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COVER: Satellite Map of Balochistan (Courtsey, SUPARCO, Karachi)

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GEOMETRY AND TECTONICS OF THE ORNACH-NAL FAULT, A SOUTHERN EXTENSION OF THE CHAMAN TRANSFORM ZONE, PAKISTAN

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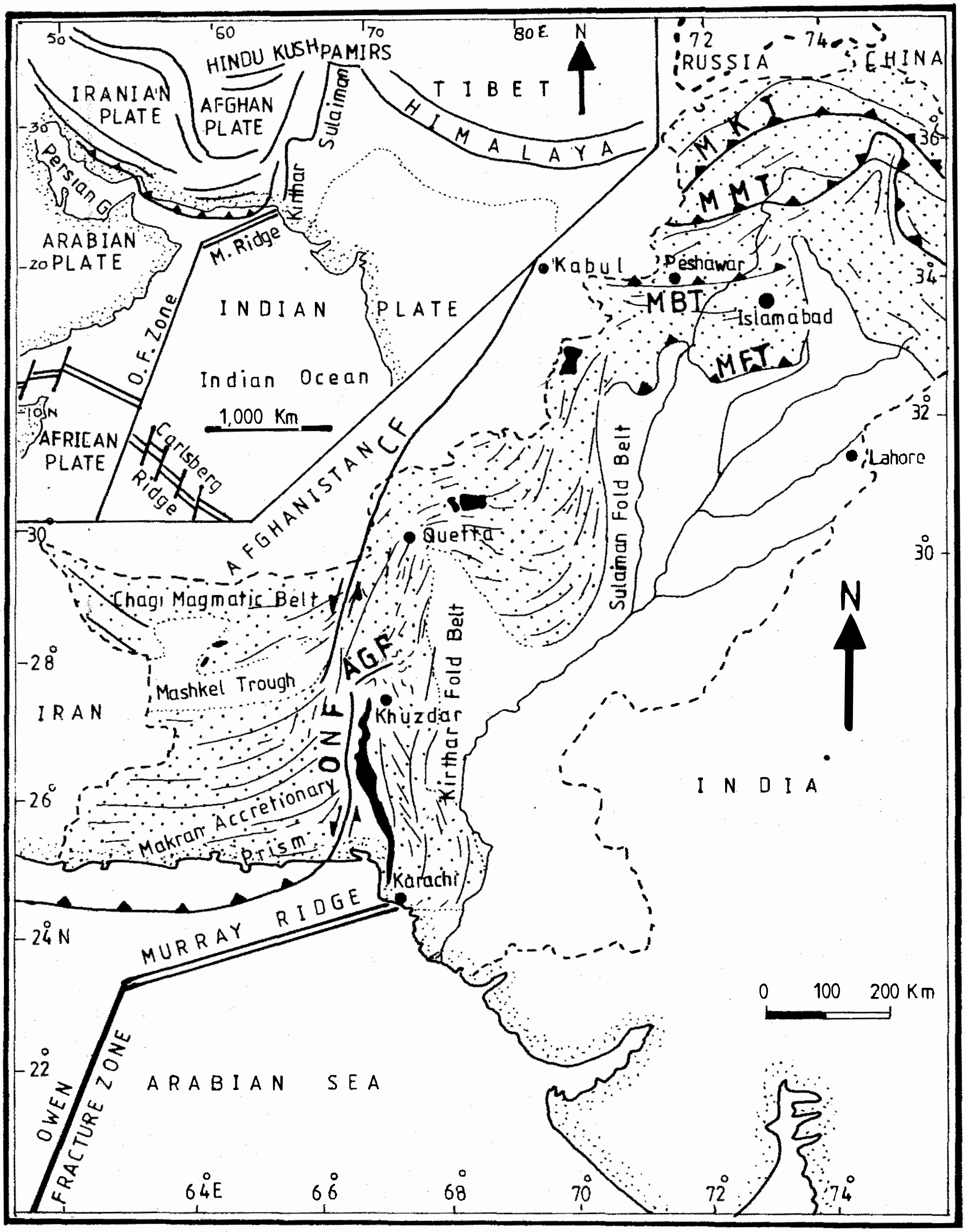
ABSTRACT

The Ornach-Nal Fault, a branch of the Chaman Transform Zone at the northwestern edge of the Indian Plate has a complex geometry and different senses of displacement with depth. The drag in the Makran Accretionary Prism to the west and adjacent structures to its east indicate a sinistral displacement. On the other hand relative rates of plate movements and structural orientation and geometry farther east in the southern part of the Kirthar Foldbelt and adjacent areas suggest a dextral sense of displacement at depth where oceanic lithosphere of the Arabian Plate partly underthrusts the continental lithosphere of the Indian Plate. This suggests that at shallow levels it is an upright fault but dips at an angle eastward at depth. The contrasting senses of displacement along the upper and lower levels of the fault is facilitated by a zone of decoupling at depth between the accretionary prism and the oceanic lithosphere of the Arabian Plate.

INTRODUCTION

The Ornach-Nal Fault (ONF) is the southernmost component of the Chaman Transform Zone (CTZ) which in turn is the northwestern boundary of the Indian Plate (Fig.1) in the Balochistan region (Lawrence 1979; Jacob and Quittmeyer 1979; Farah and others 1984). The CTZ extends from Kabul in the north to the Arabian Sea in south. Its northern part is north-northeasterly oriented, while it attains a northerly orientation in the southern part. The northern segment of CTZ is the Chaman Fault (CF) which swings westward at its southern terminus along the southern border of the Mashkel Trough which is a kind of fore-arc basin. To the south the ONF starts slightly west of Khuzdar after a left stepping with the CF and runs southward towards the Arabian Coast where it swings westward and becomes a thrust parallel to the coast within the accretionary prism (Hunting Survey Corporation 1961; Bakr and Jackson 1964; Kazmi 1979a 1979b; Kazmi and Rana 1982). This paper deals with the geometry and tectonics of the Ornach- Nal Fault which is over 250 kilometer long, north-south oriented strike slip fault, with an apparent sinistral displacement. The north-south oriented Pab and Kirthar faults east of the ONF end in the south at the Murray Ridge which is a spreading type of boundary with dextral strike-slip component.


HINDU KUSH
PAMIRS
TIBET
HIMALAYA
IRANIAN PLATE
AFGHAN PLATE
Sulaiman
Kirthar
Persian G.
ARABIAN PLATE
M. Ridge
O.F. Zone
INDIAN PLATE
Indian Ocean
1,000 Km
AFRICAN PLATE
Carlsberg Ridge
RUSSIA
CHINA
MKT
MMT
Kabul
Peshawar
MBT
Islamabad
MFT
AFGHANISTAN
CF
Sulaiman Fold Belt
Lahore
Quetta
Chagi Magmatic Belt
AGF
Mashkel Trough
IRAN
Khuzdar
ONF
Kirthar Fold Belt
Makran Accretionary Prism
Karachi
INDIA
MURRAY RIDGE
OWEN FRACTURE ZONE
ARABIAN SEA
0 100 200 Km
N

STRUCTURAL SETTING

The Chaman Transform Zone, brought the Indian Plate against two different plates in the region. In its northern part it is sliding along the Chaman Fault against continental lithosphere of the Eurasian Plate (Lawrence 1979), whereas towards south it is in contact with oceanic lithosphere of the Arabian Plate along the ONF. The oceanic lithosphere of the Arabian Plate which extends northward probably up to north of the Mashkel Trough is overlain by a thick sequence of flysch deposits dominantly of Tertiary period with east-west oriented thrusts constituting the Makran Accretionary Prism (Farhoudi and Karig 1977; DeJong 1982).

To the east of the Ornach-Nal Fault the Bela ophiolites have been thrusted on top of the shelf sediments of the Indian Plate in Paleocene (Sarwar 1992). Farther east of the Ornach-Nal Fault, north-south trending deep seated Pab and the Kirthar faults constitute the Bela block and the Khude Range Foldbelt block which are of special characters (Fig. 2). The folds are disposed in an en-echellon pattern in the Khude Range Foldbelt between the Pab and the Kirthar faults. Here north-northwest trend of the folds is incompatible with sinistral displacement in the Chaman Transform Zone. In the Bela block bounded between the Ornach-Nal and the Pab faults north of Bela structures are arcuate in plane, convex northward. These tectonic blocks end up in north against complexly folded Khuzdar Knot which in turn end up against sinistral northeast oriented Anjira-Gizan Fault. To the south the Pab and the Kirthar faults probably terminate at the Murray Ridge in the Arabian sea. To the west the structures of Makran Accretionary Prism are at a high angle to the Ornach-Nal Fault at a distance but, by a northward swing, become sub-parallel to it in adjacent area (Hunting Survey Corporation 1961; Bakr and Jackson 1964) constituting the Makran Orocline (Sarwar and DeJong 1979).

SENSES OF DISPLACEMENT AND PLATE MOVEMENTS

In strike-slip faults drag in structures indicates the sense of displacement (Sylvester 1988). All along the Ornach -Nal Fault drag structures indicate a sinistral displacement (Hunting Survey Corporation, op. cit., Bakr and Jackson, op. cit., Kazmi and Rana, op. cit.). This sinistral drag is in accordance with northward movement of the Indian Plate relative to the Makran Accretionary Prism. Arabia-Eurasia convergence in the Makran region is over 5 cm/year (McKenzie 1972), while India/Eurasia convergence is 3.7 cm/year in Balochistan (Minster and others 1974). The Arabian Plate is moving faster than the Indian along Owen Fracture Zone where slip vector is 1.6 cm/year (McKenzie and Sclater 1971). Comparative studies indicate that the Arabian Plate is converging faster than the Indian towards Eurasia along the Ornach-Nal Fault (Fig. 2 of Jacob and Quittmeyer 1979).

Along the Ornach-Nal Fault the sinistral displacement in surface rocks as indicated by drag in the Makran Accretionary Prism is incompatible with faster Arabia/Eurasia convergence than the India/Eurasia in the region. To the east anomalously oriented folds in the Khude Range Foldbelt and structural pattern in the Bela block give a clue to the enigma. Structural pattern in this region indicate a dextral shear along the Pab Thrust and also a component of dextral shear along the Kirthar Thrust.

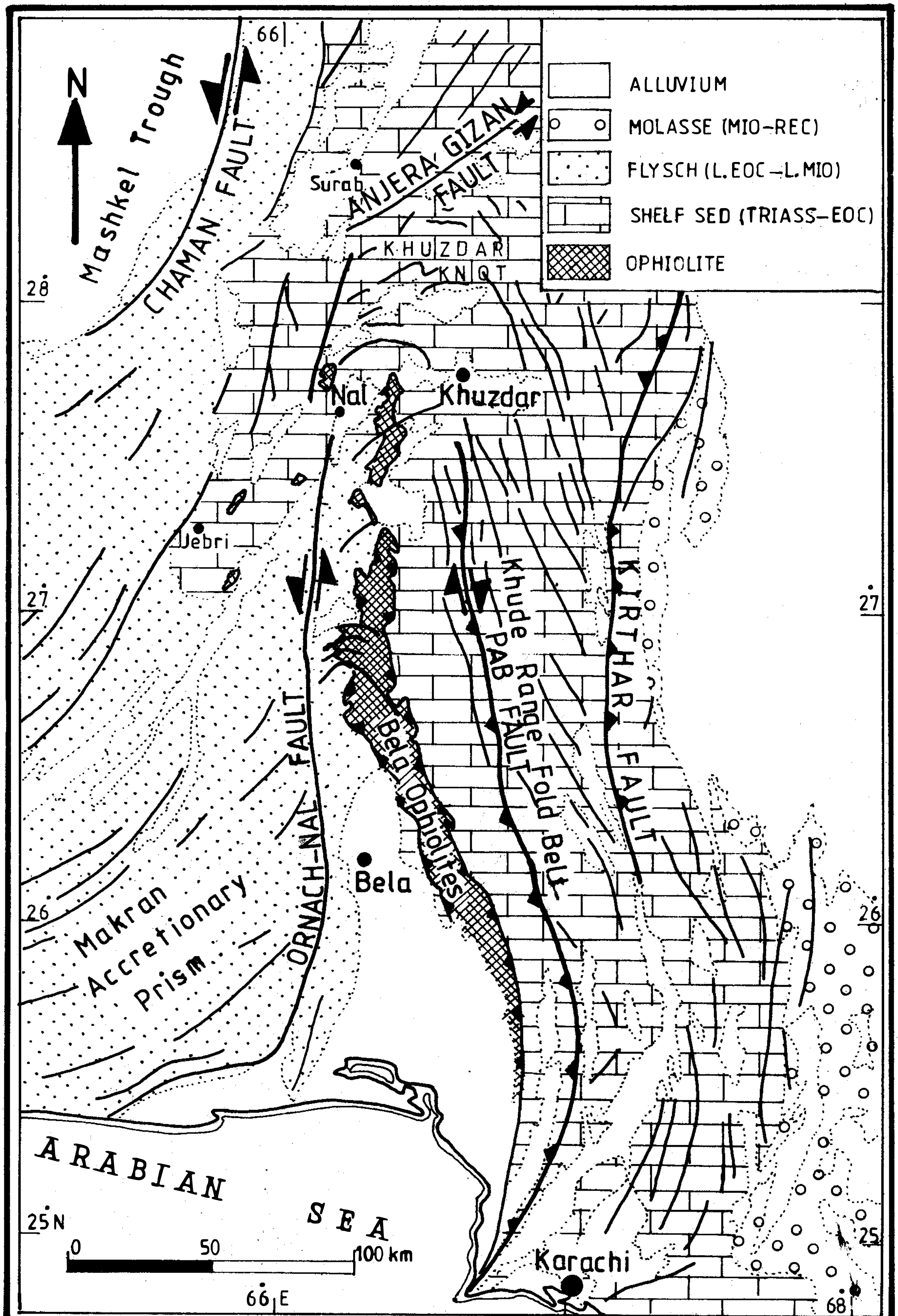
Figure 1. Structural trends in the Pakistani fold belt. CF is Chaman fault; ONF is Ornach-Nal fault; AGF is Anjira-Gizan fault; MKT is Main Karakoram thrust; MMT is Main mantle thrust MBT is Main boundary thrust and MFT is Main frontal thrust, ophiolitic bodies are marked by black shaded areas. Inset is plate boundaries and structural trends at the Indian-Eurasian and Arabian-Eurasian collision and subduction zones respectively, modified after Jacob and Quittmeyer (1979).

This dextral shear indicates that somehow the Bela block and to some extent the Khude Range Foldbelt block have moved northward faster than the rest of theIndian lithosphere. This rapid movement of the two blocks indicates that the Arabian Plate which is converging faster than the Indian Plate towards Eurasia partly underthrust the Indian Plate in the region and consequently ripped off slices of continental lithosphere of the Indian Plate. Geophysical studies also indicates that oceanic lithosphere of the Arabian Plate underthrusts continental lithosphere of the Indian Plate along the Ornach-Nal Fault (Zaigham 1991). These slices coupled with the Arabian Plate moved northward faster to produce a dextral shear with the main mass of the Indian Plate along the Pab and the Kirthar faults. This phenomenon resulted in the formation of en-echelon fold belt of the Khude Range, where structures are anomalously north-northwest oriented and arcuate structures in the Bela block (Niamatullah, in press). The detachment of slivers from the Indian lithosphere and their northward movement is definitely post Paleocene and have occurred after the emplacement of the Bela ophiolites. However, it is more probably of late Tertiary because the rocks involved in the en-echellon fold belt of the Khude Range are as young as Oligocene. This is analogous to the sliver of the Californian coast west of the San Andreas Fault which is moving northward in relation to the rest of the America because it is coupled with the Pacific Plate which is converging northward along the fault (Anderson 1971). Here in Pakistan the northward movement of the Bela block has been halted at sinistral Anjira-Gizan Fault at a high angle to it where complex Khuzdar Knot has developed. The refolding in the Khuzdar Knot is due to a drag along the Anjira-Gizan Fault where structures were previously oriented similar to that of the Khude Range Foldbelt (Niamatullah, op. cit.).

DISCUSSION

The question arises that why surface structures like the Makran Orocline and structures east of the Ornach-Nal Fault gave rise sinistral drag if the Arabian Plate is converging at a faster rate than the Indian towards Eurasia. The fact is that the Makran Accretionary Complex is a thick prism of flysch deposits whose thickness in coastal region is about 10 kilometer and becomes more than 25 kilometer thick to the north, beneath the northern Makran ranges (Jacob and Quittmeyer 1979). The accretionary prism is not moving at the same rate northward as the Arabian Plate because of a zone of decoupling between two, probably evident by the presence of mud volcanoes along the Makran Coast (Hunting Survey Corporation 1961). The presence of aseismic slip at depth also supports the idea of a zone of decoupling at the base of accretionary prism (Quittmeyers and others 1979). In off-shore region the east-west oriented folds and thrusts as well as increased thickness of the Makran Accretionary Prism and increased thrust's dip of the prism northward also indicate a zone of decoupling between the oceanic lithosphere of the Arabian Plate and the prism (White 1979) where the former underthrust the latter. The Indian Plate is moving at a faster rate than the Makran Accretionary Prism which in turn is not totally intact with the Arabian Plate that underlies and thus sinistral displacement in surface structures appear. On the other hand at depth where continental lithosphere of the Indian Plate is in contact with the oceanic lithosphere of the Arabian Plate the displacement is dextral with minor underthrusting is

Figure 2. Map showing geology of an area around the Ornach-Nal Fault and southern part of the Kirthar Foldbelt. The Bela block is bounded between the Ornach-Nal Fault and the Pab Fault, whereas the Khude Range Foldbelt block is located between the Pab and the Kirthar faults. The Makran Orocline is to the west of the Ornach-Nal Fault.



ALLUVIUM
MOLASSE (MIO-REC)
FLYSCH (L.EOC-L.MIO)
SHELF SED (TRIASS-EOC)
OPHIOLITE
N
Mashkel Trough
CHAMAN FAULT
ANJERA GIZAN FAULT
Surab
KHUZDAR KNOT
Nal
Khuzdar
Jebri
Khude Range Fold Belt
PAB FAULT
KIRTHAR FAULT
ORNACH-NAL FAULT
Bela Ophiolites
Bela
Makran Accretionary Prism
ARABIAN SEA
Karachi
0
50
100 km
66 E
68
28
27
26
25 N

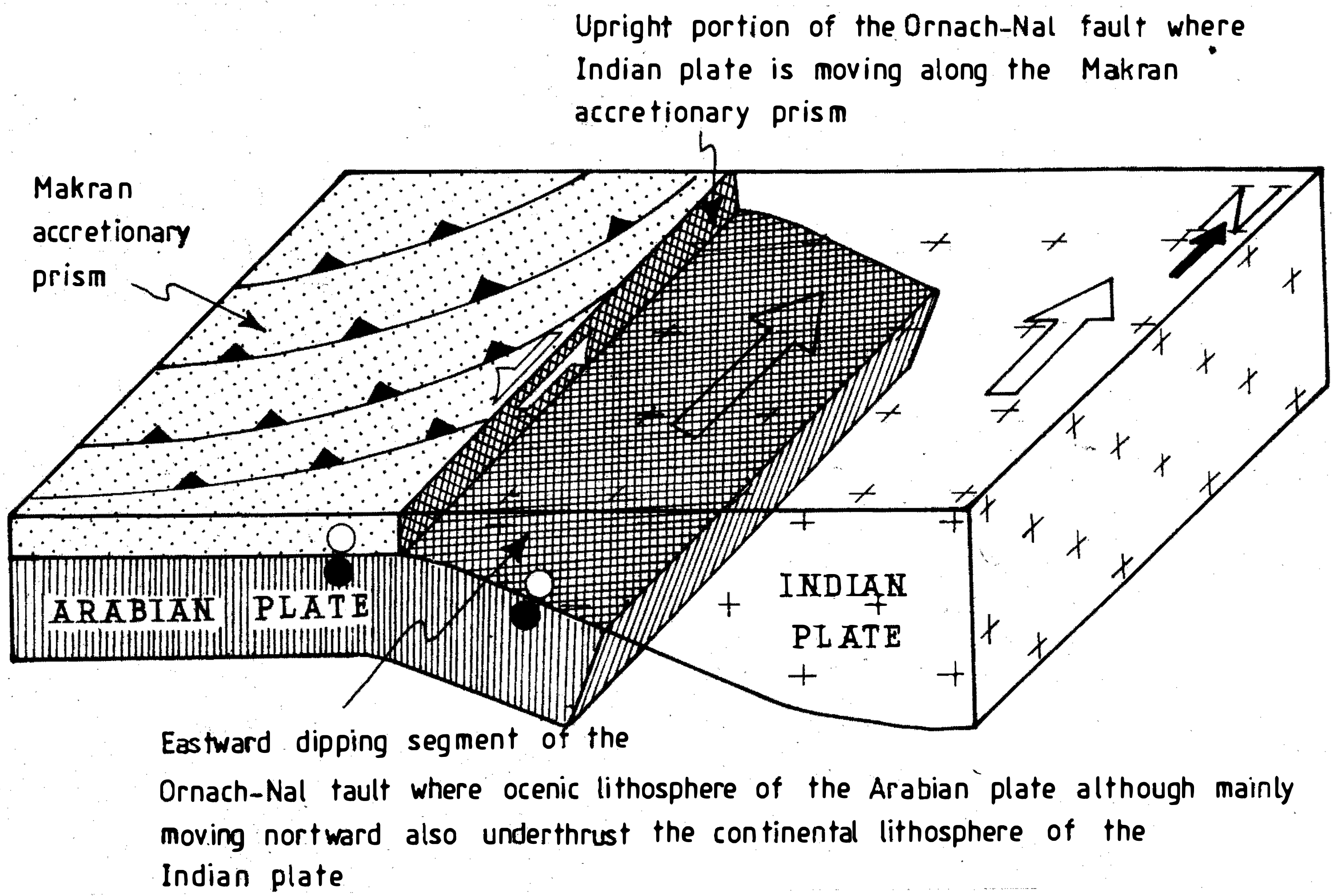


Figure 3. **Schematic diagram showing plate movements in the region. The three tectonic units shown in the diagram are: continental part of Indian Plate, oceanic part of the Arabian Plate and the Makran Accretionary Prism. The length of the arrows marked on the plate surfaces indicate respective plate motions . Circles indicate relative plate motion: solid, away from the observer and open towards the observer.**

compatible with Murray Ridge displacement (Fig. 3). In other words the Ornach-Nal Fault is such a fault along which the three tectonic units are in contact. To the east is the three tectonic units are in contact. To the east is the continental lithosphere of the Arabian Plate whereas to its west oceanic lithosphere of the Indian Arabian Plate is present at depth, the latter is overlain by the Makran Accretionary Wedge. The faster drift of the Indian lithosphere than the prism produces sinistral displacement at surface, while faster converging Arabian Plate towards Eurasia gives rise to a component of dextral displacement at depth along the same fault. The Ornach-Nal Fault is upright at shallow level but dips eastward at depth. This completely satisfies the model in the south, but it cannot be applied to the north of Khuzdar Knot across the Anjira-Gizan Fault where structural orientations are different and tectonic elements are not exactly the same.

CONCLUSION

The Ornach-Nal Fault at the northwestern plate boundary of the Indian Plate has a complex geometry which changes in depth. It is an upright fault at shallow depth but dips eastward at deeper level. Near surface where the Indian Plate is shouldering along the Makran Accretionary Prism drag in the surface structures indicate a sinistral displacement. On the other hand structures to the east of it indicate that the same fault has dextral component of displacement at depth where oceanic lithosphere of the Arabian Plate partially underthrusts the continental lithosphere of the Indian Plate. This dextral displacement is induced by faster convergence of the Arabian than the Indian Plate towards the Eurasia. This different sense of displacement of the Makran Accretionary Prism and the Arabian lithosphere with the Indian lithosphere is facilitated by a zone of decoupling between the two former units.

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AUGMENTING GROUNDWATER RECHARGE BY PROTECTING NATURAL RESOURCES THROUGH LEGISLATION IN BALOCHISTAN, PAKISTAN

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ABSTRACT

Balochistan, the largest province of Pakistan, covering 347,190 km^2 is dominated by 12 major hyrologic basins. These basins hold a major part of the groundwater in the form of aquifers developed in unconsolidated valley fill sediments. Balochistan falls under the semi-desert category of regions where average annual precipitation varies between 50 and 300mm only. The temperature ranges from extreme warm (50°C) to very cold (-15°C). Throughout Balochistan groundwater is almost the only source of water for potable, municipal, industrial and agricultural purposes. About 98% domestic (urban and rural) water supply, 81% irrigation water and 100% mining and industrial water comes from the groundwater.

The urbanization and rapid population growth has increased the demand of water which has consequently turned water extrusion into water mining. The natural recharge of groundwater has been drastically reduced due to environmental degradation and/or over exploitation of one or several natural components of the groundwater system. Among them are the unplanned use of range land, unchecked tree cutting and over pumping of groundwater as these are some of the major causes of deforestation, desertification and soil erosion. The unplanned human activities have damaged the natural echo-system which has resulted in a continuous decline of water table in many parts of Balochistan. For example the descent of water table from 1969 to 1989 in Quetta sub-basin is 4.6 meter(m), in Mastung sub-basin from 1976 to 1989 is 8.2m, in Mangocher sub-basin from 1976 to 1990 is 15.2m and in Pishin sub-basin from 1976 to 1989 is 4.0m. More over, during past 25 years, 25% Karezes have been dried up, whereas dried open wells and dried tube wells are common almost everywhere in Balochistan. For artificial recharge of groundwater in Balochistan about 100 delay action dams and a few related projects have been completed on experimental basis. However, their current impact on groundwater recharge is negligible mainly because of siltation. The existing artificial recharge techniques

have their limitations for they may not be effective enough to stabilize and increase the water table of entire hydrologic basin/sub-basin.

If present practices continue, artificial(?) drought in some parts of Balochistan will force a mass migration of inhabitants at an unprecedented scale. Therefore there exists an urgent need of proper planning and management of groundwater resources of Balochistan which must be duly supported with adoptable (and implementable) legislation. For this purpose a complete package for the protection, conservation, planning, management and monitoring of groundwater systems and all allied natural resources with adequate draft legislation is presented in this paper. To minimize the over exploitation of groundwater reserves, a sustainable groundwater conservation strategy is also proposed and recommended for implementation. It is anticipated that the proposed package would help rehabilitate the entire watershed/water-catchment/water-basin and ultimately stabilize groundwater table.

INTRODUCTION

The environmental degradation is a major problem which is directly related to the socio-economic conditions of the communities. In case of Balochistan, the natural recharge of ground-water through precipitation is reduced due to over exploitation, poor planning and ineffective management of one or several interrelated nat-ural resources such as groundwater, surface water, irrigation, agriculture, livestock, range-lands, forests, desert, soil erosion and popula-tion. To augment the natural recharge of groundwater, a multi-disciplinary environmental rehabilitation process is required for implementa-tion which includes the study, planning, manage-ment, protection, conservation and regulation of natural resources. In this regard the present situation of Balochistan, methodologies and re-commendations are discussed in this paper with the expectation of positive results such as max-imizing groundwater recharge, optimizing sur-face water yield, maximizing base flow of strea-ms and rivers, stabilizing groundwater tables, reducing intensity of flash floods, lessening soil erosion and minimizing siltation of water reservoirs.

POPULATION AND SETTLEMENT PLANNING

The increased population growth and heavy influx of refugees (Afghans, Iranians, Iraqis etc.) has put an extra burden on groundwater resources of Balochistan specially on Pishin River Basin. The enumerated (upto 1981) and projected population growth rate for Balochistan is given in Table-1.

Year	Population	Growth Rate (%)	Water Demand
1941-51	-- - 1.2	1.8	-- - 72
1972-81	2.4 - 4.3	7.0	148 - 262
upto 2010	14.6	3.0	890

Table 1. Population and groundwater demand of Balochistan. Population figures are in millions and water demands are in million cubic meters per year (mm^3/y).

A relationship between population growth and groundwater demand of Balochistan for present and future is shown in Fig-1. The data is taken from the estimation reported by WAPDA

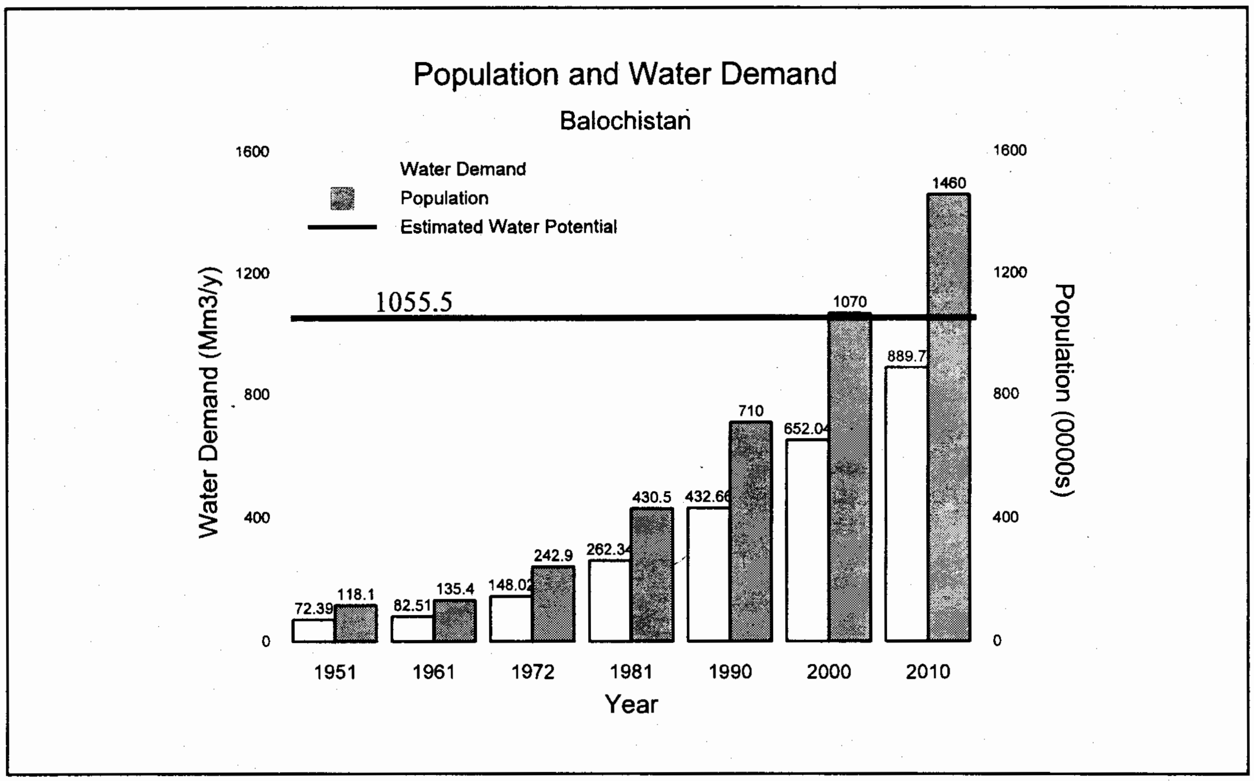

Figure 1. Relationship between Population and Groundwater Demand of Balochistan.

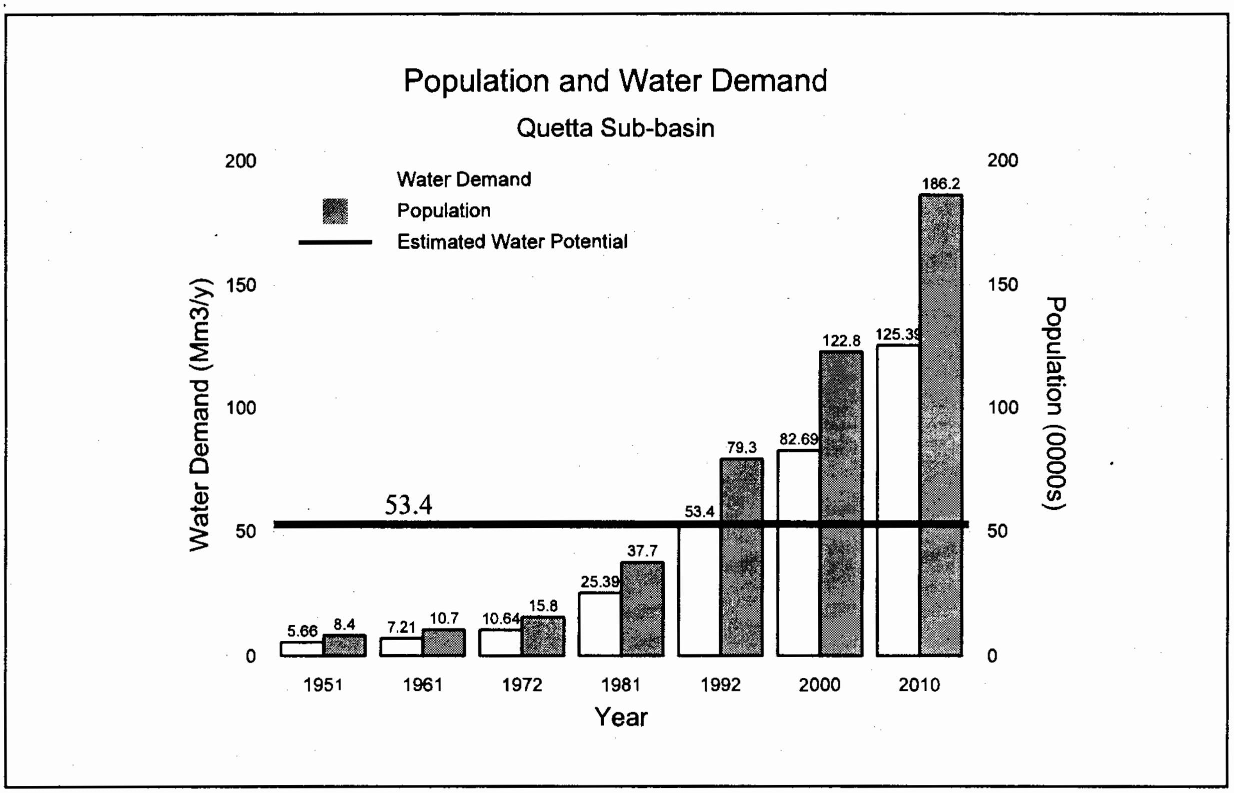

Figure 2. Relationship between Population and Groundwater Demand of Quetta Sub-Basin.

Hydrogeology in their report published in 1993. They have estimated that the total reserves of the groundwater in all the hydrogeologic basins of Balochistan is 1055.5 Mm^3/y (Fig. 1). It is important to note that the difference between Water demand and projected population is increasing continually. With the present practice of water mining, the extraction will cross the maximum water potential causing sever depletion of all groundwater reserves of Balochistan. It is to be noted that in some hydrogeologic basins of Balochistan e.g. Pishin River Basin which includes the Quetta sub-basin, the groundwater extraction has already crossed its maximum potential (Fig. 2).

The urban population of Balochistan is 15.6% of the total population. The population of Quetta city in 1941 was 37000-65000 (depending on source of data) whereas in 1981 it was 250,000 and in 1990 it increased to 500,000. Although there is no official censusu, but approximately 80,000 to 120,000 Afghan refugees are permanant inhabitants of Quetta city and its suburbs. With present 6-7 % growth rate, the population will be over one million by the year 2000. For the municipal water demand about 100 tubewells are pumping out water from the sub-surface aquifers of the Quetta valley. Despite of heavy groundwater mining all inhabitants of Quetta city are suffering from the water shortage. It is estimated that with the present scale of pumping, the groundwater resources would hardly fulfill the demands of next 20 years or so. The population growth and water demand comparisons for Quetta sub-basin are given in Fig. 2.

To reduce the pressure on groundwater and related resources it is imperative to defuse the population bomb. A systematic family planning programme is essential to reduce the average family size. To stop the migration toward urban centers, the developmental activities and provision of basic urban facilities at divisional and district levels are essential. To release the population burden on Quetta City all new indus-trial states should be developed out of the Quetta Valley. In order to reduce the degradation of natural resources of Quetta Valley the nearby settlement centers like Mastung and Pishin should be made attractive for future major projects and industrial units.

GROUNDWATER RESOURCES

The groundwater in Balochistan occurs both in consolidated and unconsolidated aquifers. In about all basins and sub-basins, groundwater generally flows from catchment boundaries to the axis of the valleys and then follow the general trend of surface drainage. Depth of water table varies from 1-100 meters but typically ranges from 5-50 meters. The groundwater potentials of 12 hydrologic basins of Balochistan are estimated to be 1055.5 Mm^3/y, as reported by WAPDA. In 1993 about 356 Mm^3/y (34%) was being extracted while 699.5 Mm^3/y (66%) were available for further exploitation. Current statistics of water extraction are not available at this time.

About 60% rural population of Balochistan receives drinking water from 1000 township and rural water supply schemes. The major water supply sources and technologies in use are tubewells, springs, open/dug wells, rivers, streams, canal waters, Karezes, infiltration galleries, rain water collection ponds and hand pumps. About 96% rural water supply depends on groundwater as shown in Table-2.

Source	No. of Schemes	% of total schemes
Tubewells	846	84.60
Springs	70	7.00
Open-Wells	28	2.80
Dug-wells	16	1.60
River/Canal	10	1.00
Dam	4	0.40
Flood water	2	0.20
Unidentified	24	2.40
Total	**1000**	**100%**

Table 2. Rural water supply schemes based on different sources as of March 31, 1996.

The modern technology and approachable deep well drilling techniques have made it easy to drill deeper and deeper wells. The availability of cheap power supply helps to install deep well turbine/submersible pumps for more waters. The number of tubewells in the province increased 101% i.e. from 8126 to 16303 during last deca-de (1983-84 to 1994-95).

Due to drastic increase in the number of tube wells installed and uncontrolled pumpage through them, a continuous decline of water table has been observed in many parts of the province. Some alarming monitoring results are given in Table-3.

Sub-Basin	Duration	Total Depletion (Meters)	Depletion per year (Meters)
Quetta	1969-89	4.6	0.23
Mastung	1975-89	8.2	0.59
Mangocher	1976-90	15.2	1.09
Pishin	1976-89	4.0	0.31

Table-3 Depletion of water table in four sub-basins of Balochistan

To stop the groundwater mining a groundwater conservation package, given in Table-4, is proposed for implementation with strong will and legislative support.

a)	Tubewell licensing system.
b)	Limitation on the total depths of tubewells.
c)	Fixed tubewell diameter and discharge rates.
d)	Restrictions on pumpage timing.
e)	Water metering system for domestic and industrial usage.
f)	Realistic electricity and water charges.
g)	Effective cost recovery system.

Table-4. Package for groundwater conservation.

PACKAGE FOR GROUNDWATER CONSERVATION

In Balochistan many federal and provincial government departments and organizations are engaged in groundwater developmental and research work with a variety of foreign aided projects. However, there is no coordination and data exchange system among these or with higher educational and research institutions. In this regard it is proposed that a single "Directorate" or a "Catchment Area Management Board" for each basin and sub-basin should be established by abolishing/ merging the groundwater and drilling sections of WAPDA, PHED, I&P, BIAD, BDA, QDA and other relevant departments. This new Directorate or Board should have adequate resources to initiate the systematic groundwater studies, inventory and monitoring of all water points, prepare hydrogeological maps, estimate groundwater potential and water budget of all basins and sub-basins. Current implicit and explicit subsidy for tubewell drilling should be abandoned and more funds be allocated for water conservation. The private sector should be encouraged to invest in borehole drilling and installation of tubewells.

SURFACE WATER RESOURCES

Hydrologically Balochistan is dominated by 12 major perennial river systems that receive water from many inland and coastal streams. The estimated annual water potential of these rivers/streams is 6148 Mm^3/y and that of flood water is 3074 Mm^3/y. These quantities vary with time and precipitation. In addition, the Nasirabad Division receives 2496 Mm^3/y of water from Indus River System by Kirther and Pat Feeder Canals emerging from Sukkur and Giddu Barrages respectively.

The geographic area of Nasirabad Division is about 5% of the total area of Balochistan. However, in Nasirabad Division an organized canal based farming and irrigation system is developed which is 85% of the total canal-irrigated area of Balochistan. In rest of the province the flood water and base flow, which are 4.5-17.8 Mm^3/y, are captured by 0.5-3.0 meters high *bunds* (earth embank-ments) for the use on farms and agriculture fields.

Surface water flow is limited to occasional peak floods caused by short monsoonal rainstorm in summers. The heavy silt load carried by these flood causes great damage to floodwater diversion schemes, which generally survive only for a few years. River plains of Balochistan are narrow and limited covering about 8000 km^2. Flood water is the only resource of considerable potential which may be exploited considerably if exact amount and frequency is known. There are about 73 major and minor rivers in the province. However, to measure the flow of these rivers and their tributaries, the Surface Water Directorate of WAPDA established a gaged system at only 21 localities which are now monitored by the Bureau of Water Resources of Provincial Irrigation and Power Department.

Construction of dams, bridges, highways, and planning of major projects are based on climatical, environmental, hydrological and hydrogeological data of previous years. The length, accuracy and availability of recorded data provide bases for the success of a system or a project. For present and future planning a continuous monitoring network for all natural resources covering the whole province needs to be established.

Small and large reservoirs are required for the collection and utilization of flood waters. Establishment of flood water diversion schemes are imperative, however, their economic impact and mechanism for their efficient utilization at grass root level should be clearly defined and publicized. Similarly construction of delay action dams on small streams and gorges will help increase groundwater recharge and also help reduce the occupance and the intensity of flash floods.

LIVESTOCK AND RANGELAND MANAGEMENT

Sheep and goats are the dominant livestock in Balochistan which are continually increasing with the increase in their demand by human population as shown in Table 5.

About 75% of the small stock is supported by the northern Balochistan. About 5-10% livestock is in nomadic herds, 40% of the nomadic herds belong to locals and 60% to *Pawindas* (Afghan nomads). Most of the livestock is sedentary and transhumant and returns overnight to the village or seasonal settlement.

Small stock reportedly depend almost completely (90-95%) for their food on rangelands. Range is a self-regenerating and self monitoring vegetation used for livestock grazing that supplies the bulk of forage and fuelwood in Balochistan. About one-third of Balochistan is considered rangeland.

Livestock	1976 (million)	1986 (million)	% increase
Sheep	19.0	23.0	21.1%
Goats	22.0	30.0	36.4%
Total	41.0	53.0	29.3%

Table-5. Livestock census of Balochistan.

The rangelands of Balochistan are damaged severely by devegetation, conversion into unpalatable vegetation, over-exploitation of forage and fuelwood etc. Due to over-exploitation and degradation of rangelands the surface water retention capacities of surface soils and infiltration and natural recharge of groundwater is reduced. In this regard a biotechnological approach for desirable increase of groundwater recharge would be the increase in vegetation cover on the floodwater infiltration areas. A sustainable and effective increase in vegetation cover can be obtained by protecting the areas from fuelwood exploitation and grazing. The increased vegetation cover in the rangeland and/or floodwater infiltration areas would have a two fold beneficial effect: a) slowing down the flash floods and b) improving the infiltration capacity of the soil. The re-vegetation on catchment slopes reduces the intensity of surface runoff thus increasing the catchment water yield and recharge capacity.

Sheep and goat grazing in piedmont and flood infiltration areas should be allowed conditionally. Awareness about importance of rangeland and involvement of local communities in rotational grazing, protection of vegetation cover and the proper utilization of fuelwood would play a positive role in conserving the vegetation cover thus increasing the water recharge.

The attempt to replace arid land pastoralism by ranching has been failed in Balochistan e.g. Maslakh and Hazarganji. However, the salt-bush/gravelly fans package recommend by AZRI for range improvement can be adopted by adding water-spreading from innovative discharge-regulating reservoirs. The range degradation on the mountain slopes is irreversible even in decad-es, but gravelly fans and terraces, which is 22 % of total area can be rehabilitated with in 5-10 years. On gravelly terraces planting of forage shrubs and trees would greatly help reduce further degradation of rangelands.

AFFORESTATION

The hyper arid to dry climate of Balochistan is suitable for natural forests at high altitudes and at run-off locations. Timber and fuelwood plant-ation is not possible without irrigation. Natural woods cover only a few percent of Balochistan. The natural woods grown on mountain slopes are generally in mid and high altitude areas i.e. above 1500 meters above sea level.

About one million hectors (3% of the total area) of Balochistan has been gazetted as state forest. These state forests, for the major part , contain 70-80% grass and shrubs. In the remain-ing 300,000 hectors, in the northern half of Balochistan the coniferous trees are in 100,000 hectors, riverine forests in 5000 hectors in the Sibi-Kachhi plains, whereas widely scattered shrub cover an area of 140,000 hectors.

Several state forests have been destroyed completely due to settlement of Afghan refugees (e.g. Popalzai State Forest). Illegal timber cutting for commercial use as fuelwood and house construction is damaging natural forests. Even the rare juniper forest of Ziarat has not been spared. Afforestation has been carried out by the UNHCR income generating projects in Afghan refugee camps and nearby areas. The provincial Forest Department has also planted trees along 300 km of roads and along 400 km of canals. The survival rate of planted trees are, however, very low to nil.

In Balochistan 25,000 hectors of shifting sand dunes has been stabilized by afforestation in coastal areas of Pasni, Jiwani and Ormara and partly in highland Balochistan in Mastung and Nushki areas. Mesquite has shown to be suitable for sand dunes stabilization in coastal areas. For inland afforestation package was developed by the Provincial Forest Department consisting of Spanish Reed rhizomes with cutting of Tamarix and Calligonum polygonoides. This package has been applied successfully and should be conti-nued and extended in more areas.

The over-exploitation of the relict woods and trees for fuelwood is locally increasing due to the unavailability of alternate fuel. The natural gas is available in Quetta, Pishin, Mastung and enroute villages for domestic and industrial use. Gas cylinders are also spreading rapidly in all over the province. This would help decrease the demand for fuelwood. The gas is cheap but the poor sections of the population still use fuelwood. Conservation of fuelwood, trees and rangelands will be best served by economic development, diminishing poverty and by the repatriation of Afghan refugees. Ultimately it will help stabilize mountain slopes, protect soil erosion, increase forest areas and vegetation cover, reduce intensity of flash floods and enhance natural recharge of groundwater.

