ISSN 0257 - 3660

ACTA MINERALOGICA PAKISTANICA

Volume 5 1991

NATIONAL CENTRE OF EXCELLENCE IN MINERALOGY
(UNIVERSITY OF BALOCHISTAN), QUETTA, PAKISTAN

ACTA MINERALOGICA PAKISTANICA

VOLUME 5, 1991

CHIEF EDITOR : ZULFIQAR AHMED

REFEREES FOR THIS VOLUME

AFTAB AHMAD BUTT, PUNJAB UNIVERSITY, PAKISTAN.
ALI NASIR FATMI, QUETTA, PAKISTAN.
ANTHONY HALL, RHBNC, LONDON UNIVERSITY, UK.
DUANE M. MOORE, ILLINOIS STATE GEOLOGICAL SURVEY, USA.
FAIZ AHMED SHAMS, PUNJAB UNIVERSITY, PAKISTAN.
FAROOQ AHMED KHAN, P.O.L., RAWALPINDI, PAKISTAN.
GEORGE R. McCORMICK, IOWA UNIVERSITY, USA.
R.A. KHAN TAHIR KHELI, N.C.E. GEOLOGY, PESHAWAR, PAKISTAN.
RHYS G. DAVIES, SURREY, U.K.
R.A. HOWIE, RHBNC, LONDON UNIVERSITY, UK.
SHAFEEQ AHMAD, PUNJAB UNIVERSITY, PAKISTAN.
SHAH-JEHAN, P.M.D.C., ISLAMABAD, PAKISTAN.
ZULFIQAR AHMED, N.C.E. MINERALOGY, QUETTA, PAKISTAN.

ISSN 0257 – 3660

PRICE:

PREPAID ORDERS FROM PAKISTAN: RS. 90.00
OTHER COUNTRIES: U.S. $ 12.00 OR U.K. £ 8.00
This price includes postage and handling charges.

Published in December each year.
Printed at KASHMIR OFFSET PRESS, QUETTA, PAKISTAN.

ACTA MINERALOGICA PAKISTANICA VOLUME 5, 1991

CONTENTS

PICTURES ON THE OUTSIDE COVER

Field photographs of the mafic rocks of Bela ophiolite.

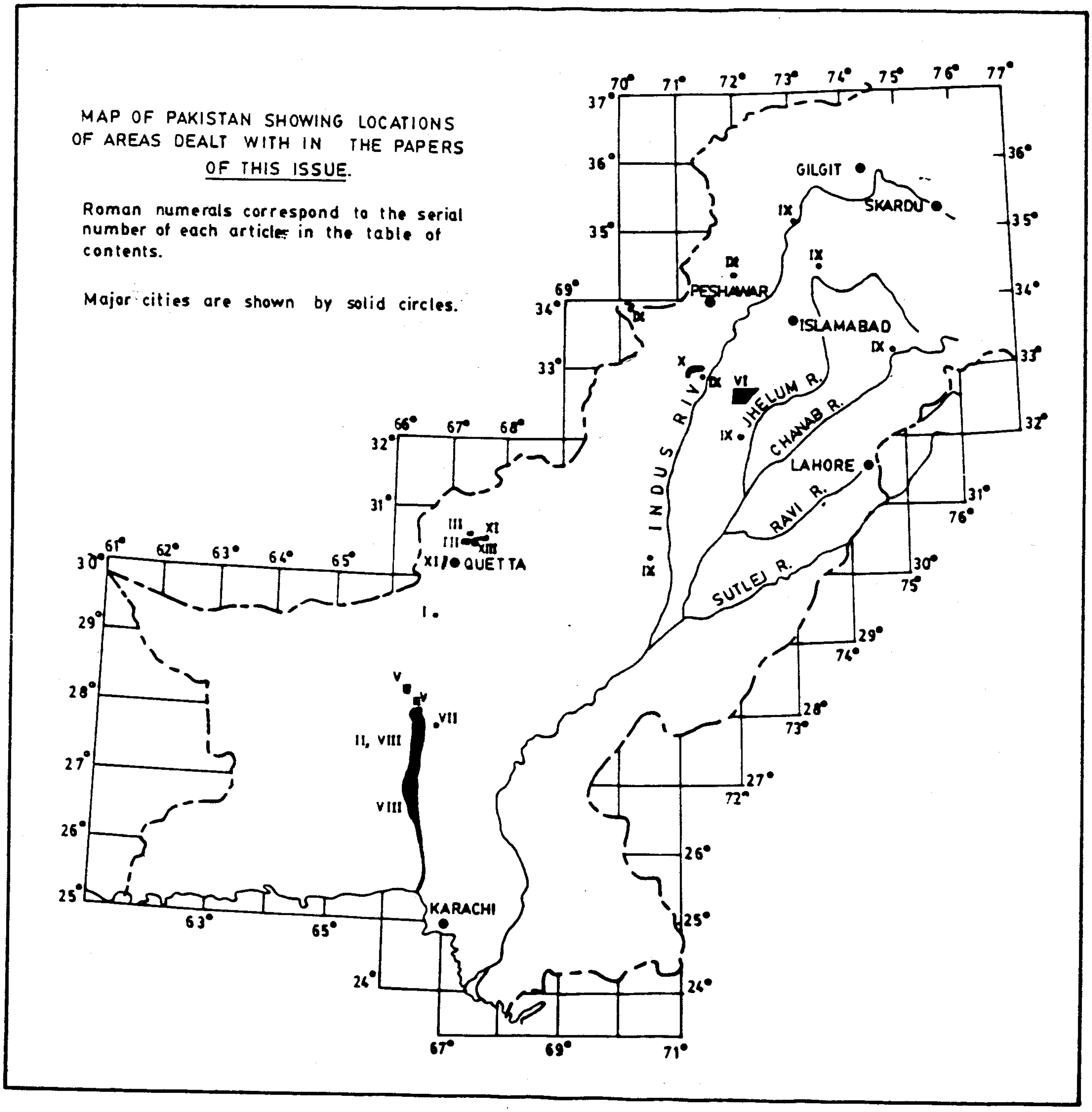
Top, left: Greenish copper-stained chert found in the interspaces between pillow-lobes exposed in the Bora Jhal (stream) at latitude 26° 38' 36"N and longitude 66° 18' 46" E.

Top, right: An outcrop of layered gabbro at Kabar Nai (stream) near the highway bridge at latitude 27° 2' 25"N and longitude 66° 17' 47" E.

Bottom, left: A pyrolusite-rich manganese ore vein transecting the basaltic and cherty host rock at a mine face in the Kohan Jhal (stream) at latitude 26° 37' 57"N and longitude 66° 18' 18"E.

Bottom, right: Ropy surfaces of sub-aerial basalt eruption occur together with the submarine basalt eruption with pillow structure located south of Goth Shafi approximately at latitude 27° 32' N and longitude 66° 24' E.

(Located and photographed by Zulfiqar Ahmed)


MAP OF PAKISTAN SHOWING LOCATIONS OF AREAS DEALT WITH IN THE PAPERS OF THIS ISSUE.
Roman numerals correspond to the serial number of each article in the table of contents.
Major cities are shown by solid circles.
GILGIT
SKARDU
PESHAWAR
ISLAMABAD
LAHORE
QUETTA
KARACHI
INDUS RIV.
JHELUM R.
CHANAB R.
RAVI R.
SUTLEJ R.
I
II, VIII
III
V
VI
VII
VIII
IX
X
XI
XIII

FLUID INCLUSION EVIDENCE FOR THE GENESIS OF FLUORITE DEPOSITS IN THE KALAT REGION OF BALOCHISTAN PROVINCE, PAKISTAN.

DAVID H.M. ALDERTON
Department of Geology, Royal Holloway & Bedford New College, University of London, Egham, Surrey TW20 0EX, U.K.

ABSTRACT: The Kalat region fluorite deposits resemble the Mississippi Valley-type deposits in mineralogy, form and the likely mode of formation. Fluorite contains fluid inclusions rich in water and / or hydrocarbons. Fluorite was deposited from a low-temperature (90-140°C) Na-K-Cl fluid of about 4 wt % NaCl equivalent. A subsequent higher salinity fluid percolated into earlier fluid inclusions. The source region of fluids had hydrocarbon potential.

INTRODUCTION

The study of fluid inclusions forms a powerful technique for obtaining information of the genesis of mineral deposits. In particular, fluid inclusions allow us to place constraints on the temperature and chemical composition of the mineralizing fluid, and thus indicate the most likely environment of mineralization. This paper summarises the results of fluid inclusion studies applied to the fluorite deposits of the Kalat Region in the province of Balochistan (Pakistan). These extensive and well-known deposits have been the subject of several geological studies, but little has been said concerning their mode of formation.

FLUID INCLUSION THEORY

Crystals which grow from a fluid may well trap small portions of that fluid within their structure. These *fluid inclusions* are usually very small (often only a few microns across) but can often be observed in a thin section of a transparent mineral using a normal petrographic microscope. The most useful fluid inclusions are those that developed at the same time as the host mineral was growing, as the trapped fluid will be representative of the hydrothermal fluid. These are known as *primary* fluid inclusions and can be distinguished from those formed during a later hydrothermal event and which occur in fractures crosscutting the mineral (these are called *secondary* inclusions).

There are now a wide variety of physical and chemical tests which can be carried out on fluid inclusions to determine their nature, but probably the most widespread involve observing phase changes within the fluid inclusion in response to heating and cooling the sample on a thermometric microscope stage. Further details on these, and many other techniques, can be found in Roedder (1984) and Shepherd et al. (1985).

(a) Heating

If the mineral grew from a homogeneous liquid phase, at the temperature of trapping the fluid inclusion will be totally filled with liquid. After hydrothermal activity has ceased the sample and fluid inclusion will cool, and as they do so, both will contract. On cooling, the pressure in the inclusion will reduce until the differential contraction between liquid and host mineral will be sufficient to allow the formation of a vapour bubble. The bubble will continue to increase in size on further cooling, so the relative size of the bubble compared to the inclusion cavity at room temperature is a measure of the temperature through which the sample has cooled.

Using a special heating stage attached to the microscope it is possible to reverse this process and heat the sample. In such a case as described above the vapour bubble will contract progressively as the liquid phase expands until at a specific temperature (the temperature of homogenisation or Th) the bubble will dissappear. The Th gives a minimum temperature of mineral formation as a positive temperature (for the effects of pressure) needs to be applied. Quite often the pressure at the time of mineral formation is not known so only the minimum temperature (Th) is known for certain.

(b) Freezing

The addition of salt to a fluid depresses its freezing point below O°C. The freezing-point of the salt-water mixture gives a direct measurement of the salt content (salinity). This feature can be utilised in fluid inclusion studies to measure the salinity of the liquid phase. In practice the liquid is first *frozen* and then warmed in a controlled fashion, and the temperature at which the last ice (or in saline inclusions hydrohalite, $NaC1.2H_2O$) *melts* is measured. This temperature is used to give a direct measurement of salinity, which is usely expressed as if the fluid was pure NaCI, the dominant constituent in most fluid inclusion.

In addition the temperature of *first melting* of the frozen liquid in the inclusion can provide information on the fluid composition. In the NaC1-water system the temperature of first melting (the 'eutectic') is -20.8°C. Addition of potassium to this fluid has little effect on the eutectic, but addition of calcium gives a marked depression. The $CaCl_2$-water system has a eutectic at -52°C, and so it is possible to use the temperature of first melting as an indication of the Ca/Na ratio of the liquid phases.

FLUORITE DEPOSITS IN THE KALAT REGION

Deposits of fluorite are widespread in the Kalat Region of Balochistan (Abu Bakr, 1962; Mohsin and Sarwar, 1974; 1980). They are hosted by the Middle Jurassic Chiltan Limestone, just underneath the unconformable contact with the shaley Createaceous Parh limestone unit. In the mineralised areas the limestones are folded into a series of tight, north-easterly trending anticlinal structures. The fluorite bodies occur as irregular pods and lenses which have replaced the limestone. Some bodies are clearly solution cavities and some appear to be either parallel to the bedding of the limestone, or filling joints. Large, tabular veins are not common, but several of the bodies are joined by smaller, less well defined and irregular veinlets. The size of individual bodies is variable, but typically up to a few metres. The associated minerals are calcite and barite, and sulphides are notably absent. The crystals have a coarse grain size (up to a few cms) and crustiform and vuggy textures are abundant. Overall they show a mineralogy and form which are close to those exhibited by the classic Mississippi Valley- type lead-zinc deposits (but without the galena and sphalerite).

