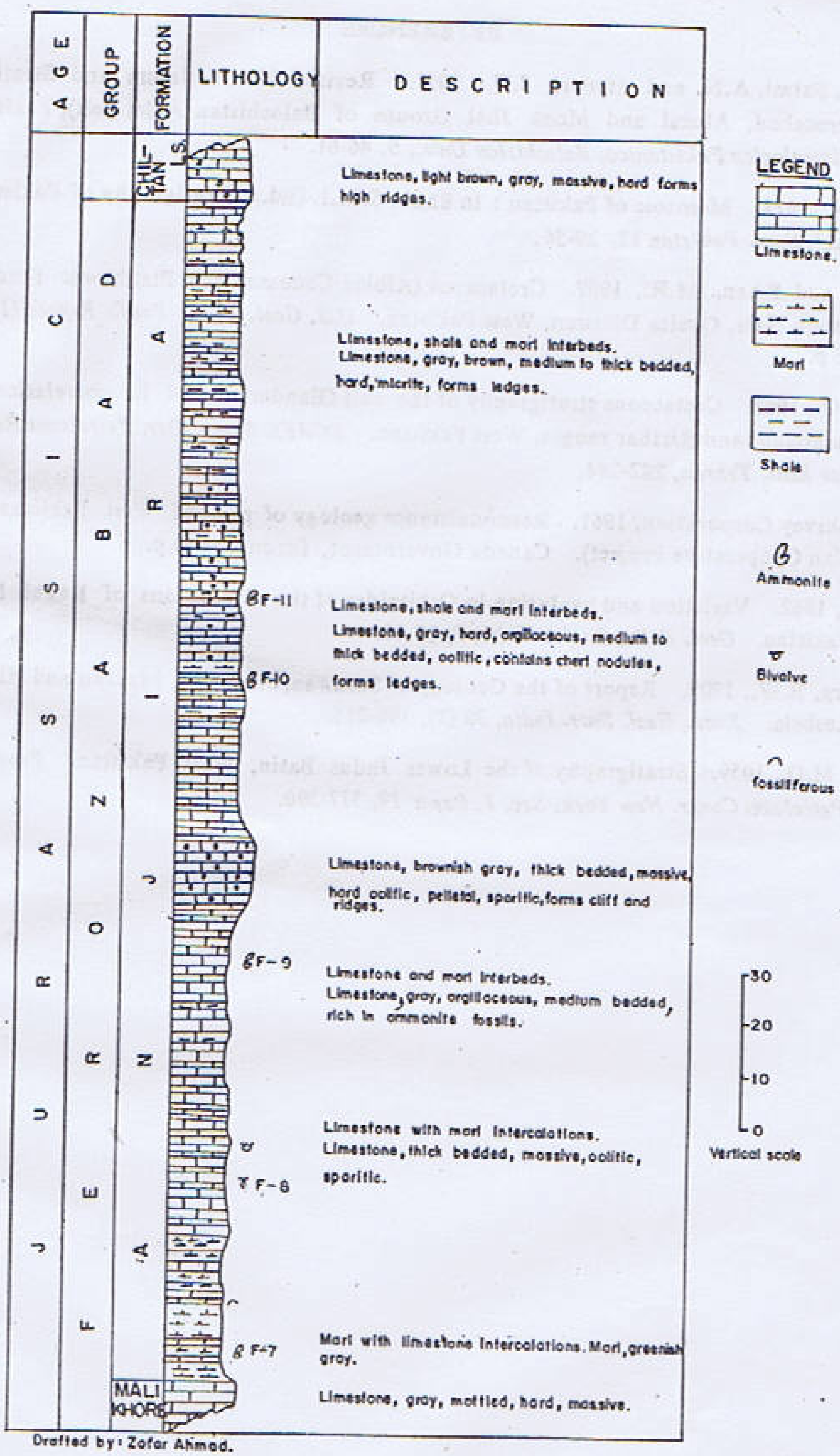


FIGURE.3. COLUMNAR SECTION OF ANJIRA FORMATION, NORTH OF BALELI CHECK POST.