The rate of man-made accelerated erosion is considerable, but negligible compared with that of natural erosion. In Balochistan it is not the amount of arable soil that is limiting agricultural production but rather it is because of the unava-ilability of water. Therefore, man-made soil erosion is not perceived by the farmers as a threat to their subsistence. However, this over all surplus of arable soils may actually reverse into a deficit in a few river basins or sub-basins if not managed and used properly. Planned and sus-tainable afforestation, protection of fuelwood and vegetation cover would greatly help reduce the soil erosion and ultimately the silt load of streams and rivers.

IRRIGATION AND AGRICULTURE MANAGEMENT

Agriculture is the mainstay of the economy of Balochistan. More than half of the GDP (54.4%) comes from Agriculture. Eighty percent of the total population is engaged in agriculture, either directly or indirectly, producing crops worth of Rs. 10.8 billion annually.

In Balochistan 801,257 hectors of land is irrigated through canals, tubewells, open/dug wells, *Karazes* and Springs. By excluding the area cultivated through Indus River System, the land area cultivated by groundwater is 81% of the total cultivated area. Crops can be divided according to their source of water and is shown in Table-6.

Irrigation Source	Crops
Flood irrigated agriculture	Winter: Wheat Summer: Sorghum and vegetable.
Run-off irrigated agriculture	Winter: Wheat Summer: Sorghum and vegetable.
Dug & Tubewell irrigated agriculture.	Fruit orchards and vegetable
River, Spring & Karezes irrigated agriculture.	Fruit orchards and vegetable
Indus Canal irrigated agriculture	Winter: Wheat Summer: Rice.

Table-6. Sources of Irrigation Water and Associated Crops.

Flood irrigated and run-off irrigated agriculture are collectively known as *barani* or rainfed agriculture. Flood irrigated agriculture is found throughout Balochistan. Traditional structures are used to divert the flood water onto the agriculture land. Some modern flood water control schemes has also constructed by the Irrigation Department. Kachhi/Sibi plains and Las Bela/Uthal lowland piedmont plains are the major areas of flood Irrigation. Run-off agriculture is the traditional type of agriculture in most of Balochistan and is practiced on all plains where there is a combination of good soil and slope. In open/dug well and tubewell irrigated agriculture system water is pumped into small canals for individual fields. The expansion of well-irrigated agriculture has certainly low-ered groundwater levels in many areas. Most of the tubewell pumps are electricity driven because electricity is cheaper than diesel oil. WAPDA levies a fixed electric charge on tubewells, causing a catastrophic effect on groundwater. Groundwater reservoirs are being depleted at a much faster rate than at which they are being recharged. The fixed water charges ensure that there is no inducement to use less electricity as such less water. Where available

a) Timely irrigation and use of appropriate amount of water, subject to the local climatical and seasonal conditions, with a frequency suitable for both the plants and the soil.
b) Provision of complete irrigation and drainage networks least susceptible to water loss.
c) The adoption of modern and developed irrigation methods with a goal to economize water and high yield.
d) The construction of small and large reservoirs for flood water storage and utilization.
e) Intensification of the water extension services for farmers.
f) Full utilization of water resources so as to get more benefits from the irrigation projects.
g) Strengthening, management, organization and setting up the rules for the operation of water supply systems.
h) Coordination with relevant agriculture measures.
i) Introduction of On Farm Water Management Programmes
j) Conjunctive use of surface and groundwater.
k) Construction of *pucca* (concrete) water storage tanks and lining up of canals and distributories.
l) Carrying out precision land levelling of the fields.
m) Introduction of trickle water and sprinkler irrigation system.

Table 7. Package for Water Conservation in Irrigation and Agriculture.

the permanent base flow of some rivers is used to cultivate trees. Permanent flow is also available from springs and Karazes. Karazes are a particular irrigation system in which shallow groundwater is diverted through an underground tunnel onto the farm land. In Nasirabad division only syste-matic canal irrigation exists which is a part of Indus River System. Water Conservancy Deve-lopment Plans are required for agriculture sector. For better management and operation of the existing projects to yield the optimum benefits, the rehabilitation and modernization of irrigation and drainage systems is essential. This can be achieved by adopting new effective tech-niques for water use and land reclamation and by monitoring the surface- and groundwater quantity and quality on regular basis. In addition to technical aspects, implementable water laws, regulations and other decrees concerned with water resources managements and conservation, as well as pollution control, should be stipulated and adopted. Strategy for water conservation in irrigation and agriculture, proposed in this regard, is outlined in Table-7.

LEGISLATION

Currently three different laws are enacted in Balochistan dealing with different aspects of water use, administration and rights.

1. Balochistan Groundwater Rights Ordinance, 1978. (Ordinance IX of 1978)

The Balochistan Groundwater Rights Ordinance proclaims that it is a law "to regulate the use of groundwater and to administer the rights of various persons therein". It attempts to register all existing open surface wells, tubewells, *karazes* and springs with the Provincial Water Board, lying with the area of a designated groundwater basin, which in turn are required to be notified by the Water Board.

The Water Board is also responsible for lying down policies for conserving and developing groundwater resources, making rules and regula-tions for use of groundwater resources and administering the water rights of various persons, notifying water basins which it intends to regulate, and determine the "Safe yield" in respect thereof by prescribing the distances between wells and *karazes*.

2. Balochistan Canal and Drainage Ordinance, 1980. (Ordinance XX of 1980)

The Balochistan Canal and Drainage Ordinance, 1980 in its preamble states, that, the "Provincial Government is entitled to use and control for public purposes the water of all rivers and streams flowing in natural channels, and of all lakes, sub-soil water and other natural collection of still water".

3. The Balochistan Water User Association Ordinance, 1981. (Ordinance V of 1981).

The Balochistan Water User Association Ordinance provides a law for the "formation, operation and promotion of Water User Associations" in the province.

In addition to the above three laws, there exists a federal law that relates to Water and Power Development Authority (WAPDA) and deals different aspects of the surface and groundwater use.

4. Pakistan Water and Power Development Authority Act, 1958.

The WAPDA supplies electricity to Balochistan and WAPDA is required to prepare for the Government "a comprehensive plan for the development and utilization of the water and power resources of Pakistan" and may frame schemes for any province or part thereof providing for all or any of the following matters

i- Irrigation, water supply and drainage and recreational use of water resources.
ii- The generation, transmission and distribution of power, and the construction, maintenance, and operation of power houses and grids.
iii- Flood control
iv- The prevention of water logging and

reclamation of water logged and salted lands
v- Inland navigation, and
vi- The prevention of any ill effects on public health resulting from operation of the Authority.

WAPDA may also cause studies, surveys, experiments or technical research to be made.

5. Tribal Water Rights

Water rights in Balochistan are entirely determined by Customary Tribal Laws which are derived from customary land rights. Water can be used freely for drinking, animal watering and domestic purposes by everybody. This applied to all sources of water like *karazes*, rivers, springs and tubewells.

River channels which are occupied by a number of clans or tribes, have a fixed share of water for every tribe. Each builds a temporary dam across the river, without depriving the lower riparian of water. From the impounded water a number of water channels are dug in accordance with the number of clans. From these channels minor channels are laid out into the individual fields. Torrent flood water is diverted into embanked fields through distribution chan-nels. The upper riparian has the prior right to water. Run off belongs to the person in whose land the water enters. A spring belongs to the land owner. The right to use groundwater by a dug well or borehole belongs to the person who owns the land above. *Karezes* are usually of group-ownership, with a fixed share of water for each individual. In Balochistan there is a *riwaj* (tradition) that a tubewell can not be installed within 457m (1500 feet) of *kareze*-tunnel in the gravelly and coarse sandy soils and not within 229m (750 feet) in silty soils. The same distan-ces are applicable in case of two tubewells and the mother-well of *karezes*. However, this *riwaj* is loosing its importance specially in and around the urban settlements.

As mentioned above the *riwaj, jirga,* tribal laws and different ordinances pertaining to water are applicable at the same time throughout Balochistan. Majority of them are ill-defined and not based on technical footings. No qualified hydrologist or hydrogeologist is recommended to become a member of Provincial Water Board and District Water Committees. It is recommen-ded to formulate a committee for the unification of all existing laws with an easy, realistic and applicable approach. The committee should comprises of the members of recommended Directorate or Catchment Area Management Board. The District Water Committee should assign powers to fine or to punish for violation of rules. Measures as recommended for groundwater conservation should be enforced in all basins/sub-basins through District Water Committees.

Water is a good solvent and has the capacity to dissolve a great variety of salts and minerals some of which may be hazardous to health. There are certain minimum and maximum limits of all these salts and minerals adopted by many countries as their own "National Standards", depending upon water quality, source, climate and general health conditions of the utilizing communities. World Health Organization has its own standards which are very flexible. The different water treatment technologies are adopted on the basis of water standards and salt concentrations. It is high time to assign this job to Provincial Water Board and District Water Committees under legal protection for the form-ulation of different standards. The members of the sub-committees should comprise Doctors of Community Health, Community Health Engi-neers, Hydroscientists and Hydrochemists etc. The major task of these committees should be to study the health conditions and chemical beh-avior of different waters of all sub-basins and to establish water standards for various use.

CONCLUSIONS AND RECOMMENDATIONS

In order to efficiently control the rapidly deteriorating water resources in Balochistan the following recommendations are proposed.

1. To reduce the pressure on groundwater and related resources it is imperative to defuse the population bomb, with a systematic family planning programme for the reduction of average family size.

2. To stop the migration toward urban centers, the developmental activities and provision of basic urban facilities should be provided at divisional and district levels .

3. To release the population burden on Quetta City, all new industrial states should be developed outside the Quetta Valley and nearby settlement centers like Mastung and Pishin should be made attractive for future major projects.

4. A comprehensive frame work for licensing of tubewells covering limitation of the total depth, diameter, discharge rate and pumpage timing should be imposed through proper legislation.

5. A mechanism for water conservation through water metering system for domestic and industrial usage, realistic water charges and effective cost recovery system, should be devised with legal protection.

6. Electric supply for tubewells should be metered and the flat-rate charges should be abolished.

7. To increase the quality of work all existing departments and organizations engaged in water resource management should be merged into a single Directorate to be known as "Catchment Area Management Board" (CAMB) for each basin and sub-basin.

8. Subsidized cost for tubewell drilling should be discouraged and more funds be allocated for water conservation and groundwater recharge projects.

9. Private sector should be given incentives for investment in bore hole drilling and tubewell development work.

10. An effective monitoring network covering the whole province should be developed for climatical, environmental, hydrological and hydrogeological data collection on regular basis.

11. Small and large reservoirs for the collection and utilization of flood waters, flood water diversion schemes and delay action dams on small streams and gorges should be constructed.

12. To conserve the rangeland, grazing should not be allowed on piedmont and flood infiltration areas in normal conditions. Community-based awareness programmes should be launched projecting the importance of rangeland, rota-tional grazing, stock density, protection of vegetation cover and the proper utilization of fuelwood.

13. Piped natural gas should be made available on priority basis to communities living in forested areas where wood is the only source of fuel. The easy access to gas cylinder should be ensured throughout Balochistan.

14. A comprehensive strategy for water conservation in irrigation and agriculture should be adopted which must include, timely irrigation, amount and frequency of water, adoption of modern and developed irrigation methods, intensification of the water extension services for farmers, coordination with relevant agriculture and irrigation measures, adaptation of trickle and sprinkler irrigation system and conjunctive use of surface and groundwater through a complete irrigation and drainage network.

15. A qualified hydrologist or hydrogeologist should be a permanent member of Provincial Water Board.

16. All existing water laws should be amended so as to make them easy, realistic and effectively applicable.

17. Provincial Water Board in coordination with the propose of Catchment Area Management Board should establish appropriate water standards for various use.

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STRUCTURES IN THE SHEETED DYKE COMPLEX OF THE MUSLIM BAGH OPHIOLITE, PAKISTAN

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ABSTRACT

The sheeted dyke complex of the Muslim Bagh ophiolite is regionally mappable unit. It has a consistent stratigraphic position with overlying gabbroic rocks. More than two hundred chilled margins of the dykes were measured in the field. Sheeted dyke exposures provided structural data that allowed the reconstruction of the paleo-spreading ridge axis that was oriented 145° for the region. The complex was formed during a single sea-floor spreading episode. Based on composition and orientation four types of dykes are found in the sheeted dyke complex. In some places the sheeted dykes were observed to root in high level gabbro.

INTRODUCTION

The occurrence of sheeted dykes is a characteristic, but not universal feature of ophiolites. Swarms of sub-parallel dykes without intervening screens of other rock types are present in many ophiolites, for example Troodos (Wilson 1959; Gass & Masson-Smith 1963; Gass 1968), Macquarie Island (Varne et al. 1969; Varne & Rubenach 1973), the Newfoundland complexes (Church & Steven 1971: Williams & Malpas 1972) and Oman Ophiolote (Reinhardit 1969: Gelennie et al. 1973), but are absent in others such as Papua (Davies 1971) and New Caledonia (Coleman & Irwin 1974). In Muslim Bagh ophiolites sheeted dykes complex represent 100% extension. Deformation structures are present. The existence of sheeted dyke complexes, especially where one way chilling can be demonstrated (Kidd & Cann 1974; Kidd 1977), is one of the strongest pieces of evidence for ophiolites originating at oceanic spreading axes. This plutonic sequence is usually interpreted as the product of crystallisation in a mag-ma chamber at an oceanic spreading axis.

The main purpose of this study was to recognize the real sheeted dykes that represent the paleo-ridge and differentiate them from post intra-oceanic ridge dykes (late intrusions).

THE SIGNIFICANCE OF SHEETED DYKES IN OPHIOLITES

Sheeted dyke complex is an essential component of complete ophiolite suites, lying stratigraphically above gabbroic rocks and below pillow lava flows (Penrose Conference defini-tion, Geotimes 1972). It consists of series of pa-rallel intrusive sheets that were successively injected as feeders for the overlying lavas. The presence of a well-developed sheeted dyke complex is generally re-garded as prima facie evidence of ophiolite formation at oceanic spreading axis (Gass 1968; Moores and Vine 1971; Church 1972 Smewing et al 1975; Coleman 1977; Dewey and Kidd 1977).

The dominant sheeting attitude of a dyke complex indicates the orientation of the paleo-spreading axis relative to the other members of the ophiolite suite. This provides a relative age frame work for petrological and geophysical studies, based on the sea floor spreading model. Over large regions, divergent sheeting attitudes reveal structural discontinuities in an ophiolite nappe, such as paleo-transform faults (Moores and Vine 1971; Smewing 1979).

Statistical studies of the facing directions of dyke chilled margins in the Troodos, Betts Cove, and Smartville ophiolites, and computer aided simulation of dyke distribution (Kidd and Cann 1974; Kidd 1977) provided details of the ocean floor spreading model and suggest paleo spread-ing ridge orientations. The distribution of one way chilling is used by Kidd and Cann (1974) to deduce ophiolite symmetry. In addition to one way chilling, the orientation of diabase sheeting with respect to other members of the ophiolite suite may be used to indicate ophiolite symmetry (Cann 1974; Jackson et al. 1975).

THE SHEETED DYKE COMPLEX OF THE MUSLIM BAGH OPHIOLITE

The term 'sheeted' is used following Wilson and Ingham (1959) to describe the repetition of parallel dykes (geometric sheets) in the direction normal to the dyke planes. This yields an apparent stratified outcrop appearance (Fig. 4a). The sheeted dyke unit is referred to as a 'complex' because the intrusive sequence is complicated. Multiple intrusions in the same planar orientation has resulted in dyke splitting. One sided dykes are separated from their mates by younger dykes that commonly are also split.

The sheeted dyke complex in Muslim Bagh has been studied by Ahmad & Abbas (1979), Salam (1986), Sawada et al. (1992), Mahmood (1994), Siddiqui et al. (1994), and Mahmood et al. (1995). The area covered by sheeted dyke complex makes a synclinal shape structure which is easily accessible to study the nature of the dykes (Fig. 1).

Four types of sheeted dyke were recognized in the complex, these are:

A. Meta dolerites, plagiogranites and diorites.
B. Intrusions discordant to type 'A' showing slight deformation
C. Intrusions discordant to type A showing no deformation and are the minor consti-tuent of the complex.
D. Basaltic dykes.

The total thickness of the sheeted dyke complex is about 5km. More than two hundred chilled margins of the dykes were measured in the field (Fig. 2) The plagiogranites, diorites and metadolerites are strongly deformed(?). The contacts and chilled margins between these dykes are very sharp and clear, so these contacts are measured as the margins. The foliated planes with in different rock types of this family are always parallel to the contacts and foliation in each rock type. The dioritic dykes also give chill margins and are foliated, the foliation in these rocks is marked by amphibole. Whereas in plagiogranites the foliation is marked by quartz, showing a strong fabric under the microscope (Fig. 3a). The chilled margins of the dykes are parallel to the hydrothermal circulation and the epidote veins. Under the microscope these rocks show mylonitic texture. Quartz is recrystallized and elongated, (Fig.3a). These parallel dykes aresometime cut by later dykes, confirming their origin as underplating the roof of an active magma chamber (Dewy & Kidd 1977). These dykes have been hydrothermally metamorphosed to green schist and amphibolite facies.

The trend of most of the dykes is about 140-130° with the dominant dip direction NE (Fig. 4a). At some places good exposures of vertical dykes within the complex are present (Fig. 4c). The multiple intrusive nature of dykes is illustrated in Fig. 4b&c. The dark colour represents the chilled margins of a single dyke. Apparently the process has been that one dyke

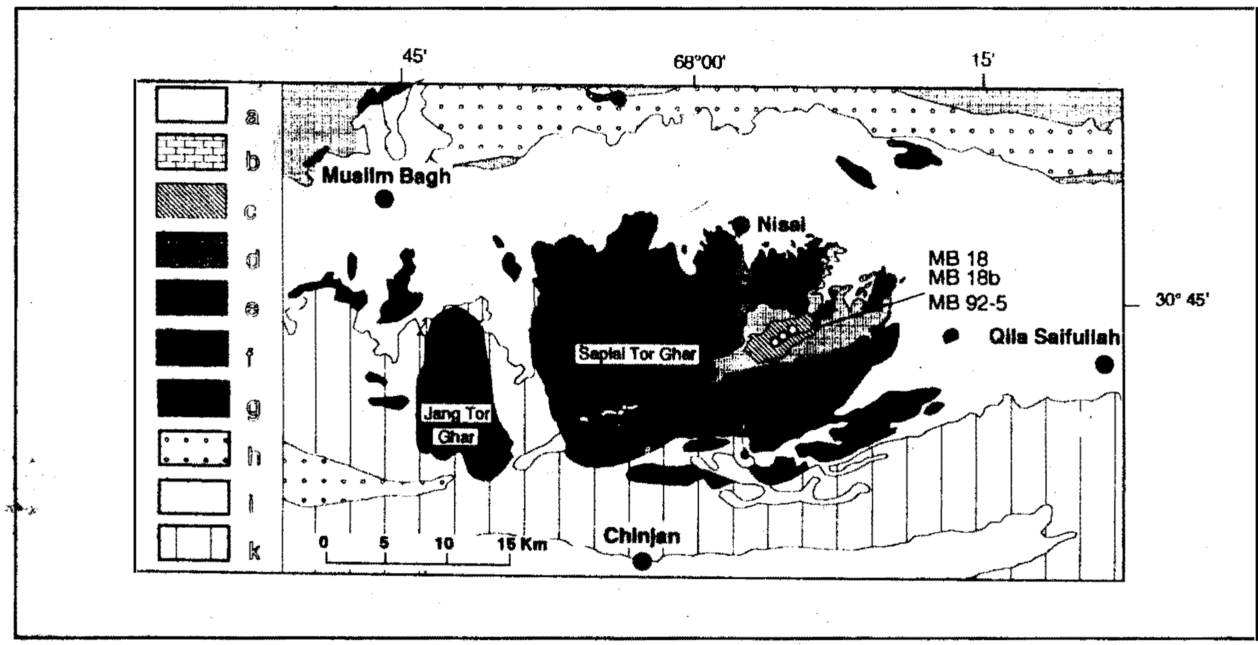

Figure 1. **Geological map of the Muslim Bagh ophiolite showing outcrops of the Jang Tor Ghar and Saplai Tor Ghar massif (after Mahmood et al. 1995). a=Quaternary; b=Tertiary; c=sheeted dyke complex; d=gabbros; e=mantle sequence with pyroxenite/gabbro intrusions; f=metamorphic sole rocks; g=melange with serpentinite matrix; h=molasse; i=flysch; k=Mesozoic carbonates.**

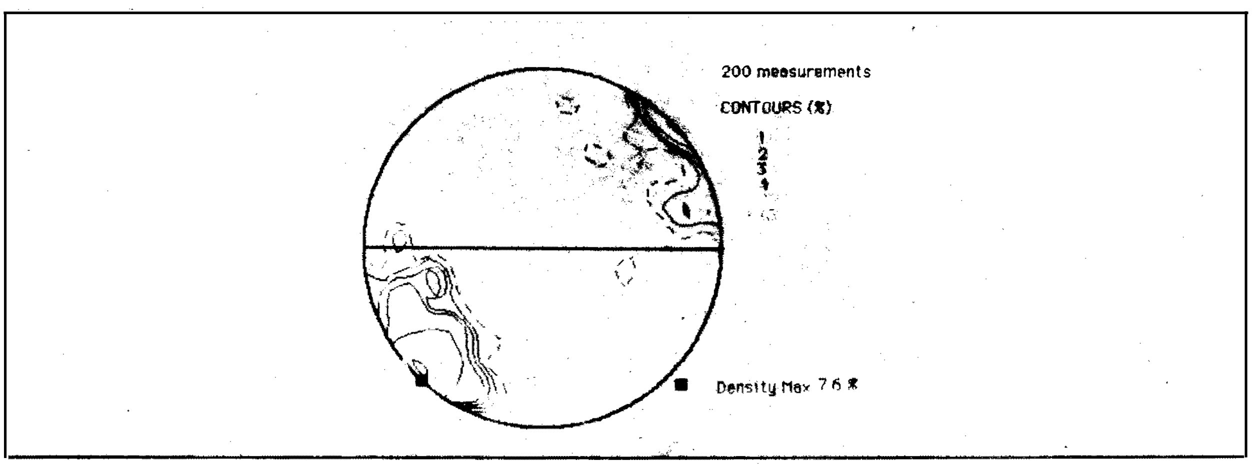

Figure 2. **Sheeted dyke complex poles to dykes planes (200 measurements).**

is intruded and has its margins chilled against the wall rock. Then the next dyke intrudes upon the middle of the previous one, and in turn forms chilled margins, then the next one repeats, and so on. Most dykes are oriented so that their dip is vertical (Fig.4 b&c). Quartz diorite is present as screens in plagiogranites and vice-versa. Lenses of margins can be found isolated within the foliated plagiogranites which are elongated parallel to foliation (Fig.4b). These are interpre-ted as pieces of protodyke margins which had been detached and stretched into the foliation during flow.

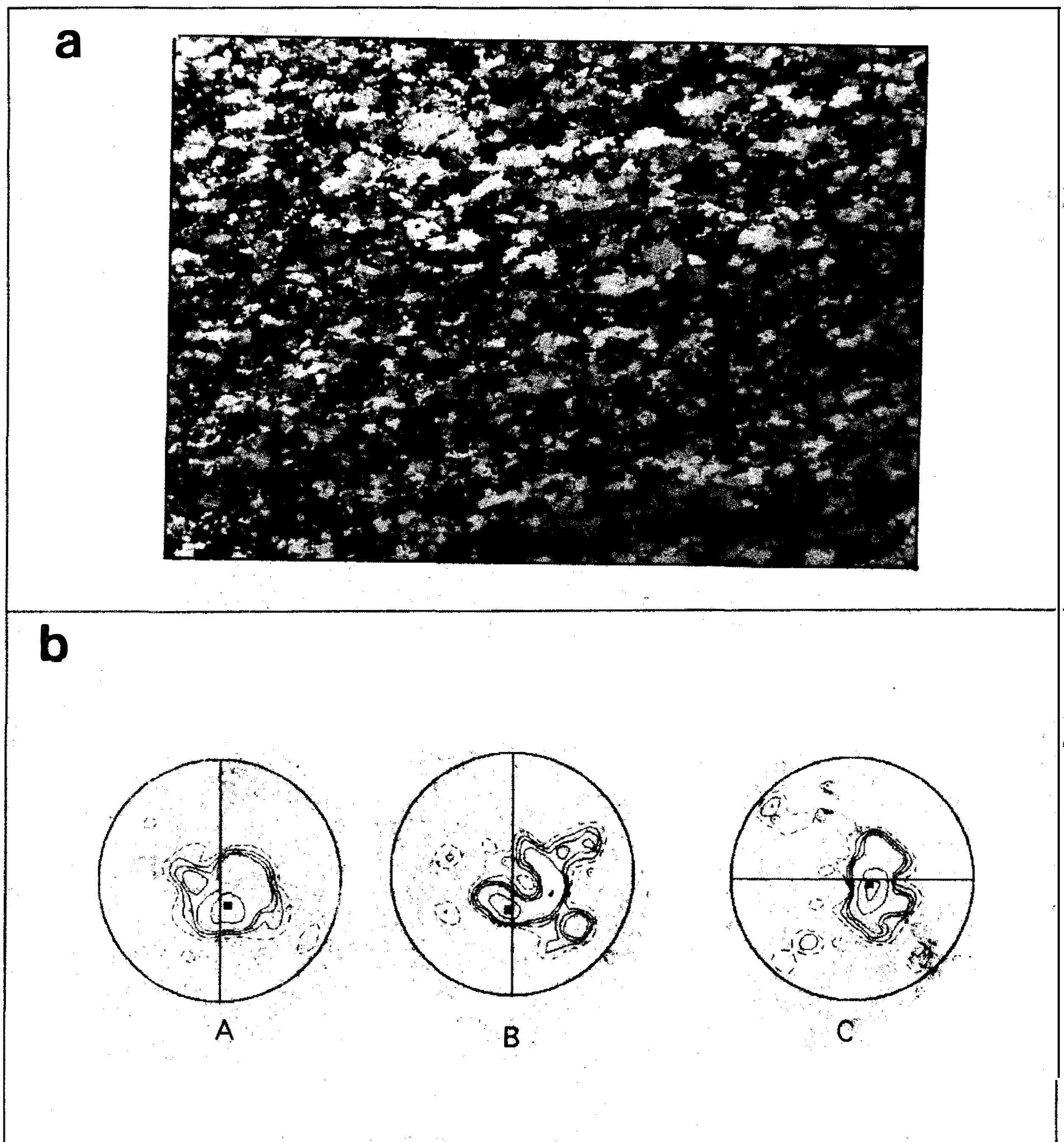

Figure 3. a) Thin section photograph of sample 18b (XZ-plane; location in Fig. 1) plagiogranite showing mylonitic texture. b) representative quartz fabric from the plagiogranites samples a 210, B 100 etc 100 measurements. A=MB 92-5, B=M.B. 18 et C=M.B 18b on Fig. 1).

Primary sheeted dykes (type A) are amphibolitized due the hydrothermal activities at the ridge. The second family of intrusions (type B) which are discordant to the family A are slightly foliated and show metamorphism in amphibolite to green schist facies. They have chilled margins also. The dykes of the third family (type C) which are found only in the small hills with in the complex are doleritic in composition and it is very difficult to observe their chill margins in the field due to the weathering. The measurements were made by looking the variation of grain size towards the border. These dykes do not show any deformation.

Beside these three types of dykes, few basaltic dykes are also observed in the complex. These dykes are brownish in colour and do not show chilled margins. These are interpreted as the last products of the ridge magma chamber injected during roof fracturing.

MICROSTRUCTURAL ANALYSIS

To know the lattice preferred orientation (LPO) and slip system a universal stage of five axis was used for detailed optical study of petrographic thin sections of plagiogranites to determine the quartz c-axis (optic axis) orientation of individual grains with in the structural frame work (stretching lineation and flattening foliation) The three fabrics (Fig.3b) are marked by a maximum of the C axis on Y position, it means in the foliation and perpendicular to the lineation . This type of fabric is interpreted as a result of intracrvstalline slip following the system [prismatique a] (Bouchez 1977; Nicolas et Vialon 1980). This is the system of slip evident in the conditions of amphibolite facies deform-ation; and it confirms the conditions thermiques of the ductile deformation which affected the metadolerites, diorites and plagiogranites.

DISCUSSION

More than two hundred chilled margins of the dykes were measured. The dykes of the first family exposed in the central part of the complex were observed, even in the gabbroic rocks of the upper level. The strong metamorphism is an evidence that these dykes are older then the dykes of the other families (i.e. B,C and D). These dykes are more abundant than any other family of dykes. These are true sheeted dykes forming roots for other dykes and lava flow. The metamorphism of the sheeted dyke complex took place at the ridge side by the hydro-thermal process, not during the emplacement as reported earlier (Siddiqui et al. 1994), because hydrother-mal metamorphism has been noticed even in the upper part of the gabbroic section. The dykes which are not metamorphosed are younger ones and probably they are of the same family as the dykes found in the mantle section and are late intrusion, that took place after the intra oceanic emplacement of the Muslim Bagh ophiolite. There is a difference between the cooling ages of amphibole of the sheeted dyke and amphibole from the base of the ophiolite (Mahmood et al. 1995).

The pronounced foliation and petrofabric analysis of quartz from the plagiogranites sugge-st that these rocks are plastically deformed, and this deformation was caused at the ridge side. The presence of diorite and plagiogranitic dykes in the gabbro of upper level is a good evidence for these dykes to be called as protodykes. The shear sense which indicates that the whole of the sheeted dyke complex has been moved down-ward relative to the gabbroic section producing a syn-form structure. This was caused by normal faulting at the ridge. The multiple intrusions and multiple chilling effect imply the emplacement of the material, hence extension, and a slow rate of spreading to allow for the production of chilling effects. This suggest that spreading rate of the ridge was fairly slow.

The plagiogranite dykes are common and significant volumetrically. This probably is the result of both extreme fractional crystallisation

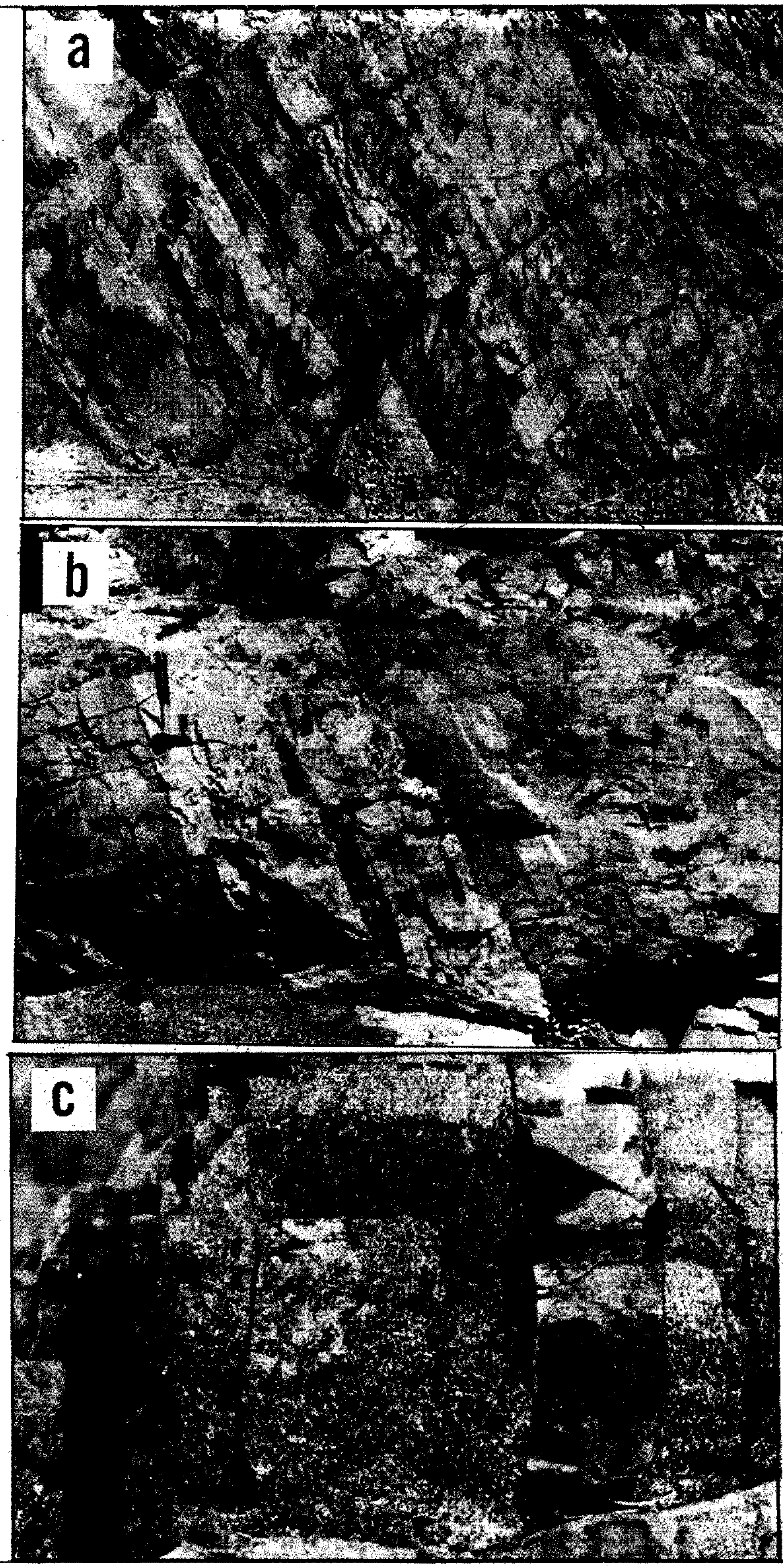

Figure 4. Field photographs a) diorite (dark) and plagiogranite (light) dykes. b) diorite (dark) and plagiogranite (light) dykes. Lenses of plagiogranite are seen in the diorite parallel to the foliation plane & vice versa. c) photograph showing unfoliated doleritic dyke (dark grey) intruded into foliated doleritic dyke (light grey).

and partial melting of the chamber roof. The magma chamber was affected by periodic replenishment. The dype complex is composite with respect to both its intrusive and seafloor hydrothermal alteration history.

Vertical dykes possibly suggest a role for fluid pressure and forceful injection of dyke material, causing the rock to fracture perpendicular to minimum compressive stress. Plagiogranite dykes were intruded into the proto-dyke and after some times foliated in amphibolite facies conditions. The foliation is not magmatic but is solid state deformation. Meta-dolerites have been developed due to the hydrothermal circulation, as indicated by change of pyroxene to amphibole which takes place at 600-700°C. The rooting is observed in the southern part of the complex where we observed the plagiogranite dykes in the upper level of the gabbroic rocks. The contact of the sheeted dykes with the gabbroic section is transitional.

CONCLUSIONS

Field evidences suggest that the dykes having trend 140-135 are the real sheeted dykes and this marks the direction of the paleo ridge. Dykes from the sheeted dyke complex have been found to have root within the high-level garbbro. Petrofabric studies indicate downward move-ment of the complex relative to the gabbroic rocks.

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HYDROGEOLOGY AND GROUNDWATER RESOURCES OF BALOCHISTAN, PAKISTAN - AN OVERVIEW

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ABSTRACT

Balochistan is a mosaic of different physiographic, morphologic, geologic, structural and techtonic features which controls the occurrence and movement of groundwater. The exposed lithologic units range from Permian to Recent age, among them alluvium deposits and Pleistocene formations formed best productive aquifers. Karstified limestones also produce significant amounts of groundwater. Balochistan is dominated by 12 major river systems of catchment areas covering 4,188-83,500 km^2. The hydrogeological parameters show great variations from basin to basin. The depth of water table and hydraulic gradient range from 1-79m and 0.14-108m/km respectively. Permeability values range from 0.2-428m/d and transmissivity from 10-27,000m^2/day. Specific yield/ storage coefficient of aquifers varies from 3-25%. The total recharge value of twelve river basins varies from 44-1,833 Mm^3/year. Estimated groundwater potentials were 23-150 Mm^3/year during 1983 and reduced to 6-116 Mm^3/year during 1989. In comparatively more inhabited basins/sub-basins a continuous decline of water table observed from 0.1-3.5 m/year. All basinal groundwaters are of different chemical quality, however, in most basins the springs and tubewell waters are acceptable for drinking and irrigation.

INTRODUCTION

Balochistan, province of Pakistan has an area of about 374,190 km^2. The human population was 4.33 million in 1981 and estimated as 6.55 million in 1992. The average annual precipitation ranges from 50-400 mm and evaporation from 1,830-1,930 mm. The average annual minimum and maximum temperature varies between 5° and 38°C respectively. The average temperature and precipitation values attribute that climatically Balochistan falls in Medeterranean and monsoonal arid zone. The altitude determines the cool-temperate to tropical temperate regimes. No river or stream have perennial flow throughout their courses. Surface water resources are limited, the groundwater is the only dependable source. Springs, Karazes, dug and persian wells are the traditional means of groundwater utilization. The mechanized system of tubewell instal-lation was initiated in 1960. The systematic hyd-rogeological investigations were started by the Hydrogeology Directorate, WAPDA during 1969. Basinal investigation and groundwater monitoring reports and hydrogeological maps were prepared, which are the basic source of data for this paper. Analyses of available groundwater data by some individuals and national and expatriate consultants also provided valuable information.

The study and description of 12 hydrologic basins and their 74 sub-basins form part of this paper. The names and description of sub-basins are not mentioned, the collective study of hydrologic basins represents the sub-basins. The small streams of coastal areas and along the extreme north and north-eastern part of Balochistan are not part of this study.

HYDROGEOLOGY

The geology of Balochistan is dominated by five depositional basins, (i) Chagai-Raskoh Volcanic Arc, (ii) Makran-Kharan Basin, (iii) West Pakistan Fold Belt, (iv) Pishin Sub-basin and (v) Sibi Sub-basin. The surface drainage divided these depositional basins into 12 hydrologic/river basins. The neo-tectonic movements (Bender and Raza 1995) divided the hydrologic basins into 72 intermountain hydrologic sub-basins. The sedimentary rocks are widely exposed in all the depositional or hydrologic basins, which are mainly calcareous and arenaceous. Limestone, shale, marl and clay are the oldest rocks of Permian age, exposed in Zhob, Nari and Pishin river basins.The Mesozoic and Cenozoic rocks are mainly composed of limestone, shale and sandstone and are widely exposed in all river basins. Rocks of igneous origin range from Cretaceous to Oligocene and are mainly exposed in Gaj, Porali, Hingol, Hamun-E-Lora and Hamun-E-Mashkhel river basins. Ophiolites of Cretaceous age are predominantly exposed in Zhob and Porali basins. A simplified hydrogeological map of 12 hydrologic basins is shown in Figure 1 prepared with help of Geological Map of Pakistan (Bakr & Jackson 1964). The major lithological units shown in the hydrological map are alluvium, undifferentiated limestone formations, sedimentary units, igneous rocks and the ophiolites. The sedimentary units are mainly composed of shale, sandstone, limestone and conglomerate. The major lithologic units of Balochistan are summarized in terms of hydrogeologic characteristics, lithology, age, and their presence in hydrologic basins (Table 1). In the table, the hydrogeologic characteristics of individual formations and groups are mentioned in terms of capacity to transmit water. The exposed lithologic units in 12 hydrologic basins of Balochistan are classified into 37 formations and groups. For clarity, the obsolete names of ormations and groups are not mentioned. Similarly, the members of the formations and groups are also not mentioned. The type section, thickness, detailed lithology, depositional environment and contact relationships of lithological units may be obtained from the published literature (Shah 1977; Bender & Raza 1995).

Hydrogeologically the exposed formations are grouped into three general types i.e., (i) permeable, (ii) semipermeable, and (iii) impermeable. The first group consists of mostly unconsolidated basin fill clastic material which readily transmit water. At some places the term also applied for karstified rocks (Syed 1990). The other groups are composed of semi-consolidated to consolidated rocks. The alluvium is wide spread in all depositional and hydrologic basins. The piedmont deposits are composed of gravel, cobbles, boulders and fine sediments of different proportions. The intermountain sub-basins are filled with the Recent deposits of fluviatile, lacustrine and eolian sediments. The thickness of Recent material differs from basin to basin and ranges from a few meters to more than 100 meters. The valley fill materials formed principal aquifers where groundwater occurs in unconfined, semiconfined and confined conditions.

Bostan, Haro, Jiwani, Ispikan, Lie, and Gwadar formations of Pleistocene are mainly composed of poorly cemented conglomerate and sandstone. These formations form productive aquifers and are exposed in Zhob, Nari, Kachhi, Pishin, Porali, Hingol, Dasht, Rakhshan and Hamun-E-Mashkhel river basin Rakhshan and Hamun-E-Mashkhel river basins. The limestones of Kirthar group of Middle Eocene - Early Oligocene, Dungan Formation of Paleocene - Early Eocene, Parh Limestone of Late Cretaceous and the Takatu Limestone of Middle Jurassic are karstified at places. These limestone formations are exposed in Zhob, Nari, Pishin, Mula and Gaj river basins. Springs of considerable discharges emerg from these formations. In Zhob basin majority of the rural water supply schemes are based on springs. The Momani Group of Middle Miocene - Oligocene, Khojak

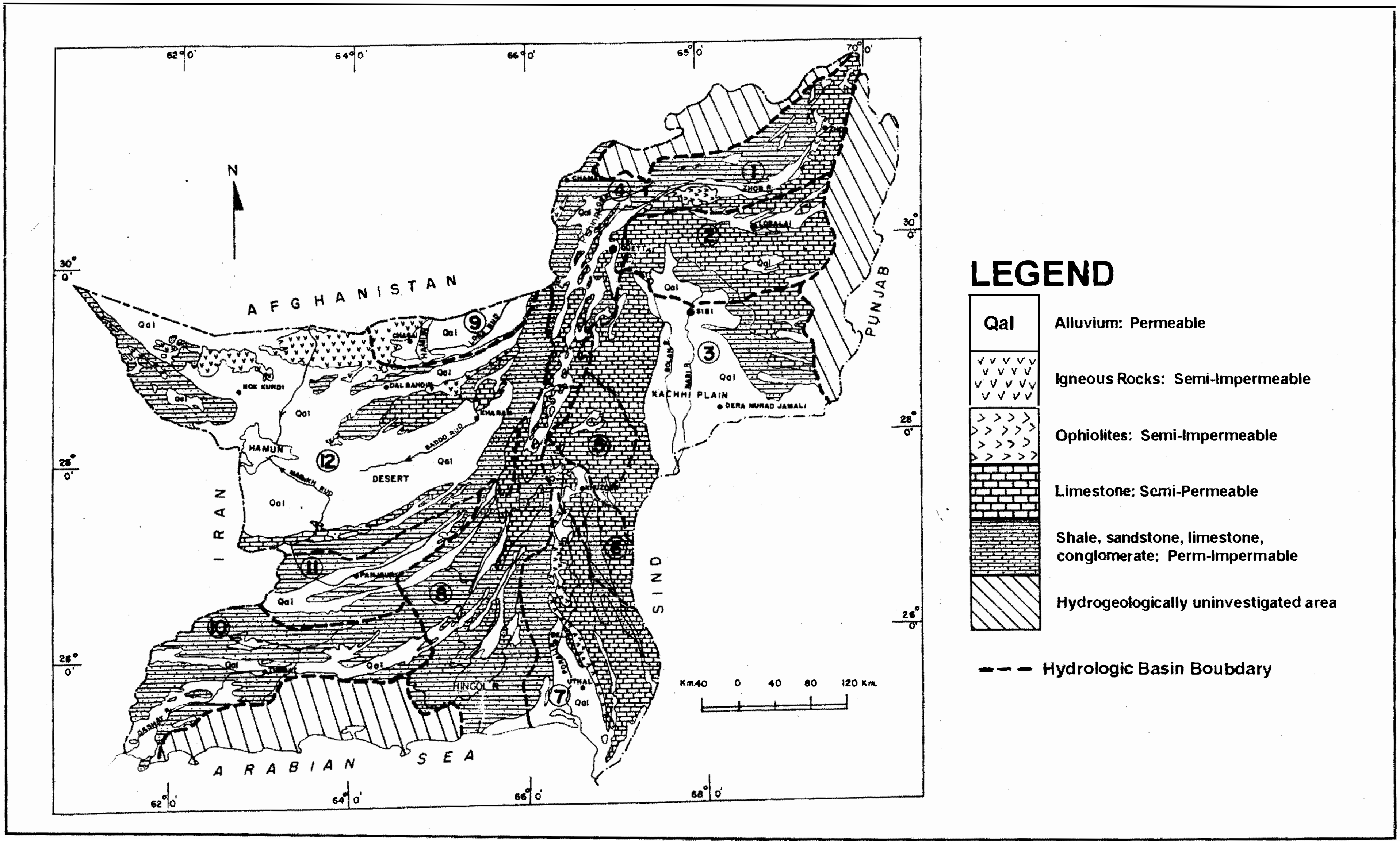

Figure 1. Generalized geological map of Balochistan showing boundaries of 12 hydrologic basins. 1; Zhob Basin, 2; Nari Basin, 3; Kachhi Basin, 4; Pishin Basin, 5; Mula Basin, 6; Gaj Basin, 7; Loralai Basin, 8; Hingol Basin, 9; Hamun-e-Lora Basin , 10; Dasht Basin, 11; Rakhshan Basin, 12; Hamun-e-Mashkhel Basin.