Fluid inclusions in the fluorite

The fluorite contains abundant, large fluid inclusions. Furthermore, these are notable because of the abundance of hydrocarbons ('oil') contained within them - so much so that a distinct smell of oil is obtained on hitting the samples with a hammer. Optical examination has revealed that three dominant types of fluid inclusion are present:

a) Water-rich inclusions (Fig.1)
b) Hydrocarbon-rich inclusions
c) Mixed water-hydrocarbon inclusions (Fig.2)

Thermometric studies have been carried out on these inclusions by Rankin et al. (1990) and during the present study. Further comprehensive details can be found in the former reference.

The water-rich inclusions occur as planes of primary and secondary inclusions, each with an irregular shape. They consist either of monophase aqueous inclusions, or have a small contraction vapour bubble. Temperatures of homogenisation vary from 90 to 140°C. First and last ice melting temperatures of these inclusions suggest that the trapped fluid was Na-K-Cl brine with a salinity of about 4 wt % NaCl equivalents. The secondary inclusions show a similar temperature range and have slightly higher salinities (10 wt % NaCl equivalents). However, first ice melting temperatures of around -50 °C suggest that this fluid contains high concentrations of additional salts such as $CaC1_2$.

The hydrocarbon-rich inclusions have a distinct brown colour and larger vapour bubble. These inclusions tend to have a larger size (typically a few hundred microns, but sometimes greater than 1mm) and a more rounded shape. Temperatures of homogenisation plot around 100°C. The hydrocarbon fluoresces in ultraviolet light. Fourier transform infrared spectroscopy of these inclu-

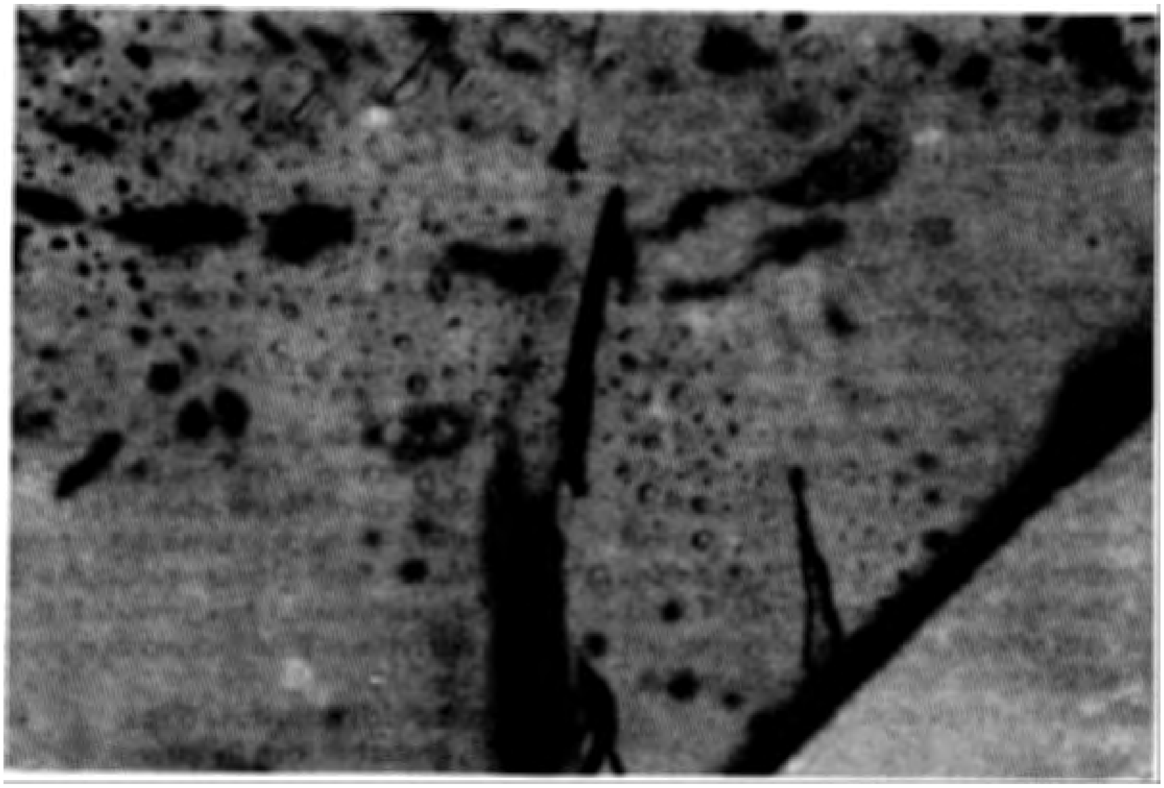


Fig. 1. Typical plane of secondary (?) water-rich fluid inclusions in fluorite from Koh-i-Maran. Some are monophase whilst some have a small contraction vapour bubble. Field of view is approximately 1mm.

Fig. 2. Three oil-water fluid inclusions in fluorite from Koh-i-Maran. The inclusions contain a vapour contraction bubble (v), brown oil (o), and a droplet of water (w). Field of view is approximately 1mm.

sions has shown that the hydrocarbon is dominated by light, saturated species with minor amounts of aromatic/aliphatic hydrocarbons (Rankin et al.,1990).

The mixed water-hydrocarbon inclusions are abundant, and the aqueous and hydrocarbon phases show similar characteristics to those of the inclusions mentioned above. The presence of two separate liquid phases in the inclusions (oil and water) points to immiscibility and the presence of a heterogenous fluid phase. However, oil-water mixtures in fluid inclusions typically exhibit 'water-wet' conditions, i.e. the fluid was dominated by an aqueous phase but contained immiscible droplets of oil. Fig. 3 illustrates such an example in fluorite from Mexico, in which the brown oil occurs as a 'droplet' in the water, and surrounding the vapour bubble. The fluid inclusions in the flourite from the Kalat region are unusual in being 'oil wet', i.e. the water appears to be present as droplets in the hydrocarbon. It is difficult to envisage how fluorite could crystallise from an oil-dominated fluid and thus Rankin et al. (1990) have suggested that such features have a secondary origin. They have proposed that the aqueous component of these inclusions was secondary and percolated into the oil-rich inclusions via microfractures after their formation. They further suggest that the reversal of wetting characteristics in these inclusions may be related to the high concentrations of salts such as $CaC1_2$ in the fluid.

Formation of the fluorite deposits

The fluid inclusion studies have indicated that the fluorite deposits in the Kalat region were deposited from a low temperature Na-K-C1 fluid of about 4 wt% NaC1 equivs., which contained substantial amounts of an immiscible light hydrocarbon. Minimum temperatures of formation were mostly around 120°C. It is uncertain at present what temperature additions need to be added to these figures to take account of the prevailing pressure, but the true temperature of fluorite crystallisation is unlikely to be much higher than

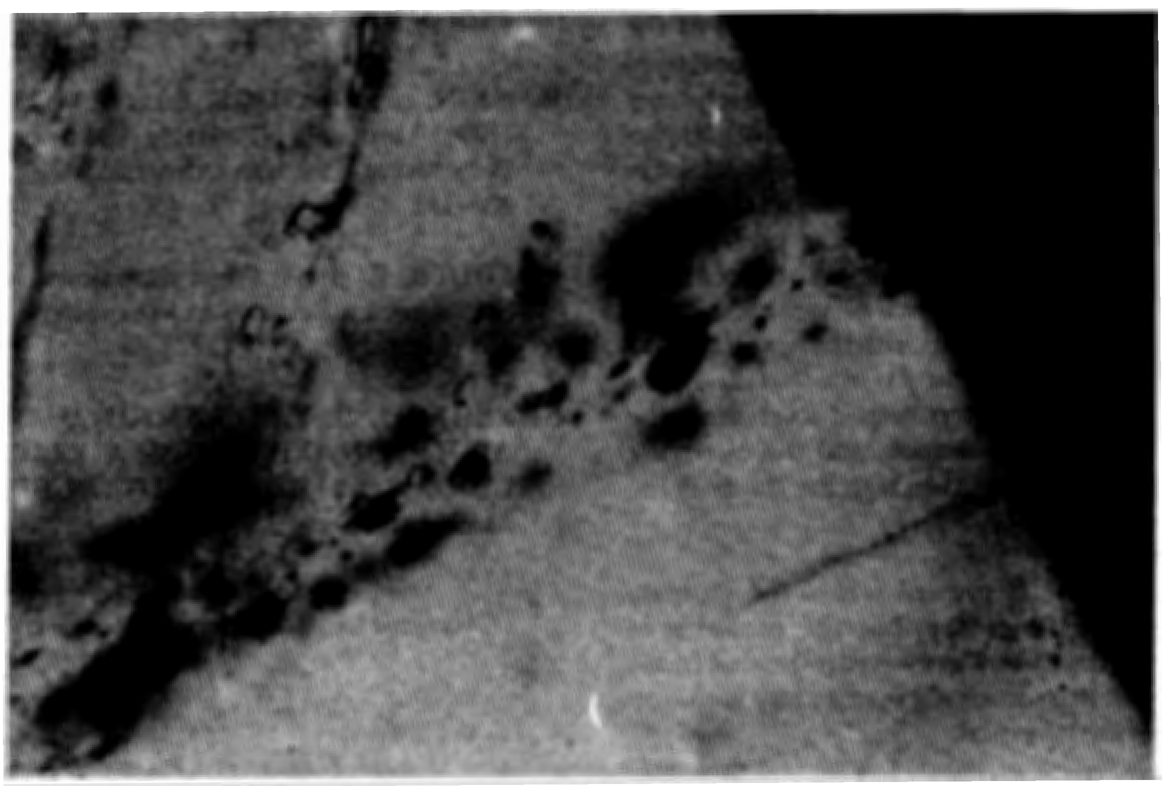


Fig. 3. A plane of oil-water fluid inclusions in fluorite from Mexico. Here the brown oil forms a droplet in the water and surrounds the vapour bubble. Field of view is approximately 1mm.

160°C. At a subsequent stage a second hydrothermal fluid was introduced into the region. This fluid had a similar temperature as the earlier fluid, but the salinity was slightly higher (10 wt% NaC1 equivs.) and there was a marked enrichment in Ca (and/or Mg). This later fluid may well have percolated into the earlier fluid inclusions, thus causing a reversal of their wetting characteristics.

The characteristics of these deposits, namely their fluid inclusions (low temperature, the presence of hydrocarbons, and the Ca-rich nature), their mineralogy and form, and their presence in limestone host rocks, are all strikingly similar to those exhibited by many Mississippi Valley-type lead-zinc-fluorite deposits (Roedder, 1984). There is still much debate about the genesis of such mineralisation but there is a growing consensus that such deposits were generated from the expulsion of hot brines during the compaction of deep sedimentary basins, and an igneous source does not need to be invoked. These fluids would represent connate and meteoric waters which became incorporated in the subsiding basin. As the basin subsided the fluids would heat up, and eventually be expelled due to the weight of the overlying sediment. For the classic Mississippi Valley - type deposit the fluids would leach large amounts of lead and zinc from the lithologies through which they passed. As lead and zinc appear to be absent from these deposits it is assumed that favourable lithologies were not present. The fluids then migrated into adjacent lithologies (here limestones), exploited planes of weakness (bedding, joints, faults), reacted with the host rock, and caused precipitation of the fluorite. No doubt the folds in the Kalat Region helped to channel the fluids in to specific horizons, and the overlying shaley lithologies helped to trap the fluids in the limestone.

It is unclear at present where the ultimate source for the fluids lay, but the presence of abundant hydrocarbon in the hydrothermal fluids suggests that this source region may have some oil or gas-bearing potential.