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Geol. Bull. Punjab Univ., 26, 1991, 65-70

THICKNESS AND FACIES CHANGES OF MIOCENE GAJ FORMATION IN INDUS OFFSHORE BASIN AND ADJOINING LAND AREA

BY

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Abstract : *The Indus Offshore Basin and adjoining land area, located between Murray Ridge on the west and Indian border on the east (23° to 26°N lat ; 66° to 68°E long.), has been investigated geologically from the point of view of thickness and facies variation in Miocene Gaj Formation.*

Gaj Formation of Miocene age in Indus Offshore Basin and adjoining land area consists of limestone, shale/clay, siltstone and sandstone in different proportions. It is dominantly limy facies in the Indus Offshore Basin coastal area nearly parallel to shoreline in the east as encountered in Dabbo Creek-1, Patiani Creek-1, Korangi Creek-1 and Karachi 1-2 shoreline exploratory wells as well as outcrops in the eastern portion of Karachi Trough but becomes dominantly detrital shaly-silty clastics in the west as encountered in Indus Marine A-1, B-1 and C-1, Karachi South A-1, Pak Can-1 and Sadaf-1 Offshore exploratory wells as well as in the outcrops in the western portion of Karachi Trough. Thickness of Miocene Gaj Formation increases from Indus Offshore coastal area of less than 100 metres in the east i.e. 67 meteres in the Dabbo Creek-1, 66 meteres at Patiani Creek-1 and 54 metres at Korangi Creek Offshore exploratory wells to more than 3000 metres in the west at Indus Marine A-1 and B-1, Pak Can-1 and Sadaf-1 wells drilled in Indus Offshore Basin.

Petrographic study of rock cuttings of Offshore wells indicate several cycles of relative rise and fall of sea level with major fall of sea level during Middle/Lower Miocene ttme resulting in the deposition of thick coastal and marine clastic sediments. Indus River seems to be major source for the supply of detrital materials.