LITHOLOGIC UNITS	AGE	LITHOLOGY	HYDROGEOLOGIC CHARACTERISTICS	HYDROLOGIC BASINS											
				ZHOB	NARI	KACHHI	PISHIN	MULA	GAJ	PORALI	HINGOL	H - E - L	DASHT	RAKHSHAN	H - E - M
Alluvium	Holocene	Silt, Sand, Gravel, Boulder	Permeable	■	■	■	■	■	■	■	■	■	■	■	■
Amalaf Formation	Oligocene	Volcanic Rocks, Ash, Shale	Impermeable												■
Bela Ophiolite	Cretaceous	Ultamafics, dolerite dykes, Chert	Semi - Impermeable							■					
Bibai Formation	Cretaceous	Basalt, Agglomerate, Marl	Impermeable				■			■	■				
Bostan Formation	Pleistocene	Silt, Clay, S.st. Cong.	Perm. - Impermeable	■			■				■				■
Chaghi Intrusions	L. Cretaceous - E. Paleocene	Volcanics, Shale, Congl.	Semi - Impermeable									■			■
Dungan Formation	Paleocene - E. Eocene	L.st. Shale, Marl, Cong. S.st.	Semipermeable		■		■	■							
Ghazij Group	E. Eocene	Shale, C.st. L.st. S.st.	Impermeable		■		■	■			■				
Goru Formation	Cretaceous	L. St., Shale, Siltstone	Semi - Impermeable		■		■		■						
Gwadar Formation	L. Pliocene - Pleistocene	Clay. S.st. Cong.	Perm. - Impermeable								■		■		
Haro Conglomerate	Pleistocene	Cong. S.st. Silt.	Perm. - Impermeable							■	■		■	■	
Hinglaj Formation	Miocene - Pleistocene	S.st. Shale, Siltstone	Semi - Impermeable							■	■		■	■	
Humai Formation	Cretaceous	Shale, S.st. Siltstone, L.st.	Impermeable									■			■
Ispikan Conglomerate	Paleocene	Cong.	Permeable										■		
Jiwani Formation	Pleistocene-Holocene	L.st. S.st. Cong.	Permeable										■		
Kharan Formation	E - M. Eocene	L.st. Shale. S.st.	Semipermeable												■
Khojak Formation	Oligocene	Shale. S.st. Cong.	Semi - Impermeable	■			■			■		■	■	■	■
Kirther Group	M. Eocene - E. Oligocene	L.st. Shale, Marl.	Semi - Impermeable		■		■		■						
Lie Conglonerate	Pleistocene	Cong.	Permeable		■	■									
Momani Group	M. Miocene - Oligocene	Shale. S.st. Cong. L.st.	Semi - Impermeable		■		■		■	■					
Moro Formation	Cretaceous	L.st. S.st. Cong.	Semipermeable		■				■						
Muslim Bagh Ophiolite	Cretaceous	Ultamafics, dolerite dykes, Chert	Semi - Impermeable	■											
Nisai Formation	Eocene - E. Oligocene	L.st. Shale, S.st. Cong.	Semi - Impermeable	■	■	■	■	■	■	■			■	■	■
Pab Sandstone	L. Cretaceous	S.st. Shale, L.st.	Semi - Impermeable	■	■				■	■	■				
Parh Limestone	L. Cretaceous	L.st. Shale, Marl	Semipermeable	■			■	■	■	■			■		■
Permian of Balochistan	Permian	L.st. Clay	Semi - Impermeable	■	■		■								
Porali Intrusions	Cretaceous	Volcanics, Shale, S.st.	Semi - Impermeable						■	■	■				
Rakhshani Formation	Paleocene - M. Eocene	S.st. Volcanics, L.st.	Semi - Permeable						■	■		■			■
Ranikot Group	Paleocene	L.st. S.st. Shale	Semi - Impermeable					■	■						■
Raskoh Flysch Formation	L. Cretaceous - E. Paleocene	S.st. L.st. Igneous Rocks	Impermeable												■
Saindak Formation.	Eocene	Shale, S.st. L.st. Volcanics	Impermeable									■			■
Sembar Formation	L. Jurassic - E. Cretaceous	Shale, Siltstone, L.st.	Impermeable		■										
Shirinab Formation	E - M. Jurassic	L.st. S.st. Shale	Semi - Impermeable	■	■		■	■	■						
Sinjrani Volcanic Group	Cretaceous	Agglomerate, Tuff, Lavaflow	Impermeable								■	■			■
Siwalik Group	E. Pliocene - E. Pleistocene	Cong. S.st. C.st.	Semi - Impermeable		■	■	■								
Takatu Limestone	M. Jurassic	Limestone.	Semipermeable		■	■	■								
Wulgai Formation	Triassic	Mudstone, Shale, L.st.	Impermeable	■	■				■	■					

Table 1. Basin-wise lithology and hydrogeologic characteristics of exposed lithostratigraphic units of Balochistan. H - E - L; Hanun-E-Lora, H - E - M; Hamun-E-Mashkhel, E; Early, M; Middle, L; Late, C.st.; Claystone, S.st.; Sandstone, L.st.; Limestone, Cong.; Conglomerate.

Formation of Oligocene, Ghazij Group of Early Eocene, Humai Formation of Cretaceous. Sembar Formation of Late Jurassic-Early Createceous are mainly composed of shales. These formations are exposed in Nari, Pishin, Porali and Hamun-E-Mashkhel river basins and formed impermeable beds and negative boundaries. The Amalaf Formation of Oligocene, Saindak Formation of Eocene, Raskoh Flysch Formation of Late Cretaceous - Early Paleocene, Bibai Formation and the Sinjrani Volcanic Group of Cretaceous are composed of basaltic and volcanic rocks, volcanic conglomerate, agglomerate and tuff. These formations are mainly formed semipermeable to impermeable beds and are exposed in Porali, Hingol, Hamun-E-Lora and Hamun-E-Mashkhel river basins. Chaghi Intrusion of Late Cretaceous - Early Paleocene and Porali Intrusion of Cretaceous are composed of plutonic and volcanic rocks, shales, sandstone and conglomerates. These rocks formed semi-permeable to impermeable beds and are exposed in Gaj, Porali, Hingol, Hamun-E-Lora and Hamun-E-Mashkhel basins. Bela and Muslim Bagh Ophiolites of Cretaceous are exposed in Porali and Zhob river basins respectively. The ophiolites are composed of ultramafic rocks, dolerite dykes and chert which formed semipermeable to impermeable beds.

Many sedimentary formations are composed of shale, sandstone, conglomerate, limestone etc. representing different hydrogeological characteristics at different depths and levels. Such type of formations are widely exposed throughout Balochistan in all hydrologic basins. The permeable and semi-permeable lithologic units serve as aquifers under suitable hydrodynamic conditions, structural controls, thickness, lateral extent and exposure to recharge area.

GROUNDWATER RESOURCES

Among the 12 hydrologic basins of Balochistan, the Hamun-E-Mashkhel is the largest basin with the catchment area of about 83,500 km^2. The catchment areas of Kachhi, Porali, Hingol and Dasht river basins are greater than 25,000 km^2. Hingol river is the longest river, 656 km., while Nari, Rakhshan and Pishin river courses are greater than 400 km. The major physical characteristics of all river basins are tabulated in Table 2 (Asian Development Bank 1996; Soil Survey of Pakistan 1992).

Almost all the hydrologic basins/sub-basins are bordered by mountains which are adjacent to piedmont plains and grades into flat valley floors. Many of the sub-basins developed as internal drainage basins, that drain downstream following structural features. Some of the sub-basins are hydraulically linked and groundwater flows to and from the adjacent basins. In small sub-basins groundwater discharge and/or baseflow of upstream basins is a significant component of inflow of surface and groundwater of downstream basins. Kachhi, Mula and Gaj river basins situated along the border of the Punjab and Sind provinces of Pakistan, drain towards the east and southeast into the Indus River. Porali, Hingol and Dasht river basins drain towards south and southwest into the Arabian Sea. Rivers of the north western Balochistan drain into Hamun-E-Lora and Hamun-E-Mashkhel basins. [*Hamuns* are playa lakes form during wet season, but remain dry for most of the year].

Surface and groundwater resources of Balochistan fluctuate greatly throughout the year depending upon the variations in precipitation. Due to the scarcity of rainfall, no river or stream has perennial flow throughout their course. In northern and southeastern highlands the precipitation is maximum and ranges from 250-350 mm per annum. In these areas particularly in Zhob and Nari river basins perennial flows may be observed at some parts of streams and rivers. In southern and western parts of Balochistan the precipitation vary from 50-150 mm per annum, where intermittent and ephemeral streams are common. The estimated surface water potential of all river basins is 6,148 Mm^3/y (million cubic meter per year) whereas flood water supply 3,074 Mm^3/y. An additional 2,496 Mm^3/y is received by canals of Indus River for irrigation. The perennial baseflow of Zhob river is about 89 Mm^3/y which is the highest in Balochistan.

Hydrologic Basins	Coordinates	No. of Sub-Basins	Average Annual Temp. (°C)		Average Annual Precipitation (mm)	Population (millions)		Physiographic Units (Sq.Km)			
			Min.	Max.		1981	1997	Mount-ain	Pied-mont	Valley Floor	Catch-ment
Zhob	30°30'-31°30'N 67°30'-69°45' E	6	5	30	200-350	0.22	0.36	9876	1657	2318	13851
Nare	29°40'-31°00' N 67°10'-69°45' E	11	5	30	250-300	0.37	0.76	15149	5631	1049	21829
Kachhi	27°50'-29°25' N 67°15'-69'15 E	2	5	38	100-150	1.01	1.8	11465	1687	15148	28300
Pishin	28°43-31,00' N 66°12'-67°43' E	11	5	30	150-250	1.27	2.58	9055	3336	4537	16928
Mula	28°00'-28°57' N 66°15'-67°03' E	3	5	30	160-175	0.045	-	3256	598	334	4188
Gaj	26°50'-28°17'N 66°13'-67°10'E	5	5	35	85-175	0.042	-	5102	984	777	6863
Porali	24°54'-27°34'N 65°55'-67°62'E	8	10	35	150-200	0.27	0.49	17288	2318	6164	25770
Hingol	25°20'-28°50'N 64°30'-66°30'E	13	5	38	80-170	0.23	0.63	24090	5360	4740	34190
H-E-L	29°02'-29°50'N 64°15'-66°06'E	-	10	30	50-100	0.04	0.066	2082	761	4841	7684
Dasht	25°02'-26°38'N 61°40'-64°55'E	5	10	35	80-140	0.38	-	19000	3260	4840	27100
Rakhshan	26°30'-27°15'N 63°15'-65°30'E	2	5	35	50-115	0.096	-	6550	3170	2690	12410
H-E-M	27°05'-29°52'N 60°55'-66°22'	6	5	35	50-100	0.23	-	31940	10330	41230	83500

Table 2. Physical data of hydrologic basins of Balochistan. H - E - L: Hamun-E-Lora, H - E - M: Hamun-E-Mashkhel.

Hydrologic Basins	Depth of Water Table (m)	Hydraulic Gradient (m/Km)	Tubewell Discharge (M^3/h)	Specific Drawdown (m/100m^3/h)	Permeability (m/d)	Transmissivity (m^2/d)	Specific Yield/ Storage Coefficient (%)	Groundwater Quality	
								TDS (mg/l)	EC (mm/cm)
Zhob	6-76	1.5-42	9-136	1.5-83	-	50-26860	9-19	330-2100	430-3100
Nari	3-79	1-10	9-102	1.0-69	-	200-8690	10-23	330-16500	400-25500
Kachhi	2-46	0.4-2.5	13-102	1.2-69	-	20-5850	7-20	620-53000	900-75000
Pishin	4-78	3-15	5-114	1.0-137	-	1240-5850	7-22	270-32000	360-4500
Mula	6-67	3-48	23-102	6.7-69	1.223-56	40-2736	5-25	320-1200	400-1900
Gaj	1-47	3-6	14-102	1.0-137	0.265-82	50-11500	15*	300-1600	450-2350
Porali	5-33	-	14-102	0.3-137	0.97-428	20-27000	13*	240-34000	350-52000
Hingol	1-51	2-4	5-114	1.2-137	4.07-204	10-6000	5-25	320-26000	400-40500
H-E-L	3-24	2-15	22-114	0.6-137	0.204-69	1240-2900	10*	600-18000	950-27500
Dasht	5-30	0.4-6	9-89	0.6-17	0.82-210	1245-2490	10.7*	300-12000	450-18500
Rakhshan	5-40	1-8	9-100	0.6-137	41-82	1240-6200	3-25	500-7000	800-11000
H-E-M	3-32	3.8*	4-100	1.0-137	<205	1240-6220	3-25	340-46500	450-78000

Table 3. Aquifer parameters and groundwater quality of hydrologic basins of Balochistan. H - E - L: Hamun-E-Lora, H - E - M: Hamun-E-Mashkhel. Asteric represents average values of specific yield/storage coefficient.

Hydrologic Basins	Recharge (1983)	Discharge (1983)			Estimated Potential	
		Springs+Wells + Baseflow	Evapo-Transpira-tion	Total	1983	1993
Zhob	1077	660	417	1077	112	76
Nari	356	141	215	356	107	89
Kachhi	1833	1682	151	1833	85	62
Pishin	601	303	298	601	129	NIL
Mula	69	31	38	69	23	14
Gaj	94	30	64	94	34	16
Porali	397	125	272	397	138	98
Hingol	501	223	278	501	150	132
H - E - L	45	7	38	45	25	20
Dasht	162	70	92	162	46	36
Rakhshan	44	13	31	44	26	20
H - E - M	178	57	121	178	61	56

Table 4. Groundwater balance and potential of hydrologic basins of Balochistan. All values are in million cubic meters per year (Mm^3/y). H - E - L: Hamun-E-Lora, H - E - M: Hamun-E-Mashkhel. Perennial baseflow of streams/rivers are consi-dered part of groundwa-ter.

The baseflow of other streams/ rivers varies from 0.47 to 4.7 Mm^3/y. The flood flow-base-flow ratio is about 2:5, the lower ratio represents western winter rain basins and the higher represents eastern basins with dominance of monsoonal summer rains. The perennial baseflow of rivers and streams are considered as a part of groundwater.

In all basins and sub-basins the depth of water level ranges from 1-79 meters. It is deepest in Nari, Pishin and Zhob basins. In general the groundwater attains its maximum levels from January to April and lowest from September to December. Hydraulic gradient is lowest in Hingol and Dasht basins and highest (48 m/km) in Mula River basin. The tubewells of very low discharges i.e., 4-23 m^3/h (cubic meter/hour) and upto 100m^3/h have been installed in all river basins. The tubewells of highest yield have been observed in Zhob river basin. The specific drawdown is lowest in Dasht River basin and about 137 m/100m^3/h (meter per hundred cubic meter per hour) in other river basins (Table 3).

The aquifer characteristics show wide variations from basin to basin and within sub-basins (Table 3). The lowest values of permeability (1.223-56m/d) were observed in Mula River basin and highest (0.978-428 m/d) in Porali River basin. The transmissivity ranges from 10 m^2/d in Hingol River basin to 27,000 m^2/d in Porali River basin. The specific yield/storage coefficient values vary between 3-25%; the highest values observed in Mula, Hingol, Rakhshan and Hamun-E-Mashkhel basins. The piedmont areas contributes major amount of recharge to the aquifers developed in valley fill sediments. The fractured consolidated and karstified rocks formed recharging boundaries where adjacent to piedmont deposits. The groundwater moves from recharge area or from the basin periphery to its center and follow the drainage pattern. The total piedmont area of all river basins is about 39,092 km^2 which is about 14% of the total catchment area. The piedmont areas of Hamun-E-Mashkhel basin is 10,330 km^2, whereas Nari and Hingol basins piedmont are greater than 5,000 km^2. Precipitation is the major source of recharge in all the basins. Winter rains of low intensities are more effective for groundwater recharge as compared to summer rainfalls. Other sources of recharge are channel and flood flows. For recharge calculations about 5% and 20% values were taken of average annual floods and annual rainfalls over mountain highlands respectively (Hydrogeology WAPDA 1982-84). The recharge values of river basins vary between 44-1,833 Mm^3/y and the cumulative recharge is about 5,357 Mm^3/y. Basinalgroundwater balance and potential estimates are tabulated in Table 4.

About 96% water supply schemes of Balochistan are based on groundwater. Groundwater abstraction for irrigation represent probably greater than 90% of the total withdrawal. Irrigation return is considered negligible (Hydrogeology WAPDA 1982-84) and the annual potential evapotranspiration exceeds rainfall throughout the year in many basins/sub-basins. Springs, Karazes, dugwells and tubewells are the major source of groundwater abstraction with a cumulative discharge of 3,342 Mm^3/y which is maximum in Kachhi and Zhob basins. The groundwater loss through evapotranspiration varies from 31-298 Mm^3/y. The total evapotranspiration of all basins is about 2,015 Mm^3/y, which is about 38% of total recharge (Government of Balochistan 1989).

The estimated total groundwater potential of 12 basins for future utilization as calculated by WAPDA during 1983 was 936 Mm^3/y which was decreased to 619 Mm^3/y during 1993. For Pishin river basin it was estimated by WAPDA during 1993 that no groundwater potential is available for future development. The yearly decrease in groundwater potential of other river basins vary from 0.8-5.3%. The yearly decrease is maximum in Gaj, Mula and Zhob river basins and very limited amounts of groundwater is available for future utilization. The groundwater conditions for further development are satisfactory for Hamun-E-Mashkhel, Hamun-E-Lora and Hingol river basins. The groundwater monitoring results of selected basins of Balochistan verify the depletion of groundwater potential estimates. Groundwater monitoring of Pishin River basin from 1989-96 indicate a continuous decline of water table from 0.2-3.5 m/y (meter per year) in Quetta sub-basin, 0.1-3.2 m/y in Mastung sub-basin and 2.7 m/y in Mangochar sub-basin (Bureau of Water Resources 1997).

The groundwater of all basins and sub-basins are of different chemical quality, the concentrations of $NaHCO_3$, Na_2SO_4 and NaCl are maximum. The concentration of total dissolved solids (TDS) ranges from 240-53,000 mg/l (milligram per liter) and the electric conductivity (EC) values ranges from 350-78,000 mm/cm (millimeter per centimeter). The quality of groundwater is generally good in Zhob, Pishin, Mula and Gaj basins. The poor quality of groundwater is common in Hamun-E-Lora, Dasht and Rakhshan river basins. In Kachhi, Porali, Hingol and Hamun-E-Mashkhel basins the quality of groundwater is saline to highly saline. The minimum and maximum TDS and EC values of individual basins are summarised in Table 3 (Government of Balochistan 1989; Bureau of Water Resources 1997).

CONCLUSIONS

Balochistan lacks a strong institutional base for survey, investigation and research in the fields of hydrogeology and groundwater resources. No systematic procedure exists to monitor and collect data for precipitation, recharge, runoff, baseflow, discharges and infiltration rates of all river basins. The available hydrometeorological, hydrological, hydrogeological, groundwater quality and to some extent the geological data are of reconnaissance level. Simple methodologies and assumptions were used to interpret the limited data. In some cases the data is incomplete or unreliable; considerable discrepancies are evident in different studies and reports. The following suggestions are presented hereto improve the present depleting and deteriorating conditions of groundwater resources of Balochistan:

1. A data collection network of all water related resources and groundwater monitoring of 12 river basins/sub-basins be established.
2. The available data are required to be refined through systematic investigations, detailed surveys and research programmes by involving higher educational institutions.
3. Numerical modelling of individual basins/sub-basins be made for precise groundwater balance and potential estimates.
4. A single authority or board be established under legal coverage to take measures for the planning, management and conservation of groundwater resources.

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A NATROLITE OCCURRENCE FROM BELA OPHIOLITE, KHUZDAR, PAKISTAN

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ABSTRACT

The zeolite mineral natrolite was found as fracture fillings in a slightly boudinaged dolerite dyke in serpentinized harzburgite, ESE of Hazarganji, Khuzdar District. The mineral occurs as up to 35 cm long acicular, bundle-shaped aggregates and as up to 12 cm long prismatic milky white or transparent crystals. The mineral was determined by X-ray techniques. Both, the shape of idiomorphic crystals and the low-temperature assemblage indicate a structurally highly (Si, Al)-ordered natrolite. The occurrence of natrolite is the result of low-temperature hydrothermal fluids causing serpentinization of the surrounding harzburgites and rodingitization of doleritic dikes. These processes are related to movements along the Ornach-Nal-Ghazaband Fault systems which affected the western parts of the Bela Ophiolite outcrops.

INTRODUCTION

Natrolite (ideally $Na_2Al_2Si_3O102*H_2O$) is a zeolite mineral which belongs to the structurally related series together with mesolite ($Na_2Ca_2Al_2Si_3O_{10}*8H_2O$) and scolecite ($CaAl_2Si_3O_{10}*3H_2O$). The name is derived from the Greek nitron=soda and lithos=stone. Orthorhombic natrolite was first described by Klaproth (1803). The structure of the mineral was determined by Pauling (1930), Taylor et al. (1933) and Meier (1960). The later showed that natrolite has an ordered (Si, Al) distribution. Gonnardite, a disordered "natrolite" found at Gignat, France, was first described by Lacroix (1896) and its structure was resolved by Mazzi et al. (1986) Recently, two other chemically similar minerals with close structural relationship were described as tetragonal tetranatrolite (Krogh et al. 1969; 1990; Chan and Chao 1980) and monoclinic paranatrolite (Chao 1980). Tetranatrolite was observed at Llimaussaq, Greenland and both tetranatrolite and paranatrolite were observed as overgrowth on natrolite at Mont St-Hilaire, Quebec, Canada (Chan and Chao 1980; Chao 1980). A detailed work on the order-disorder and chemical relationship of the natrolite-group minerals was published by Alberti et al. (1995). In his work it was proposed that Si/Al ratios close to 1.5 indicate ordered natrolites and ratios <1.5 indicate disordered gonnardites. Ratios ≥ 1.5 indicate unusual genetic conditions (such as high H_2O pressures) where metastable paranatrolite forms, which under atmospheric conditions dehydrates to the more stable tetranatrolite. Tetranatrolite was so far found only in association with peralkaline intrusions. However a clear discrimination between natrolite, paranatrolite, gonnardite and tetranatrolite on chemical basis alone seems to be impossible (Alberti et al. 1995). The basic structure of natrolite is an aluminium silicate framework composed of (Si-Al) tetrahedra. Each oxygen is shared by two tetrahedra and the negative charge is balanced by cations (Ca, K, Na...) situated in cavities in between. The structure of the natrolite-group zeolites contains a fundamental chain-like unit of edge-shared tetrahedra oriented parallel to the c-axis (Fig.1).

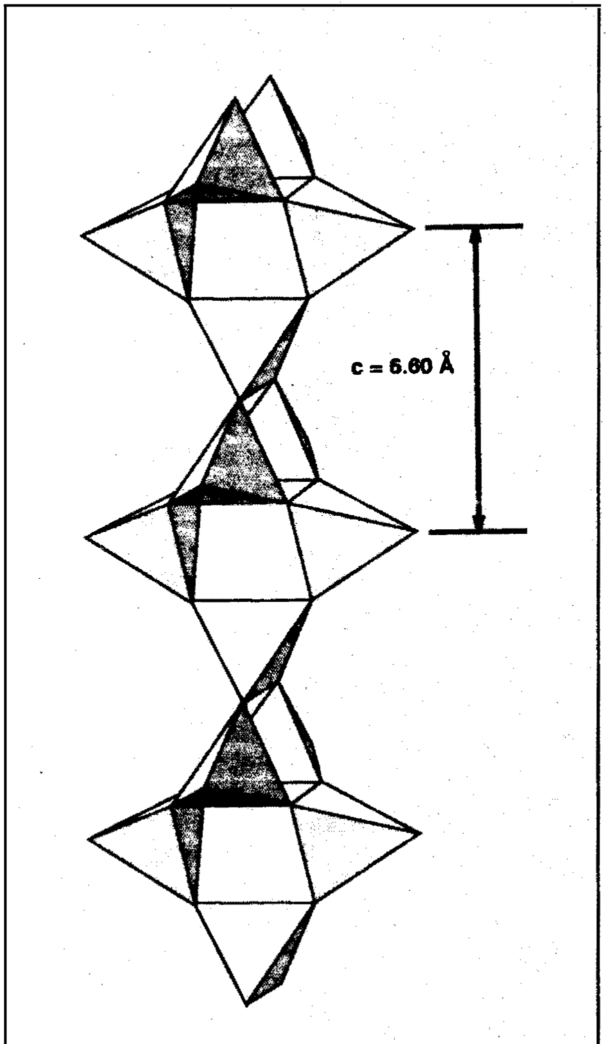

Figure 1. Basic chain-like orientation of Si, Al-tetrahedra in natrolite which explains the preferred fibrous growth of the mineral.

This is the reason for the "fibrous" morphology of this mineral group (Plate 1). Although natrolite is structurally related to mesolite and scolecite, it shows only limited solid solution with less than 0.5 Ca per unit cell present in natrolite. Other elements which may be present in small amounts in the structure are magnesium and potassium. Natrolite occurrences are characteristically associated with basaltic rocks, alkaline intrusions, basic rocks in serpentinites and salt lake environment (alkaline brines). In basaltic rocks well developed crystals form in vugs (e.g. Hegau, Germany, Faeroes island, Auvergne, Bohemia) or in association with hydrothermal alteration (e.g. seafloor metamorphism). Natrolite associated with alkaline intrusions is, for example, described from Kola, USSR, Llimaussaq, Greenland, San Benito, California and the Kimberley diamond mines. Natrolite associated with basic rocks in serpentinites is reported from the Borus Mountains (Judin 1963) and from the Johnston asbestos mine in Quebec, Canada (Poitevin 1938). Natrolite formation in association with alkaline saline brines is reported from Tanzania (Hay 1966), and from salt lakes in the USA. Similar occurrences can be expected in salt lakes in Pakistan (e.g. Ras Koh and Chagai areas). However to the best of our knowledge Natrolite from any part of Pakistan has not been reported so far.

REGIONAL GEOLOGY

The Bela Ophiolite is part of the Western Ophiolite Belt in Pakistan (Bela-Muslim Bagh-Waziristan) which was emplaced onto the edge of the Indo-Pakistani plate during Maastrichtian/ Paleocene (Allemann 1979; Mahmood et al. 1995). A nearly complete ophiolite sequence (Penrose Conference 1972) was mapped in the Sunaro area (Khan, in prep.). Peridotites and subophiolitic metamorphic rocks were intruded by doleritic dikes during the late stage of emplacement. After emplacement the ophiolite was folded (e.g. Sarwar 1992) and in several areas strongly faulted. This post-emplacement alpine fault tectonic and deformation resulted in serpentinization of the peridotites, and fracturing and rodingitization of doleritic dikes. The natrolites of this study are from a difficultly accessible peridotite massif, located ESE of Hazarganji, east of the Ornach-Nal Fault system (Fig. 2) The specimens are from monomineralic

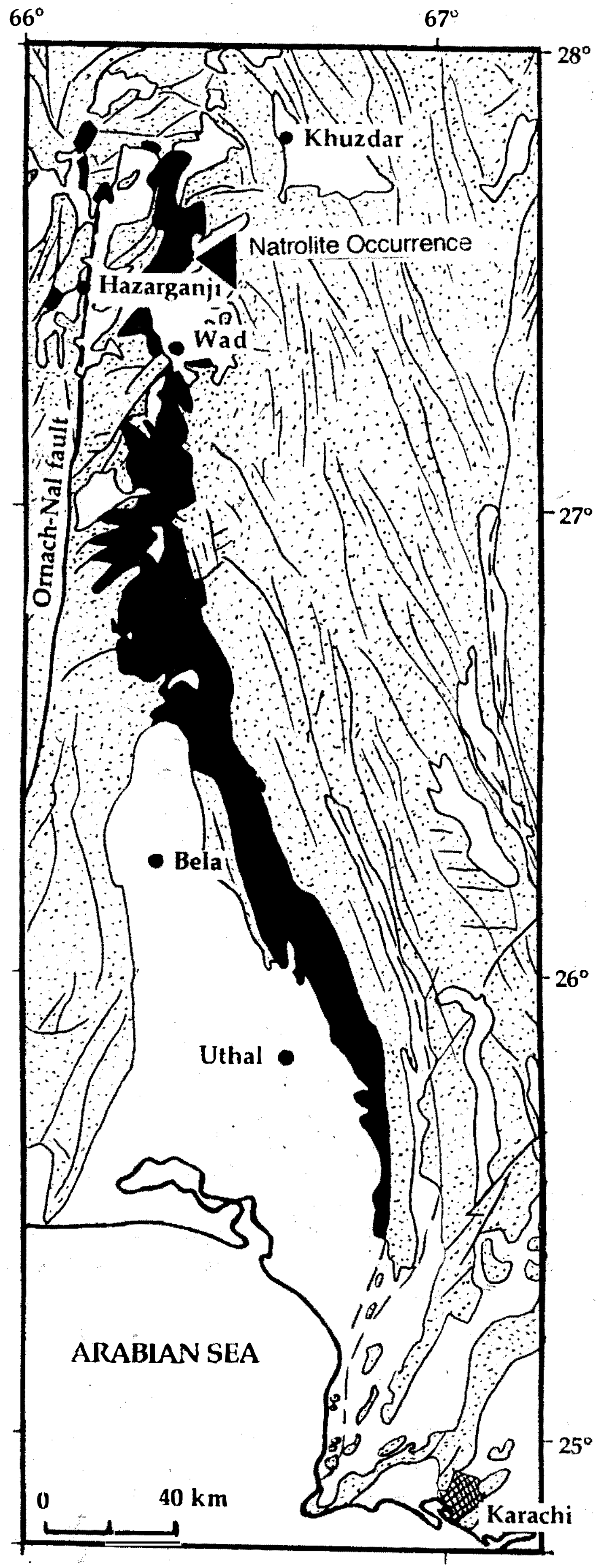

Figure 2.
Generalized map of the Bela Ophiolite (black) and surrounding Mesozoic and Tertiary rocks (stippled). The map is based on Hunting Survey Corporation (1961) and Sarwar & DeJong (1979).

crack fillings in a several meter thick dolerite dikes in serpentinized harzburgite. Only calcite (<2 vol.%) was found as part of the paragenesis with natrolite. Smaller dolerite dike in the serpentinized harzburgite of the same area are strongly rodingized and commonly boudinaged. White weathering is typical for rodingized dikes. The formation of boundins is associated with the formation of cracks and fissures in thicker (competent) dikes which are commonly covered with small (<1 mm-sized) "demantoid" (andradite) crystals. Fibrous xenotlite, $Ca_6(Si_6O_{17})(OH)_2$, the hydrous low-temperature analogue of wollastonite is also commonly found as fracture fillings. Three samples were analysed on a X-ray diffraction and on a Guinier apparatus and the mineral identified as natrolite. Most of the natrolite crystals occur in the form of a dense milky-white mass filling the cracks completely. A few cavities contained freely-grown white to transparent crystals which allowed a study of the morphology. The crystals are morphologically simple with dominant {110} prism and {111} pyramid, and smaller {100} prism and {101} pyramid (Fig.3, Fig.4). The lack of a centre of symmetry is evident on one double-terminated crystal which is unequally developed on either end. The samples show no fluorescence in long or short-wave ultraviolet light, although fluorescence was described for other samples (Laurent 1941).

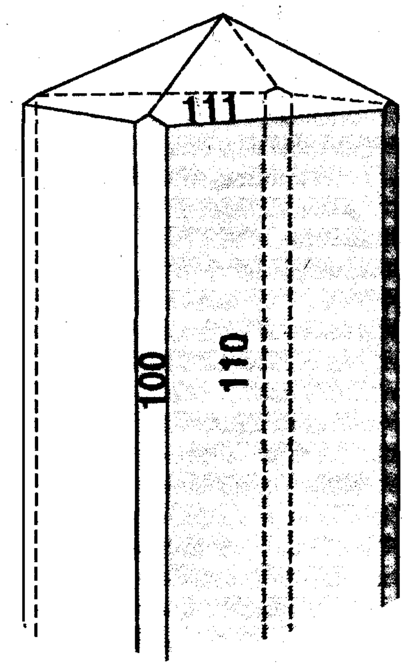

Figure 3. Morphology of the natrolite of this study. The {110} form is sometimes absent, where-as in some twinned crystals a second pyramidal form {311} was observed (see Fig. 4)

DISCUSSION

Heating experiments by Van Reeuwijk (1972) showed that natrolite dehydrates and transforms to metanatrolite at 285°C under atmospheric pressure. On the other hand, natrolite can grow under atmospheric conditions in saline lake basins. In natural hydrothermal assemblages, fibrous zeolites generally occur in the highest temperature zone (Alberti et al. 1995). Thus comparing similar occurrences, and the presence of demantoid and xenotlite allow a conservative estimate of 150-285°C for the natrolite formation of this study. The proposed low-temperature hydrothermal origin of the natrolites also suggest a structurally strongly ordered natrolite (Alberti et al. 1995). The natrolite formation is related to fault tectonics in this area which are the result of alpine tectonics. The alpine tectonic in this area is closely related with the extrusion of the Afghan Block due to the Himalayan collision (Tapponnier et al. 1981) which occurred mainly along the Chaman, Ornach-Nal, Ghazaband and other parallel fault systems. The compressional tectonic also caused an outward rotation of the Khuzdar Block, enhancing formation of faults in the Northwestern part of the Bela Ophiolite (Bannert et al. 1992). Natrolite is probably not an unusual mineral in Pakistan and can be expected in vugs in alkaline lavas or in hydrothermal veins associated with alkaline intrusions, as well as in alkaline lake deposits.

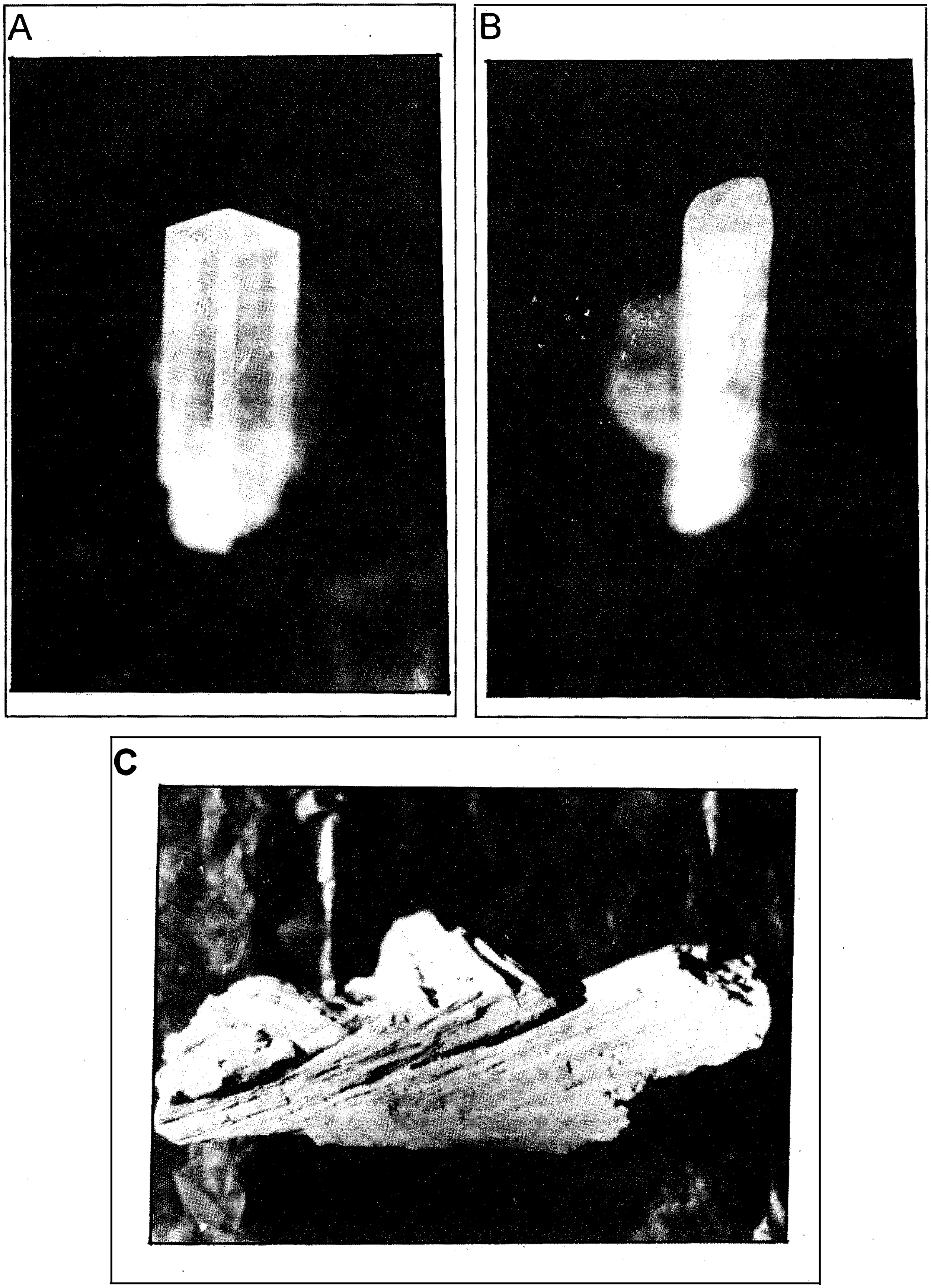

Figure 4. Photographs: (A) a 5cm long, transparent crystal showing the morphology drawn in Fig. 3.; (B) a 6 cm long twinned crystal of natrolite with second {311} pyramide developed; (C) 30cm long bundle-shaped, fibrous natrolite.

The crystal size of up to 35 cm and the development of idiomorphic crystals of this occurence, however, are exceptional. Many good crystals of Natrolite collected in the field, are now displayed in the Museum of Centre of Excellence in Mineralogy, University of Balochistan, Quetta.

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FACIES AND PALEOENVIRONMENTS OF THE ALOZAI GROUP (TRIASSIC), NORTHEAST BALOCHISTAN, PAKISTAN

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ABSTRACT

The Alozai Group consists of a thick sequence of thin bedded, fine grained, arenaceous limestone with shale interbeds. The limestone is mostly characterized by sedimentary structures such as graded bedding, parallel and cross laminations, convolute lamination, flute marks and groove marks indicating deposition by turbidity currents. The interbedded black shale is mostly hemipelagic/pelagic with some associated mud, which may have been introduced by turbidity currents. The low diversity of bioturbation, black colour of the pelagic shale and gradual change in colour from greenish grey to dark grey in the turbiditic mudstone suggest deposition in low oxygenated bottom water conditions. The lack of abundant slump beds indicate that the sediments were deposited at the base of the slope. However, some beds show small (10-50cm) localized slumps. The limestone dominated sequences show small scale (mostly less than 5m) commonly thickening-upward, less commonly thinning-upward and occasionally symmetrical cycles that are interpreted as allocycles.

INTRODUCTION

The Triassic carbonate flysch sequence, Wulgai Formation of Shah (1977) and Alozai Group of Hunting Survey Corporation (1961) is 800-1000m thick and comprises thin bedded, fine grained arenaceous limestone and inter-bedded shale. These rocks are exposed in a continuous strip from Kozh Kach (12 Km east of Khanozai) to Alozai Village (24 Km east of Qila Saifulla), near Wulgai Village and Tangai Village (Fig. 1). Otsuki et al. (1989) differentiated these rocks into "true Alozai Group" and "false Alozai Group" on the basis of lithofacies and fossil assemblage. They believe that the rocks of the false Alozai Group are older and were deposited on the Tethys Ocean Floor, and obducted as a result of the closure of Tethys Ocean.

Kassi (1986) was the first who recognized carbonate turbidites in a small section of the Alozai Group exposed as a thrust slice near Tangai Village which inspired the authors to visit the Alozai Group exposed along the southern margin of the Zhob Valley, in the northeast Balochistan. This study is mainly concerned with the sedimentology of the true Alozai Group, emphasizing on the palaeo-environments and depositional processes. For this purpose, the bed thickness, sedimentary structures, grain size and lithologic variations were studied in detail near Qila Saifullah, Kozh Kach and Tangai Village.

FACIES

Based on lithology, Alozai Group can be divided into two main facies, that are limestone and shale (Fig. 2) with some nodules of chert. The overall ratio between limestone and shale is variable in different places. The Kozh Kach section is dominated by shale with subordinate interbedded limestone (Fig. 3) whereas the Qila Saifullah (Fig. 2) and Tangi Village sections show more or less equal proportion of the limestone and shale characterized by rhythmic alternations of limestone dominated and shale dominated sequences.

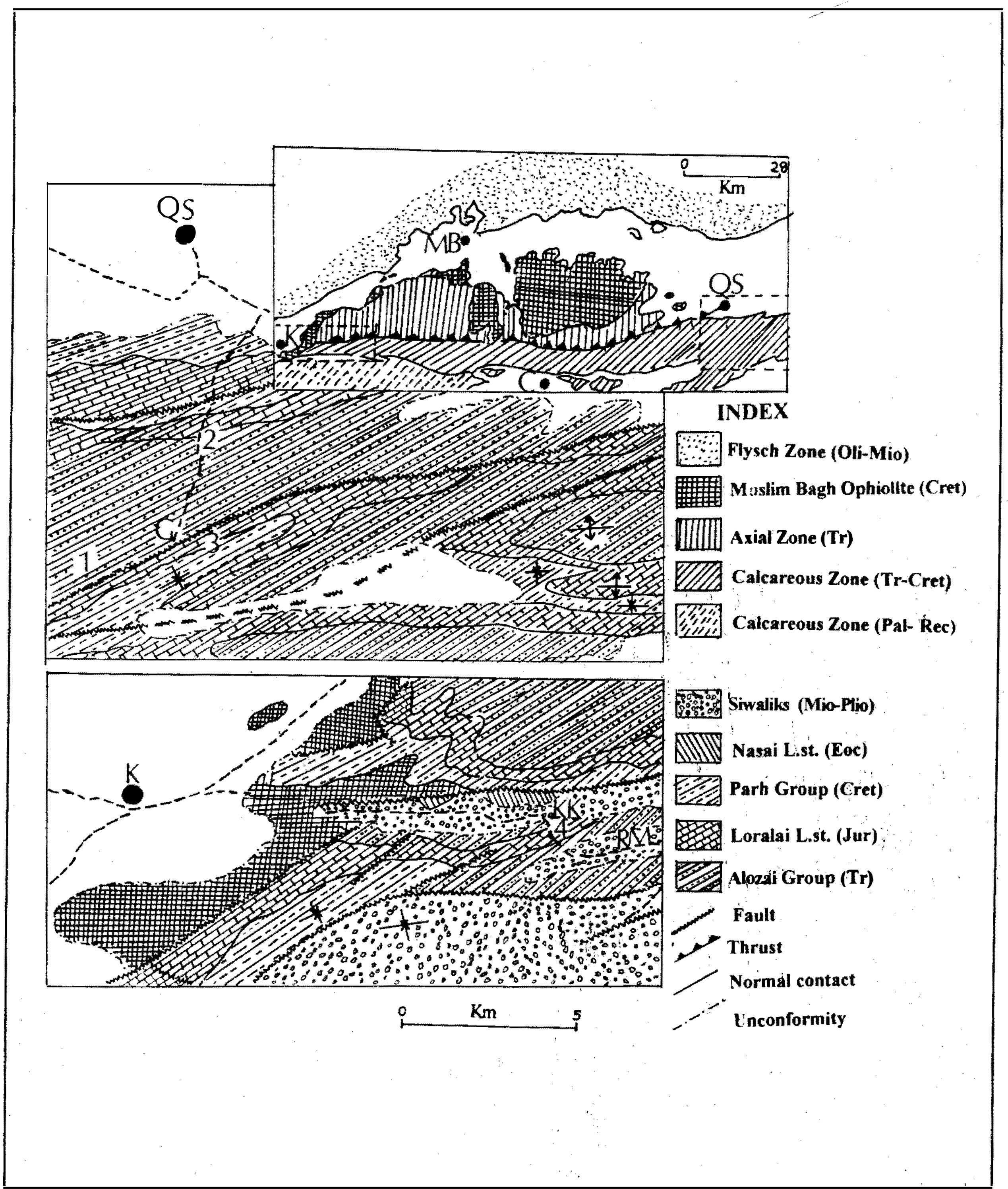

Figure 1. Geological map of the studied area and surroundings showing outcrops of the Alozai Group and locations of the sections studied. 1, 2, 3 and 4 represent locations of the sections measured. QS (Qila Saifulla), MB (Muslim Bagh), K (Khanozai), G (Gharang), C (Chingan), KK (Kozh Kach) and RM (Rud Malazai).

LIMESTONE FACIES

This facies constitutes 40 percent of the total succession of the Alozai Group and occurs interbedded with shale. Bed thickness is quite variable, ranging from less than 1cm up to 30cm. However, limestone beds between 5cm to 10cm are very common. The thinner beds are fine grained (dominanted by silt size grains), and the thicker beds may have medium to fine sand size particles and are classified as calcilutite and calcarenite respectively. Most of the beds are planar with sharp and occasionally slightly erosive lower contacts while the upper contacts is either sharp or gradational to the overlying shale. Grading in very fine grained beds is not obvious and is not discernable in outcrops, whereas thicker and coarser beds are well graded. Other internal sedimentary structures like parallel lamination and cross lamination are very common and occur in sequence comparable to Bouma (1962) sequence of internal sedimentary structures recognized in clastic turbidites. Only few beds possess a complete Bouma sequence. Beds showing Bouma Tbc, Tbcd, Tcde, Tcd and Tde sequences are common (Fig.4 & 5). Thicker beds are characterized by Bouma Tbc and Tbcd sequences while, thinner beds show Bouma Tcd, Tcde and Tde sequences. In some cases, apparently single bed may show more than one sequence of sedimentary structures with no obvious erosional surface between the adjacent ones. Amalgamated beds with erosional boundary between them are also present (Fig. 6). Sole marks like flutes, grooves and small load casts, and surface features like asymmetrical ripples are also common in this facies.

SHALE FACIES

This facies constitutes 60 percent of the total succession of the Alozai Group and occurs as thin partings between the limestone beds and as a thick interval (up to 2m) comprising several beds. Shale occurring as thin partings is generally dark grey in colour and highly cleaved. It is characterized by uniform bioturbation represented mainly by tiny *chondrite* burrows filled with darker material (Fig.7). It shows no obvious current induced sedimentary structures and has sharp boundaries with the overlying and underlying limestone beds (Fig. 6). Shale which occurs as thick intervals is well bedded with very thin (up to 5cm), lenticular bands of calcareous material at the base. On fresh surfaces, single bed of the apparently thick bedded shale consists of several small units ranging in thickness from less than 1cm up to 10cm. Each unit is characterized by greenish grey material at the base which gradually changes into dark grey at the top. It shows sharp and slightly erosive base with gradual upward increase in the bioturbation. In some cases, it is finely laminated at the base. Gradation can also be seen from the basal limestone bands to the overlying mudstones.