ACKNOWLEDGEMENTS

I would like to thank Rab Colvine, Zulfiqar Ahmed, and Mehrab Khan for assistance and advice during two recent field visits to the Kalat area. This study forms part of a British Council funded link between Royal Holloway and Bedford New College and the Centre of Excellence in Mineralogy (Quetta) to investigate the mineral deposits of Balochistan.

REFERENCES

ABU BAKR, M. (1962) Fluorspar deposits in the northern part of Koh-i-Maran Range, Kalat Division, West Pakistan.

MOHSIN, S.I. & SARWAR, G. (1974) Geology of Dilband fluorite deposits. Geonews (Geol. Surv. Pakistan) **4**, pp. 1-8.

——— & ——— (1980) Preliminary studies of fluorite mineralization in Kalat Region, Baluchistan Province, Pakistan. Acta Mineralogica-Petrographica, Szeged, **24/2,** pp. 209-217.

RANKIN, A.H., HODGE, B.L., & MOSER, M. (1990) Unusual, oil-bearing inclusions from Balochistan, Pakistan. Mineral. Mag., **54,** pp. 335-342.

ROEDDER, E. (1984) Fluid inclusions. Mineral. Soc. America Reviews in Mineralogy, No. **12,** 644 p.

SHEPHERD, T.J., RANKIN, A.H., & ALDERTON, D.H.M. (1985) A PRACTICAL GUIDE TO FLUID INCLUSION STUDIES. Blackie and Sons, 237 p.

Manuscript received on December 30, 1991.
Accepted for publication on December 30, 1991.

ACTA MINERALOGICA PAKISTANICA
Volume 5 (1991) pp. 9–24.

A SUPRA-SUBDUCTION ZONE ORIGIN OF THE BELA OPHIOLITE, INDICATED BY THE ACIDIC ROCKS OF KHUZDAR DISTRICT, PAKISTAN.

ZULFIQAR AHMED
National Centre of Excellence in Mineralogy, University of Balochistan,
G.P.O. Box 43, Quetta, Pakistan.

ABSTRACT : The most complete and the largest ophiolitic outcrop of Pakistan——the Bela ophiolite——contains a wide range of leucocratic rock types. These include leucogabbro, basic pegmatite, diorite, quartz diorite, trondhjemite, epidote trondhjemite, granite, keratophyre and acidic pegmatite. The plagiogranite forms large outcrops as well as small dykes and lensoid bodies. In places, the acidic rock occurs interdigitating with the surrounding diabase. At a few locations, the acidic melt has intruded diorite. The characteristic very low potash and high soda-containing acidic plagiogranite is accompained by granitic rocks with higher potash content.

Radiogenic isotopic measurements on samples from both potassic and sodic types are distinct and related to their separate tectonic environments. U-Pb isotopic measurements on zircons separated from the acidic plagiogranite samples yield a crystallization age of 65 ±1 Ma for both sodic and potassic samples. The sodic plagiogranites could have been derived from basic magma by fractional crystallization. The potassic granitic rocks may have been generated by crustal anatexis in the subduction zone by the residual heat of the ophiolite. On the basis of geochemical data a suprasubduction zone origin with partial marginal basin environment is proposed for the Bela ophiolite.

INTRODUCTION

Plagiogranites form conspicuous outcrops of relatively very small dimensions in most ophiolites. Based on the specific geological features of each occurrence (e.g., Coleman & Peterman, 1975; Flagler & Spray, 1991; Pedersen & Malpas, 1984) plagiogranitic rocks are shown to form in a variety of different ways. One goal of this paper is to characterize the acidic rocks of the Bela ophiolite (Ahmed, 1986; 1990), and to discuss the possible origin and the nature of their K-bearing varieties which make unusual features in most ophiolites. The rock suite described herein is hosted by the ophiolitic rocks that occur well-exposed in a large stretch of land spanning the geographic Districts of Khuzdar, Bela, Uthal and Kalat. The leucocratic rock exposures, however, occur only in the Khuzdar District. Plagiogranites of this large size and diversity are not known from anywhere else in Pakistani ophiolites. Except the potassic granites, the identified rock types, conform to the features of oceanic plagiogranite of Coleman & Peterman (1975). The potassic granitic rocks are comparable to the anatectic granites (e.g., Pearce, 1989).

This work includes data on major, trace and rare-earth element abundances in acidic rocks obtained by the direct current plasma spectrometric (DCP), X-Ray fluorescence (XRF) and inductively coupled plasma emission spectrometric (ICP-AES) techniques. Radiogenic isotopic data on two samples, one sodic and the other potassic, are also included. This data contributes towards understanding genesis, age and tectonic settingof the Bela ophiolite. The palaeotectonic environment of the ophiolite suggested herein is a supra-subduction zone. The plagiogranite probably formed in the mid-ocean ridge of a marginal basin.

Table 1. Ophiolitic leucocratic rock types from the Khuzdar District, their sample numbers (each with prefix Z) grid references (each with prefix GR) and topographic map numbers (each with prefix M).

A. Potassic (K_2O > 1.9%) acidic (SiO_2 > 66%) rocks:

1. *Pinkish acid pegmatite:* ZA1554, GR 382-583, M-351/1.
It occurs as veins crosscutting high-Al potassic trondhjemite (no. 4 below), found NNW of Nal town.
2. *Pink granite:* Z1741, GR 505-897, M-35 1/8.
It occurs as discrete outcrop adjacent to the ophiolitic basalts at the eastern top end of ophiolite exposed in the Porali River.
3. *Granite:* Z1442, GR 774-223, M-35 1/7.
It occurs as minor bodies emplaced tectonically in microgabbro.
4. *Potash-rich trondhjemite:* Z1450, Gr 708-855, M-351 1/8.
It occurs as a large, conspicuous white outcrop at Purwait Bhut. Another sample Z1656 is taken from the same outcrop but lower horizon, located towards the western contact with diorite.
5. *High-Al, potash rich trondhjemite:* ZB 1554, Gr 382-538, M-35 1/1.
Greyish coloured rock hosts pinkish pegmatitic veins. Also has thin mafic bands of dolerite. Outcrops NNW of Nal.
6. *Botite trondhjemite:* Z1552, GR 382-538, M-35 1/1.
Occurrence same as in no.4 above. It contains andesine in mode and may be called calcic trondhjemite. Zircon, apatite and biotite are also present.
7. *Granitic rock:* Z1440, GR 780-722, M-35 1/7.
It occurs as a cluster of dykes interdigitating dolerites.
8. *Keratophyre,* Z 1405, GR 639-790, μ-35 1/8.
It outcrops near Belar and hosts porphyritic basalt dykes.

B. Sodic acidic (K_2O < 1.9 %; SiO_2 > 66%) rocks.

9. *Trondhjemite:* Z166, Gr 709-856, M351/8.
It occurs as a discrete outcrop, exposed about 100 m NE of no 4 above.
10. *Trondhiemite:* Z1451, GR 710-856, M-35 1/8.
A part of the same outcrop as for no. 4 above.
11. *Trondhjemite:* Z1672, GR 528-657, M-35 1/8.
12. *Trondhjemite:* Z1673, GR 528-657, M-35 1/8.
It occurs as large discrete outcrop adjacent to that of the epidote bearing rock of no. 14 below and hosts the rock as in no. 13 below.
13. *Epidote trondhjemite:* Z1671, GR 528-657, M-35 1/8.
It occurs as veins in trondhjemite of no. 11 above.
14. *Epidote trondhjemite:* Z1674, GR 528-657, M-35 1/8.
The outcrop is in contact with that of no. 12 above.
15. *Granophyric trondhjemite:* Z1671, GR 487-730, M-35 1/8. It overlies gabbro.
16. *Trondhjemite:* Z1498 and Z1499, GR 8186-7875, M-35 1/7.
A small lensoid outcrop, south of Wadh town. It shows green copper staining and contains albite, chlorite, epidote, zircon and sphene.
17. *Calcic trondhjemite,* Z1746, Gr 487-730, M-35 1/8.
It overlies gabbro, adjacent to no. 15 above.

C. Rocks with SiO_2 below 66% :

18. *Granophyric quartz diorite:* Z1418, GR 346-752, M-351/6.
It forms discrete large outcrop close to the tectonic ophiolitic melange area of Samanadh Jhal and is overlain immediately by the Nal Limestone of Eocene age.
19. *Diorite:* Z1382, GR 798-351, M-351 1/6.
It forms veins in gabbro at Samandh Jhal area.
20. *Basic pegmatite* Z1669, GR 709-856, M-351 1/8.
It is hosted by diorite of no. 21 below, NE of Purwait Bhut.
21. *Diorite:* Z1668, GR 709-856, M-35 1/8.
It occurs as a large outcrop below trondhjemite and hosts dolerite dykes and basic pegmatite, NE of Purwait Bhut.
22. *Leucogabbro:* Z1740, GR 480-752, M-351/8.
It outrops south of Kurki Jhal, east of Ornach Cross.

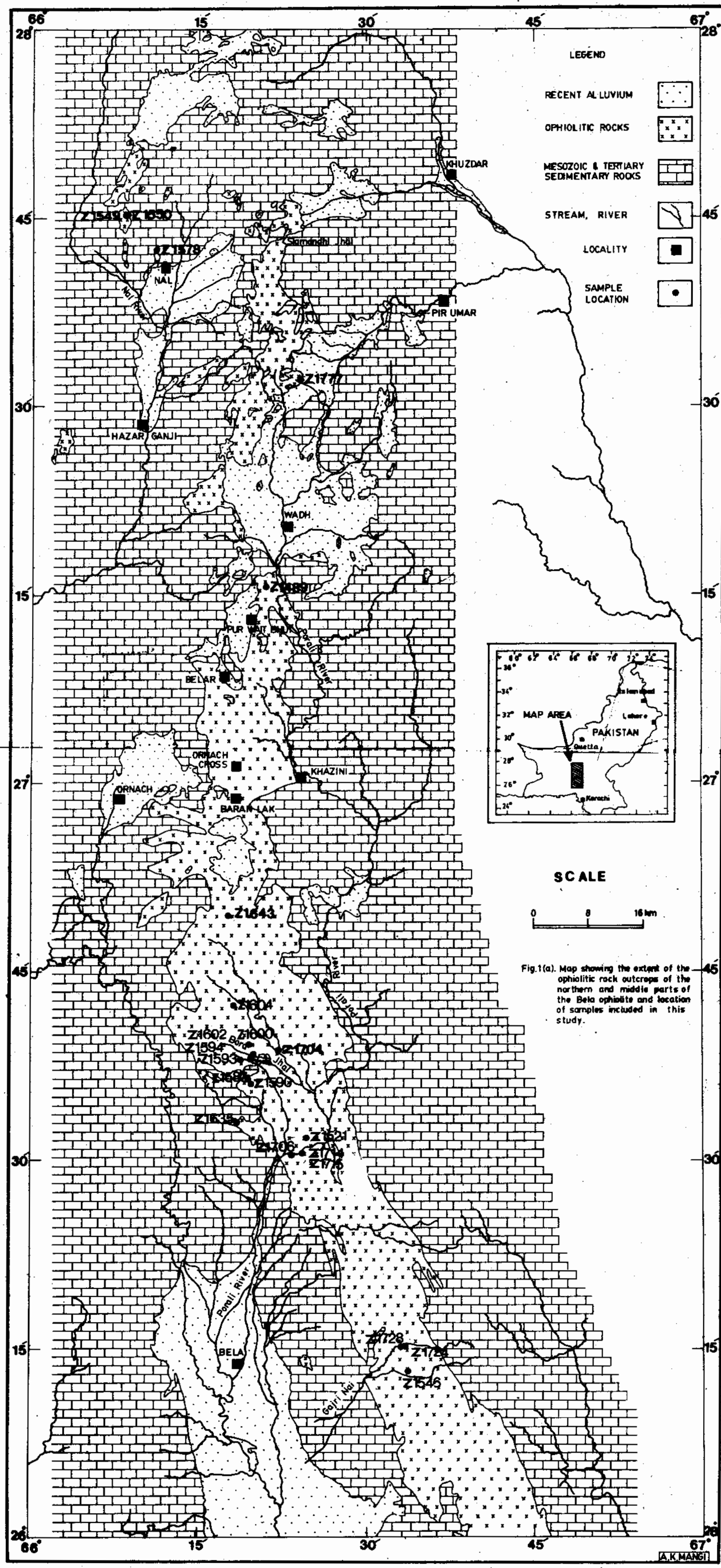


Fig. 1. Map showing the extent of the ophiolitic rock outcrops of the Bela ophiolite in the Khuzdar and Bela regions; and the locations of samples included in this study.