INTRODUCTION

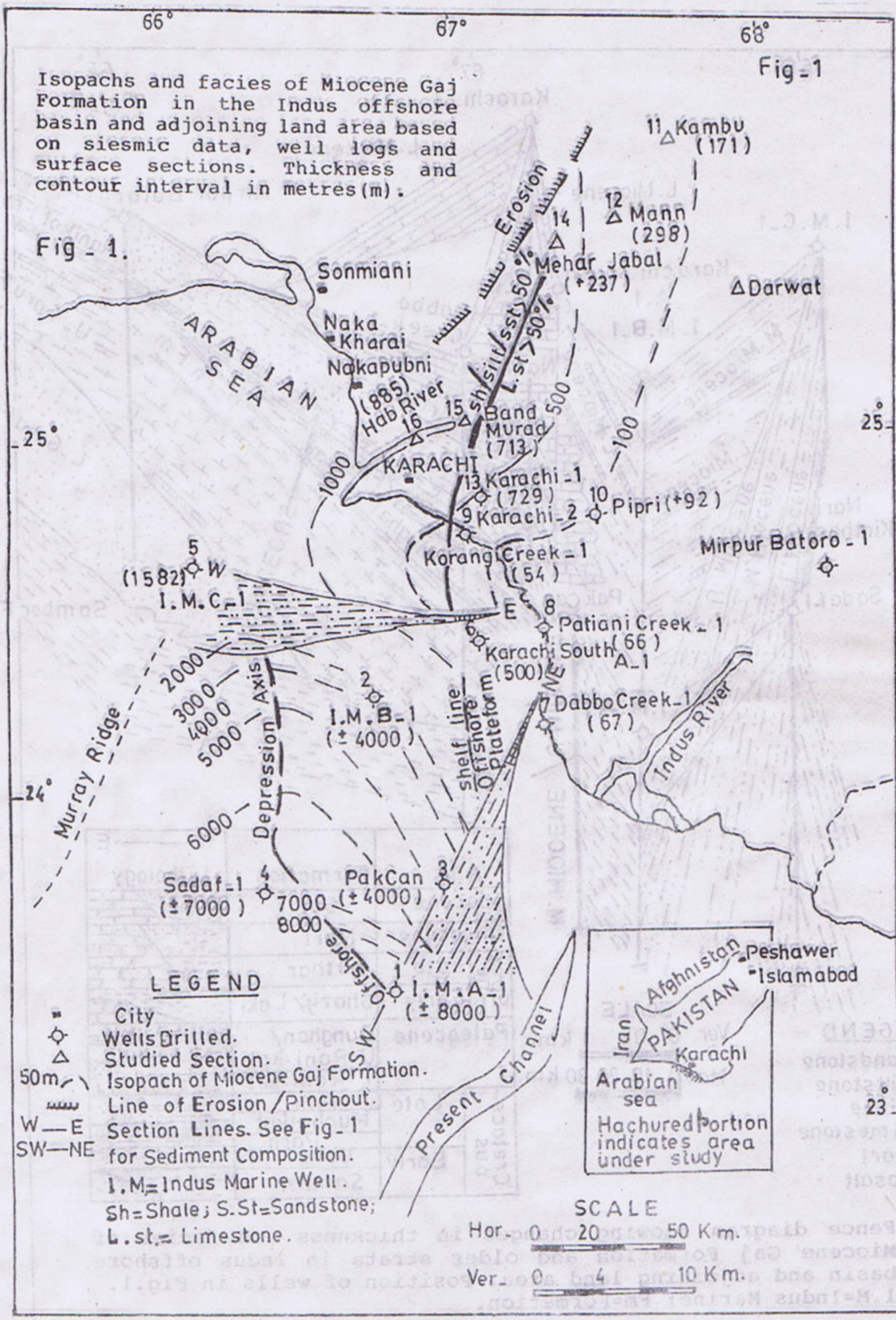
Offshore Indus Basin and adjoining land area include Offshore basin, Karachi Trough and western portion of Thar Slope Platform between Murray Ridge on the west and Indian border on the east 23° to 26° north latitude and 66° to 68° east longitude). Miocene sediment increases in thickness from north-east to south-west in Offshore basin and from east to west in the adjoining land. It is dominantly limestone along offshore coast and adjoining land in the east but becomes dominantly clastics in the west from shoreline (Figs. 1-2). Eleven exploratory wells were drilled in the area, all encountering Miocene sediment, five in offshore Miocene depression namely Indus Marine A-1, B-1 and C-1, Pak Can-1 and Sadaf-1, five along shoreline namely Dabbo Creek-1. Patiani Creek-1, Korangi Creek-1, Karachi 1 and 2 and Karachi South A-1 between offshore Miocene depression and shoreline (Fig. 2).