FACIES INTERPRETATION

Limestone Facies

Carbonate turbidites have been described from both ancient successions (Tucker 1969; Bernoulli & Jenkeyns 1970; Mackenzie 1970) and modern environments (Rusnak & Nesteroff 1964; Davies 1968; Schlanger & Johnson 1969; Bornold & Pikley 1971). They may constitute major part of the total volume of the deep marine sedimentary deposits.

The sedimentary structures like grading, parallel lamination, ripple-drift cross-lamination, flute and groove casts and bioturbation in the uppermost part of each unit suggest that the limestone facies of the Alozai Group is not in situ development but rather were deposited by turbidity currents. This interpretation is based on the following evidences:

i. This facies shows a large variety of current induced sedimentary structures characteristic of turbidites that are ripple-drift cross-lamination, flute and groove marks. Sedimentary structures (hummocky stratification, basal lags and wave ripples) diagnostic to storm deposits (Aigner 1982; Jeffery & Aigner 1982; Seilacher 1982) are absent in this facies.
ii. This facies exhibits conspicuous grading from base to top characteristic of the waning flow.

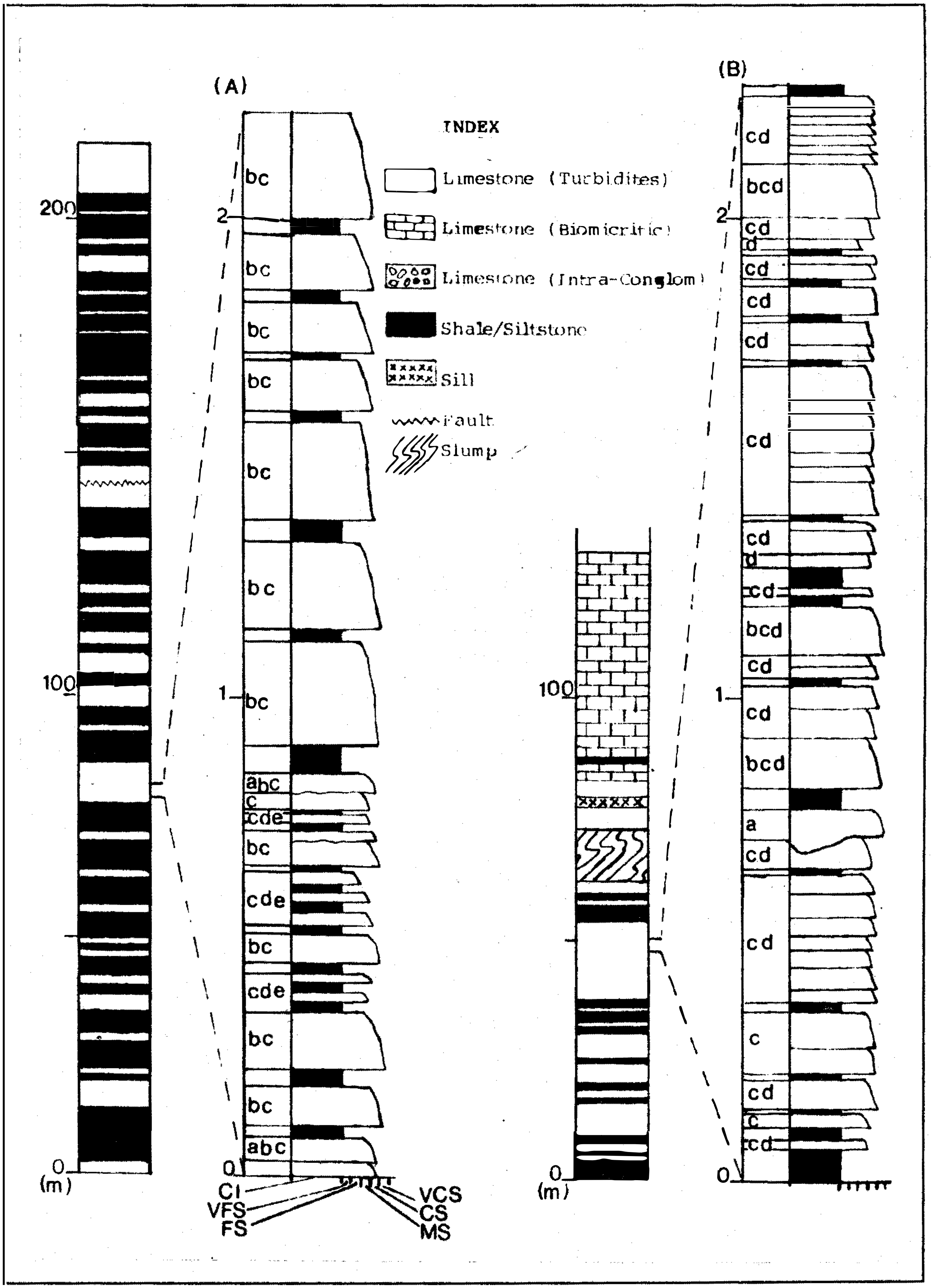

Figure 2. Sedimentary logs of the Alozai Group showing facies and facies associations in, (A) stream section near Garang area, southeast of Qila Saifullah, (B) road section, south of Qila Saifullah. a, b, c & d represent Bouma (1962) sequences. VCS (very coarse sand), CS (coarse sand), MS (medium sand), FS (fine sand), VFS (very fine sand) and Cl (clay/siltstone).

iii. The lack of bioturbation.in the limestone beds, except the overlying mudstone which is well bioturbated, indicate that the limestone units were deposited very rapidly allowing no organisms to thrive the sediments with subsequent repopulation of the organisms during inter-turbidity current periods.

iv. This facies shows various types of sedimentary structures characteristics of classic sandstone turbidites (Bouma 1962) and fine grained turbidites (Stow and Bowen 1980).

Major source of the limestone turbidite facies appears to be slope or deeper shelf. This is suggested by the lack of bioclasts diagnostic of shelf environments. Events such as periodic earthquakes triggered movement of unstable and uncemented accumulation of chemically precipitated sediments on the slope and generated downslope moving turbidity currents. The shale dominated, thin bedded, poorly graded, fine grained limestone sequence of the Kozh Kach section (Fig. 3) is believed to be distal equivalent of the coarser limestone succession of the Qila Saifulla area (Fig. 2).

Shale Facies

Recognition of depositional mechanisms and processes in very fine grained sediments (mudstones) is difficult, because in such sediments, primary sedimentary structures are either absent or not easily discernable both in the field and in the laboratory. Accordingly, they have been largely ignored compared to their associated coarser sediments. In most of the early studies of the turbidite sequences, all or most of the associated muds/mudstones were regarded as pelagic sediments deposited during interturbidite periods (Dzulynski et al. 1959; Gorsline and Emery 1959; Stanley 1963). However, numerous later studies have shown that considerable part of the deep sea mud/mudstone layers have also been deposited from turbidity currents (Kuenen 1964; Stanley 1970; Piper 1978). It is now well acknowledged that mud turbidites may constitute 80% of the total volume of the fine grained sediments deposited in the deep sea (Piper 1978; Einsele and Kelt 1982; Stow and Piper 1984; Stanley 1985; Porebski 1991).

The associated shale seems to be deposited by a combination of turbidity currents and pelagic settling. Shale occurring as thin partings between limestone turbidites was deposited by slow and continuous sedimentation (pelagic settling) during the intertubidity current periods. This interpretation is based on thorough and complete bioturbation, lack of any current induced sedimentary structures even in polished slabs and thin sections, sharp boundaries with overlying and underlying limestone beds. The rate of bioturbation was greater than that of sedimentation and animals had enough time to rework the sediments several times. Sediments most likely were derived from the shelf by resuspension by storm waves and some may also have been introduced from land through wind.

Shale occurring as thick interval with sporadic interbeds of limestone which is regarded here as distal sequence is believed to be the products of turbidity currents. This is indicated by discontinuous sedimentation. This is evidenced from multiple units of apparently single bed. Each unit is characterized by sharp and slightly erosive base with gradual increase in bioturbation, gradual change from greenish grey material at the base to dark grey at the top, and fine lamination at the base. Deposition took place from low velocity and low density turbidity flows in low oxygenated bottom water conditions. This is reflected from greenish grey sediments (aerated) at the base and dark grey material (nonaerated) at the top. Turbidity currents may have temporarily aerated bottom water through introduction of fresh water (Hulsemann and Emery 1961). The low diversity of burrows, mostly chondrites which are low oxygen tolerant animals (Wetzel 1984) also suggest oxygen-deficient bottom water conditions.

BATHYMETRY

Most of the features associated with the Alozai Group suggest that it was deposited inrelatively deeper water conditions (at least

Figure 3. Photograph of the Alozai Group from the Koz Kach section showing greater proportion of the shale.

Figure 4. Photograph showing geneal view of the limestone dominated turbidite sequence of the Alozai Group from road section south of Qila Saifullah

Figure 5. **Photograph of the limestone turbidites of the Alozai Group from road section south of Qila Saifullah showing close-up view of Bouma Tbcde and Tde sequences.**

Figure 6. **Photograph of the Alozai Group from the Qila Saifullah section showing erosional boundary at the base of the limestone turbidites. Interbedded pelagic shale is also seen.**

Figure 7.
Photograph of the polished slab of shale of the Alozai Group showing Chondrite Burrows. Sample is 13cm in length.

below wave base), however it is difficult to determine absolute water depth. Evidence for deep water origin includes: (a) absence of shallow water sedimentary features e.g. evaporites, fenestral fabric, (b) absence of any shallow water fossils, (c) low faunal density, (d) dark coloured nature of limestone and associated shale, (e) absence of wave formed sedimentary features suggesting deposition below wave base, (f) presence of deep water trace fossils e.g. paleodictyon and chondrites (Fig.7), (g) monotonous alternations of fine grained limestone and shale/marl. The rarity of the slumped beds indicates that deposition took place on flat area most probably at the base of the slope.

ENVIRONMENTS OF DEPOSITION

Turbidites have been described from a variety of modern environments (Nelson and Nilsen 1984; Stow 1985). The most important are submarine fans, slope aprons and abyssal plains. The recognition of such environments in ancient sequences usually is based on facies, facies associations, trends of bed thickness, grain size in vertical sequences (cycles) and understanding of the processes responsible for the formation of these cycles (Ricci Lucchi 1975; Walker 1978; Mutti 1985). Thinning- and fining-upward cycles have commonly been attributed to channel-filled deposits, whereas thickening- and coarsening-upward cycles have been interpreted as progradation of the depositional lobe (Mutti and Ricci Lucchi 1972, 1975; Ricci Lucchi 1975; Walker 1978). Submarine fan turbidites are characterized by channel and channel associated facies (levee and interchannel deposits).

The Alozai Group succession is characterized dominantly by small-scale (upto 5m thick) thickening upward cycles with some thinning upward and symmetrical cycles. The formation of thinning and thickening upward cycles can be influenced by external processes, such as sea-level changes, random variation in sediment supply and regional and/or local tectonics. A change in any of these three processes will cause a shift in the position of the shoreline. For example, a decrease in the sea level would shift the position of shoreline seawards which ultimately lead to an increase in the volume of sediments capable of being transported to the deeper part of the basin. Mutti (1985) suggested that much of the small-scale cycles in the turbidite sequences are probably the result of sea-level changes. Due to lack of facies and facies association diagnostic to submarine fan turbidite system (channel, levee and interchannel facies), it is suggested that sediments of the Alozai Group were deposited at the base of slope and the thickening- and thinning-upward cycles have been controlled externally (allocycles) rather than by depositional sites (autocycles).

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GOLDEN JUBILEE OF PAKISTAN ISSUE

CHEMICAL QUALITY OF GROUNDWATER OF QILA SAIFULLAH AREA, PART OF ZHOB RIVER BASIN BALOCHISTAN

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ABSTRACT

Detailed chemical analysis (i.e., salinity hazard, total dissolved solids concentration, residual carbonates, pH and concentration of individual cations and anions) to determine groundwater quality of Qila Saifullah area were carried out. The major constituents are magnesium, calcium, sodium, chloride, sulphate and bicarbonate with minor potassium and carbonate, although magnesium and chloride are predominant among them. The specific conductance (concentration of total dissolved solids), magnesium, chloride, calcium and sodium increase along the hydraulic gradient whereas carbonate and bicarbonate decrease. Sulphate and potassium are approximately same throughout the study area and under useable limits. Based on percentage of major anions and cations the hydrochemical facies are 1) magnesium chloride, magnesium chloride bicarbonate, magnesium chloride sulphate and magnesium mixed anion type, 2) Alkaline earth exceeds alkalies, 3) Non carbonate hardness (secondary alkalinity) exceeds 50 percent and 4) No anion-cation pair exceeds 50 percent. The groundwater of the studied area is not harmful to health and irrigation purpose as the salinity hazard is medium to high and sodium hazard is low. However, it is alkaline with the pH value more than 7.0 and the residual carbonates are absent. The soil and surrounding geology have influenced the groundwater quality of the studied area. When the water infilters through the pore spaces of soil and rocks, and perculates downgradient towards the zone of saturation, it dissolves different soluble constituents from such soil and rocks.

INTRODUCTION

This paper describes the chemical properties such as concentration of major anions and cations, alkalinity and salinity hazards, residual carbonates, total dissolved solids concentration and determines the quality of groundwater of the Qila Saifullah area for drinking and irrigation use. The study area is a part of Zhob River basin about 200 kilometers northeast of Quetta (Fig. 1). Various parts of Zhob River basin have been previously investigated, mainly for tubewell installtion, by many government agencies e.g. WAPDA, BDA, Irrigation and Power Department, Public Health Engineering Department and Agricultre Department (Halcrow 1995). However, no agency has carried out a detailed and systematic study of chemical quality of the groundwater in the study area.

All the streams of the area are ephemeral, so the groundwater is the only source for all purposes. Chemical characteristics of water resources of the area have been analyzed to evaluate their influence on drinking, irrigation and industrial use. The salinity hazard, alkali hazard, residual carbonates and concentration of boron are the main factors which influence the suitability of groundwater for irrigation use. The salinity hazard is expressed in terms of electrical conductivity in microsiemens per centimeter at 25°C. The excessive concentration of sodium over calcium and magnesium yields the sodium adsorption ratio (alkali or sodium hazard) (Richard et al. 1954).

Sodium adsorption ratio

$(SAR) = Na^{+} / \sqrt{(Ca^{++}+Mg^{++})/2}$

Where the ion concentration of the constituents are expressed in milli equivalent per liter. The residual carbonate is a measure of excess of the sum of the carbonates and bicarbonates over the sum of calcium and magnesium (Ragunath 1987).

Residual carbonates

$(RC)=(CO_3^{--}+HCO_3^{-})-(Ca^{++}+Mg^{++})$

The concentration of total dissolved solids (TDS) is calculated by the formula (Ragunath 1987)

Total dissolved solids (mg/l) $(TDS)=0.64xEcx10^{6}$

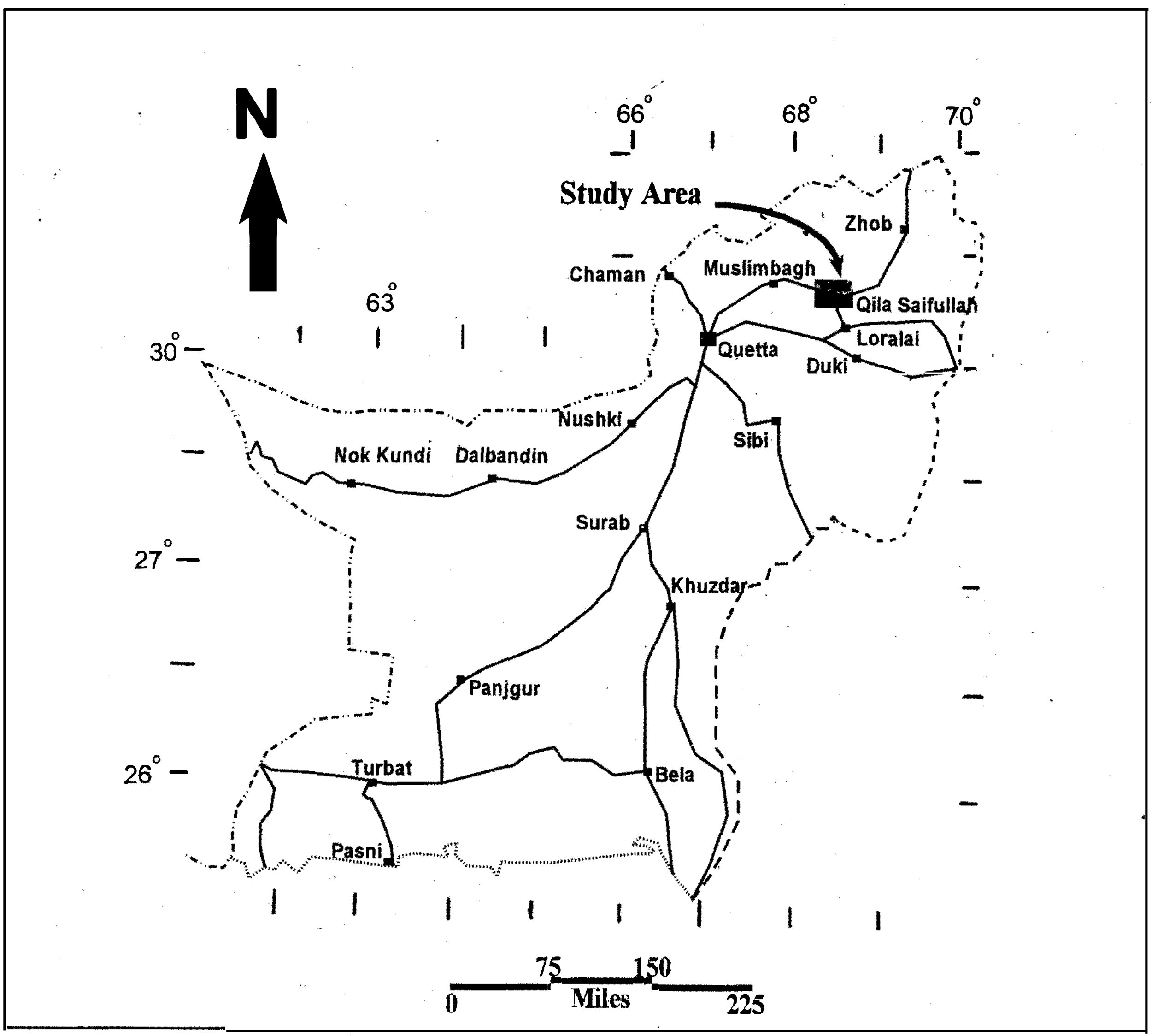

Figure. 1 Road map of Balochistan showing location and accessibility of the study area.

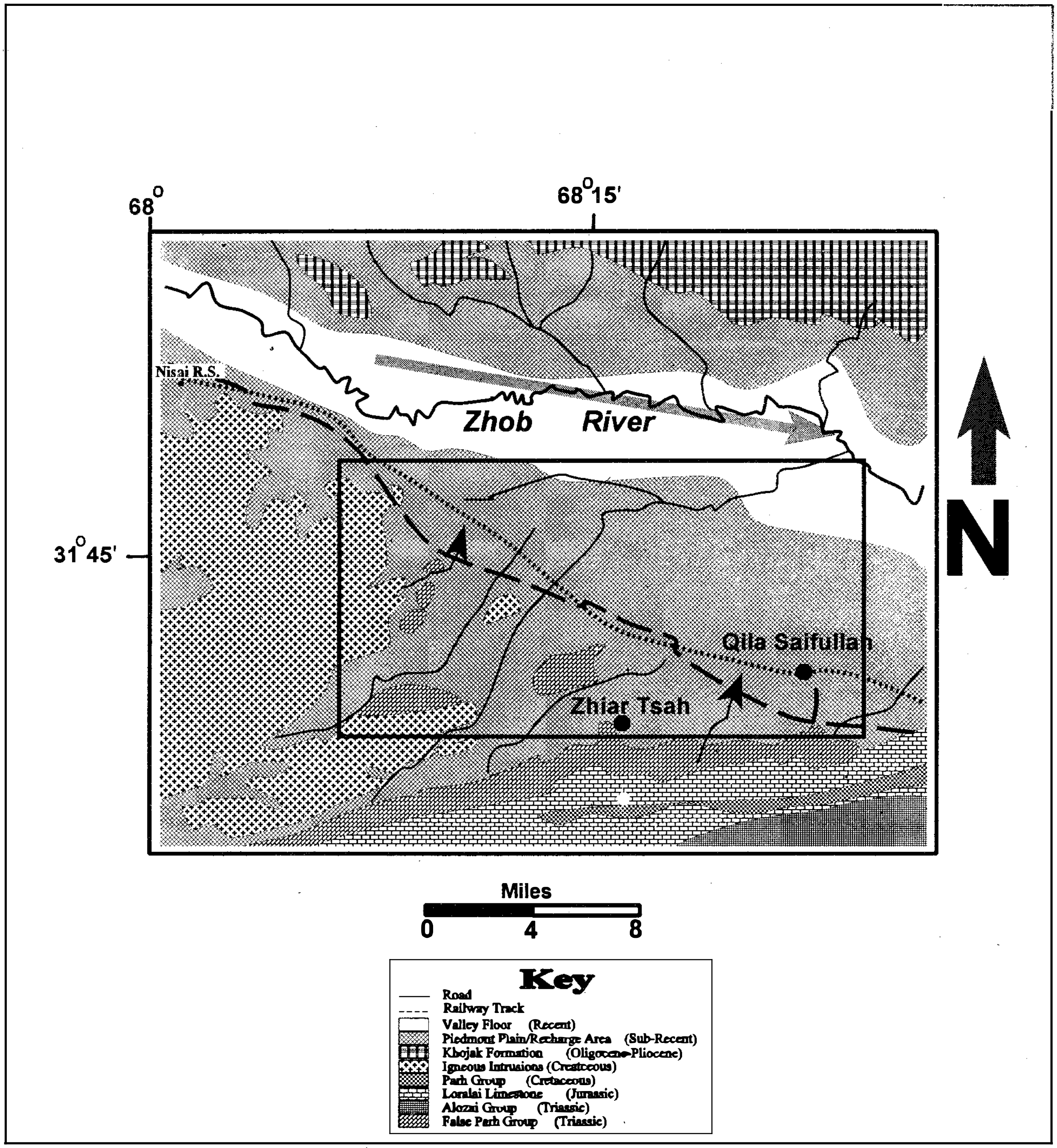

Figure 2. Map showing the general geology of the study area. The inside box shows the area for hydrochemical survey covered during this study. The arrow shows the direction of flow.

METHODOLOGY

Water samples were collected for 36 scattered tubewells throughout the study area. All the aquifers are of unconfined type ranging in depth from 32.9m to 152.4m below general ground surface. Temperature, colour, taste and electrical conductivity were determined in the field. The electrical conductivity was measured by using conductivity meter (Jenwey Model 4060). The intensity measurements (concentration of sodium and potassium) were made with flamephotometer Perkin - Elmer model 52 (Richard et al. 1954). All reagents were of analytical grade and distilled deionized water was used in all experiments. The stoch solution of sodium and potassium were prepared by dissolving known quantity in water. Working

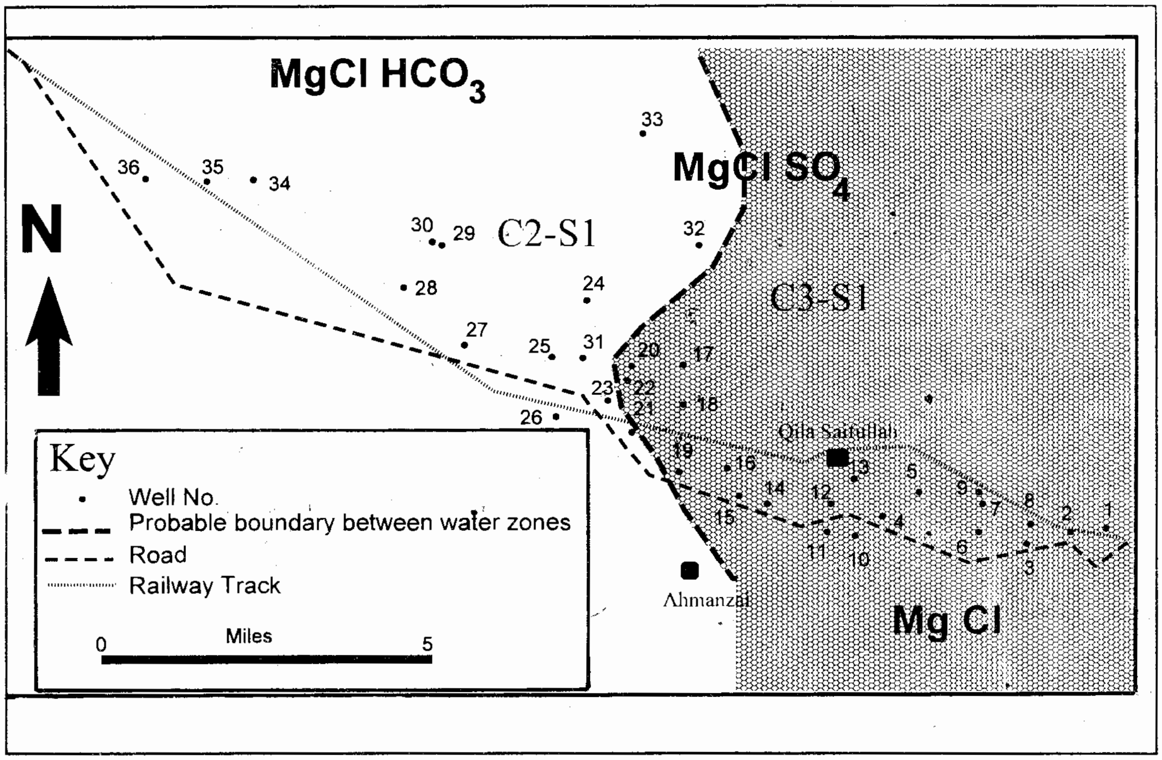

Figure 3. **Well location map showing the hydrochemical facies and water classes based on specific conductance and SAR values.**

standards containing both sodium and potassium were prepared by appropriate dilution covering the ranges 1mg/l to 6mg/l potassium and 5 mg/l to 35mg/l sodium. The pH value was determined with pH meter (model-72 Beckman chem-Mate). Calcium and magnesium were determined by titration with ethylene diamine tetra acetate while carbonate and bicarbonate were determined by titration with sulphuric acid, and sulphate were determined by titration as barium sulphate (Richard et al. 1954).

RESULTS AND DISCUSSION

The specific conductance in the groundwater of the Qila Saifullah area ranges from 523 microsiemens per centimeter to 2266 microsiemens per centimeter. The groundwater of study area may be grouped into C2 and C3 with the exception of one sample (QS-6) which falls in the C4 class (Fig.3 & 7). Since the sample No. QS-6 is very close to the boundary of C3 , it may be considered in C3. The specific conductance of groundwater in the Nisai area is from 670 to 2320 microsiemens per centimeter and are classed as C2 and C3 (BDA 1981). The sodium adsorption ratio (SAR) is a measure of sodium hazard. The SAR value is very low in the investigated area i.e., 0.04 to 0.39 and are grouped as S1 (Fig. 3 & 7) while in the Nisai area it ranges from 0.6 to 6.8. The chief constituents in the groundwater of Qila Saifullah area are calcium, magnesium, chloride, sulphate and bicarbonate with minor sodium, potassium and carbonate. In the Nisai area (adjacent to the west of the study area) magnesium, sodium, bicarbonate and chloride are the dominant constituents with sulphate and calcium as a minor constituents (BDA 1981). Magnesium and calcium concentrations range from 4.1 meq/l to 29.6 meq/l and from 0.6 meq/l to 6.4 meq/l respectively. Both calcium and magnesium increase along hydraulic gradient (Fig. 4c,d) whereas water in the central part of the valley is dominant in calcium and magnesium (Fig. 5c,d). Sodium and potassium range from 0.19 meq/l to 1.47 meq/l and 0.03 meq/l to 0.15 meq/l respectively. Sodium is higher in the valley floor (Fig. 5e). The chloride is principal constituent among the anions that ranges from 1.0 meq/l to 8.65 meq/l. The concentration of sulphate ranges from 0.08 meq/l to 6.4 meq/l and bicar-

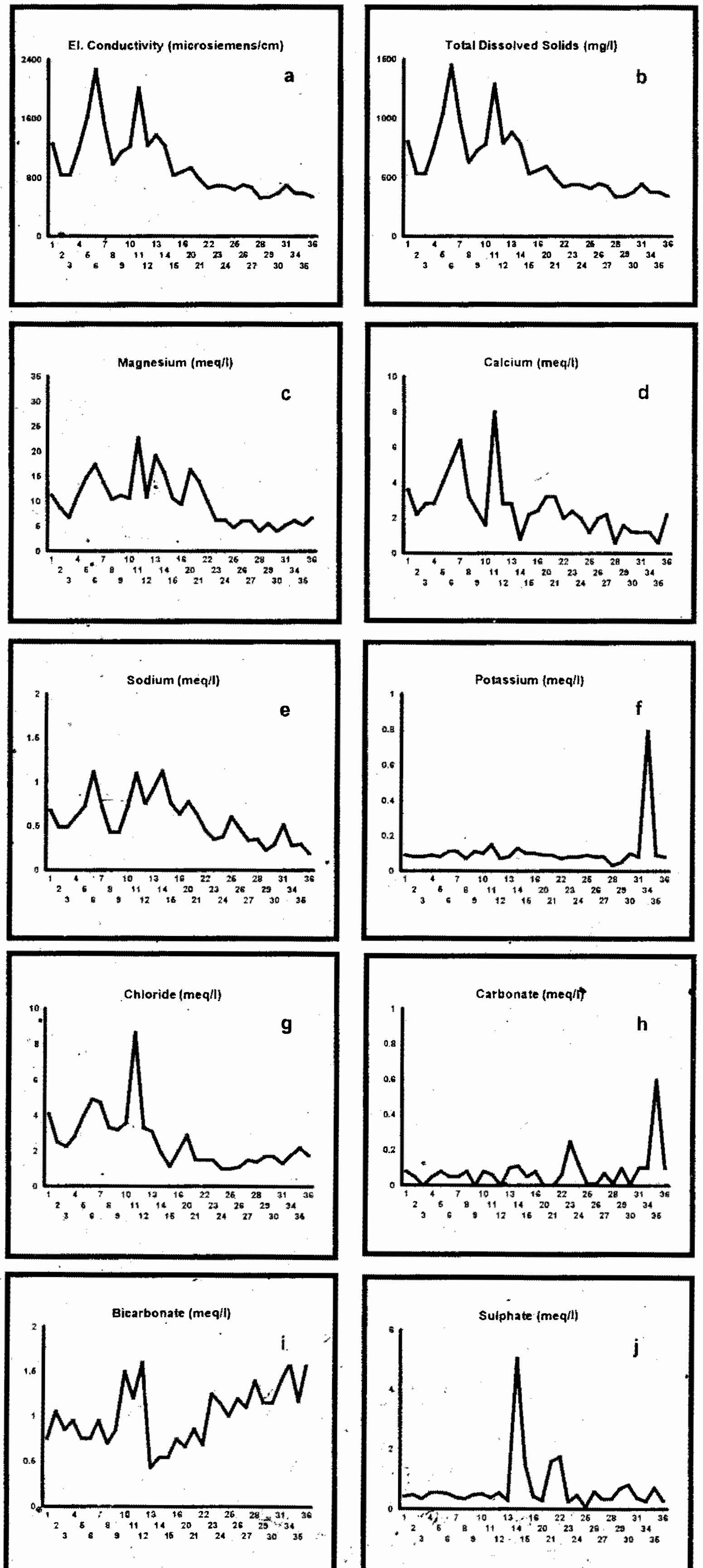

Figure 4.
Plots showing the trend in the change of Concentration of cations, anions and other papameters along (NE-SW) the Zhob River Valley. Concentrations are shown along the Y (vertical) axis, whereas the Well No. from where the water samples were collected are given along the X (horizontal) axis. Loca-tion of the Wells are given in Fig. 3 and the results of the chemical analyses are tabulated in Appendix.

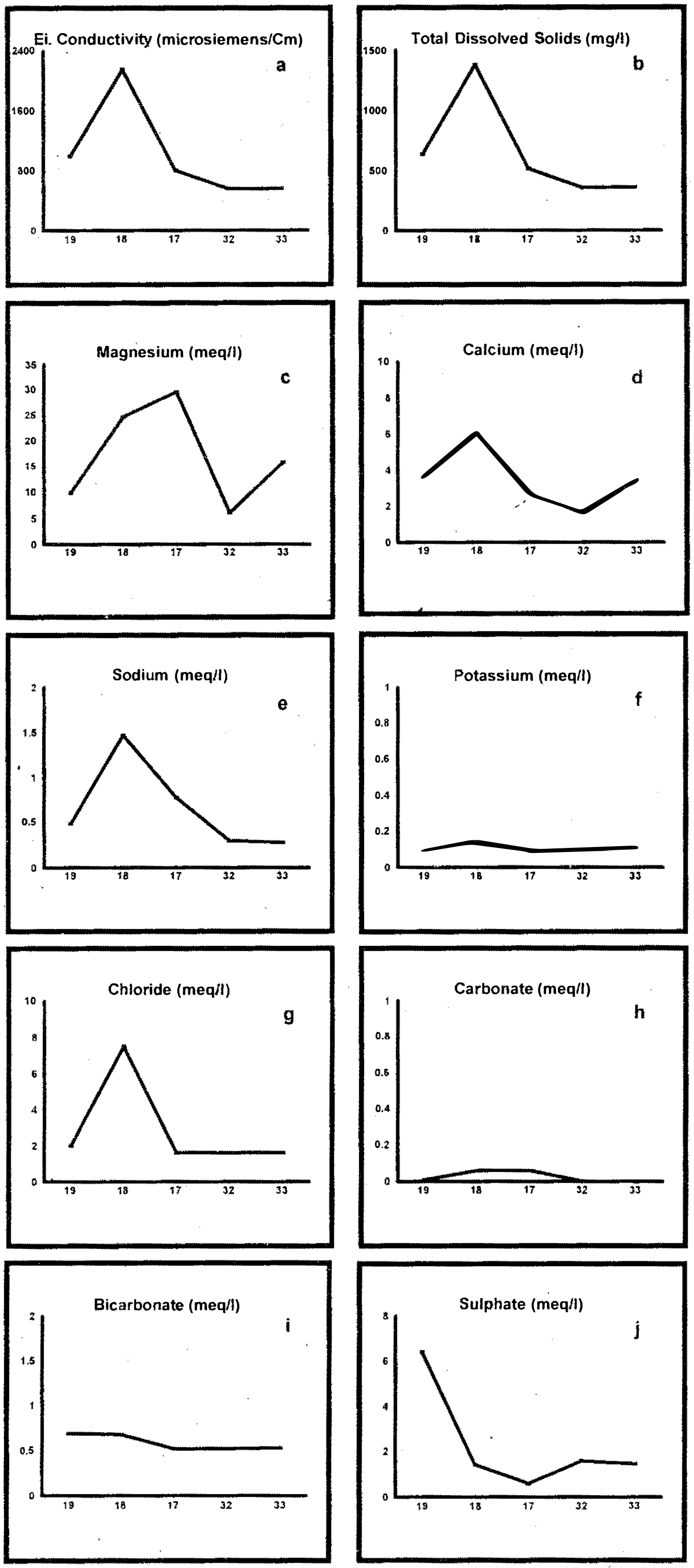

Figure 5.
Plots showing the trend in the change of Concentration of cations, anions and other papameters across (E-W) the Zhob River Valley. Concen-tration are given along the Y (vertical axis) and Well No. from where the wa-ter samples were collec-ted are shown along the X (horizontal) axis. Location of the Wells are given in Fig. 3 and the results of the chemical analyses are tabulated in Appendix.

bonate concentration ranges from 0.43 meq/l to 1.63 meq/l. The chloride increases along the hydraulic gradient whereas carbonate and bicarbonate decrease along the hydraulic gradient (Fig.4g, h, i). The concentration of chloride and sulphate is higher in southern part of the area (Fig. 5g, j). The total dissolved solids in study area ranges from 341 mg/l to 1450 mg/l . The total dissolved solids in the Nisai area is 484 mg/l to 1660 mg/l (BDA 1981). The total dissolved solids increase from west-northwest to east-southeast (Fig. 4b). However groundwater in the northern part of the study area is characterized by low concentration of total dissolved solids (Fig. 5b). In Nisai area the pH value of the groundwater ranges from 7.6 to 8.8 (BDA,1981) whereas in the Qila Saifullah its value ranges from 7.66 to 8.97 and is classified as alkalin

The term hydrochemical facies refers to a classification based on the proportions of major cations and anions in the natural water (Back 1961; Pipper 1944; Peter et. al. 1992; Robertson 1991). Using the classification proposed by Piper (1944) the groundwater of the study area (Fig. 6) are classified into the following zones.

Zone	Groundwater Characteristics
1	Alkaline earth exceeds alkalies
6	Non carbonate hardness (secondary alkalinity exceeds 50 percent)
9	No cation-anion pair exceeds 50 percent.

Two major hydrochemical facies dominate the groundwater in the study area, which are magnesium chloride and magnesium chloride bicarbonate whereas the minor hydrochemical facies are magnesium chloride sulphate and magnesium mixed anions (Fig.3 & 6). The groundwater in the southeastern part is of magnesium chloride type, in the northwestern part is of magnesium chloride bicarbonate type and in the northeastern part (valley floor) is of magnesium chloride sulphate type (Fig. 3).

Factors to be considered in evaluating the usefulness of groundwater for irrigation are, the concentration of total dissolved solids, the concentration of individual constituents, the relative proportion of the constituents, the nature and composition of the soil and subsoil, the topography of the land, and position of the groundwater table (Walton 1970). The most important factors which affect water quality for agriculture are, silt, the total concentration of salt, the proportion of sodium to other cations and special toxic ions like boron or from some crops chloride, sodium or bicarbonate (Thorne and Peterson 1954).

The quality of dissolved constituents in a natural water depends primarily on the types of rocks or soils with which the water has been in contact and duration of contact (McKelvey 1974). Calcium is widely distributed in the earths crust and is present nearly in all waters (Garg 1978). Groundwater in contact with sedimentary rocks of marine origin derive most of their calcium from solution of calcite, aragonite, dolomite, anhydrite and gypsum (Davis and Dewiest 1966). Calcium is dissolved from almost all rocks and soils, but the highest concentrations are usually found in waters that have been in contact with limestone, dolomite, and gypsum (McKelvey 1974). Magnesium is dissolved from many rocks particularly from dolomitic rocks (McKelvey 1974). Magnesium is one of the most abundant elements in igneous rocks (Garg 1978). The carbonate and bicarbonate are dissolved in natural waters from carbonate rocks (McKelvey 1974). Sulphate is dissolved from most sedimentary rocks and some types of shale (McKelvey 1974). Most chloride in groundwater comes from ancient sea water entrapped in sediments, solutions of halite and related minerals in evaporites, concentration by evaporation of chloride continued by precipitation and solution of dry fallout from the atmosphere (Walton 1970). The primary source of most sodium in the groundwater is from the release of soluble products during weathering of sodic plagioclase (Davis and Dewiest 1966). Clay minerals may release large quantities of exchangeable sodium (Walton 1970). Common sources of potassium are the products formed by the weathering of orthoclase microcline, biotite, leucite, and nephline in igneous and metamorphic rocks (Walton,1970).

Physiographically the area can be categorized into three segments that are mountain highlands, piedmont plain, and valley floor (Fig. 2). The water of precipitation drains from mountain highlands towards valley floor, and further moves downgradient in the Zhob River (Fig. 2).

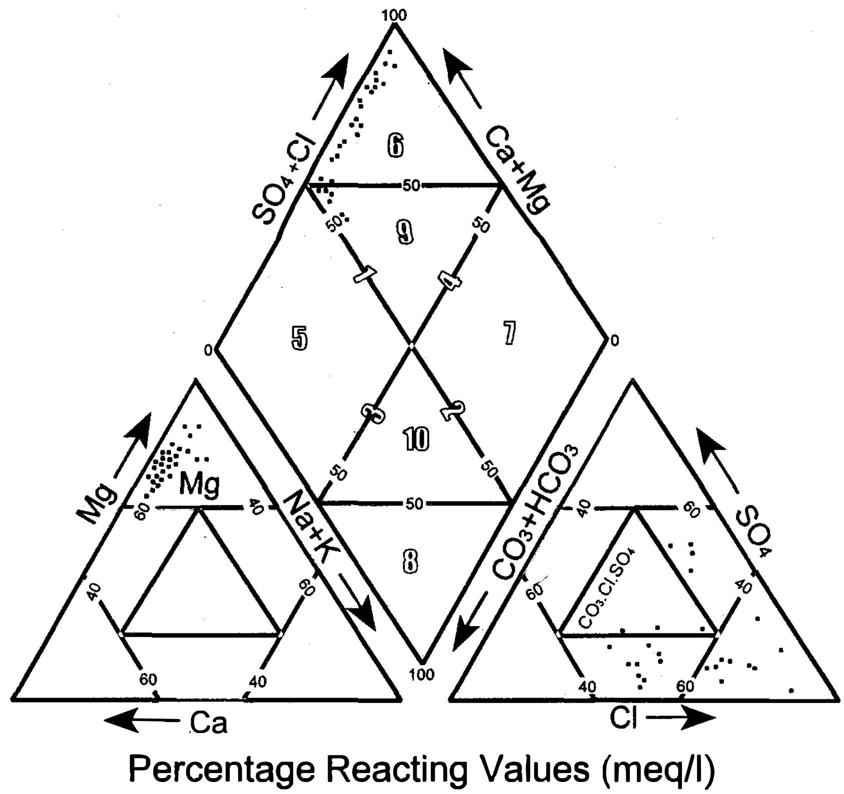

Figure 6. Hydrochemical facies of groundwater of Qila Saifullah (after Piper 1953).

The piedmont plain which contains porous and permeable deposits like sand, gravel with minor clay, is the main recharge area for groundwater, although infiltration also occurs from the banks and beds of the Zhob River and other small tributaries. The rain water dissolves and carries different constituents from the soil and rocks to contaminate groundwater naturally as it percolates towards the zone of saturation.

The geology and soil are the main causes that effect the quality of groundwater in the study area. The geology and the water bearing properties of different rock units exposed in the study area are summarized in Table 1. The soluble salts present in the soils are mostly chloride, magnesium, sulphate and sodium. The soils of the area have been formed from the alluvium derived mostly from sedimentary rocks containing generally limestone, shale, sandstone, and igneous intrusions. Texturally the soil are coarse to moderately fine, well drained, permeable, and slightly to strongly calcareous. The hydrogen ion concentration (pH) of the surface soil is from 8 to 8.2 while pH of subsoil is 7.9 to 8.4. Among the subsoil salts commonly occurring in the soils are chloride, sulphate, and sodium. Calcium and magnesium are present in comparatively less proportion (Ali et al. 1981). The soils of the Nisai area are mostly calcareous although slight surface salinity occurs at places (BDA 1981). The major constituents such as magnesium, chloride, calcium, sulphate, bicarbonate and sodium in the groundwater in the study area are the result of saline calcareous soil, limestone, sandstone, shale, and igneous intrusions. These rock types are the common lithology of the Alozai group, Loralai limestone, Parh group, and Khojak shale exposed in and around study area. The concentration of total dissolved solids and individual cations and anions may be increased due to seasonal and secularfluctuations of water table. The depth of static water table (Abbasi 1997) ranges from 11.67m to 22.96m below ground level, whereas the decline of groundwater table is from 0.089m/year (northeastern part) to 0.176m/year (western part). An other aspect of increase in concentration of dissolved solids near Ahman Zai (Fig. 3) may be attributed to poor completion and development of well No. 18.

Rock Units	General Lithology	Water Bearing Properties	Age
Alluvium	Unconsolidated deposits of gravel clay, silt, sand and their admixture.	Well sorted, coarse grained strata contain most of the water while poorly sorted, fine grained strata yield the least water.These are also the main recharge area.	Holocene
		Unconformity	
Khojak Formation	Conglomerate shale and sandstone.	Hydrogeologically the Khojak shale togather with overlying alluvium constitute a single hydrologic unit and the permeable material below zone of saturation constitute the potential aquifer in the area.	Oligocene-Pliocene
		Unconformity	
Muslim Bagh Ophiolite	Ophiolitic rocks	Not known	Cretaceous
Parh Group	Shale and limestone	Not known	Cretaceous
		Unconformity	
Loralai Limestone	Limestone with inter-bedded shale.	No primary porosity although some water is present due to secondary porosity.	Jurassic
Alozai Group	Alternate layers of limestone and shale	Not known	Triassic
False Parh Group	Limestone, shale and sandstone.	Not known	Triassic

Table 1. General lithology and water bearing properties of the rock units exposed in the Qila Saifullah area.