GENERAL GEOLOGY & PETROGRAPHY

The outcrop of the Bela ophiolite, (Ahmed, 1986) seems to start in a due-north on-land extension of the Owen-Murray fracture zone of the Arabian Sea. An ophiolitic outcrop map of the Khuzdar and Bela regions is given in Fig. 1. The ophiolite is not restricted to this area only. The ophiolitic rock exposures just west of Karachi city (Gansser, 1979) continue to appear north wards as far as the northwest of Nal town in the Khuzdar District. However, even further northwards, basaltic rocks outcrop near Takhte Siah in Kalat District; but they haven't yet been related to ophiolitic outcrops.

The north-south elongation of the Bela ophiolite parallels and lies close to the western margin of the Indian plate. This plate boundary is known to be defined by two major sinistral transforms called the Ornach-Nal and Chaman faults, respectively (Farah et al., 1984; Kazmi, 1979). However, the present study conforms to the idea that the Bela ophiolite itself marks the western boundary of the Indian plate in this sector. The minimum age of the Bela ophiolite based on overlying fossiliferous starta is late Eocene (Allemann, 1979).

All the components of the stratigraphic sequence of a typical ophiolite are exposed and are well developed in the Bela ophiolite. These include lherzolite, harzburgite, dunite, wehrlite, chromitite, clinopyroxenite, layered gabbro, isotropic gabbro, leucocratic rocks (including the dioritic and acidic rocks described in this paper), sheeted diabase dykes, basaltic pillow lavas with interbedded chert, shale and limestone. The pyroxenites and dolerites occur also as satellite dykes in the ultramafic rocks. The mantle sequence is much less in volume relative to the crustal sequence. The mafic volcanic rocks of the ophiolite indicate a composite source, and are described separately (Ahmed, this volume).

Plagiogranite forms discrete major bodies as well as minor bodies resembling dykes, veins and lenses. It is commonly surounded by mafic or intermediate rocks. At Purwait Bhut, south of the town of Wadh, a conspicuous white hillock comprises acidic plagiogranite that is intrusive into underlying diorite. The contact zone shows diorite xenoliths trapped in acidic rock which has sent apophyses into the host diorite. However, these features are restricted to the contact zone only and are not pervasive within the outcrop of either rock type. Seven kms to NW of this outcrop, granitic rock is found interdigitated with diabase.

The samples for this study were collected from outcrops in the Khuzdar District which form the northern and middle section of the over 400 km north-south length of the ophiolite. The Bela region covering the southern half of the map in Fig. 1 appears to lack plagiogranite altogether.

The leucocratic rocks of the Bela ophiolite cover a broad spectrum of lithologies (Table 1). In addition, other rock types occur. For example there are copper-stained quartz veins found near the north contact of the trondhjemite of Purwait Bhut. The Bela ophiolite displays trondhjemite as the most abundant rock type amongst the full spectrum of rock types listed by Coleman and Peterman (1975) for oceanic plagiogranite. In addition, certain other granitic rocks are found. Epidote trondhjemite contains 10 to 20 modal percent coarse, green, magmatic epidote that forms large euhedral prismatic crystals and occurs mainly at one locality, respresented by sample Z1671 in Fig. 1 and Table 1. It forms small lensoid bodies and veins enclosed in the trondhjemite lacking such epidote. It also occurs as a large discrete outcrop adjacent to the trondhjemite and diorite both of which lack such epidote.

The rocks contain the mineral assemblage quartz, albite, plagioclase (zoned from andesine to albite), orthoclase, chlorite, zirocon, ilmenite, apatite, rutile, biotite, sphene, epidote and magnetite. One granitic occurrence is biotite rich (sample no. Z1552, Table 1). Granophyric intergrowth between quartz and feldspar is prevalent in both the trondhjemitic and granitic rocks.

GEOCHEMISTRY

Analytical Methods

The leucocratic rock samples were analyzed for their major and trace elements. Those analyzed by XRF are marked with an asterisk in Tables 2 to 4; the remainder being analyzed by DCP.

Table 2. Whole rock analyses of potassic acidic rocks.

Sample no	ZA1554	Z1741	Z1442	Z1450*	ZB 1554	Z1552	Z1440*	Z1405*
SiO_2	71.30	70.19	71.20	77.23	68.82	69.23	74.62	72.25
TiO_2	0.09	0.50	0.31	0.18	0.53	0.64	0.32	0.34
Al_2O_3	14.97	14.30	13.77	12.74	16.44	15.74	12.62	13.36
Fe_2O_3	0.57	3.18	2.90	1.01	3.11	3.47	3.09	2.13
MnO	0.01	0.05	0.06	0.12	0.03	0.04	0.14	0.13
MgO	0.26	0.69	1.01	0.28	1.39	1.48	1.04	0.85
CaO	0.77	0.99	2.74	1.19	3.08	3.48	0.76	1.41
Na_2O	1.88	4.43	3.24	4.37	3.77	3.74	4.93	5.40
K_2O	8.67	5.07	3.14	2.41	2.41	1.94	2.18	1.93
P_2O_5	0.04	0.11	0.09	0.02	0.19	0.18	0.06	0.09
LOI	0.74	1.31	1.60	0.71	1.35	0.76	1.06	2.38
Total	99.30	100.82	100.06	100.16	101.12	100.70	100.82	100.27
Trace elements and REE abundances in p.p.m. :								
S	–	–	–	0	–	–	20	120
Cl	–	–	–	0	–	–	30	60
Ba	1137	356	986	460	924	729	1084	828
Rb	115	102	48	49	64	72	31	28
Th				4.8			7.2	7.1
Nb				14			8.6	7.4
Ta				2.6			0.5	0.6
La				21.4			19.6	21.1
Ce				41.7			38	
Pr				4.66			4.51	
Nd				17.4			16	
Sm				3.88			3.98	
Eu				0.73			1.03	
Gd				3.85			4.37	
Dy				4.27			5.07	
Ho				0.82			0.98	
Er				2.57			3.09	
Yb				2.83			3.09	
Lu				0.43			0.47	
Sr	578	65	108	125	528	524	69	84
Zr	25	655	106	125	172	172	140	154
Hf	–	–	–	3.7	–	–	3.7	4
Zn	11	120	41	6	74	92	43	29
U	–	–	–	1.1	–	–	2.3	2.7
Y	3	58	–	30	8	8	34	31
Ga	–	–	–	12	–	–	10	12
Pb	–	–	–	3	–	–	2.4	5
Cu	5	7	7	11	5	–	29	42
Cr	3	8	8	6	30	11	44	12
Ni	3	2	3	2	17	4	8	5
V	–	–	–	24	–	–	29	29
Sc	2	6	10	–	8	8	–	–

Table 3. Whole-rock analyses of sodic acidic rocks.

Sample no	Z1666	Z1451	Z1672	Z1673*	Z1671*	Z1674	Z1747	Z1498	Z1499	Z1746
SiO_2	75.44	77.47	73.34	74.04	75.78	78.78	75.48	71.24	69.52	69.75
TiO_2	0.12	0.13	0.20	0.22	0.18	0.15	0.22	0.33	0.37	0.62
Al_2O_3	12.52	13.00	13.10	12.91	12.55	12.07	12.45	13.78	15.46	13.93
Fe_2O_3	2.62	1.57	3.94	4.64	2.06	1.08	2.87	3.47	4.85	3.86
MnO	0.03	0.03	0.01	0.13	0.13	0.01	0.03	0.05	0.06	0.05
MgO	0.33	0.29	0.32	0.20	0.14	0.11	0.26	1.39	2.11	0.90
CaO	1.15	0.87	1.25	2.16	3.50	2.40	2.75	4.04	2.77	7.37
Na_2O	4.79	5.68	6.40	5.90	5.01	5.20	5.03	4.97	5.67	2.56
K_2O	1.29	0.34	0.14	0.16	0.19	0.11	1.01	0.03	0.04	0.01
P_20_5	0.02	0.03	0.05	0.03	0.02	0.02	0.05	0.00	–	0.22
LOI	0.82	0.77	0.68	0.65	0.77	0.51	0.86	1.60	–	2.02
Total	99.13	100.18	99.14	101.04	100.33	100.44	100.01	100.90	100.85	101.33
Trace elements and REE in p.p.m. :										
S	–	–	–	0	0	–	–	–	–	–
Cl	–	–	–	0	10	–	–	–	–	–
Ba	273	96	33	19	0	13	16	0	17	5
Rb	18	–	4	1.3	2.2					
Th				0.3	0.3					
Nb				7.1	4.3					
Ta				1.09	2.42					
La				4.3	1.7					
Ce				12.1	–					
Pr				2	–					
Nd				9.8	–					
Sm				3.44	–					
Eu				1.32	–					
Gd				4.78	–					
Dy				6031	–					
Ho				1.22	–					
Er				3.93	–					
Yb				3.89	–					
Lu				0.58	–					
Sr	139	90	75	117	157	106	97	125	109	255
Zr	110	84	145	159	185	144	232	71	88	154
Hf	–	–	–	4.1	4.8	–	–	–	–	–
Zn	6	7	4	6	2	–	6	30	49	–
U	–	–	–	0.05	0.77	–	–	–	–	–
Y	17	24	46	42	58	43	62	15	16	49
Ga	–	–	–	15	14	–	–	–	–	–
Pb	–	–	–	0.9	0.04	–	–	–	–	–
Cu	10	–	2	4	7	–	–	–	–	–
Cr	1	5	2	54	6	–	11	10	14	–
NI	1	3	2	14	3	–	8	8	11	8
V	–	–	–	26	27	–	–	–	–	–
Sc	3	7	15	13	8	11	8	13	15	15

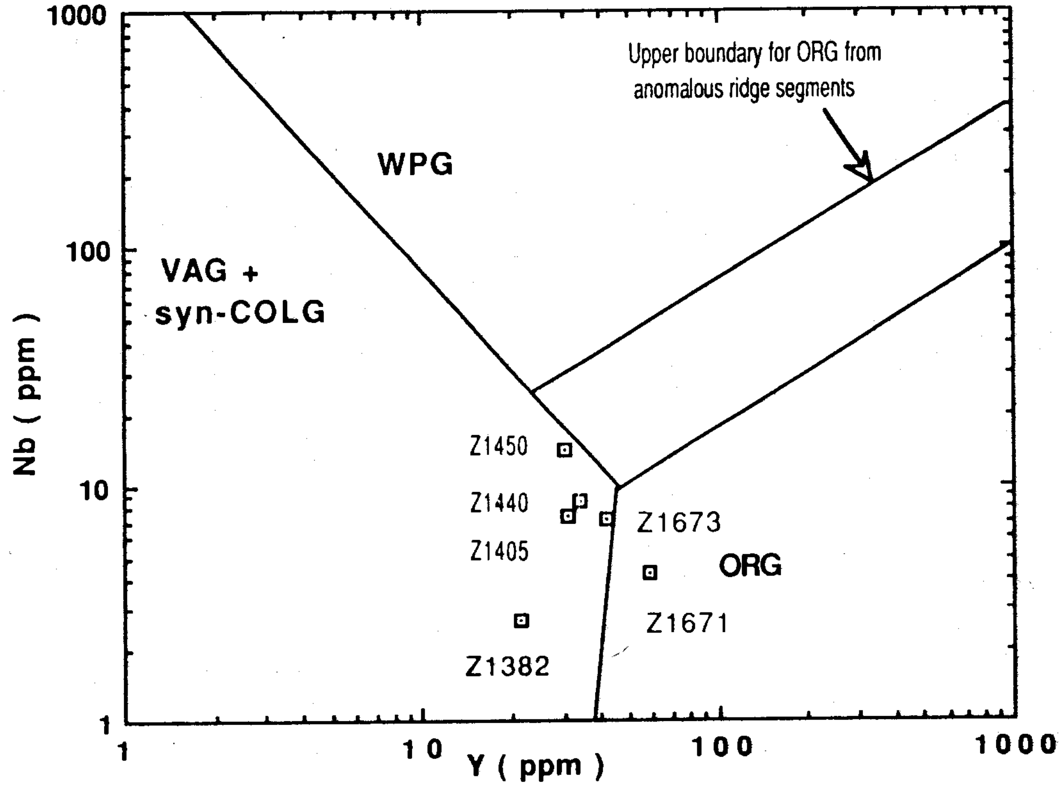
Table 4. Whole rock analyses of subacidic plagiogranitic rocks.