Petrography

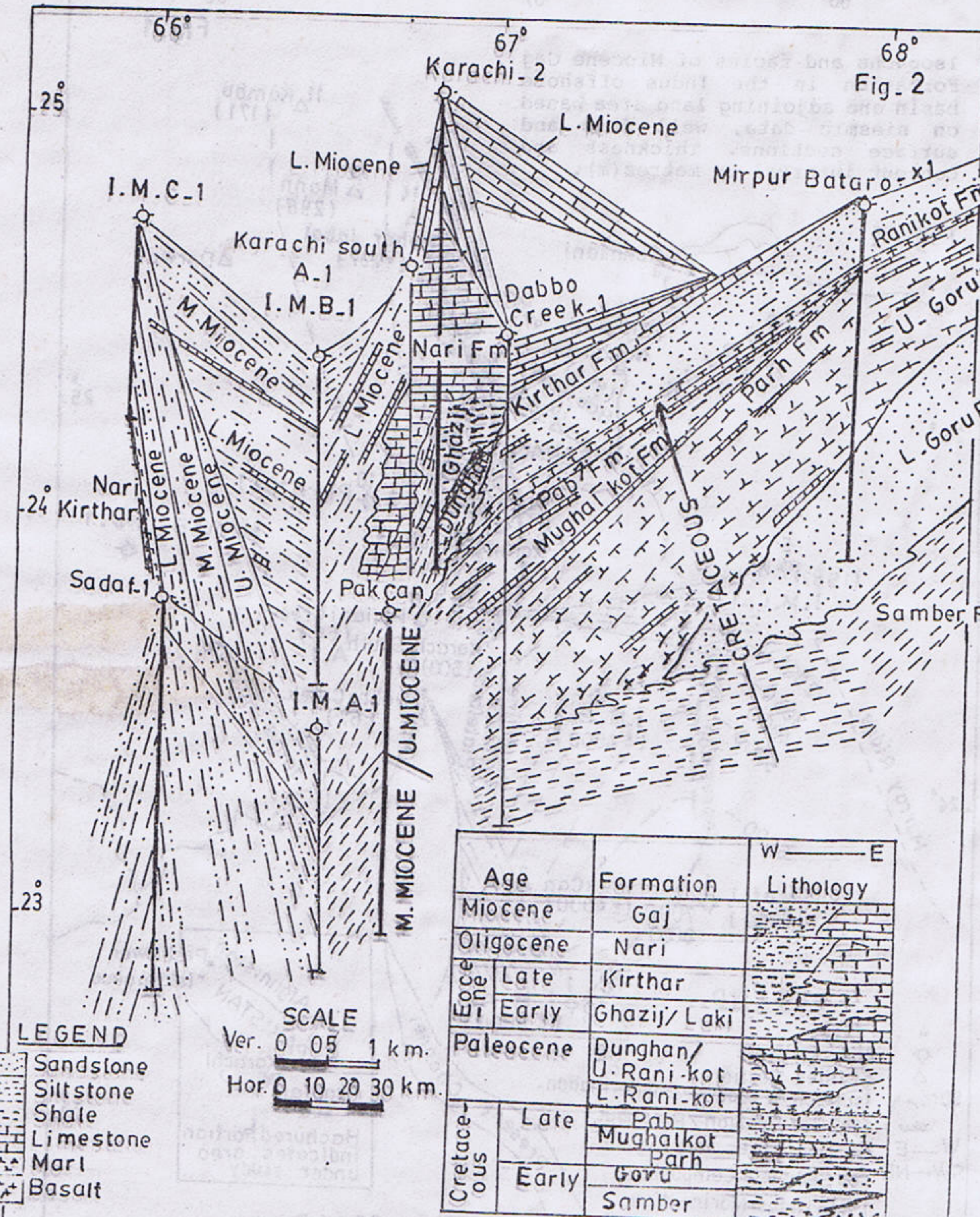
Detail petrography of Miocene sediment of Offshore Indus Basin and adjoining land area is described in Wintershall reports encountered in Indus Marine A-1, B-1 and C-1 (1973, 1974 and 1975), Husky report of Karachi South A-1 (1978), Sun reports of Dabbo Creek, Patiani Creek and Korangi Creek wells (1963, 1964 and 1965) and geological reports on outcrops in Karachi Trough area. Miocene sediment consists of mainly marine silty-shaly sequences with bands of limestone and streaks/lenses of sandstone in wells of Indus Marine A-1, B-1 and C-1, Sadaf-1, Pak Can-1, Karachi South A-1 and outcrops in the western portion of Karachi Trough whereas marine limestone with shale intercalations were encountered in shoreline wells Dabbo Creek, Patiani Creek, Korangi Creek, Karachi 1and2 and outcrops in the eastern portion of Karachi Trough (Figs. 1-2). Astudy of well cuttings of Miocene sediment from Pak Can-1 well was undertaken in 1986 as no core was taken. Five sandy depositional cycles were recognized in predominantly silty-shaly sequence of Miocene sediment at depths approximately 1683-1723, 1813-2238, 2693-2891, 2963-3083, 3418-3498 metres from sea level which prove the flactuation of sea level or change in the rate of supply/flow of detrital materials. Study of detrital minerals indicate mainly an igneous plutonic source. Sandstone is generally fine to very fine grained, highly micaceous (both biotite and muscovite), moderately sorted, mainly sub-angular to sub-rounded quartz and feldspars, having argillaceous-calcareous matrix with porosity about 20% and permeability varies from 2-27 md. Quartz is the dominant detrital mineral and form between 50 to 60%. Among feldspars both the alkali and plagioclase are present. Biotite show little or no alteration or decomposition. Zones of oxidization were also observed in Miocene sediment at depths approximately 2703-3388, 3403-3478, 3508-3518 and 3543-3553metres from sea level which seem to be formed under subarial shallow water depositional condition. Sediments from Miocene samples of Sadaf-1 well were also investigated petrographically and found mainly silty-clayey materials with bands of fine to very fine sandstone. Sandy samples have more or less the same clastics/detritals which were observed in the well cutting samples of PakCan-1 well.