The quality of water for irrigation is generally judged on the basis of four criteria (Ragunath 1987). They are a) Total dissolved solids, b) Relative proportion of sodium to other cations (SAR), c) Residual carbonates (RC) and d) Concentration of certain specific elements like boron. The electrical conductivity at 25°C in microsiemens per centimeter is a measure of total salt concentration. The groundwater may be classified on the basis of specific conductance and sodium adsorption ratio (SAR) values (Fig.7) (Wilcox 1955; Richard et al 1954; Krothe 1982; Edwin 1984). Water with medium salinity (C2) can be used successfully for plants with moderate salt tolerance whereas water with high salinity (C3) can be used for plants with good salt tolerance, but special arrangements for salinity control are required (Richard et al. 1954). The water having specific conductance less than 2250 microsiemens per centimeter (C1, C2, C3) may be used successfully for considerable time (Edwin et al. 1984). In the Qila Saifullah area, all types of groundwaters are successively used for irrigation giving no damage to the plants. Water with low sodium hazard (S1) may be used for irrigation almost on all soils but sodium sensitive crops such as avocado may accumulate injurious concentration of sodium (Richard et al. 1954) The residual carbonates (RC) are absent in the ground water of the study area. Based on the specific conductance, the sodium adsorption ratio (SAR) and residual carbonates (RC), the groundwater of the investigated area are satisfactory for the irrigation purpose. The total dissolved solids can be used to classify water (Hem 1973; Tibbals 1990) as given below:

Salinity	Dissolved solids concentration (mg/l)
Fresh	less than 1000
Slightly saline (Brackish)	1000 - 3000
Saline	3000 - 10000
Very saline	10000 - 35000

Using the above classification the groundwater of the investigated area are fresh except in few localities where the water may be classed as slightly saline. The water standards for drinking and irrigation has been proposed by Davis and DeWiest (1966) are as follows:

Constituents	Drinking water standards (mg/l)	Irrigation water standards (mg/l) Good	Poor
Magnesium	125	-	-
Calcium	200	-	-
Sodium	200	50	300
Chloride	250	100	300
Sulphate	250	200	500
Bicarbonate	500	200	500

Based on the above criteria following results are proposed for the groundwater of Qila Saifullah area. The concentration of calcium, sodium, bicarbonate and sulphate are under usable limits. The quality of groundwater is satisfactory for drinking purpose with low concentration of magnesium in western part, whereas its concentration stays slightly above the useable limits. The concentration of chloride in groundwater for drinking purpose is under useable limits (except in New Killi Essa Zai and Ahman Zai areas), whereas for irrigation purpose the chloride concentration makes the quality of groundwater as good (in the western part) and poor (in the eastern part).

CONCLUSIONS

1. The magnesium and chloride are the most abundant constituents among cations and anions respectively.
2. The salinity hazard, concentration of total dissolved solids, magnesium, calcium, and chloride increases along hydraulic gradient while carbonate and bicarbonate decrease.
3. The groundwater of the study area is classed as low sodium hazard (S1) and medium to high salinity hazard (C2 & C3).
4. The hydrochemical facies of the groundwater of the Qila Saifullah area are magnesium chloride, magnesium chloride bicarbonate, magnesium chloride sulphate and magnesium mixed anions.
5. The groundwater is fresh to slightly saline based on concentration of dissolved solids.
6. The soil and geology of the area are the main factors which affect the quality of the groundwater.
7. The groundwater of the Qila Saifullah area can be used safely for drinking and irrigation purposes.

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APPENDIX

Results of the chemical analysis of groundwater samples. M; Mankai, NQ; Nawab Qila, Q; Qila Saifullah Town, B; Bharwal, BM; Bandat Musazai, MEK; Malik Essa Killi, NKE; New Killi Essazai, HSB; Haji Syed Gul Bhawri, RS; Railway Station, KJ; Killi Jahangir, KSA; Killi Syed Abdul Rehnam, KHJ; Killi Haji Jano, A; Ahmanzai, KK; Killi Kharkaran, KS; Killi Shahzada, KMU; Killi Mohammad Usman, KAJ; Killi Abdullah Jan, KHR; Killi Haji Rozi Khan, SAJ; Killi Sardar Ali Jan, KA; Killi Allah Noor, KMK; Killi Mohammad Khan, KM; Killi Mirzai, KHA; Killi Haji Afzal, KH; Killi Habibullah, SA; Killi Shakoor Addah, KKM; Killi Khan Mohammad, KTO; Killi Tor Oskai, EC; electrical Conductivity at 25°C in miromhos/cm, TDS; Total Dissolved Solids, SAR; Sodium Adsorption Ratio. Concentrations of anions and cations are expressed in milliequivalent/liter (meq./l).

S.No.	Site	EC µs/cm	TDS mg/l	SAR	pH	Ca meq/l	Mg meq/l	Na meq/l	K meq/l	CO_3 meq/l	HCO_3 meq/l	Cl meq/l	SO_4 meq/l
QS-1	M	1253	801.92	0.25	7.94	3.60	11.20	0.68	0.09	0.08	0.75	4.10	0.42
QS-2	M	834	533.76	0.21	8.92	2.20	8.60	0.49	0.08	0.05	1.05	2.50	0.47
QS-3	NQ	832	532.46	0.22	7.98	2.80	6.8[illegible]	0.49	0.08	0.00	0.85	2.25	0.34
QS-4	Q	1186	759.04	0.23	7.92	2.80	11.20	0.61	0.09	0.05	0.95	2.85	0.55
QS-5	BM	1622	1038.08	0.23	8.27	4.00	14.80	0.73	0.08	0.08	0.75	4.00	0.55
QS-6	BM	2266	1450.24	0.33	8.00	5.20	17.40	1.12	0.11	0.05	0.75	4.90	0.51
QS-7	BM	1524	975.36	0.23	8.32	6.40	13.80	0.73	0.11	0.05	0.95	4.75	0.38
QS-8	BM	981	627.84	0.16	8.93	3.20	10.40	0.43	0.07	0.08	0.70	3.32	0.34
QS-9	B	1145	732.80	0.16	8.00	2.40	11.20	0.43	0.11	0.00	0.85	3.20	0.47
QS-10	MEK	1221	781.44	0.29	8.11	1.60	10.60	0.73	0.10	0.08	1.50	3.60	0.51
QS-11	NKE	2018	1291.52	0.04	8.17	8.00	22.80	1.10	0.15	0.06	1.20	8.65	0.38
QS-12	HSB	1232	788.48	0.29	7.93	2.80	10.80	0.76	0.07	0.00	1.60	3.30	0.55
QS-13	RS	1378	881.92	0.28	8.97	2.80	19.20	0.93	0.08	0.10	0.43	3.10	0.29
QS-14	KJ	1230	787.20	0.39	8.07	0.80	15.80	1.13	0.13	0.11	0.54	1.92	5.05
QS-15	KSA	828	529.92	0.30	8.44	2.20	10.60	0.76	0.10	0.05	0.54	1.15	1.50
QS-16	KHJ	878	561.92	0.26	8.00	2.40	9.40	0.64	0.10	0.08	0.75	2.00	0.42
QS-17	KHJ	805	515.20	0.19	8.30	2.60	29.60	0.78	0.09	0.06	0.52	1.60	0.59
QS-18	A	2156	1379.84	0.37	7.79	6.00	24.80	1.47	0.14	0.06	0.68	7.50	1.41
QS-19	A	998	638.72	0.18	8.33	3.60	10.00	0.49	0.09	0.01	0.69	2.00	6.40
QS-20	KK	929	594.56	0.24	7.66	3.20	16.40	0.78	0.09	0.00	0.66	2.90	0.29
QS-21	KS	774	495.36	0.21	7.96	3.20	14.00	0.64	0.09	0.00	0.86	1.50	1.58
QS-22	KK	656	419.84	0.18	8.21	2.00	10.00	0.45	0.07	0.06	0.68	1.50	1.75
QS-23	KMU	688	440.32	0.16	8.32	2.40	6.20	0.35	0.08	0.25	1.25	1.50	0.25
QS-24	KAJ	682	436.48	0.18	7.93	2.00	6.30	0.38	0.08	0.12	1.15	1.00	0.47
QS-25	KHR	636	407.04	0.35	8.70	1.20	4.80	0.61	0.09	0.01	1.00	1.00	0.08
QS-26	KHR	696	445.44	0.23	7.89	2.00	6.10	0.47	0.08	0.01	1.20	1.10	0.59
QS-27	SAJ	665	425.60	0.16	8.09	2.20	6.10	0.34	0.08	0.07	1.10	1.50	0.34
QS-28	KA	523	334.72	0.22	8.27	0.60	4.10	0.35	0.03	0.01	1.40	1.40	0.33
QS-29	KA	533	341.12	0.12	8.02	1.60	5.60	0.23	0.05	0.10	1.15	1.70	0.68
QS-30	KMK	584	373.76	0.18	8.92	1.20	4.10	0.30	0.10	0.01	1.15	1.70	0.81
QS-31	KM	698	446.72	0.28	8.10	1.20	5.30	0.52	0.08	0.10	1.40	1.30	0.37
QS-32	KHA	560	358.40	0.15	8.02	1.60	6.14	0.30	0.09	0.00	0.52	1.60	1.58
QS-33	KH	564	360.96	0.09	8.03	3.40	16.00	0.28	0.11	0.00	0.53	1.60	1.45
QS-34	SA	590	377.60	0.14	8.82	1.20	6.20	0.28	0.80	0.10	1.60	1.80	0.26
QS-35	KKM	585	374.40	0.17	8.64	0.60	5.30	0.30	0.09	0.60	1.17	2.20	0.72
QS-36	KTO	535	342.40	0.09	8.09	2.20	6.70	0.19	0.08	0.10	1.63	1.75	0.29

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GOLDEN JUBILEE OF PAKISTAN ISSUE

ELECTRIC SOUNDING TO SCAN GUNGA ZINC-LEAD SULPHIDE MINERALIZATION OF KHUZDAR AT DEEPER DEPTH

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ABSTRACT

Gunga Zn-Pb sulphide and Barite deposit is one of the numerous deposits found in Khuzdar-Lasbela region of Balochistan province. The deposit is hosted in the Lower Jurassic sedimentary sequence. Preliminary geological, geophysical and drilling investigations have indicated the presence of mineralization up to an average depth of about 240 metres. In order to scan further continuation of the Zn-Pb sulphide mineralization at deeper depths, the vertical electric soundings (VES) have been applied which indicate favorable conditions. The results have illustrated the presence of Zn-Pb mineralization extending at least down to a depth of 500 metres and possibly more. Moreover, the results also indicate that the percentage of Zn-Pb contents and thickness of mineralization are increasing with respect to depth indicating the possible presence of feeder zone at much greater depth due to intense deformation.

INTRODUCTION

In recent past, the Geological Survey of Pakistan has discovered several deposits of lead and zinc ores in Lasbela-Khuzdar districts of Balochistan province (Ahsan 1989; Zaigham et. al 1991; 1992). These deposits are associated with Jurassic carbonate rocks of the Ferozabad Group. Gunga deposit is one of them (Fig. 1). About 6 % combined Zn and Pb were reported within the explored mineralized zone. Results of the test drilling indicated the availability of over 11.0 million tonnes of Zn-Pb ore at Gunga near Khuzdar Town (Jankovic 1983; JICA 1987).

Gunga zinc-lead deposit is located at latitude 27°44′18″N and longitude 66°31′42″E near Gunga village, 11 kilometres north-west of Khuzdar city of Balochistan province (Fig. 1). Topographically, the Gunga zinc-lead deposit area is very rugged with slopes ranging from about 30° to 60° and at places more steeper on escarpment sides. The local elevation difference is upto 200 metres.

Based on the surface geology and the information obtained from the drill holes, it was expected that the main mineralization extends in the west and could be traced in the alluvial terrace area along the foot hills. To study the subsurface distribution of Zn-Pb sulphide mineralization, the electromagnetic and induced polarization (IP) techniques were applied (Zaigham et. al 1992; Ahmed et. al 1982), which indicated that the mineralization at least extends down to an average depth of 240 metres, which was the penetrating limit of the IP investigation.

In view to scan the deeper depth and the expected westward extension of mineralization under the alluvial terrace, three vertical electric soundings (VES) were carried out in the area. Two sites were selected at the foot hills to trace the westward dip extension of the mineralization and one site was selected in the central part of the subsurface mineralization delineated by IP anomalies to scan the deeper depth.

This paper describes the results and their impact on development of the Zn-Pb sulphide mineralization at deeper depths (down to 500 m) in Gunga deposit area.

GEOLOGICAL SETTING OF THE GUNGA DEPOSIT

Tectonically, the Gunga Zn-Pb bearing area lies in the so-called "Khuzdar Knot" located on the western margin of the Indo-Pakistan continental plate. Khuzdar knot, south of the Kalat plateau, is delineated by the Ornach-Nal-Gazan fault system to the west and north, and by the Kirthar fault to the east. In the south of the knot, discordantly north-south trending zones of ophiolites, Mesozoic and Tertiary mountain ranges extend upto the Arabian Sea. The Khuzdar knot is mainly formed of Mesozoic rocks by two successive changes in the fold trend and exhibits the east-west oriented arcuate structural trends. The abrupt structural discontinuity (i.e. Anjira-Gazan fault) between the complex structure of the Khuzdar knot and the enigmatically gentle structure of the Kalat plateau is probably a zone of thrusting and strike-slip movement.

In Gunga area, the Ferozabad Group of Lower Jurassic age is widely exposed giving rise to the rugged topography. This Group is a marine assemblage deposited in a shallow miogeosyncline (HSC 1960). The Ferozabad Group is divided into three members which are the Spingwar, Loralai, and Anjira in ascending order.

MINERALIZATION

The mineralogical and petrological studies indicate that the Gunga Zn-Pb and Ba mineralization is a low temperature stratabound and stratiform hydrothermal deposit hosted in Lower Jurassic inter-bedded limestone and shale sequence (Fig. 1). The southern part of the deposit is on the western flank of an asymmetric anticline. The crest of this anticline is exposed along a ridge of altered limestone just east of the deposit.

The outcrop of mineralization associated with a rugged hogback ridge, is over 1,200 metres long and is distinguished as a silicic gossan. The zinc-lead bearing horizon dips westward with dip ranging from 35° to 50° in the northern part of the deposit, and from 60° to 70° in the southern part.

VERTICAL ELECTRIC SOUNDINGS

The results of the IP measurements, using dipole-dipole electrode array, illustrate the detailed scanning of subsurface distribution pattern of the rock units and associated Zn-Pb sulphide & barite mineralization only down to an average depth of about 240 metres in the Gunga area. Attempts were also made to explore deeper depth levels with this array, but inspite of high transmitting current (> 5000 volts) measurements could not be made as weak field signals were received. For information from deeper mineralization zone(s), three vertical electric soundings (VES) were observed down to 500 metres in Gunga area at stations 320S/260W, 00/280W and 00/00 (Fig. 1).

The VES may be considered as "single point electrical drilling" to acquire subsurface information of lithologic interfaces and their physical electrical properties.

CHARGEABILITY AND RESISTIVITY MEASUREMENTS

For VES field operation, the Wenner electrode configuration was adopted in Gunga area. For the first operation during field measurement, each potential electrode was separated from the adjacent current electrode by a distance of 20 metres which was one-third of the current electrodes separation (i.e. 60 metres). Subsequently, the spacing of 20 metres was gradually increased about a fixed central point with an

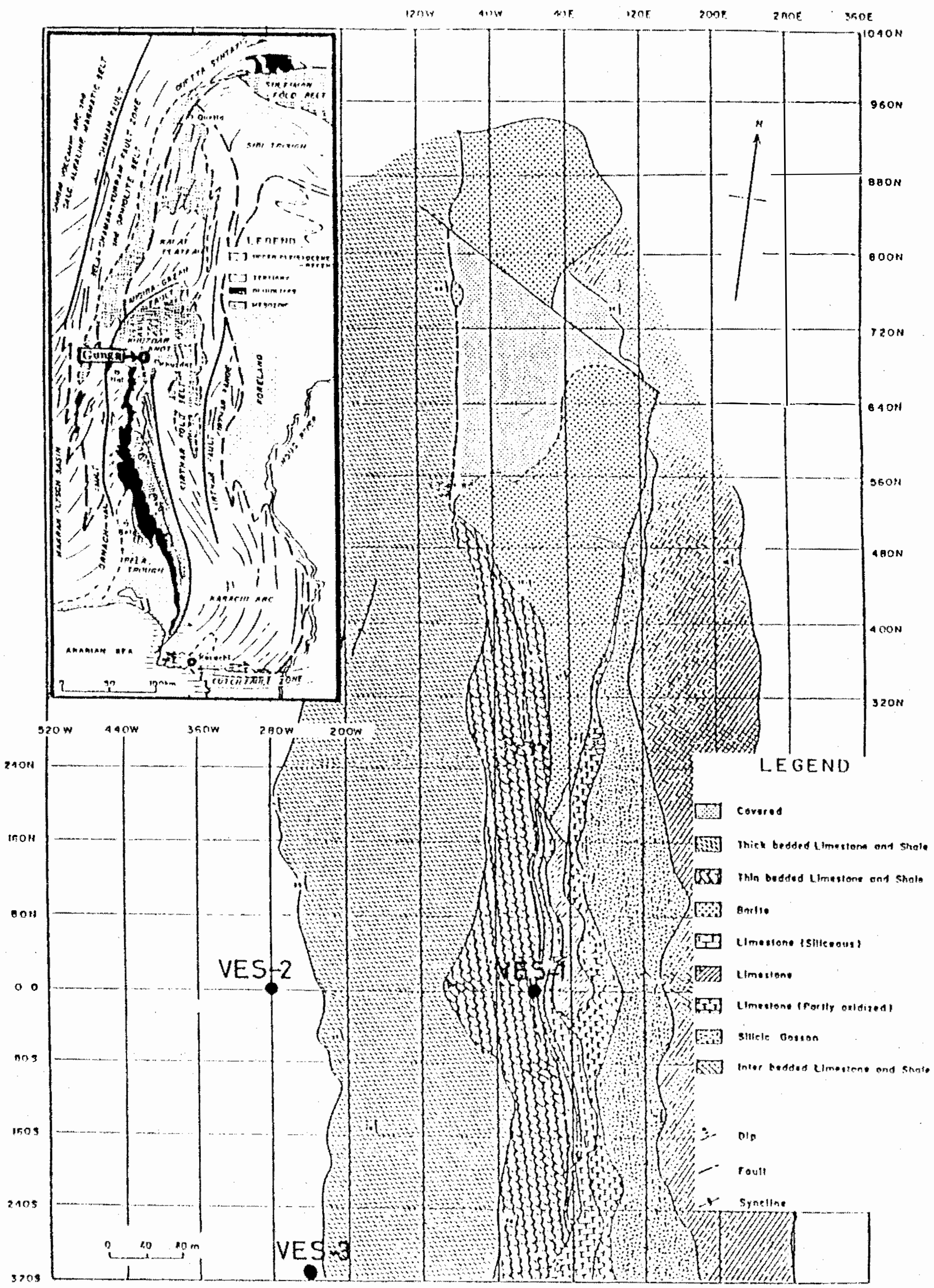

Figure 1. **Detailed geological map of Gunga zinc-lead-barite deposit showing location of vertical electric soundings. Inside frame shows salient tectonic features of the region. (Source of compilation: HSC 1960; Bakr & Jackson 1964; JICA 1987)**

increment of 20 metres upto a total spacing of 500 metres, where the surface conditions were very difficult for geo-electrode emplacement, i.e. dry, rubbly, poor soil development and an abundance of solid rock outcrops.

The field instruments used for measurements, were Scintrex transmitter IPC-7/15 KW, receivers IPR-8 & IPR-10 (Time domain), and Volkswagen generator MG 15 KW AC (Truck mounted). The current was transmitted into the earth between the current electrodes, and the potential (δV) thus developed was measured between potential electrodes. During the off-cycle of the current, the chargeability measurements were also made. The measurements were recorded in the form of chargeability (M), current (I) and voltage (δV) in the Gunga area.

The computed apparent resistivity values of each VES have been plotted on the bi-logarithmic 2×3 cycle graphs to generate field resistivity curves for qualitative and quantitative geological analyses of subsurface strata in the area.

COMPUTER MODELLING AND INTERPRETATION OF VESs

The Gunga field resistivity curves plotted on bi-logarithmic graphs have been interpreted qualitatively by the empirical method to determine the possible number of lithologic layers, their tentative depth or thickness and range of their approximate resistivity values.

For the quantitative interpretations the iteration modelling technique was used for the analysis of VES curves. The iteration modelling program "RESIST Version 1.0" of ITC has been used to generate multilayered models with respect to the resistivity parameters found in the Gunga area. The qualitative information obtained through empirical analysis of field curve regarding the number of subsurface layers, their expected depths and their approximate values of resistivity, were utilized in the computer program for the iteration modelling. The resistivity values of subsurface layers interpreted by iteration method are expressed in units of ohm.m. These values have been correlated with lithological units so that they actually represent and conform to the subsurface geological formations.

Iterated resistivity models show that there were large Root Mean Square (RMS) errors in empirical analysis of field resistivity curves. Initially, the RMS errors 27.9 for VES-1, 13.5 for VES-2 and 30.5 for VES-3 causing errors in calculation of lithological interfaces and resistivity values of subsurface layers. By the iterated modeling they were reduced to 2.8, 3.2 and 3.3 respectively rectifying the errors in thicknesses, resistivity values and depths to interfaces of subsurface layers. The comparison is given in the Tables-1, 2 and 3.

ITERATION MODELLING OF RESISTIVITY CURVE VES-1

The empirically determined parameters have been utilized as "input data" for the iteration modelling. Figure-2a illustrates the "output" of the modelling. The computer program could perform iteration process upto 2.8 RMS-error with the given parameters. The results of the resistivity model have been presented in Table 1.

No. of Layer	Resistivity of the layer (ohm-m)		Thickness of the layer (metres)		Depth of the layer (metres)	
	Q	I	Q	I	Q	I
1	10	57.7	20	13.4	20	13.4
2	2000	261.6	20	13.5	40	26.9
3	60	60.4	50	38.3	80	65.2
4	2000	891.9	10	39.8	100	105
5	60	111.8	25	33.2	125	138.2
6	400	188	20	29.7	145	168
7	100	182.3	65	19.9	210	187.9
8	500	100.7	30	19.8	240	207.7
9	10	80.1	25	19.8	265	207.5
10	2000	99.3	35	19.8	300	247.2
11	100	568.7	40	35.2	340	282.4
12	2000	171.1	40	39	380	321.4
13	10	62.2	20	40.6	400	362
14	2000	176.3	20	19.8	420	381.8
15	100	96.2	40	49.9	460	431.6
16	2000	606.7	30	28.1	490	459.7
17	100	56	-	-	-	-

Table 1. The calculated parameters of the resistivity model of the curve VES-1. Q; Qualitative, I;Iterated.

ITERATION MODELLING OF RESISTIVITY CURVE VES-2

The Figure-2b shows "output" results and the resistivity model of the field curve of VES-2. Based on the input parameters for the program, the iteration matching could be done upto 3.2 RMS-error. The results of the resistivity model are presented in Table 2.

No. of Layer	Resistivity of the layer (ohm-m)		Thickness of the layer (metres)		Depth of the layer (metres)	
	Q	I	Q	I	Q	I
1	130	119.7	55	30	55	30
2	150	1445.2	25	9.4	80	39.3
3	60	55.3	40	40.8	120	80.1
4	450	502.6	60	59.9	180	140
5	60	78	25	19.4	205	159.5
6	1000	1335.4	60	76.3	265	235.7
7	100	112.3	45	41	310	276.8
8	1500	1616.4	30	32.1	340	308.8
9	100	102.3	20	19.6	360	328.5
10	1500	1542.5	20	20.5	380	349
11	60	60.8	20	19.8	400	368.8
12	1500	1529.8	20	20.4	420	389.2
13	60	60.5	20	19.9	440	409.1
14	200	215.1	-	-	-	-

Table 2. The calculated parameters of the resistivity model of the curve VES-2. Q; Qualitative, I;Iterated

ITERATION MODELLING OF RESISTIVITY CURVE VES-3

The output results of the iteration and the resultant resistivity model of the field curve VES-3 are shown in Figure-2c. The calculated resistivity values of layers indicate the domination of very high resistivity material(s) in subsurface.

No. of Layer	Resistivity of the layer (ohm-m)		Thickness of the layer (metres)		Depth of the layer (metres)	
	Q	I	Q	I	Q	I
1	65	16.1	15	9.5	15	9.5
2	180	666.9	27	27	42	36.5
3	65	60.4	43	29.6	85	66.1
4	650	1542.5	30	23.2	115	89.4
5	100	57.5	35	15.5	150	104.9
6	180	351.8	30	59.4	180	164.2
7	100	96.4	20	30.4	200	194.6
8	180	472.4	20	28.6	220	223.1
9	80	8.8	20	28.4	240	251.6
10	100	1944	20	34.1	260	285.6
11	65	99.1	40	40.3	300	325.9
12	180	1952.5	40	39.1	340	365
13	66	9.9	40	20.2	380	385.2
14	180	1989.7	20	19.9	400	405.1
15	100	99.8	50	40	450	445.1
16	650	1986.8	30	29.8	480	474.9
17	65	99.3	-	-	-	-

Table 3. The calculated parameters of the resistivity model of the curve VES-3. Q; Qualitative, I;Iterated.

The iteration matching with field curve could be achieved upto 3.3 RMS-error. The calculated parameters of the resistivity model of VES-3 have been presented in Table 3.

COMPARISON OF RESISTIVITY AND CHARGEABILITY DATA

For the comparative study, the apparent resistivity and chargeability values obtained at each VES station have been plotted on linear scale against the vertical columns of subsurface lithologic units inferred through iteration modelling.

SITE VES-1 AT STATION 00/00

VES results show that the surface material has resistivity less than 100 ohm-m and the chargeability less than 5 milli-sec. Similarly, the resistivity curve shows a corresponding average resistivity value of 150 ohm-m.

Figure-3a illustrates the inferred lithologic units and corresponding resistivity and chargeability trends down to a depth of 500 metres. The chargeability trend indicates relatively thin layers containing some percentage of metallic sulphide minerals down to a depth of 200 metres, but after that depth, a thick zone containing relatively high percentage of metallic sulphide minerals, more or less uniformly, appears to continue down to 380 metres. Below 380 metres, alternation of thin layers of rock units containing metallic sulphide minerals have been inferred to continue down to a depth of 500 metres or more as the trend of chargeability continues.

The chargeability amplitude observed at this location indicates the subsurface rock units being devoid of any metallic sulphide minerals and only exhibit the background value of chargeability down to the depth of 500 metres. The same trend may continue for still greater depths. The corresponding trend of high resistivity associated with these rock units also suggests the above interpretation.

SITE VES-2 AT STATION 280W/00

Figure-3b shows the inferred lithology and linear plot of apparent resistivity and chargeability values indicating the rock units contribut

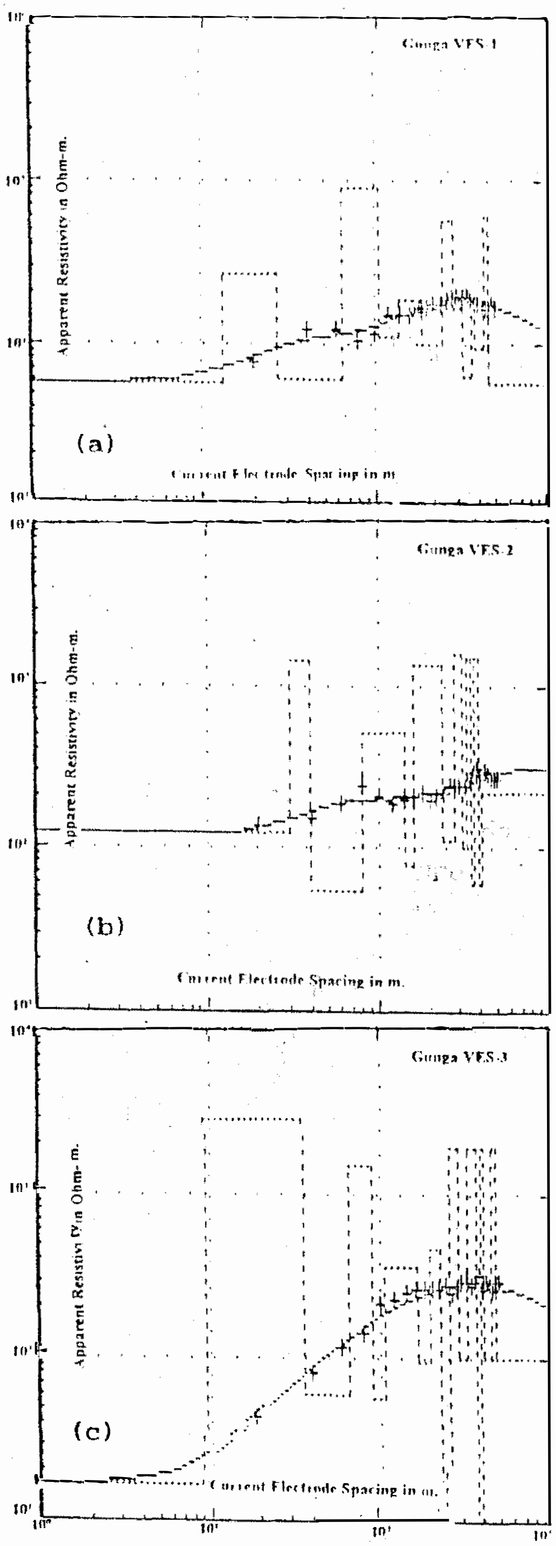

Figure 2. Computed model curves of field resistivity data collected at VES-1, VES-2, and VES-3.

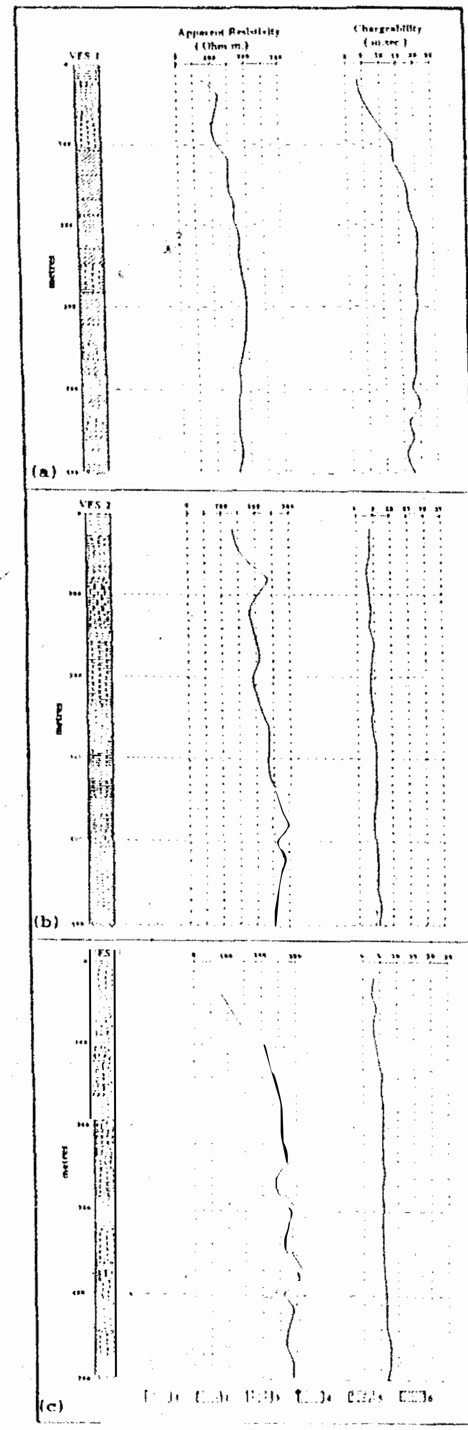

Figure 3. Comparison of resistivity, chargeability and inferred subsurface lithologic data of (a): VES-1; (b): VES-2; and (c): VES-3. Geological legend 1: Surface layer, 2: Shale, 3: Limestone, 4: Silts-tone, 5: Barite interlayered with shale and limestone, 6: Mineralized zone.

ing very low chargeability counts (i.e. average value of 5 milli-sec) and relatively high apparent resistivity ranging from 200 to 300 ohm-m down to a depth of 500 metres. The same trend of the chargeability and the apparent resistivity may continue beyond the depth of 500 metre.

SITE VES-3 AT STATION 260W/320S

Figure-3c illustrates the comparative plots of inferred lithology, apparent resistivity and chargeability of site VES-3. The chargeability and the apparent resistivity trends are very similar to those of VES-2. The chargeability values show an average of 5 milli-sec with corresponding high apparent resistivity range from 250 to 300 ohm-m indicating unfavorable environment for the occurrence of any metallic sulphide minerals upto a depth of 500 metres or more.

DISCUSSION OF VES RESULTS

Based on the surface geology and limited inclined drilling, it was generally thought that the mineralization might be continuing westward along the dip in the area covered by alluvium. However, the results of the integrated geophysical survey indicated probable termination of mineralization westward near the foot hills.

The deep vertical scanning through vertical electric sounding at stations 00/00, 280W/00 and 260W/320S has provided interesting results as regard the continuation of the mineralized zone (Fig. 3). The VES-1 at station 00/00, which is about 80 metres west of the west dipping silicic gossan bed, indicates relatively high chargeability (20 milli-sec) and low resistivity (150 ohm-m) environment from 100 metres to 500 metres. The zone is much wider vertically than that found by angular drilling. The spatial projection of the west dipping silicic gossan bed determined through angular drilling, is about 180 metres wide vertically. Considering the geology of the area and drilling results, the presence of this wide zone of relatively high chargeability and low resistivity may be inferred as due to repetition of mineralized zone.

On the contrary, the VES-2 and VES-3, which are 380 metres west of the west dipping silicic gossan bed, show relatively very low chargeability (average of 5 milli-sec) and high resistivity (average of 275 ohm-m) environment down to a depth of 500 metres vertically, indicating barren conditions for the sulphide mineralization.

From the VES results it may be inferred that the zone of mineralization does not extend westward in the area covered by alluvium outside the foot hills and the exposed west dipping mineralized zone has been thrusted over the mineralized zone occurring at depth, giving rise to the wider mineralized zones having the high chargeability and the low resistivity values.

Present study also indicates that the percentage of Zn-Pb sulphide mineralization is improving with respect to depth. In the light of the genetic model (Lydon 1983) and the present data it is inferred that the main feeder zone lies at greater depth and the whole sequence hosting mineralization has been intensely deformed tectonically as evident from the exotic nature of rock assemblage in Khuzdar knot area.

CONCLUSIONS

The "Vertical Electric Soundings" helped to determine two important facts in relation to subsurface occurrence of Gunga Zn-Pb sulphide mineralization, i.e. i) the Zn-Pb sulphide miner-alization extends down to a depth greater than 500 metres and the percentage of Zn and Pb in their ores increases with the depth, and ii) the mineralization associated with the exposed west dipping gossan unit does not extend in the west under the alluvium and that it is perhaps trun-cated at the foot hills.

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LITHOSTRATIGRAPHY, SEDIMENTOLOGY AND PETROLOGY OF THE GHAZIJ FORMATION, SOR RANGE AREA, QUETTA DISTRICT, PAKISTAN

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ABSTRACT

The Eocene Ghazij Formation in Sor Range area of Quetta District, situated west of the Sulaiman Thrust-Fold Belt, is divisible into three members arbitrarily called Lower, Middle and Upper members. The Lower and Middle members show contrasting lithofacies associations, reflecting pro-delta and delta front conditions respectively with fluvial and lagoonal influences. A thick (up to 17m) conglomerate horizon suggests deposition within channelized fluvial conditions and enhanced uplifting and erosion of older sedimentary succession of Jurassic through Paleocene age. The Upper member shows wave, tidal and storm influence indicated by occurrence of wave ripples, ripples cross-lamination and hummocky cross-stratification. Paleocurrent pattern based on randomly obtained observations throughout the formation, indicate derivation of detritus from the east.

Sandstones are classified as lithic arenite and calclithite and are particularly rich in limestone, chert, sandstone, basic igneous and intra-formational rock fragments. The conglomerates contain fragments of rock units ranging in age from Jurassic (Shirinab Formation) through Paleocene (Dungan Formation), which along with the paleocurrent pattern, suggests an earliest phase of uplifting, emergence and derivation of detritus from the Sulaiman Belt exposed to the east of Sor Range area.

INTRODUCTION

The purpose of this article is to describe the lithostratigraphy, sedimentology and petrography of the Eocene Ghazij Formation in order to interpret its depositional environment and provenance in the light of regional geological context. Studies of the Ghazij Formation (Williams 1959) were carried out in the Sor Range area, situated on the western extreme of the Sulaiman Thrust-Fold Belt (Fig. 1). Here the formation is widely exposed, exceptionally thick and divisible into three members. The formation is very important because of its huge coal reserves. Coal mining is in progress for over hundred years within the Sor Range area.

LITHOSTRATIGRAPHY

The "Ghazij Group" of Oldham (1890) was redefined as the Ghazij Formation by William (1959). Spin Tangi Section near Harnai is the stratotype of the Ghazij Formation. In Sor Range area its lower contact is with the Paleocene Dungan Formation (Table 1) which dominantly consists of nodular to massive limestone with subordinate shale and marl in its lower part. The upper contact is with the Habib Rahi limestone member of the Kirther Formation which is highly fossiliferous limestone of creamy, light grey and white colour. The Ghazij Formation has been informally subdivided into Lower, Middle and Upper parts by Hunting Survey Corporation (HSC 1960) on the basis of their lithological characters. As these subdivisions have distinct lithological and sedimentological characters, we propose to give them formal member status. Their characters are as under.

Age	Formation	Lithology
Pleistocene	Lei Conglomerate	conglomerate and sandstone
Miocene-Pliocene	Siwaliks	claystone and conglomerate
Oligocene-Miocene	Nari/Gaj Formation	claystone, sandstone and limestone
Upper-Eocene	Kirther Formation	limestone and shale
Lower-Eocene	Ghazij Formation	claystone, sandstone, conglomerate, coal and limestone
Paleocene	Dungan Formation	limestone and shale
Upper Cretaceous	Pab Sandstone/ Fort Munro Formation	sandstone, shale and limestone
	Bibai/Mughalkot Formations	pillow lavas and volcanic clastics
Lower Cretaceous	Parh Group	limestone and shale
Jurassic	Shirinab Formation	limestone with minor shale
Triassic	Wulgai Formation	limestone and shale
Base not exposed		

Table 1. Generalized stratigraphic succession of the Sulaiman Thrust-Fold Belt.

LOWER MEMBER

The Lower member is composed of a thick sequence of claystone, shales and siltstone of greenish grey to olive grayish green colour with occasional thin beds of sandstone. Claystone is blocky, fissile, gypsiferous and contains minor amount of carbonaceous matter. Sandstone is grey to greenish grey and contains a variety of sedimentary structures like parallel lamination, cross-lamination, flute casts, longitudinal ridges and other irregular type of sole marks. Thickness of the Lower member is about 780m in Sor Range area (Mohsin et al. 1991).

MIDDLE MEMBER

The Middle member is composed of claystone, shale, siltstone, sandstone, a thick bed of conglomerate and various coal seams. A conglomerate bed is present at the uppermost part of the Middle member and have been used as marker horizon for the uppermost coal seam in Sor Range area. The claystone and shale is olive grey to dusky yellow green. It is blocky, fissile calcareous and gypsiferous. The siltstone and fine grained sandstone beds commonly containing coalified plant fragments and leave prints, some of which are well preserved. Plant fragments obtained were analyzed by Dr.I.Bhuta. According to him these plant fragments mostly belong to the Sp: Salit of family Salicacene and Sp: Ulpus of family Ulmaceae which are plants of temperate climate. Carbonaceous matter is abundant throughout within the claystone, siltstone and sandstone beds. Sandstone varies in colour from yellowish brown, grayish brown, pale brown to light olive grey. It is very fine to very coarse grained, however, medium grained sandstones are most common. Various types of sedimentary structures like large scale trough cross-stratification, parallel lamination, current and wave ripples, sole marks and bioturbation are commonly present. The conglomerate bed is composed of boulders, cobbles and pebbles of various types of limestones, cherts, sandstones and rarely igneous rocks. Thickness of the conglomerate bed varies from a few meters to 17m. The conglomerate horizon contains boulders of upto 36cm across which are moderately sorted, well rounded and clast supported. Thin lenses of sandstone are also present within the conglomerate horizon.

Coal seams within the Middle member vary in thickness in different areas. In western part of the area, the bottom seam is up to 1m thick, while, the top seam is up to 5m thick. In the southeastern part of the mapped area (near PMDC mines), the top seam is generally 4m and in some localities up to 8m thick, while the

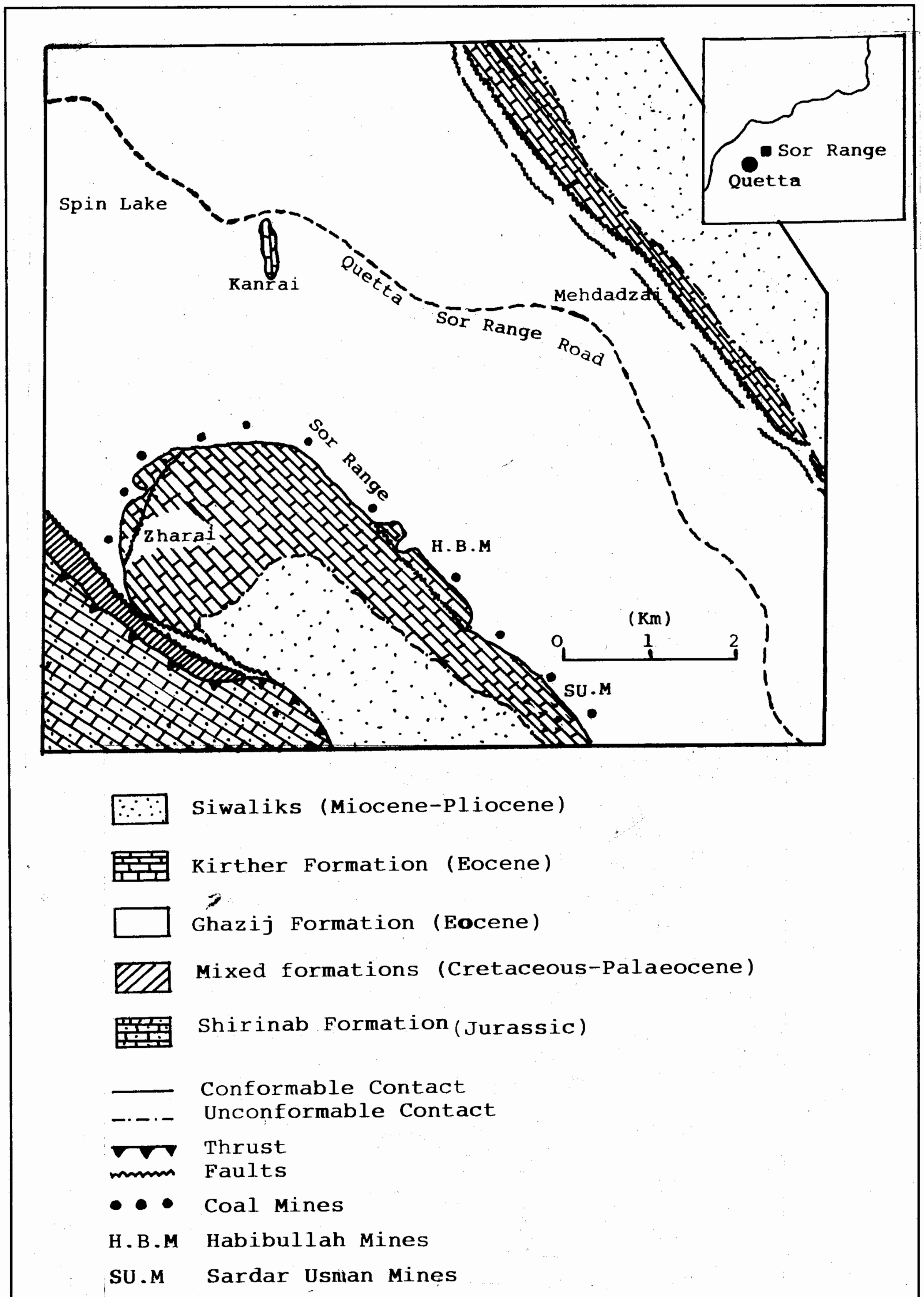

Figure 1. **Location and geological map of the Sor Range area, Quetta District.**

bottom seam is upto 0.75m thick. Thickness of the Middle member in Sor Range area varies from 30m to 75m (Mohsin et al. 1991).

UPPER MEMBER

The Upper member is composed of claystone, shale, siltstone and sandstone beds of various colors in which claystone, shale and siltstone dominate. Claystone, shale and siltstone are yellowish, maroon, red, pale green and grey. Claystone is blocky, fissile, silty, calcareous and gypsiferous. Sandstones within the Upper member are characterized by hummocky cross-stratification, wavy cross-bedding, wave ripples and soft sediment deformation. It is grey, bluish grey and reddish in colour, medium to fine grained and relatively well sorted. Thickness of the Upper member varies from 127m to 375m (Mohsin et al. 1991). An Early Eocene age has been assigned to the Ghazij Formation on the basis of obtained magafauna (HSC 1960; Latif 1964; Eames 1952; Shah 1977; Iqbal 1969).

SEDIMENTARY STRUCTURES

Sandstones of the Ghazij Formation possesses various types of sedimentary structures, namely cross-stratification, parallel lamination, ripple marks, sole marks, trace fossils, graded bedding, convolute lamination and parting lineation. Cross-stratification includes trough cross-bedding and -lamination, hummocky cross-bedding, herring-bone type of cross-bedding, and low-angle cross-bedding, however, large scale trough cross-bedding is the most common type observed. Morphology and size of cross-stratification vary within the formation. Set thickness within the observed trough cross-bedding strata range between 7cm and 34cm, and forset thickness between few mm and 3cm. Maximum dip angle of forset beds vary between 25° and 30°. Length of the exposed troughs ranges between 26cm and 170cm, while their widths vary between 15cm and nearly 1m. Current ripples observed are of sinuous / linguoid and climbing types which range in size between 6 - 14cm and 1 - 2cm respectively. In some cases ripples are exceptionally large having a wavelength of 55-70cm and amplitude of 12-15cm. Such types were observed only in a few localities.

Various types of sole marks are present which includes flute casts, longitudinal ridge marks and other types. Various other types of sedimentary structures are present which include parallel lamination, parting lineation, bioturbation, convolute bedding and graded bedding of both reverse and normal types.

LITHOFACIES ASSOCIATIONS

Various sections within the Middle and Upper members of the Ghazij Formation were studied (Fig. 2 & 3) in order to describe their facies associations. Sections were categorized into shale dominant parts containing a few thin sandstone beds and mixed parts containing sandstone, siltstone/shale, conglomerate and coal seams (Fig. 2). Sandstones of the Middle member are dominantly trough-cross bedded, parallel laminated, occasionally massive, and normally possess rip-up clasts, plant fragments and trace fossils. Some horizons also possess hummocky cross-bedding and wave ripples, however, these structures are more common in the Upper member (Fig. 3). Some sandstone horizons show pronounced amalgamation with each other. Apart from the regular coal seams present within the Middle member, plant fragments and carbonaceous matter is common almost in all sandstone / siltstone horizons throughout the formation. A few limestone horizons may be seen in which the limestone contains marine bivalves, brachiopods and gastropods. Pelitic sequences in the Upper member are mostly shales inter-bedded with very finely laminated and cross-laminated siltstone and very fine grained sandstones. Occurrence of these seem to be in contrast with the dominantly shaley and muddy character of the Lower member.