Sample no	Z1418	Z1382	Z1669	Z1668	Z1740
SiO_2	62.72	60.71	55.34	50.79	50.32
TiO_2	0.76	0.11	0.19	0.63	0.44
Al_2O_3	14.68	20.95	21.08	15.16	15.9
Fe_2O_3	9.00	1.07	1.68	8.02	6.54
Mno	0.14	0.12	0.03	0.14	0.12
Mgo	2.57	1.16	1.09	9.39	9.45
CaO	4.42	5.96	12.79	13.03	16.96
Na_2O	3.38	8.65	5.81	2.48	1.2
K_2O	3.03	0.25	0.01	0.16	0.02
P_2O_5	0.14	0.07	0.01	0.05	0.02
LOI	0.66	1.79	2.76	1.7	–
Total	101.50	100.84	100.79	101.55	100.97
Trace elements and REE in p.p.m.:					
S	–	20	–	–	–
Cl	–	60	–	–	–
Ba	140	70	4	11	–
Rb	–	4.8	3	–	–
Th	–	0	–	–	–
Nb	–	2.7	–	–	–
Ta	–	1.3	–	–	–
La	–	4.7	–	–	–
Sr	1277	205	127	224	187
Zr	76	48	137	38	16
Hf	–	2	–	–	–
Zn	72	7.2	3	–	–
U	–	0.09	–	–	–
Y	27	21.3	18	54	12
Ga	–	7.8	–	–	–
Pb	–	1.4	–	–	–
Cu	–	4.3	27	–	–
Cr	–	20	10	414	111
Ni	–	21	5	124	171
V	–	28	–	–	–
Sc	–	6	5	61	81

Standard procedures were followed for the XRF analyses performed at the Department of Geological Sciences, University of Southern California, Los Angeles, U.S.A. The samples were made into glass discs to measure the major elements; and powder pellets to measure the trace elements. The instrument used was RIGAKU System 3070, wavelength dispersive, automatic X-ray fluorescence spectrometer. The tube voltage used was 40 KV, 30 mA for the major element runs, and 55 kV, 40 mA for the trace element runs.

DCP analyses were performed at the California Institute of Technology (Caltech), U.S.A., using rock standards analyzed by Bruce Chappell, and supplied by Jason B. Saleeby. The precision of the XRF analyses is better than 3% whereas that of DCP analyses is ± 6%.

Rare-earth element (REE) analyses of 3 samples were performed by ICP-AES at the R.H.B. New College, University of London, U.K., in the laboratory of J.N. Walsh, using standards KC10, KC11, KC12 and KC13. The precision of these analyses is estimated at ± 5%.



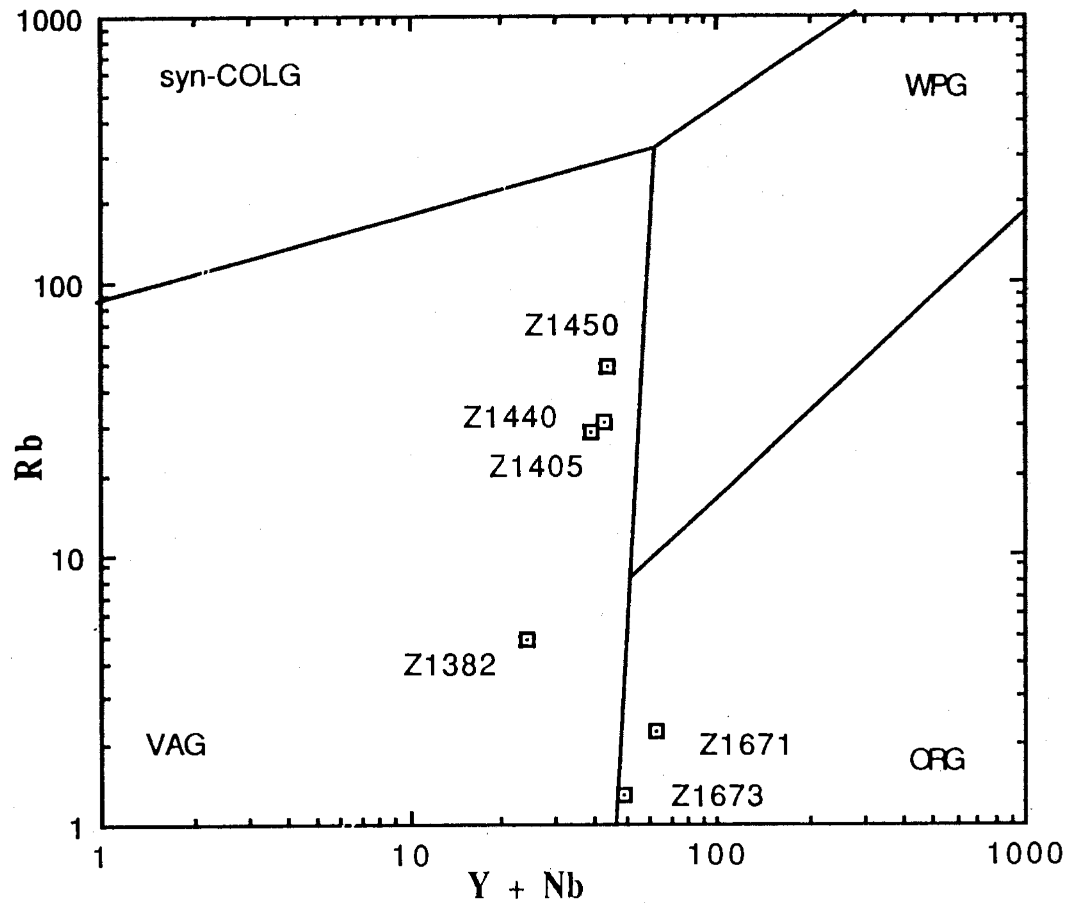


Fig. 2. Trace element data for the leucocratic rocks of Khuzdar region to discriminate between various tectonic settings: (A) Nb versus Y; (B) Rb versus Y + Nb.

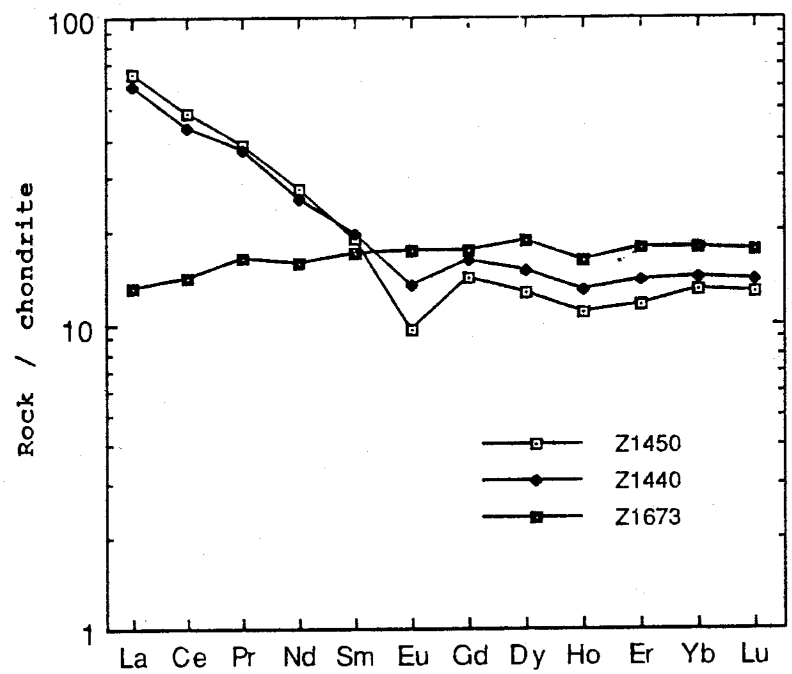


Fig. 3. Chondrite-normalized REE plot for the samples representative of the sodic and potassic leucocratic rocks of the Khuzdar region. Normalizing values after Nakamura (1974).

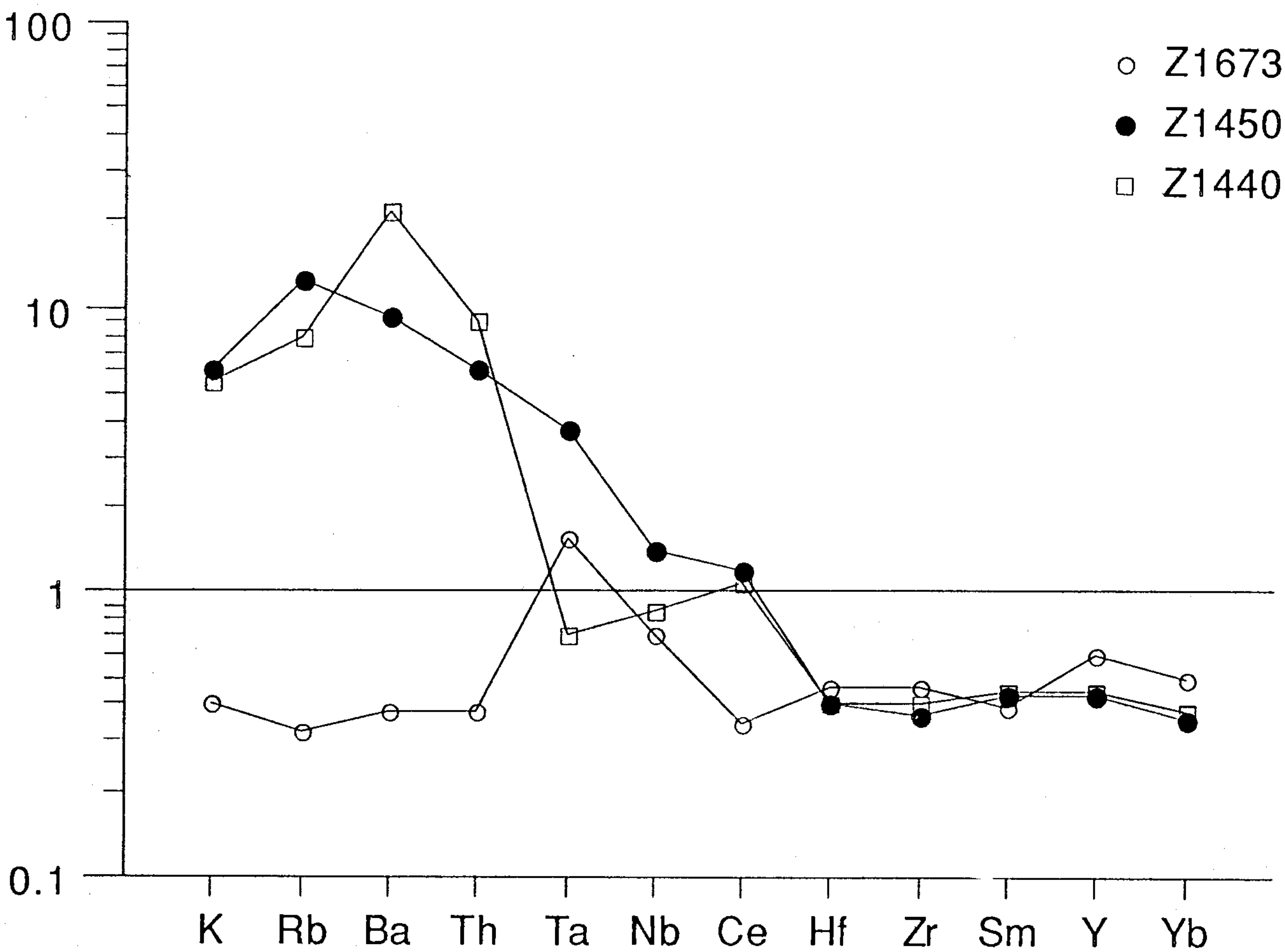


Fig. 4. Data for the leucocratic rocks of the Khuzdar region normalized to hypothetical ocean- ridge granite from Pearce et al. (1984).