CONCLUSIONS

Thickness and facies changes of Miocene Gaj Formation in wells drilled in/around Indus Offshore Basin and outcrops in adjoining land area were investigated in detail as shown in Figs. 1-2. It seems from petrographic/stratigraphic studies that upper Miocene sediment is missing in the north of offshore depression area at Indus Marine B-1 & C-1 wells whereas it is present in the south at Indus Marine A-1, Pak Can-1 and Sadaf-1 wells (Fig. 3). Both upper and middle Miocene sediments are missing in the coastal wells in the east at Karachi South A-1, Dabbo Creek-1, Korangi Creek-1 and Karachi 1 & 2 as well as in the outcrops. Miocene sediment increases in thickness from north-east to south-west but its thickness becomes more than 3000 metres at Indus Marine A-1 & B-1, PakCan-1 and Sadaf-1 positions near depression axis on the basis of the calculation from seismic data whereas it is less than 100 metres at the coastal area in the east and aiso decreases from depression axis towards Murray Ridge in the west (Fig. 2). The authors agree with Kazmi (1984) and Coumes and Kolla 1984) that Indus River came into existence after Eocene and built a delta advancing southward nd eastward along the Indus Trough bordering the Sulaiman and Kirthar Ranges and is the major source for the supply of terrigenous detrital material in Indus Offshore Basin during Miocene age.



Isopachs and facies of Miocene Gaj Formation in the Indus offshore basin and adjoining land area based on siesmic data, well logs and surface sections. Thickness and contour interval in metres(m).



Fence diagram showing changes in thickness and facies of Miocene Gaj Formation and older strata in Indus offshore basin and adjoining land area. Position of wells in Fig.1. I.M=Indus Marine; Fm=Formation.

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OCCURRENCE, GEOLOGY, PETROLOGY AND INDUSTRIAL APPLICATION OF MORE KHUN BARITE DEPOSIT OF NORTHERN AREAS OF PAKISTAN

BY

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and

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Abstract : *The Mor Khun barite deposit is a hydrothermal replacement deposit which occurs within Gujhal Dolomite close to the contact of Gircha Formation. It is exposed intermittently for hundreds of metres. The deposit is snow white and very pure with a specific gravity between 4.3 and 4.4. Chemical and physical characteristics of this deposit indicate a number of industrial applications.*

INTRODUCTION

Significant barite mineralisation is being reported from near the village Mor Khun. The deposit is located just upstream of the village Mor Khun on the left bank slopes of Mor Khun Nala in Gilgit District. The deposit is exposed intermittently for hundreds of metres. However, due to scree cover the exact dimensions could not be determined. Pitting and trenching is required to determine the extent of this deposit. The unweathered ore is white to almost snow white. The weathered surfaces are light pale white to rusty yellow brown. In hand specimen the ore has a saccharoidal appearance.