PALEOCURRENT DIRECTIONS

Paleocurrent directions based on cross-stratification, ripple marks, sole marks, parting lineations and orientation of plant fragments were measured directly and in some cases corrected accordingly, depending on the situation and types of sedimentary structures within

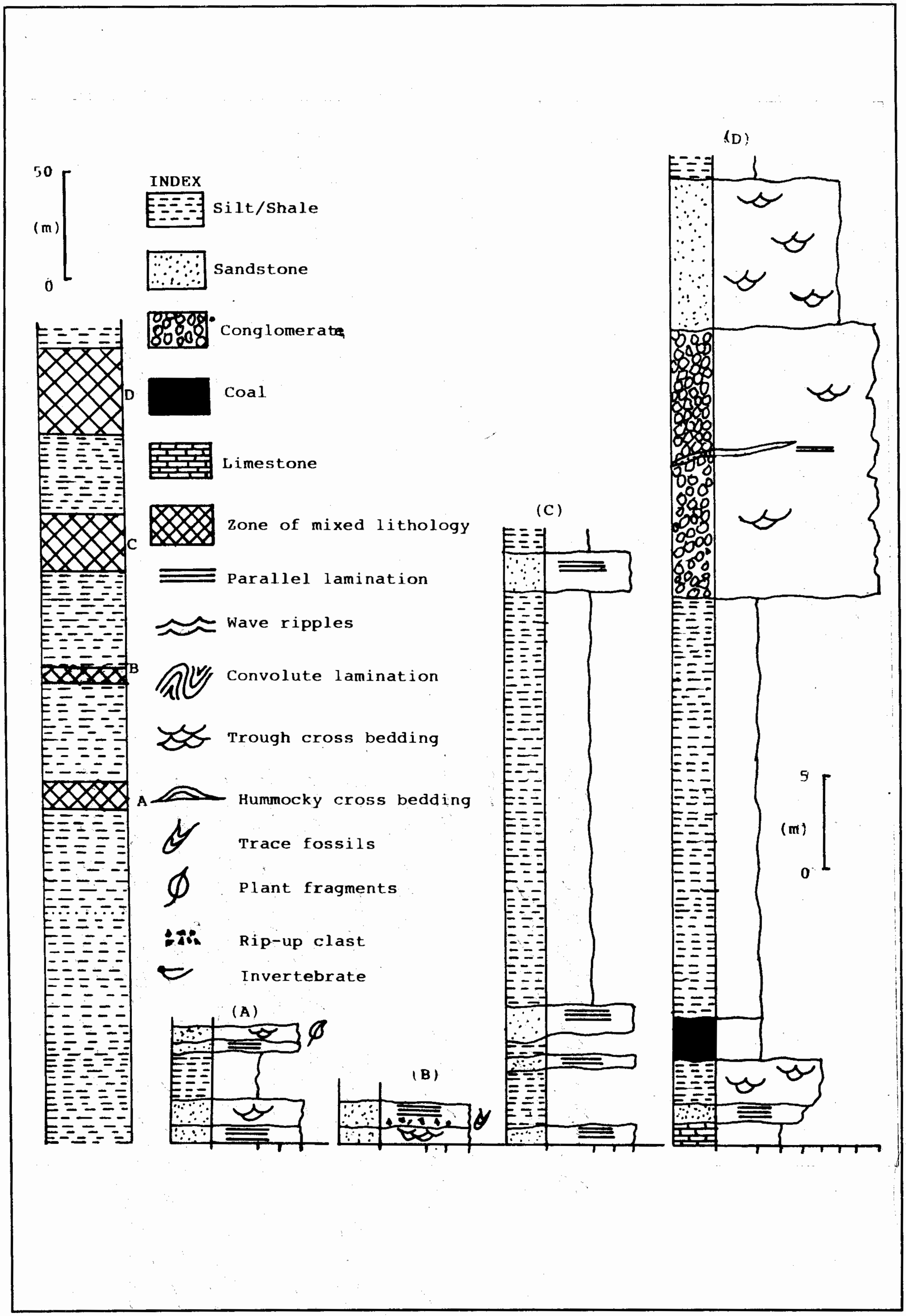

Figure 2. **Lithofacies associations within the Lower and Middle members of the Ghazij Formation. Details of mixed zones A,B,C & D are given on separate columns.**

the relevant localities. Data based on cross-stratification was corrected and rose diagram prepared (Fig. 4a). It indicates that paleocurrent directions are highly dispersed varying from northwestward through southwestward. However, modal direction is between 220° and 240° flowing towards southwest suggesting a general westward flow direction. High dispertion of the paleocurrent directions may be due to its fluvio-deltaic origin.

Paleocurrent pattern based on sole marks, ripple marks and other sedimentary structures (Fig. 4b) shows a current flow from northeast to southwest. Orientations of longitudinal ridges vary between N10E and N60E, while, the orientation of groove casts vary between N20W and N29W, which also verify the general westward trend. Paleocurrent directions based on ripples (Fig. 4b) also show a NW and SW trend of flow directions. Orientation of plant fragments and parting lineation range between N70E and N76E.

An overall westward and dominantly southwestward trend of paleocurrent directions may be established from the data obtained from sandstone horizons of the Ghazij Formation in Sor Range area, indicating the earliest phase of emergence during Early Eocene in response to the collision of Indo-Pakistani Plate with Eurasia and derivation of detritus from a landmass east of the Sor Range area. Similar trends of paleocurrent directions have been suggested for the Ghazij Formation of Kach area, Ziarat District (Kassi et al. 1987).

PETROGRAPHY AND PROVENANCE

SANDSTONES

Textural and mineralogical studies of seventeen randomly obtained sandstone samples were carried out under the polarizing microscope and estimates of the main constituents made in order to classify them. Grain size of the analyzed samples is fine to medium grained, ranging between 0.01-0.8 mm. Most of the samples are well sorted to moderately sorted and sub-angular to sub-rounded. Almost all sandstone samples show grain supported framework with very minor matrix.

Mineral constituents of the sandstones are subordinate to the rock fragments which are mainly limestone and chert fragments of various types. Quartz is most common among the mineral constituents which is dominantly of the non-undulatory type, a character which may correspond to its volcanic origin (Blatt & Christie 1963). Feldspar is subordinate to quartz (1-3%) and is mostly plagioclase and rarely orthoclase and perthite. Biotite and muscovite are also rarely present. Most of the ferromagnesian minerals have been chloritized. Chlorite is the most common among clay minerals. Heavy minerals are mostly chrome spinal, tourmaline and apatite. Cement is mainly calcite, however, matrix include clay minerals and other unidentified grains of sizes finer than silt.

Various types of igneous, sedimentary and metamorphic rock fragments were recognized (Table 2) among which limestone, chert and organic matter are most abundant which collectively range between 60 - 95%. The limestone fragments are dominantly of two main types, a dull finely crystalline micritic type and a clear coarsely crystalline sparitic type. Also chert fragments of red and grey varieties are present which commonly contain radiolaria. Fragments of quartz arenite are also present in minor amounts. Igneous fragments include basic volcanic (spilitic) and intermediate (?dacitic) types. Metamorphic fragments include quartzite and phyllite, however, such fragments are very rare. Visual estimates of percentages of mineral and rock constituents indicate that rock fragments in almost all samples are over 90%, among which limestone fragments are always more than 50%. These estimates suggest that almost all samples fall within the fields of lithic arenite and calclithite types of sandstones (Dott 1964; Folk 1968). Sandstones of the Ghazij Formation of some other localities have been analyzed and classified based on point counting by Kassi (1986) who has reported similar results. Kassi (1986) has also studied sandstone samples of the nearby Degari area which are highly rich in limestone and chert fragments and fall within the lithic arenite and calclithite varieties of Dott (1964) and Folk (1968).

Dominance of a variety of limestone and chert fragments indicate that source area was a

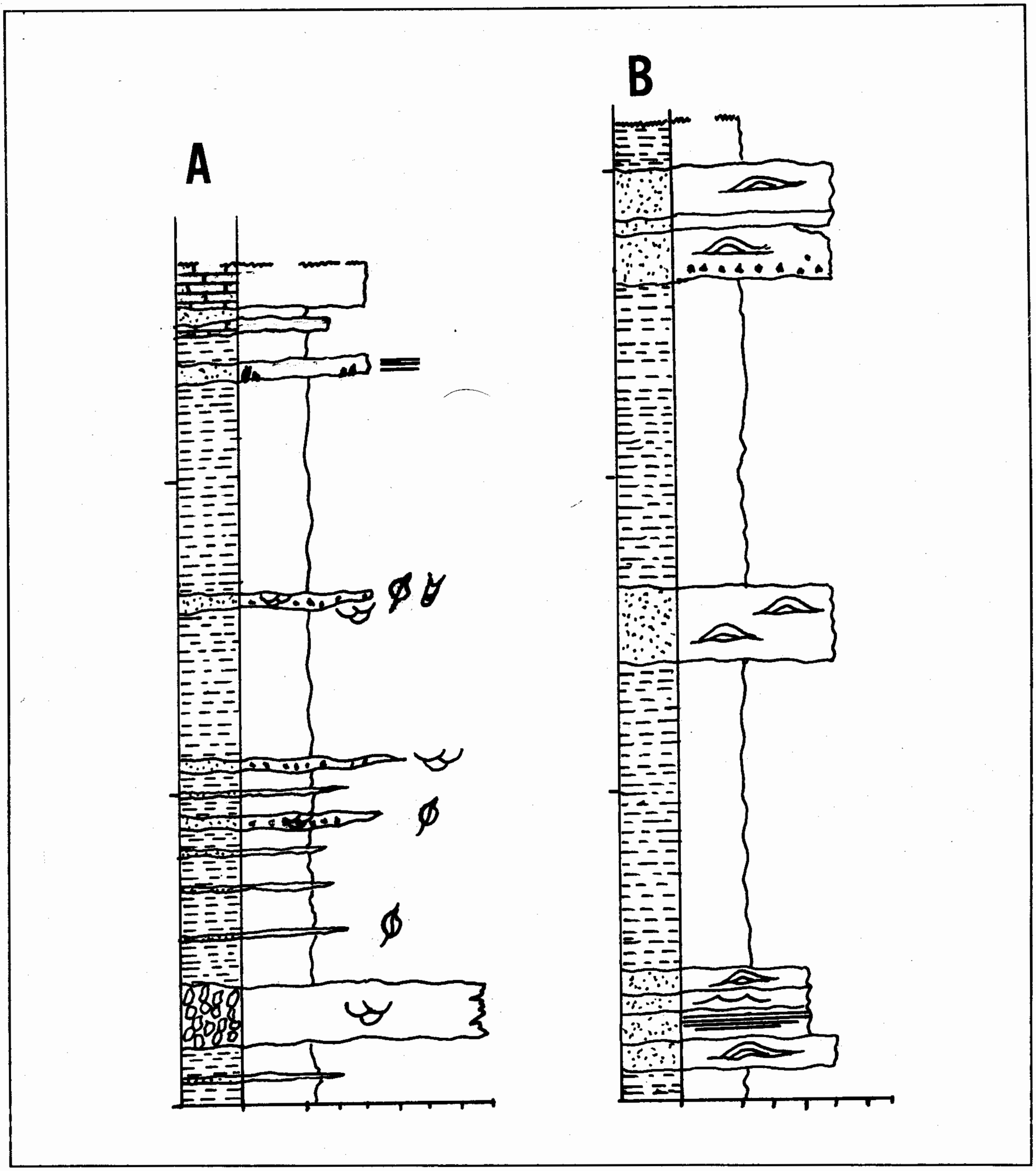

Figure 3. Lithofacies associations within the Upper member of the Ghazij Formation (A) Sardar Usman Mines (B) East of Mehdadzai. Index as in Fig. 2.

limestone dominant terrain in which quartz arenite, basic volcanic and hypabasal fragments, quartzite and phyllite fragments were also present, however, in subordinate amounts. The older sedimentary succession of Jurassic through Paleocene age within the Sulaiman Range of the Indo-Pakistani Thrust-Fold Belt on western margin of the Indo- Pakistani Plate represents a similar sedimentary terrain and detritus has been derived from it.

CONGLOMERATE

A single conglomerate horizon is present within the upper part of the Middle member which reaches up to 17m near Sardar Usman Mines. The conglomerate bed is lenticular and pinches both southeastward near Degari and northwestward near Mehdadzai. Maximum clast

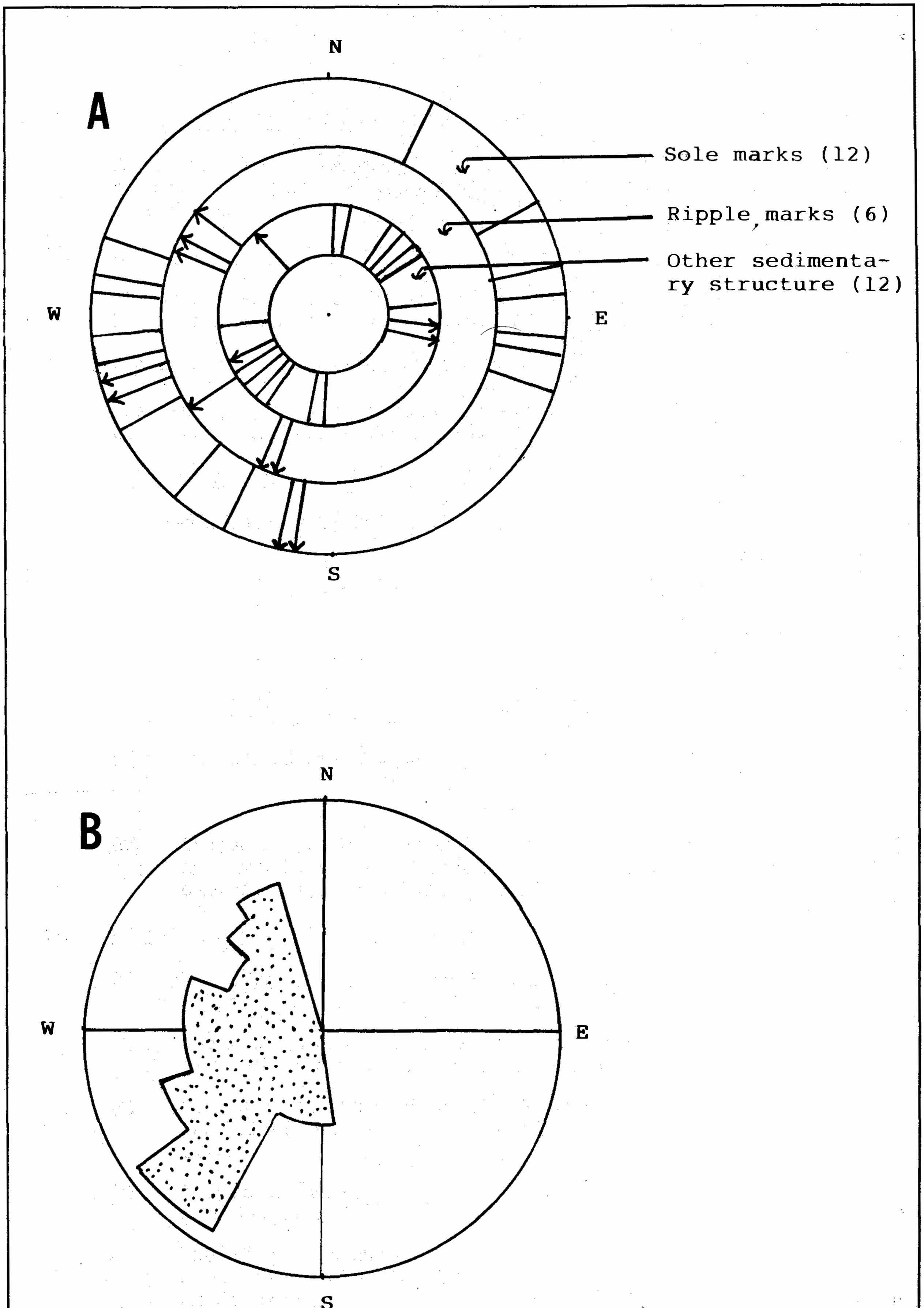

Figure 4. Paleocurrent directions within the Ghazij Formation; A) current directions based on observation of other sedimentary structures, B) Rose diagram based on observations of trough cross-bedding (n=16).

Location No.			62	67	72	36	39	45	51	60	Com.
Grid Reference			176162	245149	199102	205131	203134	214179	195145	172166	
256-128 mm	-8 – -7 φ	n	-	1	2	-	2	2	1	10	18
		%	-	14.5	1.4	-	2	3.6	1.7	12.5	2.6
		Cu%	-	1.5	1.4	-	2	3.6	1.7	12.5	2.6
128-64 mm	-7 – -6 φ	n	13	10	25	16	8	15	13	28	128
		%	14.6	14.9	17.7	14.7	8.2	27.3	22.8	35	18.4
		Cu%	14	16.4	19.1	14.7	10.2	30.9	24.5	47.5	21
64-32 mm	-6 – -5 φ	n	36	26	62	38	52	26	28	30	298
		%	5	38.9	44	34.9	53	47.3	49.1	37.5	42.8
		Cu%	55	55.3	63.1	49.6	63.2	78.2	76.3	85	63.8
32-16 mm	-5 – -4 φ	n	36	27	44	33	34	12	14	12	212
		%	40.4	40.2	31.2	30	34.7	21.8	24.6	15	30.4
		Cu%	95.4	95.5	94.3	79.9	97.9	100	98.2	100	94.2
16-8 mm	-4 – -3 φ	n	4	3	8	19	2	-	1	-	37
		%	4.5	4.5	5.7	17.4	2	-	1.7	-	5.3
		Cu%	99.9	100	100	97.3	99.9	-	99.9	-	99.5
8-4 mm	-3 – -2 φ	n	-	-	-	3	-	-	-	-	3
		%	-	-	-	2.7	-	-	-	-	0.04
		Cu%	-	-	-	100	-	-	-	-	99.9

Table 2. Grain size parameters based on size analyses of conglomerate horizon.

Location No.	Grid. Ref.	φ5	φ16	φ84	φ95	φMd φ50	Mean Mφ	Mode Moφ	σφ	$\sigma_2\phi$	βφ
62	176162	-7.2	-6.6	-4.9	-4.5	-5.8	-5.75	-5.0	0.85	0.06	-2.59
72	199102	-7.0	-6.5	-4.9	-4.5	-5.55	-5.7	-5.5	0.8	0.25	-2.56
67	145149	-7.2	-6.5	-4.9	-4.5	-5.55	-5.7	-4.5	0.8	0.37	-2.68
36	105131	-6.9	-6.4	-4.4	-3.9	-5.5	-5.4	-5.5	1.0	0.10	-2.50
45	214179	-7.4	-6.9	-5.4	-5.2	-6.2	-5.95	-5.5	0.75	0.13	-2.47
51	195145	-7.2	-6.7	-5.2	-4.8	-6.0	-5.95	-5.5	0.75	0.00	-2.60
60	172166	-8.0	-7.35	-5.55	-5.3	-6.4	-6.45	-5.5	0.9	-0.83	-2.55
39	203135	-7.0	-6.35	-5.1	-4.6	-5.7	-5.72	-5.5	0.62	0.16	-2.93
Combined Result		-7.25	-6.65	-4.9	-4.35	-5.8	-5.77	-5.5	0.87	0.00	-2.67

Table 3. Grain size parameters of conglomerate horizon. Parameters calculated according to Inman's (1952) formulae. σφ=Phi deviation measure; $\sigma_2\phi$=Phi skewness measure; βφ= phi kurtosis measure.

size observed varies between 170mm and 360mm. The conglomerate is generally clast supported having sandy matrix, moderately sorted, well rounded, imbricated and possesses lenses and bands of coarse grained sandstone which are mostly parallel laminated.

Texture and Grain Size Analyses of Conglomerate

Grain size analyses of the conglomerate horizon were carried out at 8 localities on selected cross-sectional areas, on available smooth surfaces. Cross-sectional areas ranging between 40cm X 60cm and 60cm X 90cm were selected, depending on the availability of suitable surfaces. Parallel lines, nearly 6cm apart, were drawn within the selected areas and maximum intercepts of gravel along these lines measured systematically and directly by ordinary measuring tape. Clasts less than 5mm sizes were not measured and regarded as part of the sandy matrix. The obtained data (Table 2) was classified, histograms and cumulative curves (Fig. 5) prepared and size parameters like phi median ($Md\phi$), phi mode ($Mo\phi$), phi mean ($M\phi$), phi deviation measure ($\sigma\phi$), phi skewness measure ($\sigma_2\phi$) and phi kurtosis measure ($\beta\phi$) calculated according to the Inman's (1952) formulae (Table 3).

The derived grain size parameters (Figs. 5, Table 3) indicate that the conglomerate is generally moderately sorted with phi deviation measure ($\sigma\phi$) ranging between 0.62 and 1.0 and in most cases (6 out of 8) between 0.75 and 0.9. Phi mean ($M\phi$) is between -6.45 and -5.95 and phi median ($Md\phi$) is between -5.5 and -6.4. These parameters suggest that mean sizes in most cases range between 40 and 60mm. Phi skewness measure ($\sigma_2\phi$) is between -0.83 and 0.37, indicating a general symmetrical trend. Phi kurtosis measure ($\beta\phi$) ranges from -2.47 and -2.93.

Composition and Provenance of Conglomerate

Conglomerate contains various types of sedimentary and igneous fragments (Table 4), which include a variety of limestones, cherts, sandstones and basic igneous fragments. Limestone fragments are of various types and origins. The lithological characters which were compared with the published descriptions (HSC 1960; Shah 1977). Most common type of limestone is the medium to dark grey, dark brownish grey, generally finely crystalline variety which occasionally possesses amonites and is sometimes oolitic and pisolitic. These characters resemble with those of the Jurassic Shirinab Formation. The second common group of limestone types are white, cream, greenish grey, pale green, pinkish and reddish grey, very finely crystalline, porcelaineous, breaking with conchoidal fracture and possessing micro-foraminifera. These types are derived from the Cretaceous Parh Group. Another type of limestone is the light brownish grey and pinkish grey, coarsely crystalline and fossiliferous variety which may have been derived from the Paleocene Dungan Formation.The chert fragments are mainly of two colors among which the red, maroon and pinkish types are most common and belong to the Cretaceous Parh Limestone. The black and dark grey coloured types are subordinate and have been derived from the Jurassic Shirinab Formation.

Some limestone fragments of grey colour may also correspond to the Upper Cretaceous Fort Munro Formation. Sandstone fragments are very rarely present which are mostly of quartz arenite variety resembling highly with the Late Cretaceous Pab Sandstone. Other types of rock fragments include the greenish grey, finely crystalline and equigranular basic igneous fragments, perhaps derived from sills/ dikes

Rock type		Characters	Origin
1	Lime-stone	White, cream, very finely crystalline, porcelains, concoidal fracture.	Parh Limestone
2	Lime-stone	Greenish grey, pink-ish, grey, pale, very finely crystalline, porcelaneous, concoidal fracture	Parh Group
3	Lime-stone	Dark grey, brownish grey, mostly finely crys-talline, occasionally coarsely crystalline, and oolitic.	Chiltan Lime-stone
4	Lime-stone	Light brownish grey, and pinkish grey, coarsely crystalline, fossilifer-ous.	Dungan Lime-stone
5	Chert	Pink and red coloured with radiolaria	Parh Limestone
6	Chert	Dark grey and black.	Chiltan Lime-stone
7	Basic volcanic	Dark grey, porphyritic	Bela Volcanic Gp.
8	Sandstone	Quartz arenite rich in round quartz grains.	Pab Sandstone
9	Dolarite/ diabase	Dark greenish grey	Dikes/sills
10	Basic volcanics	Very finely crystalline porphyritic.	Bela Volcanic Group
11	Quartzite	Rich in polycrystalline quartz	Basement

Table 4. Types of rock fragments and their proposed provenance observed in sandstone and conglomerate, based on comparison with published lithological characters by Hunting Survey Corporation (1960) and Shah (1977).

present within the Triassic - Cretaceous strata of the Sulaiman Belt. Also basic volcanic fragments of dark greenish grey colour and very fine grained and porphyritic texture are rarely present which are perhaps derived from the Bibai Formation/ Bela Volcanic Group (HSC 1960; Kazmi 1979). On the basis of above mentioned textural and compositional characters the conglomerate may be classified as polymictic pebble orthoconglomerate (Pettijohn 1975; Hatch & Rastall 1971). Its source area was a volcano-sedimentary terrain possessing dominantly limestone sequences ranging in age from Jurassic through Paleocene, namely, the Shirinab Formation, Parh Group,Bela Volcanic Group, Fort Munro Formation, Pab Sandstone and Dungan Formation (HSC 1960; Shah 1977).

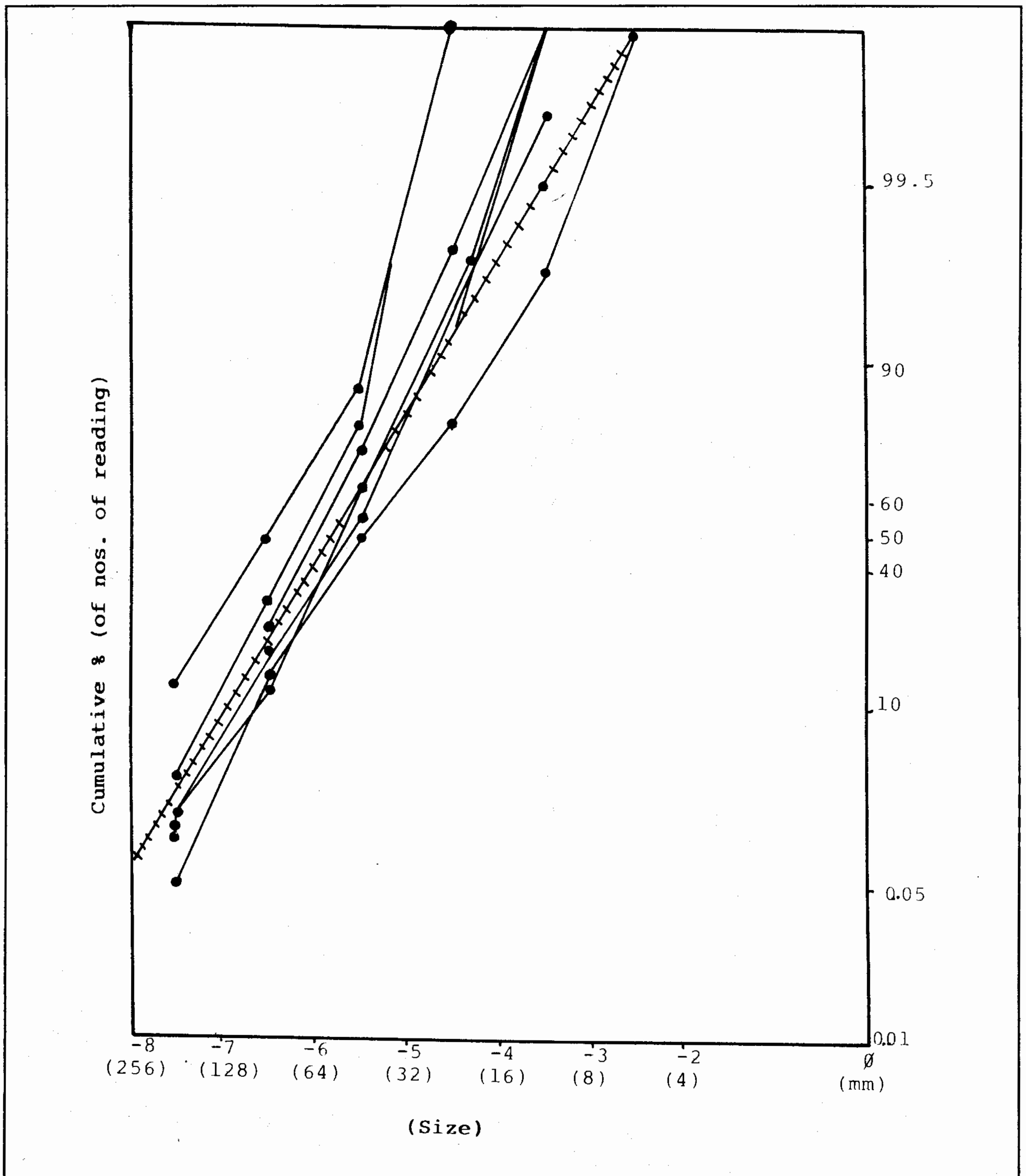

Figure 5. **Cumulative curves based on grain size analyses of the conglomerate.**

DISCUSSION

Lower member of the Ghazij Formation comprising shales / mudstone with a few sandstone and siltstone horizons, which have been reported to possess marine fauna (Iqbal 1969a), is the marine ward prodelta clays (Scruton 1960; Reneick 1970). The Middle member contains a mixture of sandstone and shales / siltstones, a single horizon of conglomerate and many coal seams. Sandstone possessing trough cross-bedding, parallel lamination, lenticular morphology of beds, highly erosional lower surfaces and profusion of rip-up clasts is characteristic of channelized fluvial sequences. However, presence of the high amount of plant fragments, marine fossils, bioturbation, wavy cross-bedding and wave ripples indicate marine and lagoonal influence. Lagoonal conditions may be indicated by regular coal seams of a few cm to 8m thick. Sandstone sequences of the Middle member belong to the distributary channels of the delta front. Conglomerate horizon within the Middle member suggests deposition within high energy channelized fluvial conditions and enhanced uplifting of the older succession of the sedimentary rocks. Paleocurrent pattern and lenticular morphology of the conglomerate horizon pinching northwestward near Mehdadzai, westward near Zharai and southwestward near Degari, also indicates the westward trend of the paleoslope.

The occurrence of hummocky cross-stratification, herrigbone type of cross stratification and wave ripples within the Upper member indicate storm, tidal and wave influence. Storm origin i.e. tropical hurricanes and intense winter storms, for hummocky cross-stratification has already been established (Duke 1985; Harms et al. 1982; Dott & Bourgeios 1982; Walker et al. 1983). The presence of massive sandstones also indicates high energy conditions of transport. The limestone beds, possessing marine fauna, inter-bedded with massive sandstone within the Middle member of the Ghazij Formation near Hazrat Agha Mines indicate intervals of normal marine conditions which in turn are followed by lagoonal / deltaic sequences. In light of the sedimentary structures, lithofacies associations and paleocurrent pattern described in previous sections, deltaic origin for the Middle and Upper Ghazij Formation is hereby supported, which has high fluvial influence in the middle part and storm, tidal and wave influence in the upper part. The presence of regular coal seams up to 8m thick and high amount of plant fragments indicate the deltaic conditions (Coleman & Wright 1975) within tropical climatic conditions. This notion is also supported by the presence of plant fragments which belong to the Sp. Salite of family Salicacene and Sp. Uplus of family Ulmaceae and studies of mega-fauna of the Ghazij Formation (Iqbal 1969).

The general westward trend of paleo-current directions indicates derivation of detritus from the east where a succession of sedimentary rocks, deposited on the northwestern margin of the Indo-Pakistani Plate, had emerged.

CONCLUSIONS

1) Based on lithological characters and facies associations, the Eocene Ghazij Formation is divided into three members arbitrarily called as Lower, Middle and Upper members. The formation in Sor Range area overlies the Paleocene Dungan Limestone and underlies the Habib Rahi Limestone member of Kirther Formation.

2) The Lower member, comprising massive claystone and siltstone possessing marine fauna, is the marine-ward pro-delta clays of the deltaic regime. The Middle member contains a mixture of sandstone, siltstone and claystones with some coal seams and a thick conglomerate horizon. Various sedimentary structures within the sandstone horizons like trough cross-bedding, parallel lamination, lenticular morphology of beds suggest that they belong to distributary channels of the delta front. Conglomerate also suggest channelized fluvial conditions and enhanced uplifting erosion of the older sedimentary succession. The Upper member, characterized by sandstones possessing hummocky cross-stratification, herring bone type of cross-bedding, wave ripples and ripple cross-lamination indicate storm, tidal and wave influence. Occasional limestone beds possessing marine fauna within the Ghazij Formation indicate periodic recurrence of normal marine conditions associated with sea-level fluctuations. High amount of

carbonaceous matter and various coal seams indicate tropical deltaic environment.

3) Paleocurrent directions are generally towards west which indicate derivation of detritus from the newly emerged older sedimentary succession to the east within the Sulaiman belt on the western margin of Indo-Pakistani Plate.

4) Sandstones of the Ghazij Formation may be classified as the calclithite variety of lithic arenite. Conglomerates may be classified as the polymictic pebble ortho-conglomerate. The source area was composed mainly of a volcano-sedimentary terrain representing fragments of the Jurassic Shirinab Formation, Cretaceous Parh Group, Upper Cretaceous Fort Munro Formation and Pab Sandstone and Paleocene Dungan Formation.

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HYDROGEOCHEMICAL STUDY OF LASBELA REGION, BALOCHISTAN, PAKISTAN

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ABSTRACT

Hydrogeochemical investigation of stream water draining through Bela Ophiolite and sedimentary rocks of Jurassic-Cretaceous age have been made. Quantitative estimation of important semi-mobile to mobile elements like Fe, Mn, Zn, Cu and Ba have been carried out. Raw and statistical data indicate anomalous concentrations of some elements in stream water in certain regions suggesting prospective areas for mineralization. Abundance and mobility of major and trace elements were discussed in the light of climatic conditions and local geology. Major ions and important parameters such as pH, total dissolved solids (TDS), electrical conductivity (EC), residual sodium carbonate (RSC) and sodium adsorption ratio (SAR) were also used to asses the suitability of these waters for drinking and irrigation purposes.

INTRODUCTION

The study area consists of ophiolitic rock assemblages of early Cretaceous age associated with sedimentary rocks of Jurassic to Cretaceous time. These ophiolite sequences have good pot-ential for the enrichment of metalliferous ore deposits of Fe, Cr, Mn, Cu, Zn, Ni, Pb and Co (Hashmi 1986). Mesozoic carbonates in the vici-nity are hosts for lead, zinc and barite deposits.

Hydrophile elements derived through the chemical weathering of above rocks are dispersed in ground water and stream channels. The abundance and mobility of these elements largely depend upon the nature of bed rock, drainage system and climatic conditions of the area. Anomalous concentration of trace metals in the water samples can be used for prospecting ore and mineral deposits in a region.

The present study is the reconnaissance hydrogeochemical survey and prospecting of ore deposits in Lasbela region. It also aims to study the suitability of water for drinking and irrigation purposes.

GEOGRAPHY

The area has a highly rugged topography due to intense deformation, uplift and erosion of the rocks. The eastern half of the study area contains undulating mountains, hills and mounds, forming a ridge and valley system striking about north-south. The western half of the area is covered by subrecent to recent material. The topography ranges from 20 metres above sea level in the southern part of the area, to 1448 metres in the north-eastern corner. The drainage is subparallel to dendritic and flows from southwest to south. Small streams are intermitent and seasonal, whereas the large ones have limited perennial flow. Most of the small

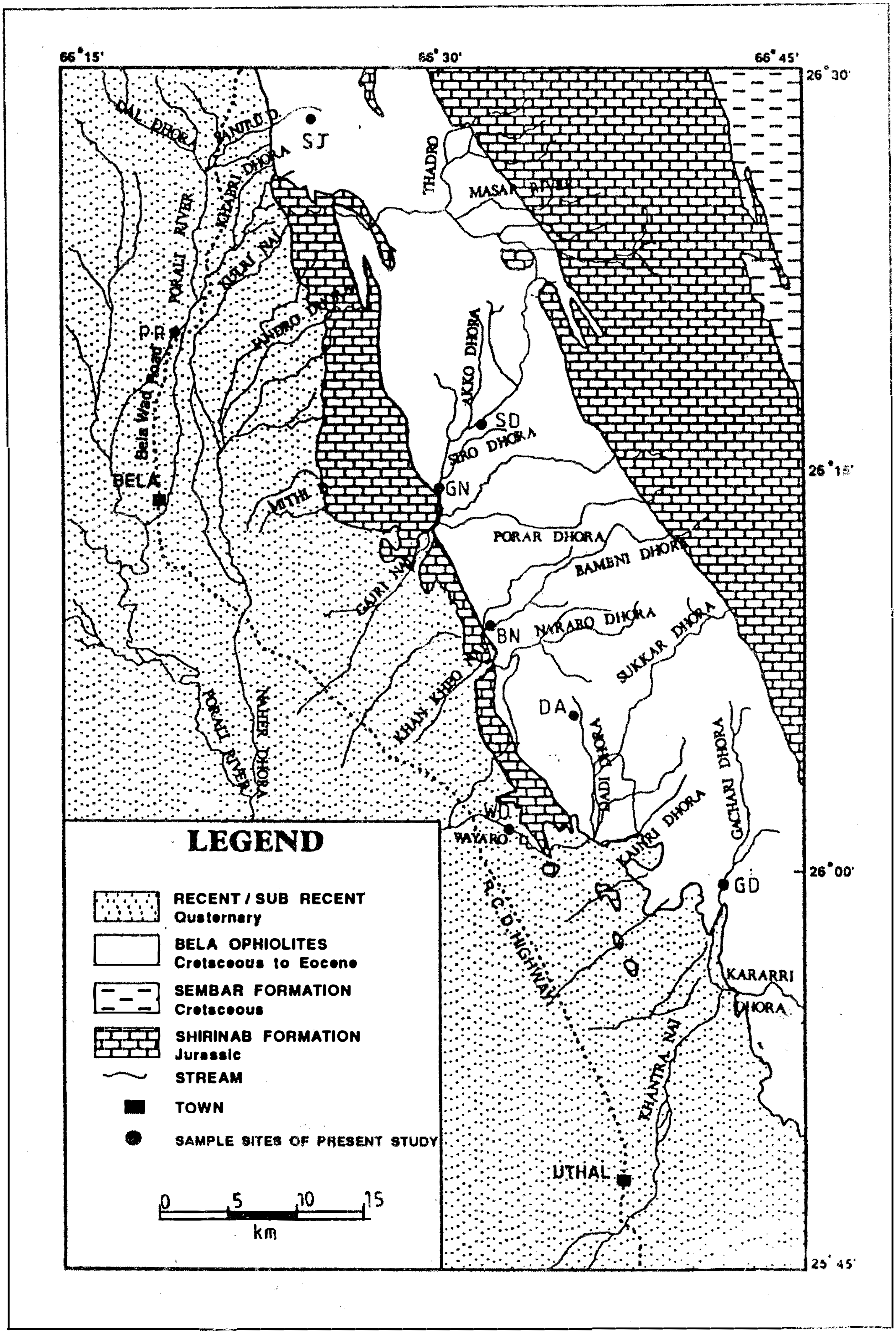

Figure 1.Geological map of the study area (Modified after Hunting Survey Corp. 1960)

streams diminish in flow before reaching the main drainage of the area. The overall climate is extremely arid and characterized by high temperature and very low precipitation. The annual rainfall is less than 10 cm, which is capricious and uncertain.

GEOLOGICAL SETTING

The study area lies in the southern part of Axial Belt of Pakistan. The general stratigraphic sequence of the area comprises sedimentary rocks of Jurassic-Cretaceous age in association with the Bela Ophiolite which was emplaced during Paleocene- Lower Eocene. Afghan and Kabul Blocks forming the southern margin of the Eurasian continent were involved in the collision with the Indo-Pakistan Plate. This collision during Paleocene led to the obduction of the Bela Ophiolite onto the western margin of the Indo-Pakistan Plate (Bannert 1992).

The rocks of Bela Ophiolite represent remnants of volcanics and sediments of the Tethys Ocean and formerly were about 4,000 km wide and located at the northern part of the Gondwana Continent prior to its final break-up at the beginning of the Cretaceous period (Bannert 1995). The upper succession of ophiolitic sequence is well exposed and consists of basaltic pillow lava and pelagic sediments (Sarwar 1992). The Bela Ophiolite is exposed as a 380-km long and 12-km wide elongated belt striking north- south. Bela Ophiolite is exposed as a sandwiched wedge within the Shirinab formation of Jurassic age (Fig. 1) forming a tectonic contact (Ahsan et al. 1988). The Parh and Goru formations of Cretaceous age are missing in the area and only the Sembar formation represents Cretaceous strata.

The Shirinab formation consists of carbonates with subordinate amounts of clastics. The rocks exposed in the western part of the area belong to the upper part of the formation comprising interbedded limestone and shale units. They increase in clastic contents upward and grade into olive green shales of the Sembar formation (Kazmi 1995).

LOCATION AND COLLECTION OF SAMPLES

The area is accessible from Karachi by the RCD Highway. Water samples were collected from different seasonal streams around Uthal and Bela in Balochistan. The sample collection sites are located on the geological map of the area (Fig. 1). Nearly all sites are accessible by a four-wheel drive vehicle. The sample localities were selected keeping in view the nature and type of bedrock and the drainage system of the area. The sampling was done from the junction of first (Porali River), second (locally known as *nai*) and third order streams (locally known as *dhora*). Therefore, the samples collected represent water draining through all the rocks present in the area and can depict any anomalous change in trace element concentration and dispersion up-stream.

SAMPLE PREPARATION AND ANALYTICAL METHOD

Total dissolved solids (TDS), pH and conductivity were determined at the site with the help of Denver instrument Model 50. The samples for trace metals were filtered and acidified to about 2 pH in order to avoid trace metal precipitation and inhibit the growth of microorganisms. These samples were stored in pre-sterilized polyethylene bottles. Chloride meter (Jenway PCLM 3) was used for the determination of chlorides. Alkalies were estimated using Gallenkamp FGA 350L Flame Photometer. Estimation of elements was made using an atomic absorption spectrophotometer (Hitachi Model No. Z-8000).

HYDROGEOCHEMICAL STUDIES

The hydrogeochemical investigations of stream water in various localities in the southern Bela Ophiolite were carried out to explore the influence of the bed rock on their compositional variations. Efforts were made to determine the degree of correspondence and inter-relationship among selected semi-mobile and mobile elements, and to present these data and result in graphical forms (Figs. 3 and 4). These plots proved to be of great assistance in the study of possible causes of enrichment and depletion of elements and their distributional patterns in different localities. Importance was also given to locate possible areas of mineralization, in contrast to background values given by Reedman (1979). The results of the study are discussed in relation to individual and groups of elements of similar geochemical affinity, in the light of bed rock composition, mobility of elements, weathering, drainage, climatic conditions and their abundance in stream water.

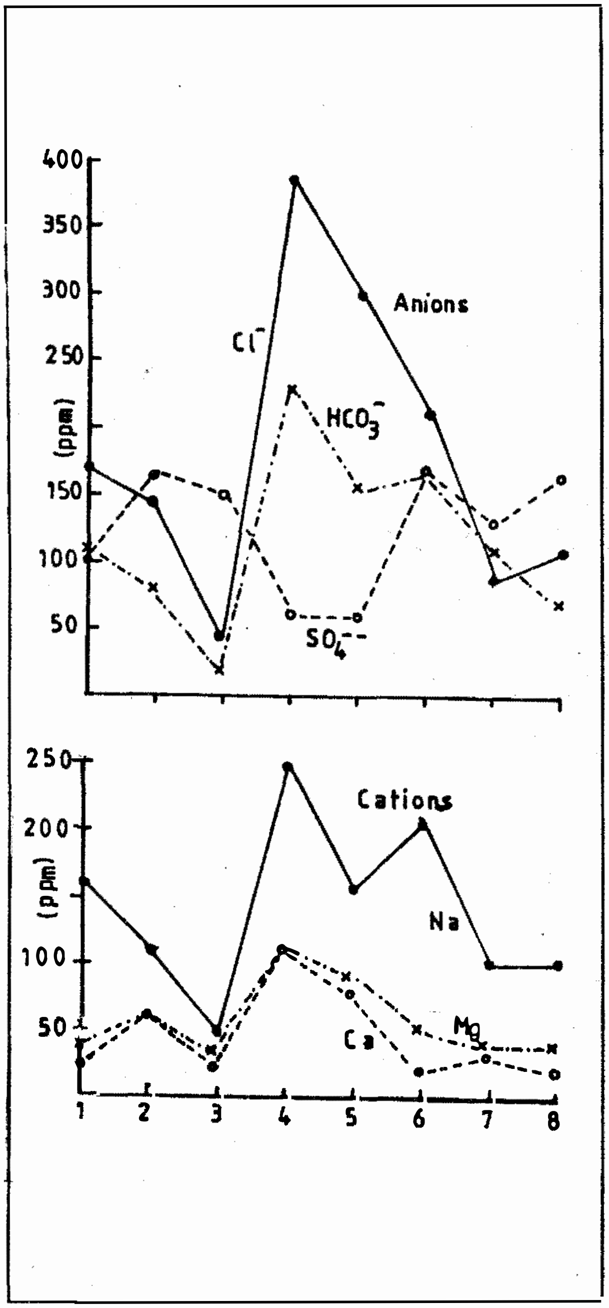

Figure 2. Concentration of major ions in different stream water of Lasbela region. Samples 1 from Gachari (GD), 2 Wayaro (WD), 3 Dadi (DD), 4 Bhampani (BN), 5 Gajri (GN), 6 Siro (SD), 7 Sanjro (SJ) & 8 Porali River (PR).