Table 5. Comparison of Rb/Sr and Sm/Nd data between the typical trondhjemite (Z1673) and a potash-rich granite (Z1450).

	Z1673	Z1450
Rb (ppm)	0.965	42.832
Sr (ppm)	113.707	122.942
Rb/Sr	0.0085	0.3484
$^{87}Rb/^{86}Sr$	0.02439	1.001586
$^{87}Sr/^{86}Sr$ (0 Ma)	0.704607	0.705397
$^{87}Sr/^{86}Sr$ (75Ma)	0.704581	0.704329
ϵ Sr (75 Ma)	2.4	-1.17
Sm (ppm)	3.614	3.967
Nd (ppm)	11.060	19.018
Sm / Nd	0.3268	0.2086
$^{147}sm / ^{144}Nd$	0.1976	0.1261
$^{143}Nd/^{144}Nd$ (0)	0.513022	0.51284
ϵ Nd (0 Ma)	7.49	3.93
ϵ Nd (75 Ma)	7.49	4.61

Table 6. U-Pb geochronological data on zircons obtained from plagiogranite.

Sample no.	Fractions	**Age (Ma) :**		
		$t\frac{^{206}Pb}{^{238}U}$	$t\frac{^{207}Pb}{^{235}U}$	$t\frac{207\,Pb}{206\,Pb}$
Z1673	<45 μ	66.4 ± 1	66.5 ± 1	68 ± 5
	45 - 62	64.6 ± 1	64.6 ± 1	66 ± 4
Z1450	<62 μ	65.6 ± 1	65.7 1	67 ± 6
		Radiogenic atomic ratios		
		$\frac{^{206}Pb}{^{238}U}$	$\frac{^{207}Pb}{^{235}U}$	$\frac{^{207}Pb}{^{206}Pb}$
Z1673	< 45 μ	0.01036	0.06765	0.04738
	45 - 62 μ	0.01007	0.06570	0.04734
Z1450	<62 μ	0.01023	0.06679	0.04737

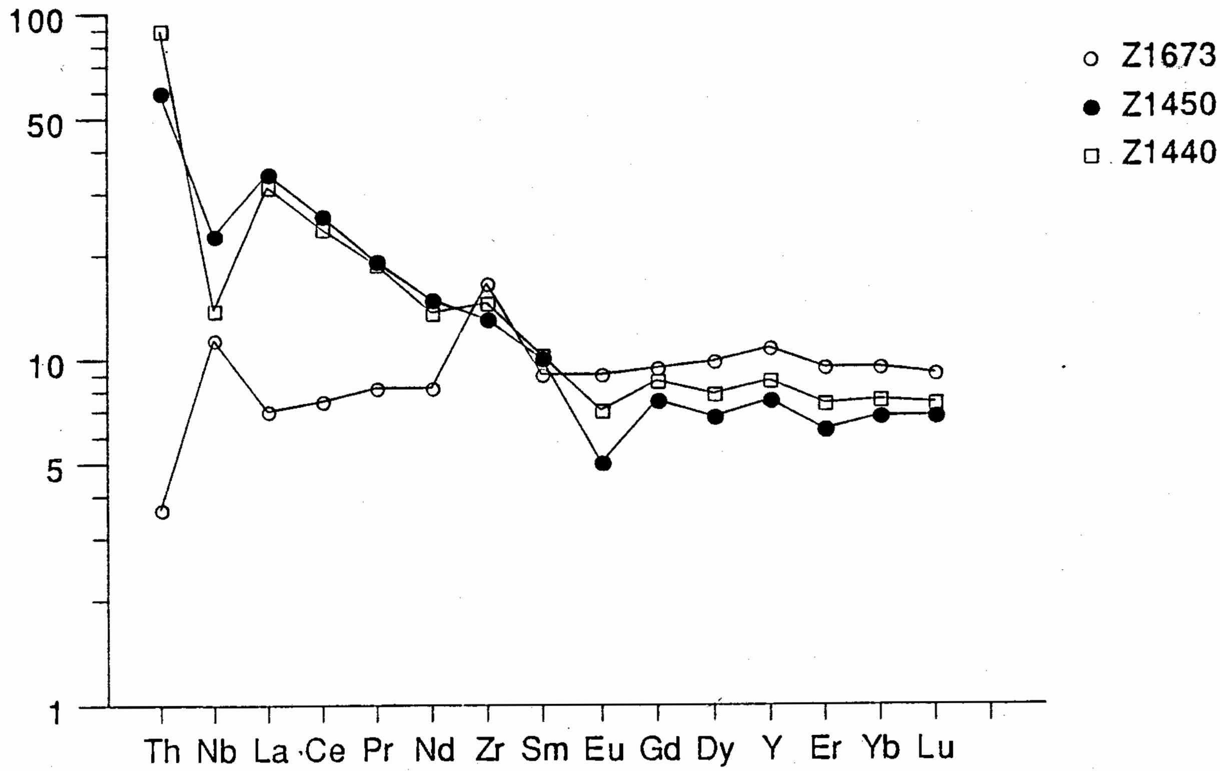


Fig. 5. Primitive mantle normalized abundances of Th, REE and HFSE in the leucocratic rocks of Khuzdar region. Normalizing values from Hofmann (1988).

For the geochronological measurements, each of two rock samples of about 3 kg weight were crushed and zircon separated using standard procedures with a Frantz isodynamic separator and heavy liquids. Final fractions were picked by needle under the microscope collecting the clear euhedra of zircon. The fractions were abraded and weighed into teflon minibombs, dissolved and subjected to chemical separation of U and Pb before their analysis with VG Instruments mass spectrometer at the laboratory of Jason B. Saleeby at Caltech. In the same laboratory, Sm/Nd and Rb/Sr isotopic determinations were made after chemical separation using the isotope dilution technique.

Chemical Compositions

Compositions of the samples representative of the rock types listed in Table 1 are given in Tables 2 to 4.

The trondhjemites (Table 3) show very low K_2O and higher Na_2O. The K_2O contents of the samples are generally low; but some of the rock samples deviate from typical oceanic plagiogranite in possessing relatively high K_2O. The upper limit for trondhjemites at 2.5% K_2O is crossed by a few samples of granite and pegmatite (Table 2).

It is generally agreed that the high - field - strength elements (HFSE: Ti, Zr, Y, Nb, Ta, Hf), the transition metals (TM: Sc, V, Cr, Ni) and REE are essentially immobile during all but the most severe sea-floor hydrothermal alteration; and the low-field-strength elements (LFSE: Cs, Rb, Ba, Sr) and elements like Si, K, Na are mobile elements (e.g., Middleburg *et al.*, 1988; Pearce, 1975; Humphris & Thompson, 1978; Wood *et al.*, 1979). The potassic granitic samples (Table 2) are, in general, richer in incompatible trace elements; and the trondhjemitic (Table 3) samples are poorer in such elements. The whole-rock trace element data was subjected to comparison with the tectonic classes of granites established by Pearce at al., (1984). The trace elements plots (Fig. 2) show that trondhjemites plot in the ocean-ridge granite "ORG" field and the granitic rocks plot in the volcanic arc granite "VAG" field. The typical trondhjemitic samples plot in the ORG field on the discrimination plot of Nb versus Y and Rb versus Y + Nb drawn after Pearce et al. (1984).

The REE geochemistry of acidic rock samples shows the presence of two types of chondrite-normalized pattern (Fig. 3). Potassic granites (e.g., sample nos. Z1440 & Z1450. show LREE enriched patterns with distinct negative Eu anomalies. The trondhjemitic sample Z 1673 shows slight depletion

Table 7. Feldspar compositions from leucocratic rocks.

Sample	Ab	An	Or	Sample	Ab	An	Or
				Z1552 Rim	67.62	31.28	1.09
Z1442	94.09	5.15	0.76	Z1552 Core	65.74	32.50	1.76
Z1442	98.33	1.50	0.17	Z1451	82.40	15.52	2.08
Z1442	4.58	0.07	95.35	Z1451 Rim	87.84	11.14	1.01
Z1442	5.23	0.40	94.37	Z1451 Core	80.61	18.64	0.75
Z1656	10.08	0.29	89.63	Z1451** Rim	95.46	4.32	0.22
Z1656	12.33	0.23	87.44	Z1451** Rim	95.36	4.36	0.28
Z1656	53.27	46.47	0.26	Z1451	90.24	9.11	0.65
Z1656	68.41	29.06	2.53	Z1451	92.81	6.73	0.46
Z1656 Core	76.76	20.38	2,86	Z1451**	89.11	9.43	1.46
Z1656 Rim	79.98	17.09	2.93	Z1451**	92.66	5.96	1.39
Z1656	86.00	13.38	0.63	Z1451	92.93	3.98	3.10
Z1656	87.34	11.44	1.22	Z1451	96.53	3.20	0.27
Z1656	87.82	9.22	2.97	Z1671	90.11	8.77	1.12
Z1656	89.57	8.87	1.58	Z1671	96.10	3.59	0.31
Z1656	93.66	4.71	1.63	Z1671	96.74	3.13	0.13
Z1656	96.68	1.87	1.45	Z1747	94.21	5.47	0.32
Z1656	98.43	1.43	0.15	Z1747	96.88	2.89	0.24
Z1552	68.07	30.12	1.81	Z1498	98.19	1.35	0.46
Z1552	68.34	30.54	1.12	Z1498	98.31	1.36	0.33
Z1552 Rim	69.44	29.56	1.00	Z1498	98.36	1.44	0.20
Z1552 Core	67.77	30.58	1.65	Z1498	99.00	0.77	0.23

** = Parts of the same grain.

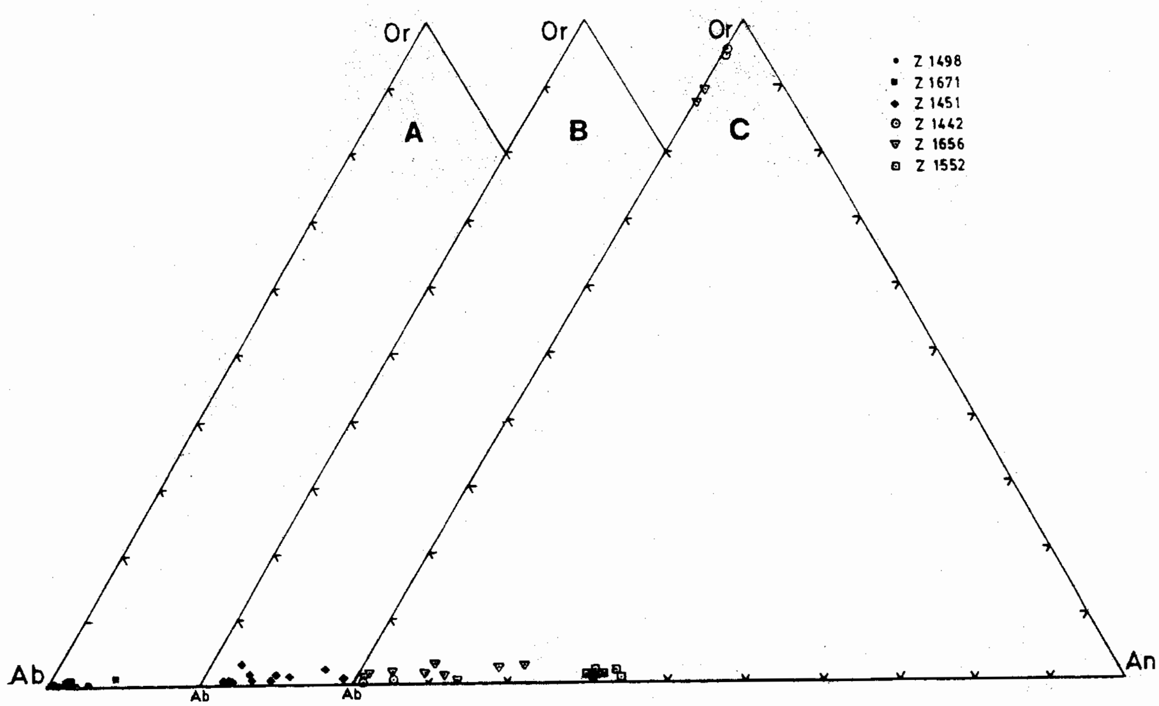


Fig. 6. Feldspar compositions from individual samples of the leucocratic rocks of Khuzdar region. (A,B) trondhjemitic rocks; (C) granitic rocks.

of LREE relative to HREE without a Eu anomaly. It has an almost flat pattern. However, it is richer in HREE compared to the potassic samples. The pattern differs from either of the two types of plagiogranite from the Karmoy ophiolite, Western Norway, described by Pedersen & Malpas (1984) which was interpreted to have formed by two separate processes: one by the anatexis of amphibolite, and the other by the magmatic differentiation through filter pressing combined with autometasomatism.