Occurrence and Geology

The barite mineralisation occurs close to the village of Mor Khun on the left bank side of the main Mor Khun stream. The deposit occurs within Gujhal Dolomite close to the contact of the Gircha Formation (Fig. 1).

The Gujhal dolomite (Desio, 1974, 1979), is composed mainly of dolomitic limestone with intercalations of grey to black slates. Desio on the basis of crinoidal stems, foraminifera and pelecypods considers this as of Jurassic to Cretaceous in age.

The nearby Gircha Formation is composed of grey to dark grey slates with beds of grey dolomitic limestone and light to medium grey quartzite. Desio (1974) on the basis of brachiopods and foraminifera regards this unit as Premo-Carboniferous in age. This formation is exposed from 3 km north of Mor Khun to 2 km south of the confluence of Khunjerab and Kilk rivers (Khan et al., 1987).

The barite deposit appears to be hydrothermal in origin and structurally controlled.

Petrography

The barite deposit was studied petrographically. The samples selected were from different parts of the deposit. The samples show a hypidiomorphic texture. The overall grain size ranges from 0.15 mm to 1.1 mm in general.

The content of barite ranges from 97.6% to 99.5%. The gangue minerals are clay (traces to 0.3%), calcite (from traces to 2.1%), quartz+ microcrystalline quartz (traces to 03.%), limonite/haematite (traces) and pyrite/sulphides (traces). The deposit is very rich in barite. Marginal contamination and within deposit replacement areas are minor and not considered here, because these may not be regarded as part of the ore and may be avoided during mining.

X-Ray Diffraction Analysis

X-Ray diffraction analysis of one sample (sample No. 56-C) was carried out. The XRD pattern is given as Fig. 2. An examination of this XRD tracee shows that barite is very pure. There is hardly any line of gangue minerals.

Specific Gravity

Specific gravity of three samples of barite was determined. The samples give a range of 4.3 to 4.4.

Chemistry

The chemical composition of three barite samples was determined by wet chemical methods. The results are presented in Table 1.

TABLE 1

	56-A	56-B	56-C
SiO_2	0.08	3.43	0.55
TiO_2	0.00	0.00	0.00
Al_2O_3	0.45	0 85	0.40
Fe_2O_3	0.04	0.04	0 43
MnO	0.00	0.00	0.00
MgO	0 00	0.00	0.00
CaO	0.00	0.00	0.00
P_2O_5	0 00	0.00	0 00
Na_2O	0.96	0.06	0.06
K_2O	0 040	0.048	0.04
$-W_2O$	0.00	0.00	0.00
$BaSO_4$	99.11	95.40	99.12
.L.O I	0,20	0.16	0.22
	99.98	99.99	99.98

The samples 56-A and 36-C are very pure and $BaSO_4$ is 99.11 and 99.12%. The sample 56-B however, contains small amount of clay and microcrystalline silica. The amount of alkalies is very small (in fact traces only). As such it is free of salts. The iron contents are very low.

Possible Industrial Applications

For a general survey of uses and application of "Barite" the interested reader is referred to Anon (1970, 1978), Bates (1960), Brobst (1970), Harben (1978), Johnstone (1954), Johnstone and Johnstone (1961), Joseph (1979) and Ross (1960)I

In view of its high specific gravity, snow white colour, a high degree of chemioal purity and relatively low values of abrasion, the Mor Khun barite can find extensive industrial applications.

However on the basis of laboratory scale preliminary testing this deposit appears suitable for drilling mud, raw material for chemical industry, fillers, heavy concrete and pigments.

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