MAJOR ELEMENTS

Major ionic composition of water from Lasbela region shows fluctuating distribution (Table 1 and Fig. 2). Cations show similar enrichment and depletion pattern. Ca and Mg follow equal and same distribution style in various localities, though they are derived from different sources. Ca is leached from Shirinab formation and mostly it has good ionic relationship with bicarbonate ions (Fig. 5). Bicarbonate ions also show nearly similar pattern (Fig. 2). Basalts and serpentines are good source rocks for Mg ions. Sulphate ions are best carrier of Mg ions in aqueous phase and its distribution is

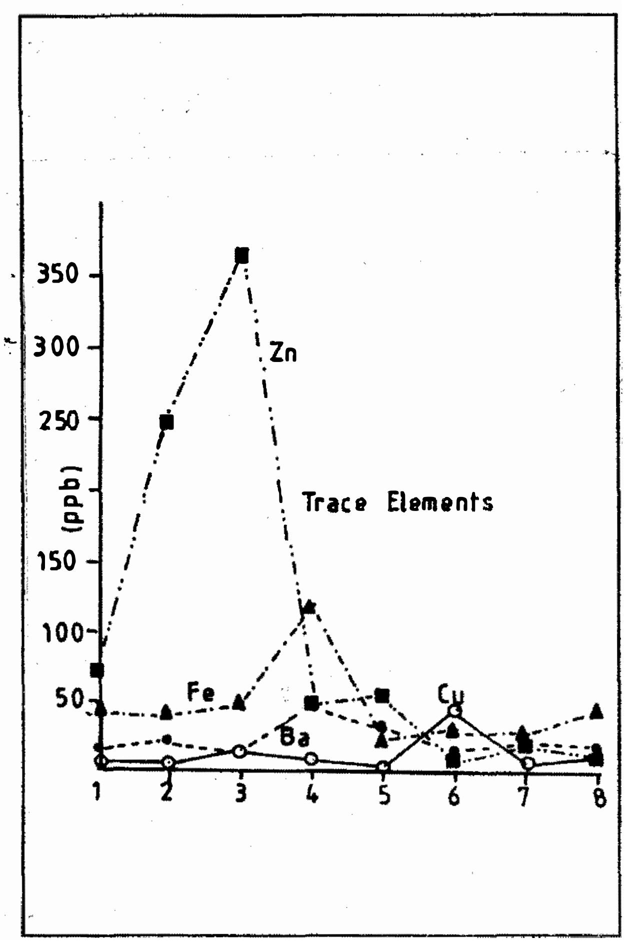

Figure 3. Concentration of trace elements in different stream water of Lasbela region. Samples numbers are given in Fig. 2.

Locality	GD	WD	DD	BN	GN	SD	PR	SJ
Major cations and anions in ppm								
Na	160	110	45	250	55	205	100	100
K	1	1	1	2	1	2	1	1
Ca	20	60	20	110	80	20	30	20
Mg	40	60	30	110	90	50	40	40
Cl	170	145	45	390	300	210	90	110
HCO_3	100	165	150	60	60	170	130	165
CO_3	20	25	20	2	30	35	35	20
SO_4	115	80	20	230	155	165	110	70
Trace metals in ppb								
Mn	2	2	7	9	7	3	1	1
Fe	45	40	50	120	20	32	30	45
Cu	5	5	16	8	4	46	7	13
Ba	10	23	18	48	31	15	24	15
Zn	70	250	370	50	55	10	20	10

Table 1.
Major and trace ions concent-ration of the study area. Explanation of loca-lities are given in Fig. 2.

Locality	GD	WD	DD	BN	GN	SD	PR	SJ
Major ionic composition in epm								
Na	6.96	4.9	1.9	11	6.74	8.91	4.35	4.35
K	0.02	0	0	0.1	0.02	0.05	0.04	0.01
Ca	1	3	1	5.5	3.99	1	1.49	1
Mg	3.29	4.9	2.5	9.1	7.4	4.11	3.29	3.29
Cl	4.79	4.1	1.3	11	8.46	5.92	2.54	3.1
HCO_3	1.64	2.7	2.5	1	0.98	2.78	2.13	2.7
CO_3	0.66	0.8	0.7	0.1	1	1.16	1.16	0.66
SO_4	2.39	1.7	0.4	4.8	3.22	3.43	2.29	1.45
pH	7.34	7.5	7.3	7.1	7.42	8.13	7.53	7.41
TDS (ppm)	640	650	345	1350	950	890	545	540
E C (mS/cm	0.96	1	0.5	2	1.43	1.33	0.82	0.81
RSC (-)	1.9	4.4	0.4	14	9.4	1.2	1.5	0.9
SAR	4.7	2.4	1.5	4.1	2.8	5.5	2.8	3
TH(ppm)	170	250	140	450	420	220	200	170

Table 2.
Major ionic concentration and physical parameters for irrigation water quality. Description of localities is given in Fig. 2.

opposite in contrast to chlorides and bicarbonates in different water samples from Lasbela region (Fig. 2). In the above different conditions close distribution pattern of Ca and Mg is somewhat enigmatic. Probably it can be explained on the basis of close geochemical properties and the arid climatic conditions which keeps constant physico-chemical environment for similar mobility of these elements in the region.

TRACE ELEMENTS

The distribution of trace elements are presented in Fig. 3. Bed rock, composition of water, pH, and others factors are mainly responsible for their distribution in water samples of Lasbela region. Except Zn which shows high concentration in few localities, other trace elements have low and nearly uniform abundance. This can be explained bt the phenomenon that Zn has relatively better mobility among other trace elements and at about 7 pH majority of the trace elements are hydrolyzed (Reedman 1979).

Iron, Manganese and Copper

Fe and Mn are lithophile elements and have very low mobility. In fresh water, the abundance of Fe and Mn is 100 and 15 ppb respectively (Rose et al 1979). In the area under study Fe ranges from 20 to 120 ppb (Fig. 3) with a mean of 48 (Table 3). Mn also shows very poor concentration (1-9 ppb) and none of any locality has reached at the average value. Only Bhampani Nai (BN) has relatively high concentration of Fe (120 ppb) whereas rest of these localities have below average values for Fe and Mn. It is important to mention that in the central part of the study area, tholeiitic pillow basalt is exposed which at places contains deposits of Mn and Fe (Naseem et al. 1997). In spite of this fact the water samples have low abundance of Fe and Mn. The possible reasons of the low abundance of Fe and Mn are: high pH, abundant organic matter and high oxygenated water. These samples have pH values >7 and both the elementss have low mobilities at this pH. Water is also rich is dissolved oxygen which brings Fe and Mn to their higher oxidation states. High temperature of the area favours the reaction and ultimately Fe and Mn are removed from the water. Organic matters, weeds and algaes and their decay products have the ability to absorb Fe and Mn.

The plot of Fe against Mg is inverse (Fig. 4), possibly Fe ions are replaced by Mg ions. During the chemical weathering of ophiolitic rocks, Mg easily leaches out because of its small ionic size and remains in solution at relatively higher pH values. Fe is gradually replaced by the increasing Mg ions except at Bhampani Nai (BN), both are high at this locality. Here, high dissolved solids (1350 ppm), minimum pH (7.13) and relatively organic matter free conditions are responsible for high concentration of Fe (Table 2). Fe and Cu exhibit nearly positive relationship (Fig. 4). Fe and Cu are associated with metalliferous sediments at the top of pillow lava in an ophiolitic sequence. The physico-chemical conditions for abundance of these elements in stream water are equally uniform.

The average abundance of Cu in stream water is 3 ppb (Rose et al 1979) and according to Reedman (1979) it is 90 ppm while over 140 ppb is considered anomalous. In the stream waters of the study area, Cu ranges from 4 to 46 ppb. None of the samples show anomalous concentration of Cu in the waters of Lasbela region. It is exceptionally high (46 ppb) in the Siro Dhora locality (Fig. 3). The plot (Fig. 4) Cu versus Mg shows a uniform distribution of Cu (<10 ppb) against variable concentration of Mg (40-120 ppm). It shows differential leaching at different localities of the study area, though both are derived from the same pillow basalts. Another reason for this uneven distribution of Mg and Cu is pH of the water. Mg is mobile at wider pH range (1-11) whereas Cu shows good mobility at 5 pH. Biogeochemical study also indicates uniform absorption of Cu in the ash of *Tamarix Aphylla* in the same study area (Naseem et al. 1995).

Zinc and Barium

Zinc is chalcophile element while barium is lithophile. In the study area these two elements are associated with carbonate hosted Zn-Pb and barite mineralizations. Under normal conditions Zn is moderately high mobile and its mobility decreases due to absorption by organic matter or it is scavenged by iron and manganese oxides. The range of abundance of Zn in the stream water is 1 to 20 ppb and above 20 ppb is considered as anomalous (Reedman 1979). The high concentrations of Zn at Dadi Dhora (370 ppb) and Wayaro Dhora (250 ppb) are most probably caused by the eastern exposures of the limestone-containing Shirinab formation which contains hydrothermal Pb-Zn mineralization (Akhter et al. 1992). The other localities having anomalous concentration of Zn include Gachari Dhora (70 ppb), Gajri Nai (55 ppb) and Bhampani Nai (50 ppb) which is most probably due to high mobility. Zn was brought into stream water from eastern side where Shirinab formation is exposed. Naseem and Sheikh (1994) also demarcated anomalous zones of Zn and Pb in this area based on lithogeochemical prospecting of stream sediments.

Sulphate abundance in surface water is a good potential indicator of sulphide deposits (Joyce 1984). The plots of Ba and Zn against sulphates (Fig. 4) provide a better tool to relate with the host rock. Zn show high abundance against low sulphate concentration in the Dadi and Wayaro Dhora localities, which has already been considered anomalous for Zn mineralization. Samples from Porali River, Sanjro Dhora and Siro Dhora localities show low Zn with variable sulphate content. Same is true for Ba against sulphate plot, which indicates that these two are directly proportional to each other.

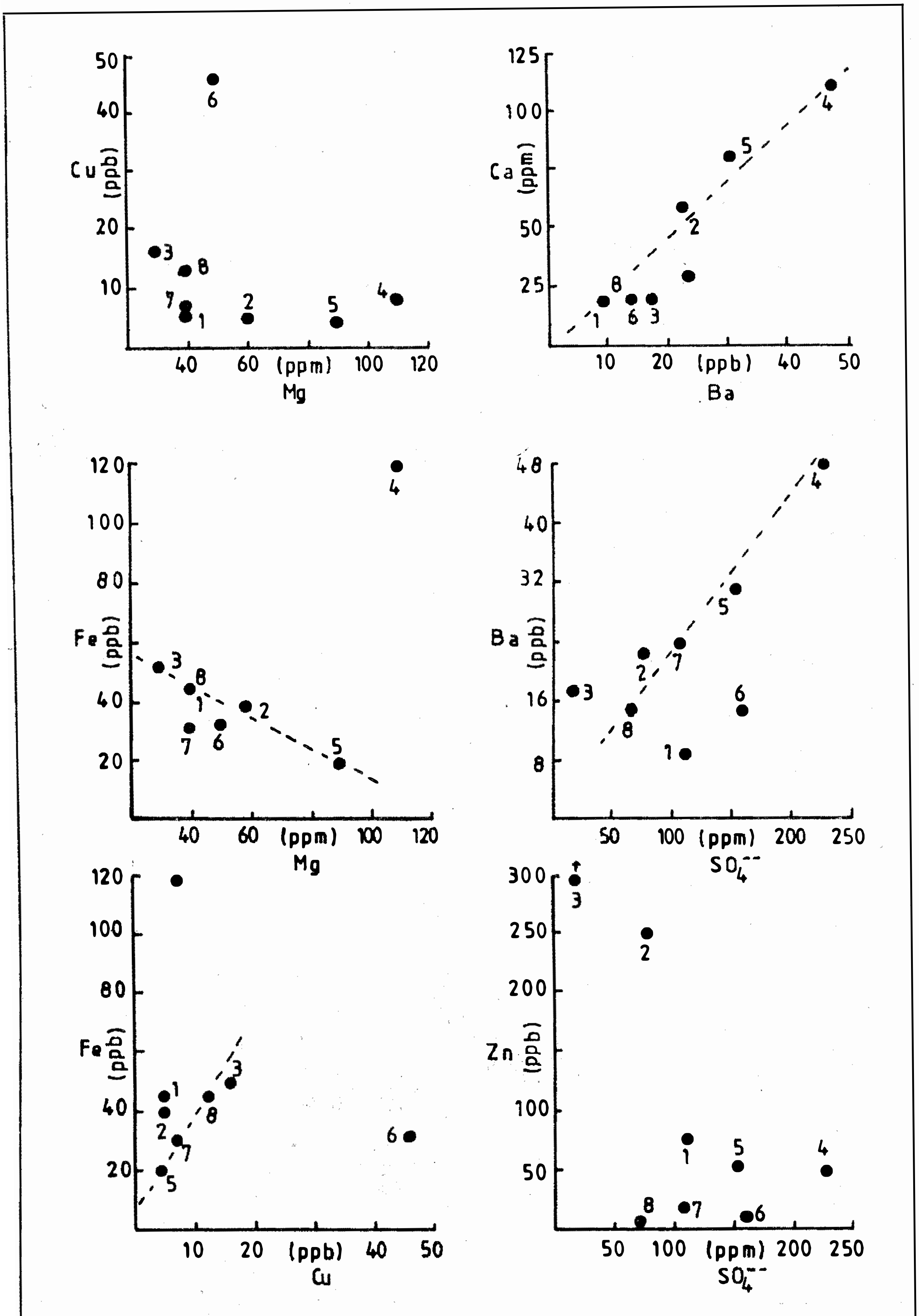

Figure 4. **Plots showing degree of correspondence among various elements and radicals in the stream water of Lasbela region. Location of the samples are given in Fig. 2.**

In stream water Ba ranges between 10 to 20 ppb while over 20 ppb is considered anomalous. It is high in Wayaro Dhora and Porali River samples and anomalous in Bhampani and Gajri Nai samples (Fig. 3). In order to evaluate the genetic relationship Ba is also plotted versus Ca. Majority of the plots show a positive linear relation indicating direct correspondence between limestones and Ba mineralization (Fig. 4).

STATISTICAL ANALYSIS

Quantitative statistical treatment of geochemical data is a useful and widely practiced technique in geochemical interpretation. Basic statistical data for certain trace elements in stream water of Lasbela area, such as mean, standard deviation and coefficients of variation are given in Table 3. The coefficient of variation is considered as a measure of relative variability

Element	Mean	SD	CV
Mn	3.75	3.45	1.08
Fe	47.75	30.78	1.55
Cu	13.00	13.97	0.93
Ba	23.00	12.02	1.91
Zn	104.37	132.70	0.78

Table 3. Basic statistical data of trace elements in stream water of Lasbela area.

variability which takes into account the mean and the standard deviation. Simply it is a measure of variability which describes how close the numbers in the data set are to their common measure of centre (Siegel 1988). For instance, as mean increases, variability for most of the observed geochemical distribution tends towards zero. Conversely, for quantities present in very small amounts, variability for the observed data distribution tends towards infinity (Hashmi 1986). Table 3 shows that the mean of trace elements ranges from 3.75 to 104.37, whereas the standard deviation ranges from 3.45 to 132.7. The variability calculated from these values of mean and standard deviation for the five elements varies from 0.78 to 1.91. This range of coefficient of variation indicates positive anomalies for these elements which are possibly due to mineralization because their standard deviation is less than twice as compared to their mean. Variation less than 0.5 indicates that the concentration of these elements is possibly due to country rock not the mineralization.

The possible causes for low concentration of Mn, Fe and Cu have already been discussed in the preceding section as a result the upper limit of concentration, necessary for positive anomaly development are lacking. Ignoring this factor, the statistical analyses result indicate some areas suitable for mineralization.

IONIC COMPOSITION

The concentration of major cations and anions expressed in milliequivalents per million (epm) are given in table 2. In order to elaborate the composition of water, major ions were plotted in the form of closed patterns (Fig. 5). This figure revealed high sodium chloride, medium magnesium sulphate and low calcium bicarbonate. These ions are easily available from the weathering and erosion of the two suites of rocks. Mg, Na, Cl are mainly derived from ophiolitic rocks, whereas Ca, sulphate and bicarbonates are derived from Shirinab formation of Jurassic age. The dominance of these ions are best reflection of bed rock chemistry. The low concentration of bicarbonate ion is probably due to low precipitation rate for long periods.

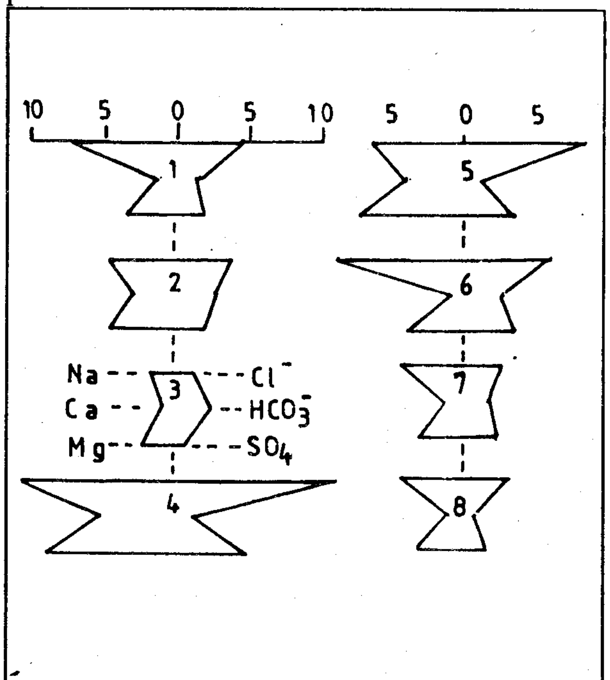

Figure 5. Ionic composition of different stream water of Lasbela region. (Hem 1970)

DRINKING WATER QUALITY

This paper also aims to assess aesthetic quality of drinking water according to the standards of World Health Organization (WHO). Major constituents such as Na, Ca, Mg Cl and SO_4 are within maximum permissible limits. Water samples from Wayaro Dhora, Gachari Dhora and Siro Dhora are slightly above the highest level of tolerance (Table 1 and 4).

Substance	Maximum acceptable concentration (ppm)	Maximum permissible concentration (ppm)
Sodium	100	200
Calcium	5	200
Magnesium	50	150
Sulphate	200	400
Chloride	200	600
Iron	0.3	1
Manganese	0.1	0.5
Copper	1.0	1.5
Zinc	5.0	15

Table 4. WHO standards for drinking water.

It is important to note that concentration of Fe, Mn, Cu, Zn and Ba are within maximum acceptable limit though the area under study is rich in mineralization of the same elements. This indicates that the water samples from Lasbela region are suitable for drinking purpose.

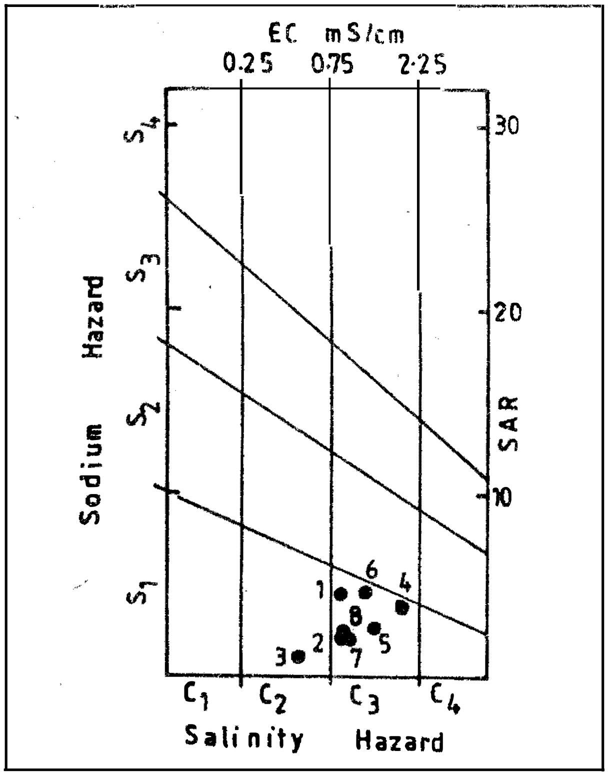

Figure 6. Classification of stream water of Lasbela region for irrigation purposes. Number (1-4) indicates low, medium, high and very high hazard zone. (simp-lified after Wilson, 1948).

IRRIGATION WATER QUALITY

Important parameters for irrigation water quality such as pH, total dissolved solids (TDS), electrical conductivity (EC), total hardness (TH), residue sodium carbonate (RSC) and sodium adsorption ratio (SAR) in stream water of Lasbela region are given in Table 2.

According to Bokhari and Khan (1992) the residue sodium carbonate (RSC) has maximum influences on the suitability of a water for irrigation. RSC is given as

$$RSC = (HCO_3+CO_3)-(Ca+Mg)$$

Where the concentrations are expressed in epm. If RSC exceeds 2.5 epm, the water is non-suitable for irrigation. If the values are between 1.25 to 2.5 epm the water is of marginal quality whereas less then 1.25 epm indicates that the water is safe. The samples from Lasbela area show RSC values as negative, indicating good quality water for irrigation (Table 2). The sodium adsorption ratio (SAR) values were computed from the following expression:

$$SAR=Na/\sqrt{(Ca+Mg/2)}$$

The SAR values in table 2 are less than 10 indicating that the water has low sodium hazard. High Na may replace Ca and Mg from the soils which reduce the permibility (Todd 1980).

A nomogram (Fig. 6) is also used to evaluate irrigation water quality. Majority of the plots of the study area are in the low Na hazard and high electrical conductivity sector. The category in the figure indicated by the data plot shows good quality irrigation water.

CONCLUSIONS

1. The bedrock chemistry, mobility of elements, nature of weathering, climate, pH and drainage system have played an important role in the enrichment and depletion of these trace elements.
2. Major and trace elements show fluctuating distributions in stream water of Lasbela area.

3. Na, Ca, Mg, Cl, HCO_3 and SO_4 are major ions in the water samples from Lasbela region. Their ionic relationship revealed that sodium chloride>magnesium sulphate and >calcium bicarbonate.

4. The Shirinab formation is indicated as to be the host rock for Zn mineralization; associated lead and barite mineralization may also be prospected in the Shirinab formation.

5. Trace elements like Mn, Fe, Cu and other ophiolite related elements did not show any appreciable enrichment in the water of Lasbela area because of high pH and abundance of high organic matters.

6. Some statistical relationships were observed from the analytical data. High variability probably indicates mineralization in the Shirinab formation and Bela ophiolite.

7. The stream water is suitable for drinking and irrigation purposes. Generally they have low sodium adsorption ratio (SAR) with moderate to high salinity hazards for irrigation purposes.

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GOLDEN JUBILEE OF PAKISTAN ISSUE

PETROGRAPHY OF ROCKS AROUND MASHKI CHAH, DISTRICT CHAGAI, PAKISTAN

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ABSTRACT

The Mashki Chah area, that covers about 80 km^2, is a part of the Chagai Volcanic Arc. This arc is developed on the southern part of the Afghan Continental Block, by subduction of the oceanic lithosphere. Sinjrani Volcanic Group of Cretaceous age covers a large part of the Mashki Chah area and consists dominantly of rhyolitic to andesitic lava flows. Based upon the detailed petrographic analyses of the rocks of Mashki Chah area undertaken during the present study the Sinjrani Volcanic Group is divided into five units: Rhyolite Unit, Rhyodacite Unit, Latite Unit, Dacite Unit and Andesite Unit. The constituent minerals and their textural relationships have been described. Chagai intrusions in the Sinjrani Volcanic Group are composed of mainly granite to diorite stocks. Quaternary lava flows present in the area are olivine bearing basalt. Mineralization of iron oxide has taken place within the rocks of Sinjrani Volcanic Group. The travertine is believed to have originated from hydrothermal springs. Skarn was formed by the metasomatic alteration of calcareous rocks due to the emplacement of Chagai Intrusions.

INTRODUCTION

Mashki Chah is located toward extreme western part of Balochistan in Chagai district (Fig.1). The area was initially studied by Vredenburg (1901). His observations remained most comprehensive until the study made by Hunting Survey Corporation during late fifties. (HSC 1960). In the later years studies about various aspects of Geology of the Chagai area were carried out by the Geological Survey of Pakistan. In the regional geotectonic framework Chagai Volcanic Arc belongs to the Zagros-Chitral convergence zone (Powel 1979). The rocks (Fig.2) exposed in the area are of igneous, sedimentary and metasomatic origin. The topographically elevated outcrops of Upper Cretaceous rocks, mainly Sinjrani Volcanics and Humai Formation form a part of North Chagai Arc. The thickness of Sinjrani Volcanic rocks ranges from 915 to 1,220m (Kazmi 1995). Sinjrani Volcanic Group is conformably overlain by Humai Formation with Maestrichtain faunas (Ahmad et al. 1972; Arthurton et al. 1979). The Sinjrani Volcanic Group comprises volcanic rocks and Chagai Intrusions of Late Cretaceous and Paleogene age with an intermediate to acidic composition (Sillitoe & Khan 1977). In this paper a detailed account of the petrography of the rocks of Mashki Chah area is presented.

PETROGRAPHIC ANALYSES

SINJRANI VOLCANIC GROUP

Petrographic studies reveal that this group consists of five different units of volcanic rocks ranging from rhyolite to andesite through rhyodacite, latite and dacite.

Rhyolite Unit

The rocks of Rhyolite Unit are dense, greenish grey and exhibit a porphyritic texture. Phenocrysts of feldspar, quartz, epidote and some chlorite together with dark coloured aphanitic matrix are present. Microscopic interpretation of this unit shows a composition of sanidine, quartz, plagioclase, epidote and chlorite. Sanidine is the most abundant mineral which makes more than 10% of phenocrysts and approximately 60% of the whole rock (Table-1). Some grains of sanidine have been altered to Kaolinite and Sericite. Quartz grains are second in abundance accounting for up to 4% of the phenocrysts and 25% of the whole rock. The grain size of quartz has an average diameter of 2mm. Subhederal and lath shaped plagioclase is oligoclase (An_{28}). Mafic contents have been replaced by epidote and chlorite. Matrix consists overwhelmingly of glass with sparsely distributed areas of crystalline mass. Crystalline portion consists mainly of K-feldspar, quartz, plagioclase, chlorite, epidote and sericite.

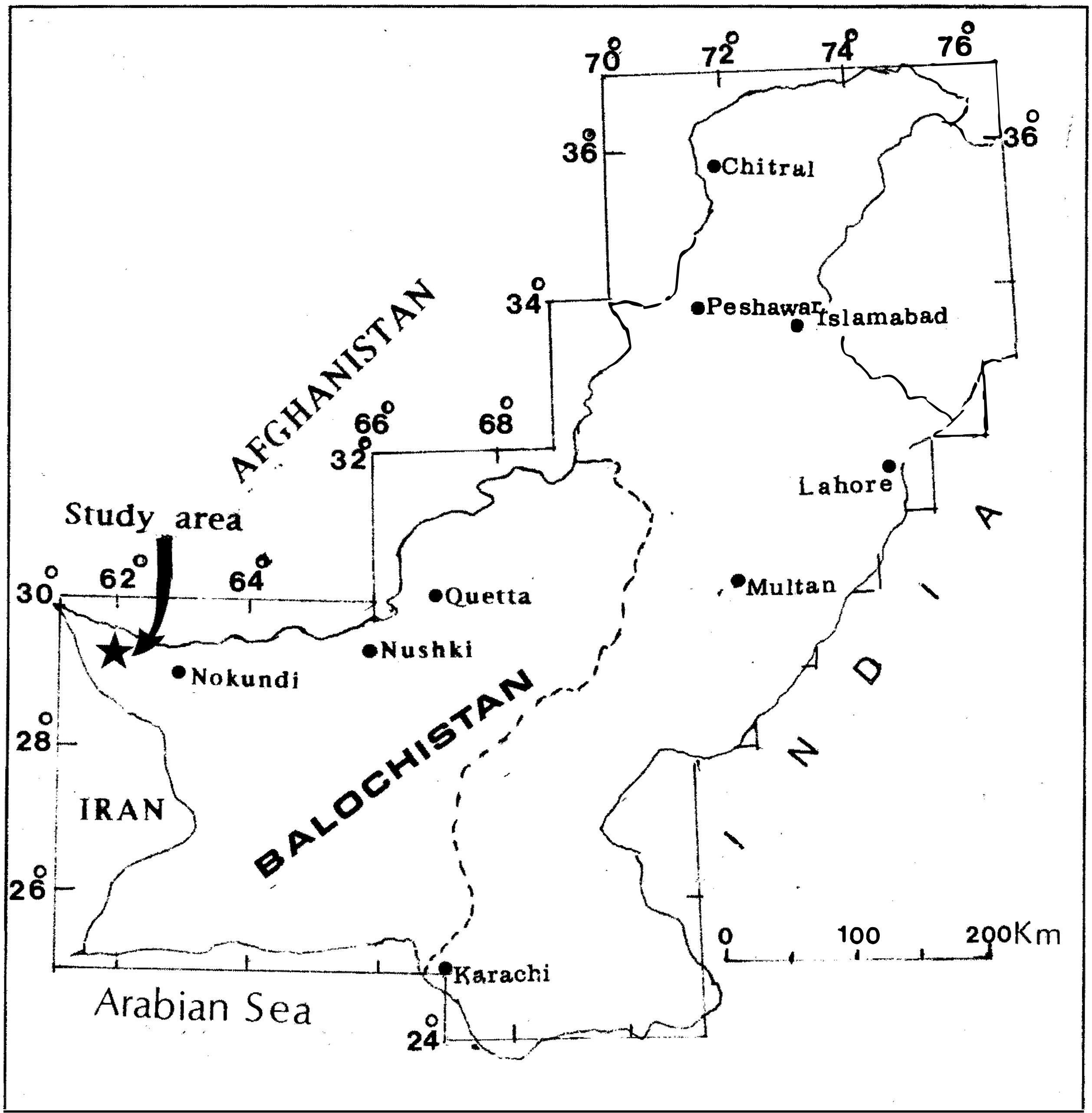

Figure 1. **Map showing the location of the study area.**

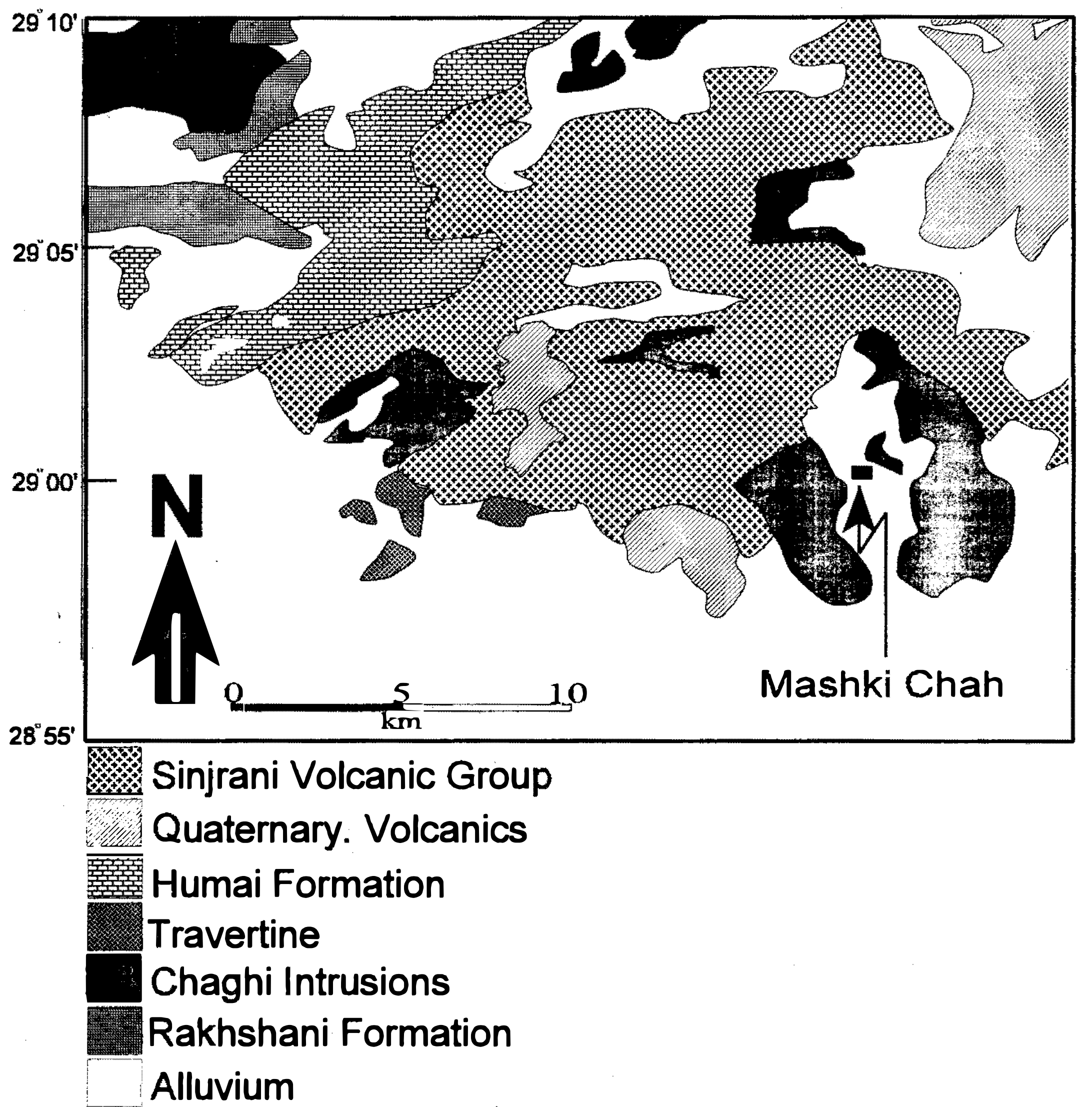

Figure 2. Generalized geological map of Mashki Chah area, Chagai, Balochistan.

Rhyodacite Unit

Rocks of Rhyodacite unit are dull greenish grey to purple grey. These rocks exhibit porphyritic texture with discernible phenocrysts of feldspar and quartz embedded in an aphanitic matrix. Approximately 15% of the sanidine grains are phenocrysts. Fractures in grains contain sericite and chlorite. Lath shaped, subhederal and upto 2mm long grains of Plagioclase are mainly andesine (An_{32-34}). Some plagioclase grains show weak zoning. Replacement to sericite is equable almost in all grains. Quartz makes up 3-7% of phenocryst phase. Mafic minerals have been completely effaced by epidote and chlorite but majority of the samples have pseudomorphs after hornblende. Chlorite forms irregular patches. Fractures are filled with brown iron oxide. Groundmass of these rocks is semi-crystalline, which is mainly composed of k-feldspar and quartz as small anhederal crystals. Some microlites of plagioclase are also present in the matrix.

Latite unit

These rocks exhibit greenish grey colour. Feldspar, chlorite and epidote are set in a greenish grey aphanitic groundmass. Sanidine grains are anhederal with sharp angular edges ranging from 0.1 to 0.5mm in diameter. Due to incipient kaolinitization sanidine appears cloudy. Plagioclase is andisine. The grain size is not more than 0.5mm in length. Quartz is minor component.

Hornblende is the mafic mineral which is altered into chlorite.

Dacite Unit

These consist of medium grey to dark grey rock with porphyritic texture. Rocks of this unit are mainly composed of plagioclase, quartz, pyroxene and hornblende. Plagioclase is andesine (An_{32-35}). It forms upto 12% of the rock as phenocrysts. These phenocrysts are usually lath shaped and upto 2.5mm in length. Some grains are slightly fractured and sericitized. Quartz form less than 5% of the rock. Mafic minerals include pyroxene and hornblende which are recognized by pseudomorphs and cleavage traces as they have been replaced by chlorite. Matrix is semicrystalline to crystalline which consists mainly of plagioclase, microlites of k-feldspar and quartz.

Andesite Unit

This unit can be divided into Hornblende andesite and Augite andesite groups.

Hornblende Andesite: This rock has greenish grey to dark grey with porphyritic texture. Plagioclase is mostly andesine (An_{30-40}), forms bulk of the rock, almost more than 70% (Fig. 3). Plagioclase is altered to Sericite. Quartz and k-feldspar (Sanidine) constitute a small fraction of the rock i.e., less than 10% and occur as phenocrysts. K-feldspar is altered to kaolinite. Hornblende is the only ferromagnesian mineral present which has been largely altered to chlorite.

Augite Andesite: In this type the main ferromagnesian constituent is augite instead of hornblende. It is present as prismatic phenocrysts in groundmass. Some grains show weak zoning. Plagioclase is more calcic (An_{46}) than that of hornblende andesite. A few grains of hornblende are effaced into chlorite. The groundmass is commonly holocrystalline and consists mainly of microlites of plagioclase, augite and hornblende.

Sample Nos.	Plagio-clase	K-spar	Quartz	Augite	Horn-blende	Biotite	Chlorite	Epidote	Acces. Min.	Ground-mass	Total
Rh-1	08.50	15.50	10.00	-	-	02.00	-	01.30	02.20	60.50	100.00
Rh-2	07.50	12.90	08.50	-	01.00	01.50	-	03.10	01.50	63.50	99.50
Rh-3	09.00	10.50	12.50	-	01.50	02.50	01.00	02.20	02.50	58.30	100.00
Rd-1	12 50	08.60	07.50	-	02.00	01.00	-	03.30	02.20	62.40	99.50
Rd-2	10.50	10.70	08.50	-	02.90	01.50	-	-	01.50	64.30	99.90
Rd-3	08.30	07.50	07.70	-	01.50	01.00	-	04.40	03.00	66.60	100.00
Rd-4	10.50	09.50	07.10	-	02.50	01.50	-	02.40	02.50	62.50	98.50
Rd-5	12.50	06.01	05.40	-	01.50	-	-	03.20	01.50	69.00	99.11
Rd-6	09.50	08.60	05.30	-	02.00	01.00	-	03.60	02.00	68.00	100.00
Dc-1	15.50	04.60	05.00	-	02.50	01.50	-	05.20	02.50	63.20	100.00
Dc-2	13.50	03.80	04.90	-	03.00	02.00	02.50	-	02.30	68.00	100.00
Dc-3	14.50	05.00	04.60	-	02.00	01.00	03.50	00.50	02.00	66.00	99.10
Dc-4	13.60	05.50	04.50	-	01.50	01.50	04.10	01.20	02.10	66.00	100.00
An-1	20.50	-	01.00	-	03.40	-	01.50	02.40	01.50	69.60	99.90
An-2	22.50	-	00.80	-	04.50	02.00	03.80	03.50	02.50	60.40	100.00
An-3	25.50	-	00.50	-	05.00	02.50	01.50	02.40	02.00	60.60	100.00
An-4	28.00	-	00.40	-	03.50	01.50	01.70	04.10	01.50	59.30	100.00
An-5	30.00	-	00.60	-	04.50	02.00	02.00	03.90	01.00	55.50	99.50
An-6	27.00	-	01.00	-	06.10	01.00	01.00	02.00	01.50	60.40	100.00
An-7	25.60	-	01.50	02.50	06.50	01.40	01.50	02.50	02.00	56.50	100.00
An-8	28.20	-	00.60	01.80	05.50	01.50	02.30	04.60	02.20	53.00	99.70

Table 1. **Model percentage of Sinjrani Volcanic Group rocks. Rh-1 to Rh-3= Rhyolites; Rd-1 to Rd-6=Rhodacites; Dc-1 to Dc-4=Dacites; and An-1 to An-8=Andesites**

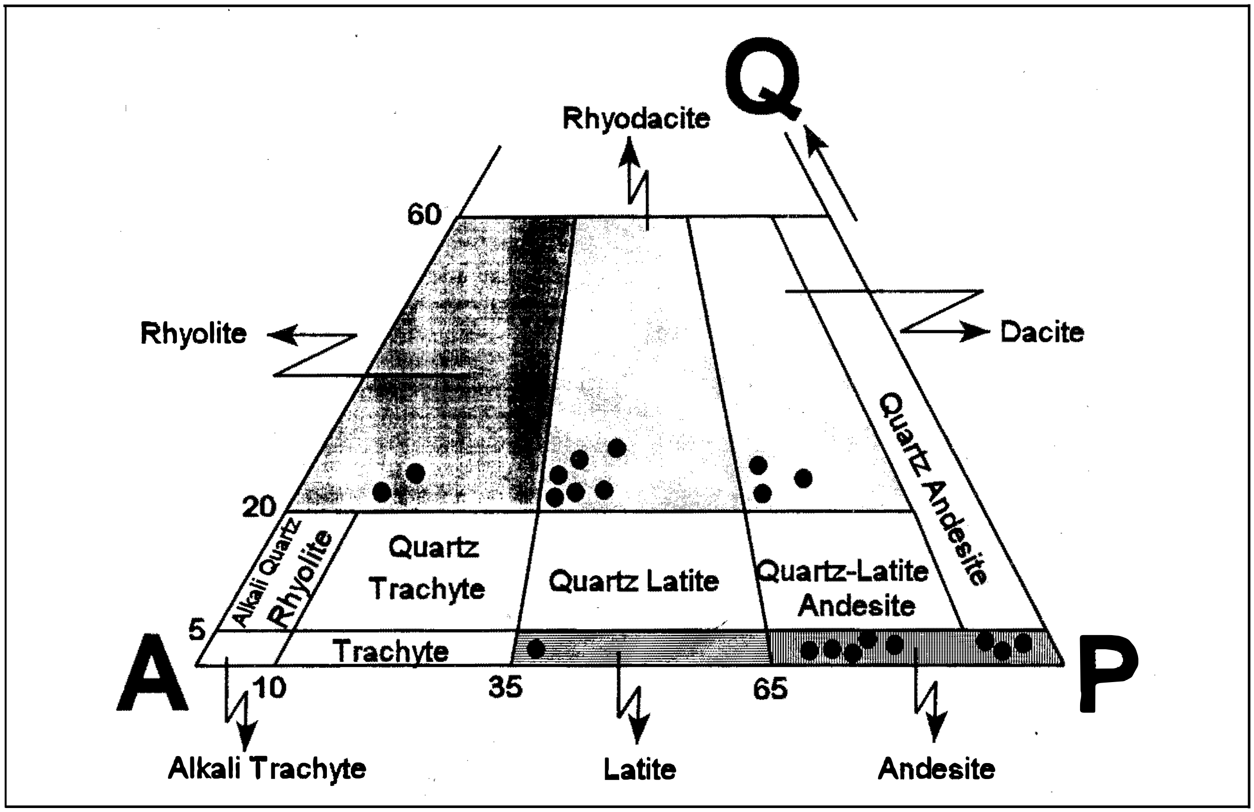

Figure 3. Plot of modes of phenocrysts in volcanic rocks of Sinjrani Volcanic Group on QAP diagram (after Streckeisen 1978). Q=quartz; A=k-spar; P=plagioclase (An<50%)

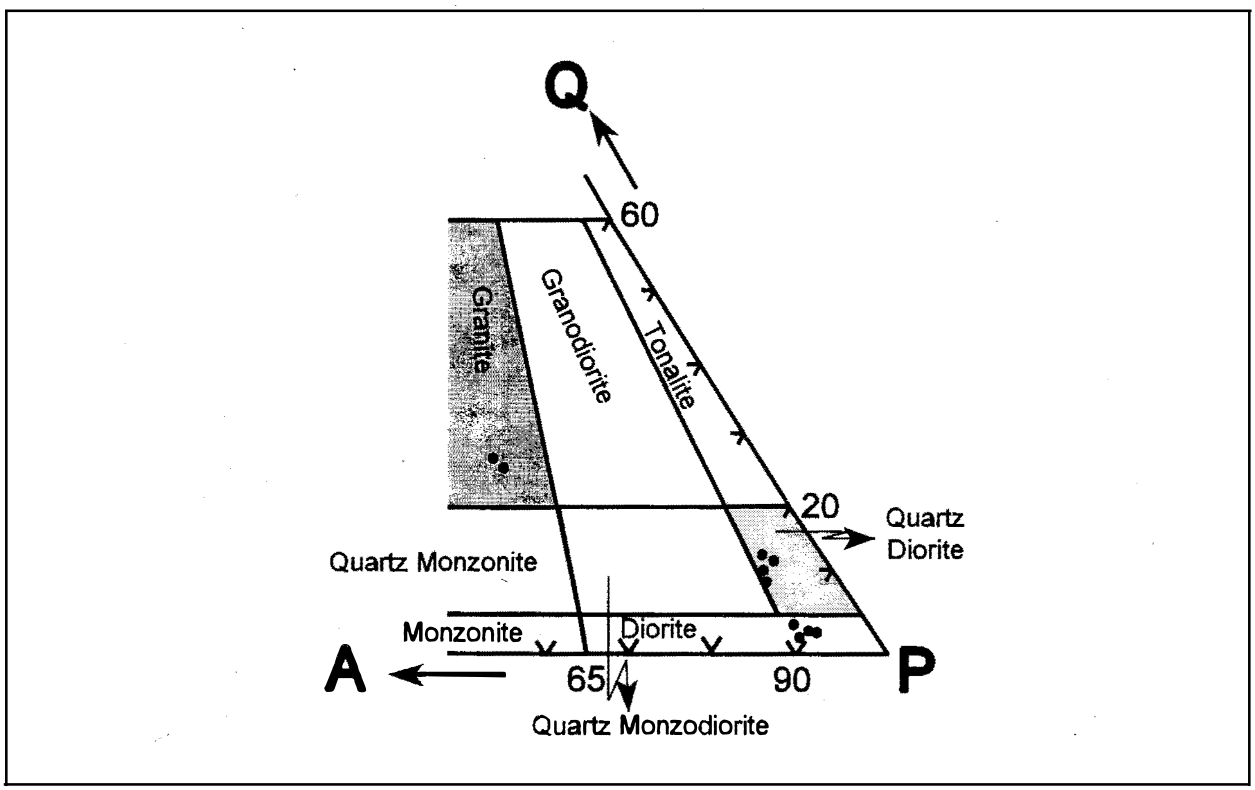

Figure 4. Plot of modes of plutonic rocks of Chaghi Intrusions on QAP diagram (after Streckeisen 1977). Q=quartz; A=k-spar; P=plagioclase (An<50%)

CHAGAI INTRUSIONS

Petrographic analyses of samples from Chagai Intrusions reveal a range of rocks from diorite to granite (Fig.4).

Diorite Unit

Considering mineralogical composition dioritic rocks are grouped in three classes.

I. Those containing augite as mafic mineral.

II. Those containing hornblende as mafic mineral

III. Those containing both augite and hornblende as mafic minerals.

All three classes contain plagioclase as the most abundant constituent, which is commonly subhederal and zoned, with an average composition of An_{40-45}. It makes up 50 to 65% of the whole rock. Augite, the principal mafic constituent in type (I) is subhederal and prismatic. It makes up 25% of the rock. Similarly hornblende (Uralite) in type (II) amounts to about 25% of the rock. Hornblende is subhederal, prismatic and some grains are replaced by chlorite. In type (III) augite and hornblende share among themselves approximately 25% of the total rock as mafic minerals, Quartz and orthoclase are less than 10% of the total rock. The percentage of quartz in some samples is high enough to change the rock type to quartz diorite (Fig-4).