Radiogenic isotopic data

The data in Table 5 reveals significant differences between the two types of acidic rocks within the Bela ophiolite. The sodic trondhjemites correspond with ORG and the potassic granites with VAG. The $^{87}Sr / ^{86}Sr$ ratios in both cases exceed the typical MORB values.

Geochronology

The zircons analyzed for geochronology are clear and colourless with minor inclusions and cracks. The crystals are faceted and euhedral with sharp terminations, interpreted to possess an igneous morphology. The U-Pb data on the zircons separated from two samples, Z1673 (sodic type) and Z1450 (potassic type) are given in Table 6. The age of crystallization derived from this data is 65 ±1 Ma for both the samples. The similarity in ages between the two samples implies a temporal relationship between the sodic and potassic types of plagiogranite and their formation in separate environments.

MINERAL CHEMISTRY

Microprobe analyses were performed on several of the samples listed in Table 1. The polished thin sections were prepared and analyzed with the JEOL 733 SUPERPROBE set up at the California Institute of Technology, U.S.A. Standard procedures for wave-length dispersive analyses were employed to acquire high quality data.

The feldspar compositions from the analyzed samples are reported in Table 7 and Fig. 6. The potassic samples contain orthoclase in addition to plagioclase. The plagioclase is commonly zoned. The variation in An content of the plagioclase seen in individual samples is considerable.

DISCUSSION

The range of whole-rock compositions do not reveal any gap implied by the possibility of genesis of these rocks as immiscible liquids in equilibrium with conjugate mafic melts. Experimental production of two immiscible liquids of plagiogranitic and Fe-rich basaltic compositions by Dixon and Rutherford (1979) was found to be inapplicable to natural plagiogranite at the Canyon Mountain ophiolite by Gerlach et al. (1981). At Bela, the large size of the sodic plagiogranite outcrops and existence of rocks of diorite and granodiorite compositions do not favour the model of liquid immiscibility.

Anatectic plagiogranite includes that formed by the partial melting of basic rocks under hydrous conditions (e.g., Pedersen & Malpas, 1984; Flagler & Spray, 1991; Spray & Dunning, 1991; Payne & Strong, 1979; Gerlach et al., 1981). High temperature, shear zone-related partial melting of hydrated gabbro have been proposed. The shear zones may be low angle asthenospheric shears extending up into the still plastic crust near an active spreading ridge (adjacent to a magma chamber). The shears may also be due to intrusion of related (off-axis) mafic bodies into the still plastic crust. The gabbros in both cases are supposed to be hot so that they cannot undergo subsolidus deformation. The formation of amphibolite requires hydrothermal fluids to facilitate hydration of the gabbros. If the acidic rocks were formed by such a process, they may bear no relation in time with the ophiolite itself. The plagiogranite of the Canyon Mountain ophiolite is considered to have formed by the partial melting of basic rocks in presence of water probably at shallow depths with total pressure below 5 kb. This plagiogranite includes varieties from diorite to trondhjemite and occurs mostly as sills (Gerlach et al., 1981). Pedersen & Malpas (1984) demonstrated the coexistence of two suites of plagiogranite in the Karmoy ophiolite: one associated with high temperature, pre-basic dyke shear zones, formed by anatexis of amphibolites, and the other formed by filter pressing of a differentiated interstitial liquid.

Fractional crystallization of basic magma has been invoked to explain plagiogranite formation by many workers (e.g., Pallister & Knight, 1981; Lippard, Shelton & Gass, 1986; Menzies et al., 1980). Coleman & Peterman (1975) held that oceanic plagiogranite forms by the low pressure differentiation of a subalkaline, tholeiitic basaltic magma at slower spreading centres. The outcrop of plagiogranite at Purwait Bhut shows gabbro in the west overlain to the east by diorite and then trondhjemite which occurs intruding the diorite and not the adjacent gabbro. Diorite forms intervening outcrop between gabbro and trondhjemite. The diorite had partly solidified before the trondhjemite was emplaced because the contact of trondhjemite against diorite is intrusive. The compositional variation within individual zoned crystals of feldspar in some plagiogranite samples is gradual and spans a large range and this supports a fractional crystallization model. The potassic granites occur within the ophiolite. Sample Z1442 which occurs as dykes in a microgabbro host, contains both potash and soda and has modal albite and orthoclase.

The trace element discrimination plots drawn after Pearce et al. (1984) in Fig.3 show that sodic samples (e.g., Z1673, Z1671) plot in the ocean ridge granite (ORG) field or close to the VAG-ORG boundary. More potassic samples (e.g., Z1450, Z1440) plot in the volcanic arc granite (VAG) field where suprasubduction zone granites also plot. A parallel result is obvious when Rb is plotted against Y + Nb (Fig. 3). Therefore, the sodic samples represent supra-subduction zone (marginal basin) ridge granites and the potassic samples represent volcanic arc granites.

Trace elements from sodic and potassic samples display separate patterns on plots normalized to the hypothetical ocean ridge granite after Pearce et al., (1984) (Fig.4). The trondhjemite (Z1673) pattern is relatively flat and is depleted in Nb through Yb and also in K, Rb, Ba and Th relative to ORG. Its lower K, Rb may be due to their loss in a volatile phase or to alteration. The pattern differs from that of the supra-subduction zone ridge granite of the Troodos Massif which contains higher Th and Ba and lower K and Rb and Th relative to Ta. The pattern parallels the line of ORG values, except for its higher Ta value due to analytical uncertainty. The depletion in K, Rb and Ba is a typical ORG feature (Pearce et al., 1984). Comparison with Fig. 1a and 1b of Pearce et al. (1984) indicates a slight supra-subduction zone influence.

More potassic samples (Z1450, Z1440, Fig. 4) show sub-ORG concentrations in the Hf to Yb stretch and have enrichment in Th relative to Nb; indicating a supra-subduction zone environment (Jenner et al., 1992). They are also rich in K, Rb, Ba, and Th, like the volcanic arc granites. The pattern of Z1450 is richer in Th, Ta, Nb, and Ce, like that of the granite from anomalous ridge segment (MAR 45° N) but differs in its high Rb and K. The patterns of potassic samples tally with the abundances of crustal-anatectic granites from Oman ophiolite (Pearce, 1989).

A primitive mantle normalized plot of the 3 samples incorporating REE, Th, Nb, Zr and Y is given in Fig.5 using the primitive mantle values after Hofmann (1988). Depletion of Nb relative to Th is featured by the potassic samples only; the trondhjemite shows reverse behaviour.

Also, in the potassic samples, Th is strongly enriched relative to La, and a negative Eu anomaly is present. This anomaly is not seen in the pattern for sample Z1673, which shows a marked enrichment in Zr relative to the REE.

Nb depletion relative to Th on the primitive mantle normalized plot is often taken as a sign of a supra-subduction zone environment (e.g., Jenner et al., 1991). This feature is clearly shown by the plots of plagiogranite samples (e.g., Z1450, Z1440, Z1405, Table 2); but not by those of the trondhjemitic samples (e.g., Z1671).

The geochemical characters of both arc and non-arc materials are observed in the samples analysed. The associated mafic volcanic rocks also exhibit a composite chemistry. The data points to the inference that the Bela volcanics and the associated leucocratic rocks formed in a suprasub duction zone environment. Modern back-arc basin volcanic rocks, within the supra-subduction zone environment demonstrate geochemical characteristics ranging from arc to non-arc. It seems likely, therefore, that the Bela ophiolite formed in a back-arc basin. The suprasubduction zone origin for these rocks also tallies with certain other features that are common in suprasubduction zone ophiolites, such as the abundance of chromite deposits, and the presence of intermediate igneous rocks such as granodiorite and diorite.

CONCLUSIONS

The Bela ophiolite is the largest and most complete ophiolite in Pakistan, exceeding 400 kms in its north-south outcrop length. The northern half of the ophiolite displays a variety of leucocratic rocks types including well-developed acidic rocks of two types: trondhjemites and higher-potash granitic rocks. Both types contrast in their major, trace, and rare-earth element concentrations and in their Rb/Sr and Nd/Sm isotopic ratios. However, their crystallization is related in time and space. Both crystallized about 65 Ma ago and both are components of the Bela ophiolite. The geochemical signatures and the age and field constraints suggest that the trondhjemites may have formed in a marginal basin by the fractional crystallization of basic magma. The associated more potassic acidic rocks developed by crustal anatexis due to heat supplied by the ophiolite in a supra-subduction zone environment. The Bela ophiolite may be the location of the western margin of the Indian plate, which is usually marked along a N-S trending transform fault zone. A mid-ocean ridge origin for the Bela ophiolite is not likely as the crystallization ages for sodic and potassic acidic rocks fall near the minimum age of emplacement of the Bela ophiolite.

ACKNOWLEDGEMENTS

The author thanks the following for extending laboratory facilities and assistance: Jason B. Saleeby, David Pickett and Mahmood A. Chaudhry of Caltech, U.S.A., for the isotopic work; J. Lawford-Anderson, Erik Bender and Vera Wilson of the University of Southern California, for the XRF work; J.N. Walsh and Claire Lowe of the R.H. B. New College, London University, U.K., for the REE analyses. Patrica LeDell of San Marino, Los Angeles, U.S.A. extended logistic support during the author's stay in California. The project was funded by the U.S.A. I.D's Pakistan Participant Training Program. Part of the sponsorship was covered by the Pakistan Science Foundation grant no. B-BU/EARTH (27); and by the National Centre of Excellence in Mineralogy, Quetta, Pakistan.

REFERENCES

AHMED, Z. (1986) Ophiolites and chromite deposits of Pakistan. In: Petraschek, W., Karamata, S., Karavchenko, G.G., Johan, Z., Economou, M. & Engin, T. (eds.) CHROMITES, UNESCO's IGCP 197 PROJECT: METALLOGENY OF OPHIOLITES, pp. 241-262. Theophrastus Publications, Athens.

——— **(1990)** An overview of Pakistani ophiolites. Science, Technology & Development, Pakistan Council for Science & Technology, Islamabad **9**, pp.31-48.

——— **(1991)** Basalt geochemistry and the supra-subduction zone origin of the Bela ophiolite, Pakistan. (This volume).

ALLEMANN, F. (1979) Time of emplacement of the Zhob Valley ophiolites and Bela ophiolites. *In:* Farah, A. & De Jong, K.A. (eds.) GEODYNAMICS OF PAKISTAN, pp. 215-242. Geological Survey of Pakistan, Quetta.