Quartz Diorite Unit

The rocks are of light grey colour with medium to sub-equigranular texture. Microscopic interpretation of this unit divulges a composition in which plagioclase forms 50 to 60% of the rock (Table.2). Quartz forms 8 to 20%, whereas k-feldspar makes up to 18% of the rock. The mafic constituents are hornblende and biotite which together share almost 20% of the bulk composition. Plagioclase is andesine (An_{32-36}) with subhederal to euhederal grains ranging in size between 1-2.5mm and is well twinned. Majority of the plagioclase exhibits pronounced zoning, moderately sericitized in the core. Quartz grains are anhederal and platy which capture the interstitial positions. Biotite is present in small amount as dark brown flakes and replaces hornblende along margins.

Granite Unit

Two types of granite have been recognized in this area. They are a) Hornblende Granite and b) Hornblende biotite Granite. Type (a) is fine grained whereas type (b) is medium grained. These rocks have mineral assemblage consisting of 25% plagioclase, 35% k-feldspar, 30% ferromagnesian constituents and about 10% (Table-2). K-feldspar in both the types is represented by orthoclase and microcline. However, microcline is less abundant than orthoclase. Plagioclase is weakly zoned oligoclase (An_{25-28}). Hornblende is the mafic mineral in type (a), whereas in type (b) it isaccompanied by biotite. Hornblende is considerably effaced to chlorite.

Sample Nos.	Plagio-clase	Ortho-clase	Micro-cline	Quartz	Augite	Horn-blende	Biotite	Access. Min.	Total
Gr-1	25.00	24.50	15.50	23.40	-	04.50	03.50	02.50	98.90
Gr-2	24.00	30.00	10.00	24.60	-	05.00	04.20	01.50	99.30
Qd-1	55.00	05.70	-	20.50	02.50	10.00	03.50	02.00	98.70
Qd-2	60.00	06.00	-	18.00		12.00	02.40	01.40	99.80
Qd-3	58.00	05.00	-	20.00	01.50	10.00	01.50	02.50	98.50
Qd-4	56.00	05.50	-	20.00	02.00	12.00	02.00	01.80	99.30
Hd-1	64.50	02.50	-	01.80	03.50	20.50	02.25	03.50	98.55
HAd-2	63.00	02.00	-	02.50	12.50	15.50	02.50	01.60	99.60
Ad-1	65.00	01.50	-	02.10	20.50	07.50	-	02.50	99.10
Ad-2	64.00	01.00	-	02.00	22.00	08.00	01.50	01.50	100.00

Table 2. Model percentage of the plutonic rocks of Chagai intrusions. Gr-1 to Gr-2= Granites Qd-1 to Qd-4 = Quartz diorites Hd-1 = Hornblende diorite HAd-2= Hornblende Augite diorite Ad-1 to Ad-2 = Augite diorite

Biotite is dark brown and strongly pleochroic. The assemblage of accessory minerals include iron oxide, sphene, apatite and zircon.

QUATERNARY LAVA FLOWS

The Lava flow are mainly composed of dark grey basalt with uniform aphanatic texture. It is the least compact as compared with the intermediate volcanic rocks of Sinjrani Volcanic Group. Microphenocrysts of plagioclase, augite and olivine are surrounded by microcrystalline groundmass. Plagioclase is mainly labradorite (An_{55-62}) which shows slight alteration to sericite. Augite and olivine grains are the mafic constituents (Table-3). Augite has prismatic habit whereas olivine forms anhederal grains. Some grains of olivine have strong coatings of iddingsite around them. A few grains are distorted and broken. Groundmass of these basaltic rocks consists mainly of labradorite microlites, olivine and augite.

DIKES

On the basis of Petrography dikes of this area have been classified into two types: (i) Rhyodacite type and (ii) Andesite type.

Rhyodacite type

Only a few dikes of this type have been observed in the area. These are light grey, aphanitic with fine specks of dark green chlorite. The rock exhibits holocrystalline, subequigranular, hypidiomorphic texture. The mineral assemblage of this rock consists of plagioclase, k-feldspar and quartz. Chlorite have been formed after alteration of biotite. Plagioclase is andisine present as small microlites, which is altered into sericites. Quartz and k-feldspar are interstitial to plagioclase microlites. Biotite is the only ferromagnesian mineral.

Andesite type

Texturally these dykes can be classified into porphyritic and non-porphyritic types. Both types contain augite as major mafic mineral. Large phenocrysts of plagioclase (An_{40}) are embedded in an aphanitic groundmass in porphyritic type. These phenocrysts are up to 5mm long. Sericitization has taken place along the fractures of these grains. Plagioclase of non-porphyritic type is also andisine which is present as microlites. Hornblende is also present as a mafic mineral besides augite.

METASOMATIC ROCKS

Skarn

A small zone adjacent to the Quartz Diorite Unit was observed in the limestone of Humai Formation. The rocks in this zone are massive, commonly coarse grained and dark in colour. Petrographic study shows that the rock has a composition mainly consisting of garnet, epidote, plagioclase, quartz, calcite and chlorite. The phenocrysts and small inclusionsof garnet crystals show an early crystallization, whereas the interstitial position of quartz between epidote crystals suggests a late crystallization.

DEPOSITS FROM HOT SPRINGS

The deposits of the brownish white travertine marble (onyx marble) are found in the area at many localities. This marble has a variety of colours e.g. white, green, red and brown etc. White and green varieties are translucent whereas red and brown varieties are opaque. The lower contact of the marble is with a calcite cement surface of rubble formed by intrusive rock fragments.

Sample Nos	Plagioclase	K-spar	Quartz	Augite	Hornblende	Biotite	Olivine	Chlorite	Access. Min	Groundmass	Total
B-1	40.00	-	-	10.50	-	-	04.50	-	01.50	42.50	99.00
B-2	45.00	-	-	08.50	-	-	03.50	-	02.00	40.90	100.00
Rd-1	32.50	08.50	10.50	-	12.50	01.50	-	02.00	01.50	30.50	99.50
Rd-2	30.50	10.50	15.50	-	10.00	02.00	-	02.50	01.00	28.00	100.00

Table:- 3. Model percentage of basalt of Quaternary Lava Flow and Rhydacite dikes. B-1 to B-2=Basalt; Rd-1 to Rd-2=Rhyodacite.

SEDIMENTARY ROCKS

Humai Formation

It is a pale reddish rock which is highly fossiliferous. Petrography of this limestone reveals that it contains fine grained rhombs of calcite, veinlets and patches of hematite. A jumble of fossil fragments and formless angular pieces of shell fragments are set in a subordinate matrix of very fine calcite.

Sandstone of Rakhashani Formation

The light grey sandstone of this formation is medium- to fine-grained with bimodal size distribution. The predominant coarser population is generally sub-rounded to sub-angular. It consists mainly of quartz and feldspar (microcline, orthoclase and plagioclase). Plagioclase feldspar exhibits euhederal crystals, well defined zoning and albite twinning. Some plagioclase grains show an alteration, mainly sericitization at core. These features are indicative of the volcanic origin of plagioclase. Microfragments of granite, diorite and volcanic rocks are also present. Accessory mineral assemblage includes zircon, tourmaline, muscovite and iron oxide. The matrix consists of tiny angular quartz, sericite, chlorite and kaolinite aggregates. The cementing material is a mixture of sericite, chlorite, clay, carbonate and some iron oxide.

ECONOMIC MINERALIZATION

The area has some economic mineralization too. Hematite is the ore mineral of iron whose deposits are present in and around the map area. Hematite occurs as veins and as irregular bodies within the rocks of Cretaceous Sinjrani Volcanic Group. The hematite veins are only 1 - 4cm thick, which cut across the volcanic rock layers along with some quartz veins. Irregular bodies of hematite actually represent mineralized zone within the rock of Sinjrani Volcanic Group. These zones range between 0.5 - 2 meter in length and breadth and show incomplete mineralization, leaving some islands of unreplaced country rock here and there.

Thin sections also reveal veins of silica present in the form of jasper, quartz and epidote. Jasper is red, while epidote is green in colour. At some places quartz veins are found to contain hematite in them. As far as the mode of origin of hematite is concerned, evidence for both cavity-filling and replacement by hydrothermal solution are present. The source for hydrothermal solutions, perhaps, lies in the granitic rock of Chagai Intrusions.

The other commodity of economic importance is the high quality onyx-marble whose deposits are found at many places in the central and western parts of Chagai district. These deposits occur as flat terraces of variable size, shape and thickness. Although there are about seven known marble deposits in Mashki Chah area (Ahmad, 1969), only one such deposit of small extent lies in the study area. It is white to light yellow in colour and exhibits fine parallel bedding. Less than 5cm thick yellowish brown layers of travertine are present in the marble. These onyx-marble are considered to have been deposited by hot water springs during Late Tertiary to Quaternary volcanic activity.

DISCUSSION AND CONCLUSION

Variation in the proportion of the phenocryst contents of felsic minerals control the classification of volcanic rocks. Quartz content (Fig-3) in rhyolite, rhyodacite and dacite remain almost uniform, only the amount of two types of feldspar determine the position of these rocks in their respective fields. Rhyolites are rich in k-feldspar and relatively poor in plagioclase; slight increase in plagioclase composition shifts it to the dacite field through intermediate rhyodacite. Plagioclase of rhyolite is oligoclase (An_{26-28}) which changes to andesine (An_{30-36}) by the increment of a few percents of anorthite. Quartz content plays an important role in andesite and latite from the rhyolite, rhyodacite and dacite which contains more than 20% of it as phenocrysts, whereas andisite is quartz and k-feldspar poor and plagioclase rich rock.

In Chagai Intrusions the plagioclase proportion remains constant in diorite and quartz diorite, but in granite it drops sharply to less than 40% from 60%. Quartz and orthoclase rise constantly towards the siliceous end and then increase sharply in the granite field (Fig. 4). Mafic constituents also decrease in proportion as the rocks approach to siliceous phase. The crystallization occurred under hydrous conditions in which hornblende developed. Biotite is the last ferro-magnesian mineral to crystallize. The aforesaid mineral assemblage is a typical one for the Andean type continental margin.

The presence of sanidine phenocrysts confirms that they belong to early stage of magmatic crystallization when the temperature was high. Corrosion of phenocrysts resulting in the rounded and embayed grains is due to the sharp local rise of temperature, preceding its expected fall, caused by the combustion and oxidation of escaping gases and rapid crystallization as the magma rushed to the surface.

Moreover, crystallization of the lava which extruded prior to the deposition of agglomerate occurred under the hydrous conditions as indicated by the presence of hornblende and its pseudomorphs. Augite andesite, the post agglomerate phase of volcanism indicates the opposite environment.

Plutons Chagai Intrusion belonging to diorite-granite series are coarse grained counterparts of andesite - rhyolite series of Sinjrani Volcanic Group. The continuous variation in the mineral composition from diorite to granite suggests that the rock types belonging to Chagai Intrusions are comagmatic or cogenetic and it has been suggested that at least some intrusions represented magmas of andesite suite that failed to reach the surface. The intrusive and extrusive rocks may represent different structural levels within a single magmatic complex. Some stocks are younger than the Sinjrani Volcanics as indicated by the xenoliths of volcanic rocks in the plutonic rocks. These xenoliths are oval to circular in shape.

The coarse calc-silicate minerals of skarn were formed by the metasomatism due to introduction of chemical constituents such as Fe, Mg, Si and Al from Chagai intrusion into the Humai Limestone. Limestone is susceptible to metasomatic replacement by the action of hot solutions and volatiles emanating from igneous rocks resulting in the formation of silicate assemblage characterized by one or more minerals of andradite (garnet). The hematite in Sinjrani Volcanic has perhaps been formed by the hydrothermal solution derived from the granite rocks of Chagai Intrusion.

The emplacement of travertine with its tuffaceous interlayers indicates that deposits are related to Late Quaternary volcanic activity represented by the tremendous outpouring of tuff and lavas at the Koh-i-Sultan volcano to the west. The bimodal distribution of sandstone particles in Rakhshani Formation shows a mixing of materials in high energy environment.

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SHORT COMMUNICATION

SIWALIKS OF THE ZARGHUN-RUDGAI AREA, EAST OF QUETTA, PAKISTAN

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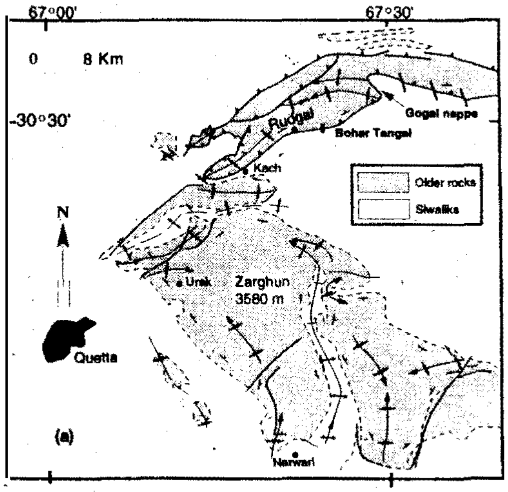
The Zarghun-Rudgai area comprising western part of the Sulaiman Thrust-Fold Belt and upper part of the Sibi Re-entrant (Fig. 1a) possesses superbly exposed succession of the Middle to Upper iwaliks. Here the succession has been correlated with the Nagri, Dhok Pathan and Soan formations of the Kohat-Potwar Basin (Stratigraphic Committee of Pakistan, Fatmi, 1974). Studies of the sedimentary facies, paleo-currents, petrography, provenance and paleo-magnetism have been initiated during the recent years (Haque et al., 1987; Kassi, 1989; Kassi et al., 1990; Durrani, 1997) and a wealth of new informations obtained.

These studies show that the Miocene Nagri Formation, lowermost part of the Siwaliks in the area, is characterised by sandstone lithofacies assemblage (Miall, 1978; 1985) of horizontal lamination (Sh), low-angle (<10°) cross-lamination (Sl), trough cross-bedded (St), ripple corss-laminated (Sr) and plannar cross-bedded (Sp); Sh (including Sl) and St being the most dominant lithothypes (Fig.1b). The Pliocene Dhok Pathan Formation is characterised by an assemblage of massive claystone (Fm), laminated mudstone (Fl), St and Sl (Fig. 1b). Lower part of the Upper Pliocene-Lower Pleistocene Soan Formation is characterised by an assemblage of massive gravel (Gm), sandstone (Sh, Sl) and mudstone/siltstone (Fm and Fl lithofacies, in which Gm, Fm and Fl are most dominant (Fig. 1b). Its upper part, however, dominantly comprises the Gm, Sl, Sh assemblage, and lack the Fm and Fl lithotypes (Fig.1b). Although the new approach of architectural elements (Miall, 1985) has not been systematically applied, our field bservations allow us to speculate on fluvial styles of the succession. The Nagri Formation comprising the architectural elements LS (Laminated Sand), SB (Sandy Bedform) and minor LA (Lateral Accretion) show high braiding parameter and low sinuosity. The Dhok Pathan Formation is dominanted by OF (Overbank Fines), LA and SB elements and show low braiding parameter and high sinuosity. The Soan Formation comprises GB (Gravel Bar), SB and OF in lower part and GB, SG (Sediment Gravity Flow) and SB in upper part, indicating intermediate braiding parameter/high sinuosity and high braiding parameter/low sinuosity in lower and upper parts respectively.

First paleomagnetic studies were carried out at the Bohar Tangai Section of the Rudgai Basin (Durrani, 1997). Correlation between the observed magnetic polarity and magnetic polarity stratigraphic scale of Cande & Kent (1992, 1995) allowes us to place the Nagri and Dhok Pathan succession of the Bohar Tangai Section between 16.5 and 14.8 Ma (Fig.1c), indicating that the Rudgai succession is well diachronic from that of the Potwar Basin (10.1 - 7.9 Ma: Opdyke et al., 1979). Based on correlation between polarity thickness and duration, sedimentation rates were estimated as ranging between 10-30 cm/1000 yrs, generally higher for sandstone (25-30cm/1000 yrs) and lower for mudstone and siltstone (15-25cm/1000 yrs). Thin section analyses of the sandstones indicate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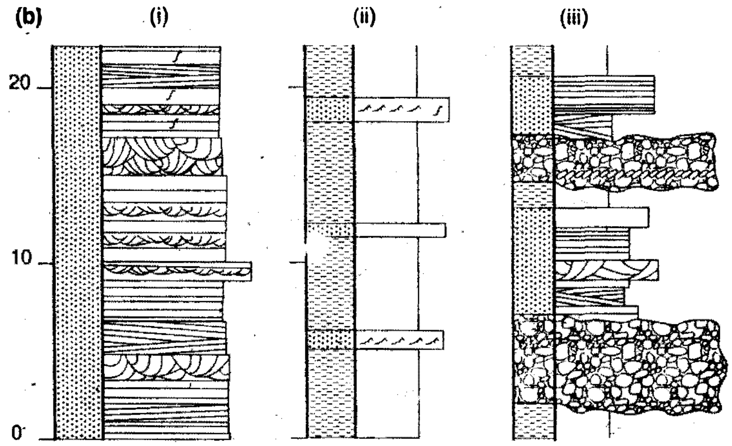
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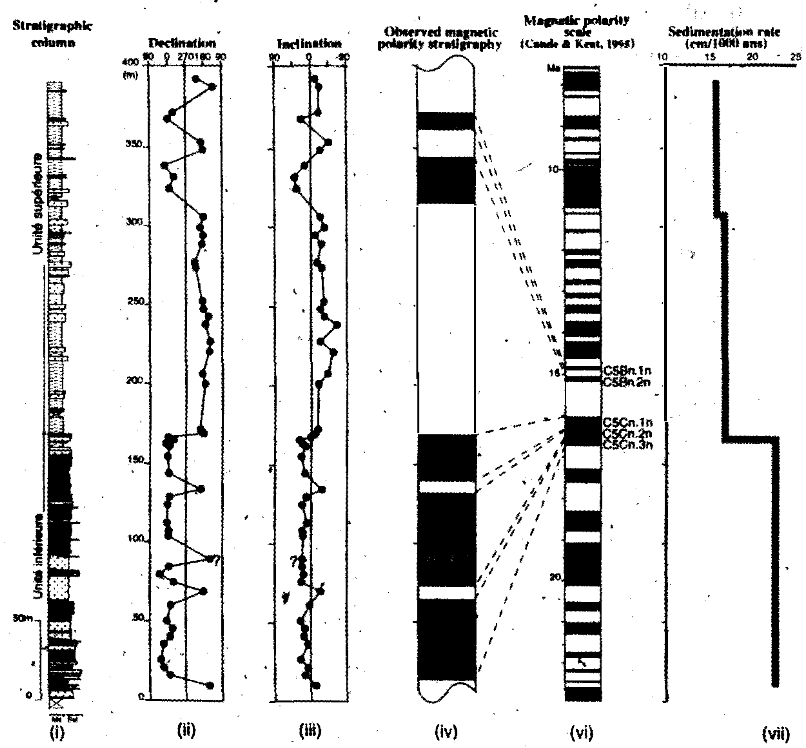
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Declination
Inclination
Observed magnetic polarity stratigraphy
Magnetic polarity scale (Cande & Kent, 1995)
Sedimentation rate (cm/1000 ans)
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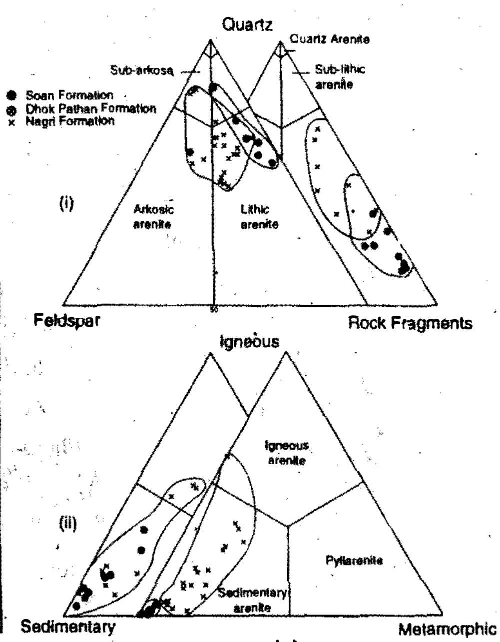
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Feldspar
Rock Fragments
Igneous
Igneous arenite
(ii)
Phyllarenite
Sedimentary arenite
Sedimentary
Metamorphic

(e)

(f)

that they are composed of various types of rocks fragments, quartz, feldspar (orthoclase, perthite, microcline, plagioclase), mica (biotite and muscovite), heavy minerals and authegenic minerals (Fig.1d). Cement is mostly calcite and matrix, comprising grains smaller than 10u, is less than 10 percent. Rock fragments are dominantly sedimentary and subordinatly igneous and metamorphic. These characters, alongwith the result of modal analyses based on point counting (Haque et al., 1987; Durrani, 1997), classify them mainly as the sedimentary arenite variety of lithic arenite and subordinatly as sub-lithic sub-feldspathic and feldspathic arenites (Fig.1e). Conglomerate of the Soan Formation may be classified as polygenetic ortho-conglomerate (Hatch & Rastell. 1971) ranging in modal size between 16 and 64 mm. It is composed of a variety of rock types (Fig.1f) which may clearly be attributed to the Triassic (Wulgai Formation) through Middle Eocene (Kirther Formation) succession of the Sulaiman Thrust-Fold Belt. Therefore, we propose that provenance of the sandstone and conglomerate of the Siwaliks of Zarghun-Rudgai Basin was the emergent Sulaiman Thrust-Fold Belt exposed not very far to the east, a conclusion also supported by generally westward flow pattarn of the paleocurrents.

On the basis of above, it may be established that Siwalik succession of the Zarghun-Rudgai Basin is not only diachronic but compositionally different and derived from a contrasting source area than those of the Potwar Basin and should not be correlated merely on the basis of lithological similarities. Therefore, we propose that local names like "Uzda Pusha Sandstone", Shin Matai Formation" and "Urak Formation" (modified after Kazmi & Raza 1970) may be reintroduced for the succession of the Zarghun-Rudgai Basin instead of the Nagri, Dhok Pathan and Soan Formations in order to avoid confusion.

Figure 1. (a) Simplified geological and location map of the Rudgai-Zarghun area, (b) Examples of lithofacies associations within the ZNagri (i), Dhok Pathan (ii) and Soan (iii)Formation, (c) Correlation diagram of the stratigraphic succession of Bohar Tangai, its observed magnetic polarity stratigraphy with the magnetic polarity scale of Cande & Kent (1995), and estimated sedimentation rates, (d) Thin section photomicrograph showing a typical poorly sorted sandstone of the Nagri Formation with grains of quartz, feldspar (perthite) and rock fragments, Crossed Nicolas (X100), (e) Plots of the results of point counting on classification diagrams (i) after Dott, (1964), (ii) modified after Folk, (1968) and their comparison with those of the Kach section carried out by Haque et. al. (1987), and (f) Photograph of the conglomerate of Soan Formation showing its polygenetic and clast supported character.

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BOOK REVIEW

*MOHAMMAD AHMAD FAROOQUI** GHULAM NABI**
AND MUHAMMAD IBRAHIM**
*Centre of Excellence in Mineralogy, University of Balochistan, Quetta Pakistan
**Geology Department, University of Balochistan, Quetta Pakistan

GEOLOGY OF PAKISTAN, edited by F. K. Bender and H. A. Raza, 1995; Printed in Germany by Gebruder Borntrarger Berlin ; Stuttgart. 414 Pages with 140 figures, 38 tables, 7 book size fold-outs and 3 poster size Satellite Imagery geological maps. Hardbound. ISBN 3-443-11025-8. Price $180.00 (or equivalent Pak. Rs.). Available in Pakistan from *Mathtech* Islamabad

The introduction of new theories concepts and technologies in geology during past twenty five years has greatly changed our understanding of the geology of Pakistan. The last book on the geology of western fold belts of Pakistan was published in 1961 by Hunting Survey Corporation. It was the time when the plate tectonic models were in premature stages and mechanism of geological evolution and processes were not fully understood. Since then a number of workers have contributed splendidly to the geology of Pakistan by incorporating new ideas and techniques. Much of the literature containing new geologic information is scattered and because of ever increasing cost of scientific literature it is becoming hard to acquire the literature. This is specially true for our university and college students who face tremendous difficulty in obtaining the up-to-date information about the contributions, developments and changes in geologic interpretations of Pakistan and surrounding areas.

Geology of Pakistan is the first book of its kind that not only covers all the areas of Pakistan, it contains state-of-the art information about all the aspects of geology of Pakistan. This book is an excellent compilation of geological work that provides bird's-eye picture of the geologic evolution and mineral resources of Pakistan. It is written in a simple and understandable language and shall definitely be used by undergraduates, postgraduates, teachers and professional geologist. The book is divided into eleven chapters with many impressive figures, charts, tables and most noticeably three large poster size coloured LANDSAT-MSS satellite imagery geological maps (1:500,000) with structural interpretations.

Chapter one is the general introduction written by Hilal A. Raza and F.K. Bender that covers the area, population, physiographic units, climate, vegetation and a succinct history of previous geological research in Pakistan. Chapter two, starts with an introduction to the geological framework and principal geological divisions of Pakistan that is written by F.K. Bender. A new set of names have been proposed in this chapter for the old geological divisions. The Chaghi and Ras Koh area– the first geological division, is described by D. Bannert and is further divided into the Chaghi Hills, the Dalbandin Trough, the Ras Koh Geanticline, the Ras Koh-Mirjawa Flysch Belt and the Mashkhel Depression. The area west of the Axial Belt (of Hunting Survey Corporation) is termed here as the Makran-Khojak-Pishin Flysch Zone and is described by H.A. Raza and D. Bannert as the second geological division. The authors have divided this zone into three segments namely the Makran Flysch Segment, the Khojak Flysch Segment and the Pishin Flysch Segment. The Axial Belt of Hunting

Survey Corporation is renamed here by D. Bannert as West Pakistan Fold Belt, the third geological division. This fold belt marks a general western boundary of Indo-Pak Plate and occupies the area east of Makran-Khojak-Flysch Zone and west of Indus Plain. A brief geologic evolution of the foldbelt is given by the author. The word *West Pakistan* in this name is slightly confusing as it reminds pre 1971 when there was an East Pakistan (which is now Bangladesh) and a West Pakistan. *Western Pakistan* Fold Belt could have been a better name. The fourth geologic division is termed as Indus Plain. Its stratigraphy and geologic evolution is described by F. Bander. The northern convergence zone in Himalayas, Karakorum, and Hindukush mountains is the fifth geologic division which has been given the name Tethyan Belt by F.A.Shams. Tethyan Belt is further divided into the Lower Himalayas, the Higher Himalayas, the Kohistan Island Arc Complex, the Karakorum Block and the Hindukush elements.

The third chapter is contributed by A.H. Kazmi in which he overviewed the stratigraphy of sedimentary rocks from Pre-Cambrian to Quaternary. The author has very skilfully and comprehensively compiled all the lithologies of various stratigraphic successions. However, the interpretation about the depositional environments of most of the lithologic units is lacking. Certain stratigraphic nomenclature has been frequently referred to which is yet to be approved by the Stratigraphic Committee of Pakistan.

Chapter four is about Igneous and Metamorphic rocks of Pakistan and is contributed F.A.Shams. The author has divided this chapter into seven sections and described the crystalline rock units exposed in Tethyan Belt, Karakorum Block, Eastern Hindukush, Indian Craton, West Pakistan Foldbelt, Chaghi Ras Koh Volcanic Arc and few other isolated places.

In chapter five and six a detailed account of the tectonics, structural divisions, palaeography and geodynamic evolution of Pakistan is given by F.K. Bander, F.A.Shams, and D. Bannert. From plate boundaries standpoint Pakistan is divided into five major tectonic zones. They are; Shield Elements and buried ridges, Indus Basin, the Chaghi Raskoh Volcanic arc, Makran-Khojak-Pishin Flysch Zone, and the West Pakistan Fold Belt which is further divided into Khuzdar Block, Sulaiman Block and the Bela-Wazirstan Ophiolite Zone. Palaeogeographic and geodynamic evolution is interpreted in chronologic order starting from Proterozoic and ending at the Cenozoic evolution of West Pakistan Fold Belt.

Chapter seven through nine is jointly written by H.A. Raza, F.K. Bender, H. Porth, A.H. Kazmi, F.A.Shams, F. Barthel, H. Forhse, and A.H. Kazmi, in which discoveries, deposits, and use of energy resources, metallic raw materials and non-metallic raw materials are evaluated. These chapters offer some valuable information for future research and development projects.

A detailed account of hydrogeological basins and their potential water resources are described in chapter ten which is written by H. Bender. Contributed by F.H. Gruneberg, the chapter eleven is about soils in which the author described the classification and distribution of soils, effects of environments on soil formation and its impact on the agriculture. The text ends with a comprehensive bibliography and subject index.

The book offers a lot of information on the present state of research, information, interpretation and scope of geology of Pakistan, covering a wide variety of geoscientific subjects. The editors and the authors have done a commendable job in producing this volume. We recommend the book as a good source of information for the bookshelves all those who are or will be involved in the Geology of Pakistan.

ANNUAL REPORT

OF THE CENTRE OF EXCELLENCE IN MINERALOGY, QUETTA. (1997)

ACADEMIC STAFF

Director

After the sad demise of Professor Dr. Abdul Haque, in November 1996, Professor Dr. Naeem M. Hassan, Dean Faculty of Science, University of Balochistan, Quetta has been given the acting charge of the Director, C.E.M. The appointment of a permanent Director is still awaited.

Assisstant Professors	**Date of Joining C.E.M.**
Javed Ahmad *M.Phil. (Balochistan Univ.)*	01-Apr-80
Lecturer-cum-Research Associates	
Mohammad A. Farooqui *Ph.D. (U.S.A.)*	05-Nov-89
Khalid Mahmood *Ph.D. (France.)*	05-Nov-89
Mehrab Khan *M.Phil. (Balochistan Univ.)*	05-Nov-89

GENERAL STAFF

Administrative Officer	
S. Shahabuddin	28-May-77
Accounts Officer	
Mirza Manzoor Ahmad	07-May-80
Sr. Technician	
Khushnood Ahmad	13-Jul-76
Asstt. Librarian	
Abdul Ghafoor	02-May-85
Superintendent	
Lal Mohammad	12-May-73
Photographer	
Hussainuddin	16-Jun-81
Steno Typist	
Ghalib Shaheen	17-Jul-87
Stenographer	
S.R. Mahjoor	06-Jun-90
Draftsman	
Ahmad Khan Mangi	01-Jul-81
Lab Supervisor	
Musa Khan	20-Aug-77
Store Keeper	
Sher Hassan	22-Aug-77
Assistants	
Mohammad Anwar	18-Sep-73
Juma Khan	12-Jun-85
Sr. Clerk	
Abdul Malik	28-Apr-87
Jr. Clerk	
Manzoor Ahmad	26-May-95
Driver	
Ali Mohammad	17-Apr-84
Saleh Mohammad	18-Aug-90
Jr. Mechanic	
Ghulam Rasool	20-Aug-77
Peons *(Naib Qasids)*	
Mohammad Rafiq	12-Oct-78
Sikandar Khan	30-Apr-76
Atta Mohammad	25-Mar-87
Janitor	
Nazir Masih	01-Apr-77
Chowkidar	
Abdul Wadood	26-Jan-92
Mr.Abdul Majeed *(Daily Wager)*	10-Nov-97

POSTGRADUATE STUDENTS

Ph.D. Programme

Student Mehrab Khan Baloch
Supervisor Abdul Salam Khan
Co-Supervisor Khalid Mahmood
Project Title
Petrological and Structural (Kinematic) Studies of the Igneous Rocks of the Baran

Lak Area Bela, Khuzdar District, Balochistan

Student Din Muhammad Kakar
Supervisor Akhtar M. Kassi
Co-Supervisor Mohammad Ahmad Farooqui
Project Title
Geology of The Tertiary Khojak Formation of Pishin, Muslimbagh And Chaghi Districts, Balochistan

Student Ghulam Nabi
Supervisor Abdul Salam
Co-Supervisor Javed Ahmad
Project Title
Petrography And Depositional Environment of Ghazij Formation (Eocene). Balochistan

M.Phil. Programme

Student Mohammad Ayub Baloch
Supervisor Abdul Haque
Co-Supervisor Abdul Salam Khan
Project Title
Petrography of Ophiolitic rocks of Goth Shafi Mohammad near Khuzdar District, Balochistan.

Student Atif Saleem
Supervisor Khalid Mahmood
Co-Supervisor Mehrab Khan Baloch
Project Title
Nature of Mafic Intrusions in the Mantle Section of Saplai Tor Ghar Ophiolite related to Mantle Rocks, Muslim Bagh, Balochistan.

Student Ahmad Jan
Supervisor Abdul Salam Khan
Co-Supervisor Jawed Ahmad
Project Title
Sedimentological and Structural Studies of the Coal Bearing Ghazij Formation Near Khost/Shahrig, Balochistan

Student Mohammad Hanif
Supervisor Mohammad Ahmad Farooqui
Co-Supervisor Mobasher Aftab
Project Title
Hydrochemistry of Nisai Sub-Basin, Zhob Valley, Muslim Bagh, Balochistan

Student Khawaja Saleem Mustafa
Supervisor Jawed Ahmad
Co-Supervisor Mobasher Aftab
Project Title
Karst Hydrogeology of Quetta Basin, Balochistan.

Student Khalil-Ur-Rehman
Supervisor Mohammad Ahmad Farooqui
Co-Supervisor Mehrab Khan Baloch
Project Title
Petrology ,Sratigraphy And Sedimentology of Parts of Khojak Formation, Khuzdar, Awaran And Turbat Districts of Balochistan.

Student Mohammad Zhir Kakar
Supervisor Mohammad Ahmad Farooqui
Co-Supervisor Din Mohammad Kakar
Project Title
Depositional Environment And Diagenesis of Lower Cretaceous Sembar Formation, Balochistan.

Student Syed Ashrafuddin
Supervisor Mohammad Ahmad Farooqui
Co-Supervisor Mehrab Khan Baloch
Project Title
Petrography, Depositional Environment And Diagenesis of Kharan Formation, Baloch-istan.

Student Mohammad Rahim Jan
Supervisor Mohammad Ahmad Farooqui
Project Title
Geology and Mineral Resources of part of Makran Coast, Balochistan.

Student Azhar Hussain
Supervisor Mohammad Ahmad Farooqui
Co-Supervisor Khalid Mehmood
Project Title
Petrology, Stratigraphy And Lithofacies Analysis of Dungan Formation District Quetta, Pishin, Ziarat And Loralai, Balochistan.

Student Abdul Rahim

Supervisor Abdul Salam
Co-Supervisor Mohammad Ahmad Farooqui
Project Title
Facies Distribution And Environmental Analysis of The Parh Group, Balochistan.

Student Shahzad Baig
Supervisor Mohammad Niamatullah
Co-Supervisor Mohammad Ahmad Farooqui
Project Title
Geology And Hydrocarbon Potential of Part of Makran Coast, Balochistan.

Student Shah Zaman Kakar
Supervisor Javed Ahmad
Co-Supervisor Abdul Salam Khan
Project Title
Facies Analysis And Reservoir Properties of Chiltan Formation (Jurassic) Northern Balo-chistan.

Student Khawar Sohail
Supervisor Abdul Salam
Co-Supervisor Javed Ahmad
Project Title
Petrology, Sedimentology And Diagenesis of Hinglaj Formation, District Khuzdar, Balochistan.

Student Hussain Buksh
Supervisor Javed Ahmad
Co-Supervisor Mobasher Aftab
Project Title
Hydrogeological Investigations of Kalat Sub-Basin, Balochistan

Student Amjad Ali Shah
Supervisor Khalid Mahmood
Co-Supervisor Mobasher Aftab
Project Title
Hydraulic Characteristic And Groundwater Behaviour of Mastung Sub-Basin, Balochistan

Student Abdul Hadi
Supervisor Mehrab Khan Baloch
Co-Supervisor Mobasher Aftab
Project Title
Hydrogeological Investigation of Pishin Sub-Basin Balochistan.

Student Arif Ali
Supervisor Javed Ahmad
Co-Supervisor Mobasher Aftab
Project Title
Assessment of Groundwater Budget of Mangocher Valley, Balochistan.

OTHER ACTIVITIES

Under the TOKTEN Scheme of Government of Pakistan, the C.E.M. invited Professor Ikram Khawaja, an Ex-patriate Pakistani to conduct a five week long Refresher Course/Workshop at the Centre of Excellence in Mineralogy during May-June 1997. The UNDP, Islamabad sponsored the visit of Dr. Khawaja, whereas the C.E.M. with the help of other organizations (i.e. Balochistan Development Authority, Directorate of Hydrogeology WAPDA, Public Health Engineering Department,and Geology Department Balochistan University) organized the local activities.

REPORT OF REFRESHER COURSE/WORKSHOP IN HYDROGEOLOGY, ENGINEERING/APPLIED GEOLOGY, ENVIRONMENTAL GEOLOGY AND RADON STUDIES

Course Supervisor
Professor Dr. Ikram Khawaja,
Chairman, Department of Geology,
Youngstown State University, Ohio. USA.

Course Coordinator
Dr. Mohammad Ahmad Farooqui,

Activities included twelve(12) open seminars covering a wide variety of topics from Hydrogeology, Engineering geology, Environmental Geology, Earthquake, Energy Resources and management, Radon measurement, and Research Projects Designing. Other activities included five (5) field trips to selected geological sites, four (4) short visits to various Government departments working for the development and management of water and mineral resources, six (6) conferences with the staff of the C.E.M. and Geology Department for curricula development, and numerous discussions with the faculty of Geology Department, C.E.M., staff of Balochistan Development Authority (BDA), staff of Pakistan Council of Research in Water Resources (PCRWR), Staff of Public Health Engineering Department, Balochistan, and staff of the Directorate of Hydrogeology, Water and Power Development Authority (WAPDA), Quetta, for development of specific projects and for future collaboration.

Seminars

A total of twelve seminars were presented to participants who represented eight (08) different public and private agencies/departments, ten of these Seminars were three and a half hour long which covered topics of hydrogeology, Environmental Geology, Engineering Geology, alternate energy resources, and radon studies. The remaining two seminars were 1½ hour long and the topic was the role of science in environmental issues. One of these seminars was presented to the faculty and students of the University of Balochistan that was also attended by the professional staff of the WAPDA, PCRWR, PHED, and BDA, whereas the other one was presented to the teachers and students of the Government Girls College, Quetta.

Curriculum Development

After a general meeting for curriculum evaluation with the staff of the Department of Geology and the Centre of Excellence in Mineralogy individual conferences were held with five (5) different staff members and specific courses were analyzed as to the topics covered and suggestions were made to update and enrich where it was appropriate. The courses included: geomorphology and field geology (Professor Ayub Baloch), Economic Geology (Professor Dr. Shamim Siddiqui), Hydrogeology (Professor Dr. Abdul Salam), Environmental Geology (Professor Ghulam Nabi), and Industrial Geology (Professor Javed Ahmad).

Field Visits

Field trips, related to the contents of the Course, were incorporated in the activities of the course.

Nasai Groundwater Development Project

The participants along with the course supervisor visited the Nasai Groundwater Development Project that is located about 100 miles northeast of Quetta at an altitude of around 1600 meters and falls in the upper part of the Zhob River Basin.

The Nasi project, developed and completed by Balochistan Development Authority, is divided into two zones A and B, which are separated by the Zhob River, in which 38 and 20 tube wells were drilled respectively. The wells are located 500 meters apart from each other and each well irrigated 80 acres of agriculture land. During the briefing, Mr. Mansoor-ul-Huda, a ground water expert, informed the participants that after the completion of the project the income from the produce of orchards planted in the project area is approximately Rs. 20 million per year.

The participants of the course discussed various aspects of the project, including groundwater recharge and discharge, agricultural development of the area, social and economic changes and particularly the monitoring system of the project. No system currently exists to monitor the changes in the groundwater conditions of the area. This is because of the fact that the monitoring system, as defined in the PC-1, has not been executed by the Provincial Agriculture Department who is currently administering the project. After long discussions with and among the participants, it was resolved that, in future if such big projects were initiated, they should be linked with the availability of the monitoring data of already completed projects.

During this trip, few stops were also made to see the ophiolitic rocks along the roadside, generally known as Muslin Bagh ophiolite. Mr. Mehrab Khan, a faculty member of the C.E.M., who is currently working on the origin and emplacement of these rocks as part of his doctoral, explained the importance of these rocks which are the primary source of chromite ores in Pakistan.

The trip was sponsored by Balochistan Development Authority whereas the lunch was arranged by Mr. Irfan Ilahi, the Deputy Commissioner of district Qila Saifullah. Over all the visit turned out to be very well organized and educational.

Burj Aziz Khan Dam Site

Burj Aziz Dam is a proposed dam to be constructed on Pishin Lora Valley near Burj Aziz Levy post, 58 Km northwest of Quetta. The purpose of the dam is to supply drinking water to Quetta town through pipes from the dam water reservoir.

The proposed dam has generated considerable political and technical controversies among the public in general and among the hydrogeologists. The purpose of this visit was to evaluate the feasibility of the project. The participants of the course had considerable discussions on various issues relating to the dam site selection, construction and feasibility of the dam. It was revealed that the dam may not be as useful as claimed in the feasibility report prepared by National Engineering Consultants of Pakistan (NESPAK) in 1990. One of the three major concerns that all the participants agreed upon is the unsuitable character of bed rock on which the dam is proposed to be built. The bed rock is composed of highly fractured and permeable sandstones of Shigalu Formation which could cause considerable amount of seepage of reservoir water. The second concern was the long distance between the dam site and Quetta town which would make the supply of water very expensive in term of consumption of electricity at pumping stations. The third concern, as identified by the participants, was the poor quality of water at the reservoir site which would require a treatment plant to make to drinkable. This will further increase the cost of the drinking water.

In general the visit was quite successful and participants, who have never visited the area before, had an opportunity to discuss and educate themselves about the hydrogeological, hydrological, environmental, and engineering geological aspects of the Dam site. Directorate of Hydrogeology WAPDA, provided the transport facilities for this trip.

Urak Valley

Because of the unavailability of the transport facilities, only a few participants could visit the area. During this short visit, Hanna Dam and Reservoir, Spin Kareze Water Reservoir, and Urak Valley surface water discharge area was visited. Various aspects of hydrogeology and geology of the area were discussed. It was concluded that extensive plantation around the standing water bodies would certainly help reduce the evaporation of water. A small pilot project may be executed for the students of the Hydrogeology to estimate the evaporation rate from Hanna Lake and Spin Karez Reservoir. The trip was arranged with the help of P.H.E.D. and B.D.A.

Ziarat and Mina Valley

One complete day was spent to visit various sites in around the Ziarat Valley. At Baba Kharwari Prospect Point the Cretaceous-Tertiary (K-T) boundary which is designated as the extinction time of dinosaurs, about 65 million years ago was seen. The unusually rapid reduction in the amount of surface water from Karvi Kach canyon during last one year was discussed with respect to the hydrogeology, geology, and climatic conditions of the area. It was concluded that a an interesting thesis may be initiated to explore the causes of such a drastic decrease in the water supply. Mina Dam in the Mina Valley was also visited, which is an artificial ground recharge establishment to recharge the Mina Valley. A few tube wells, drilled by B.D.A. along the road were also visited. The trip was sponsored by B.D.A.

Brewery Gorge

A short visit was made to Brewery Gorge to see the geology and different rock units exposed around Quetta Valley. Brewery Gorge provided an excellent opportunity to understand and extrapolate the geology of the Quetta Hydrogeological Basin which is the only source of water for the town of Quetta. Various aspects of geology and hydrogeology were discussed. The trip was sponsored by B.D.A. in collaboration the Faculty members of the Geology Department, Balochistan University.

Recommendations

In consultation with the participants of the course and after long discussions on various issues the following recommendations were made:

1. B.Sc. (Honours) programme of Geology Department must be reintroduced as a special case in order to attract more students in the Geology Department.
2. In order to increase the number of students in Geology, the provincial Education Department, Government of Balochistan should be asked to start geology programmes at B.Sc. level in at least two more degree colleges of Balochistan, preferably one in Loralai and one in Khuzdar. Curently only the Government Science College Quetta offers Geology at B.Sc. level.
3. For subjects in which specialists or qualified teachers are not available, Adjunct Professors may be hired for specific course and time on payment e.g. hydrogeologists, geophysicists and environmental geologists.
4. Considering the seismic activities in Balochistan, the specialization in Seismology should be introduced in M.Sc. and M.Phil. programmes.
5. During curricula development more and more case histories should be included in the course for better understanding.
6. Students should be involved in, cost effective, short term research projects in Hydrogeology and Radon studies. This could be done in collaboration with other science departments of the University (e.g. chemistry, Physics) or Government departments(e.g. BDA, WAPDA, PHED etc.).
7. For practical experience Internship Programmes for students should be initiated. Government and private professional organizations may be asked for assistance.
8. For more geology related activities, Balochistan Geological Society should be reactivated.
9. Admission procedure for M.Phil. and Ph.D. programmes should be made competitive and efficient. The current admission procedures are outdated and lengthy.
10. The meetings of Committee for Advanced Studies and Research should be held more frequently and regularly to finalize the admissions in M.Phil. and Ph. D. programmes.

At the end of the Course/workshop the participants were awarded with the Certificate of Participation.

INSTRUCTIONS FOR AUTHORS

Send three unbound copies, not stapled, of the complete manuscript to Editor *Acta Mineralogica Pakistanica*, Centre of Excellence in Mineralogy, University of Balochistan, Quetta Pakistan, alongwith a computer disk. Create and format your document in WordPerfect 6.0 (for windows), or MS Word, however, manuscripts saved in any major wordprocessor will also be accepted. Mark the computer disk with the name of the principal author, abbreviated title of the paper, name of the file and the software in which the document was created. We will not retype manuscripts! Except for minor editing, content will be printed as it is received on computer disk or returned to be redone if required. **Please note that manuscripts received without a computer disk shall not be considered for publication.**

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