COLEMAN, R.G. & PETERMAN, Z.E. (1975) Oceanic plagiogranite. J. Geophys. Res. **45**, pp. 1099-1108.

DIXON, S. & RUTHERFORD, M.T. (1979) Plagiogranites and late stage immiscible liquids in ophiolite and mid-ocean ridge suites: An experimental study. Earth Planet. Sci. Lett. **45**, pp.45-60.

FARAH, A., ADRAS, G. DE JONG, K.A. & LAWRENCE, R.D. (1984) Evolution of the lithosphere in Pakistan. Tectonophys. **105**, pp.207-227.

FLAGLER, P.A. & SPRAY, J.G. (1991) Generation of plagiogranite y amphibolite anatexis in oceanic shear zones. Geology **19**, pp.70-73.

GERLACH, D.C., LEEMAN, W.P. & AVE LALLEMANT, H.G. (1981) Petrology and geochemistry of plagiogranite in the Canyon Mountain Ophiolite, Oregon. Contrib. Mineral. Petrol. **77**, pp.82-92.

HOFMANN, A.W. (1988) Chemical differentiation of the Earth: the relationship between mantle, continental crust and oceanic crust. Earth Planet. Sci. Lett. **90**, pp.297-314.

HUMPHRIS, S.E. & THOMPSON, G. (1978). Hydrothermal alteration of oceanic basalts by seawater. Geochim. Cosmochim. Acta. **42**, pp.107-125.

JENNER, G.A. DUNNING, G.R., MALPAS, J., BROWN, M. & BRACE, T. (1991). Bay of Islands and Little Port Complexes, revisited: age, geochemical and isotopic evidence confirm suprasubduction zone origin. Can. J. Earth Sci. **28**, 1635-1652.

KAZMI, A.H. (1979) Active fault systems in Pakistan. *In:* Farah, A. & De Jong, K.A. (eds.) GEODYNAMICS OF PAKISTAN, pp. 285-294. Geological Survey of Pakistan, Quetta.

LIPPARD, S.J., SHELTON, A.W. & GASS, I.G. (1986). The ophiolites of northern Oman. Geol. Soc. London Mem. **11**, 178p.

MIDDELBURG, J.J., VAN DER WEIJDEN, C.H. & WOITTIEZ, J.R.W. (1988). Chemical processes affecting the mobility of major, minor and trace elements during weathering of granitic rocks. Chem. Geol. **68**, pp.253-273.

NAKAMURA, N. (1974). Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. Geochim. Cosmochim. Acta **38**, pp. 757-775.

PALLISTER, J.S. & KNIGHT, R.Y. (1981). Rare-earth element geochemistry of the Samail ophiolite near Ibra, Oman. J. Geophys. Res. **86** (B4), pp. 2673-2697.

PEARCE, J.A. (1975). Basalt geochemistry used to investigate past tectonic environments on Cyprus. Tectonophys. **25**, pp.41-67.

——, (1989) High T/P metamorphism and granite genesis beneath ophiolite thrust sheets. Ofioliti **14** (3), pp. 195-211.

——, HARRIS, N.B.W. & TINDLE, A.G. (1984). Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. J. Petrol. **25**, pp. 956-983.

PEDERSEN, R.B. & MALPAS, J. (1984). The origin of oceanic plagiogranites from the Karmoy ophiolite, Western Norway. Contrib. Mineral. Petrol. **88**, pp. 36-52.

PAYNE, J.G. & STRONG, D.F. (1979). Origin of the Twillingate trondhjemite, north - central Newfoundland: Partial melting in the roots of an island arc. *In*: BARKER, F. (ed.) TRONDHJEMITES, DACITES AND RELATED ROCKS. Elsevier, Amsterdam.

SPRAY, J.G. & DUNNING, G.P. (1991) A U / Pb age for the Shetland Islands oceanic fragment, Scottish Caledonides: evidence from anatectic plagiogranites in 'layer 3' shear zones. Geol. Mag. **128** (6), pp. 667-671.

WOOD, D.A., JORON, J.L. & TREUIL, M. (1979). A re-appraisal of the use of trace elements to classify and discriminate between magma series erupted in different tectonic settings. Earth Planet. Sci. Lett. **50**, pp.326-336.

Manuscript received on April 19, 1991.
Accepted for publication on April 30, 1991.

ACTA MINERALOGICA PAKISTANICA
VOLUME 5 (1991 pp. 25-45.

ULTRAMAFIC – MAFIC ALKALIC ROCKS FROM SPANGAR, PISHIN DISTRICT, PAKISTAN: MAGMATISM FROM THE WANING GONDWANALAND.

ZULFIQAR AHMED
National Centre of Excellence in Mineralogy, University of Balochistan,
G.P.O. Box 43, Quetta, Pakistan.

ABSTRACT: In the land stretching from Spangar peak to Garkai in Pishin District, Pakistan, ultramafic (kimberlitic) lamprophyre and mildly alkalic basaltic rocks intrude the lowermost Jurassic sediments. Both rock groups occur closely associated spatially and exhibit similar mode of occurrence. Both intrude calcareous sediments of the lowermost Jurassic age. About 25 km north-eastwards, near Kozh Kach, sodic alkalic dolerites intrude the lower Jurassic sediments. Whole-rock major and trace element variations in the three rock groups are determined. The rocks at Spangar represent magmatism within continental plate, caused probably by a hot spot. Their source seems to be the trace element enriched mantle. They are visualized to have originated during the break-up or rifting of western margin of the Indian plate away from its Gondwanaland position in proximity to east Ethiopia-Somalia. The basalts may represent "trap" volcanism of mildly alkaline character related to horizontal extension.

INTRODUCTION

This paper presents the whole-rock major and trace element characterization of ultramafic-mafic alkalic rocks that occur in the otherwise sedimentary-outcrop area between Spangar peak and Garkai in the eastern Pishin District, Pakistan. The rocks are of interest not only because of their rarity and exotic composition but also because they intrude sediments of the lowermost Jurassic age. The rocks are not found in the younger strata, and may represent the igneous activity that occurred prior to the collision of continental Indian plate with the Eurasian continental plate in Eocene. This study attempts to explain the plate tectonic implications of this magmatism which has certain unique features. The rocks are located close to the western marginal part of the Indian plate. In the Gondwanaland this part of the Indian plate was joined before Jurassic, to the east Ethiopia-Somalia region. (Fig.1).

The mildly alkaline mafic volcanic rocks seem to be associated with the splitting of the Indian plate from the pre-Jurassic position in the Gondwanaland. This was followed by the northward movement of the Indian plate. This study also reports the occurrence of a suite of sodic alkalic dolerites in the adjacent Kozh Kach region that may have a different genesis from that of the Spangar rocks.

GENERAL GEOLOGY

Figs. 2 and 3 show the geological maps of the Garkai-Spangar and the Kozh Kach areas, respectively.

General features of the geology of Spangar kimberlitic lamprophyre are given by Ahmed & McCormick (1990). The rock occurs far away from the stable Precambrian craton of India, and is located near the western margin of the Indian continental plate. It forms a cluster of small linear dykes, sills, and lensoid, conical and pipe-like bodies and plugs; intruding the early Jurassic, thin-bedded, grey - coloured limestone that has a minor shale component and belongs to the Shirinab Formation. The rock outcrops are all located in a small stretch between the Garkai stream and Spangar peak (67° 11' E to 67° 13'E longitude and 30°29'N to 30° 30'N latitude). The ultramafic "nodules" are not conspicuous in the surface exposures and have not been characterized so far. Rock samples do show xenolithic "books" of coarse

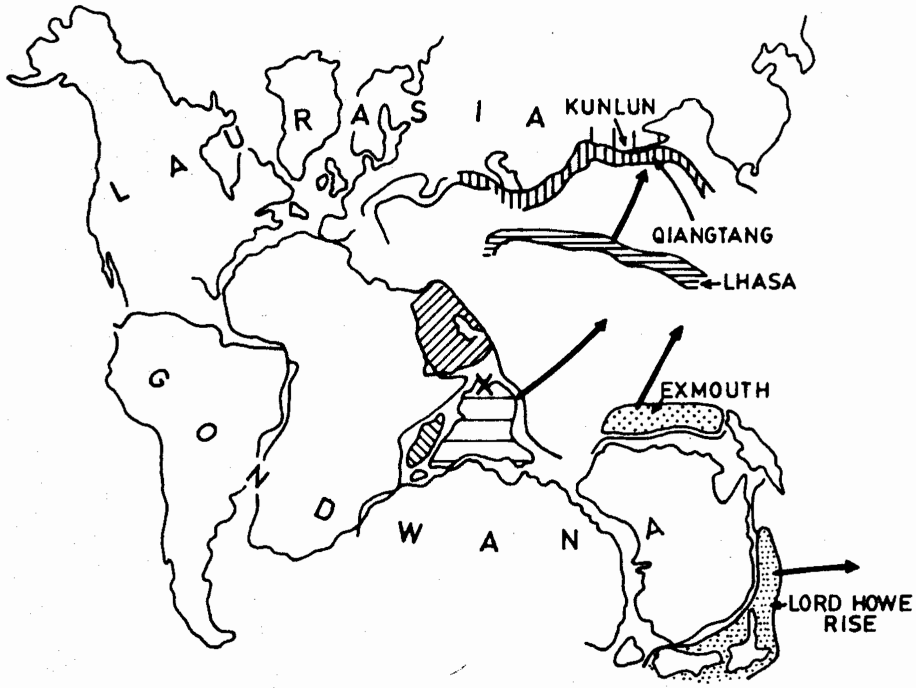


Fig. 1. Palaeotectonic reconstruction by Dewey (1988) of the Tethys for the early Jurassic. It shows various strips and blocks of continental lithosphere (ornamental) that detached from the Gondwana margin. "Approximate location of the eastern Pishin District is marked by an X".

phlogopite. The rock is not glassy or aphyric.

The area is traversed by many faults and fractures that persist at depth and trend parallel to the elongation of kimberlitic lamprophyre outcrops that may be fault-controlled. The dykes exhibit slight backing, brecciation and metasomatic effects at the contacts. Chilled margins are noticeable at some points. Some outcrops are brecciated, fragmental and tuffaceous. The small size of rock outcrop compares well with that of the known kimberlites.

Closely associated spatially and temporally with the kimberlitic lamprophyre are the alkali basaltic rocks that occur spread over the same area (67°11'E to 67°13' E longitude and 30°29'N to 30°30'N latitude). The rocks display contact effects and chilled margins at some points, and occur as small lensoid bodies and dykes.

Another occurrence of basic magmatism within the early Jurassic strata is found 20km northeastwards of Spangar, near the Kozh Kach village (30°37'N, 67°28'E). Here a dyke swarm comprising sodic alkalic dolerites intrudes the limestone of the lowermost Jurassic age called the "Spingwar Member". Its immediately overlying early Jurassic Loralai limestone lacks such dykes.

Post-Cretaceous mafic magmatism in the region is manifested by parts of the Zhob Valley ophiolite (Ahmed, 1986; Bilgrami, 1964) and by the mafic volcanics around Chinjan, Loralai District (McCormick, 1985). The Zhob Valley ophiolite has its SW terminal outcrop near Gawal (Gansser, 1979) located only a few km. west of Kozh Kach. This shows the region had a zone of weakness favourable for tectonic emplacements during Paleocene-early Eocene (Alleman, 1979). The Chinjan volcanics are hosted by the Parh Limestone of Maastrichtian age, and continue to outcrop alongside the regional structural trend till about Zhob town (31° 21'N; 69' 29'E). McCormick (1985) analyzed the clinopyroxenes of the Chinjan volcanics sampled near Gwanda Gwazai (30°33'N, 67°53'30"E), 16 km SW of Chinjan. These proxenes are titaniferous augites that plot in the "within-plate alkali basalt" field on the MnO-Na_2O-TiO_2 discriminant diagram of Nisbet & Pearce (1977).

PETROGRAPHY AND MINERAL CHEMISTRY

A. Kimberlitic Lamprophyre:

The mineral assemblage and chemistry of this

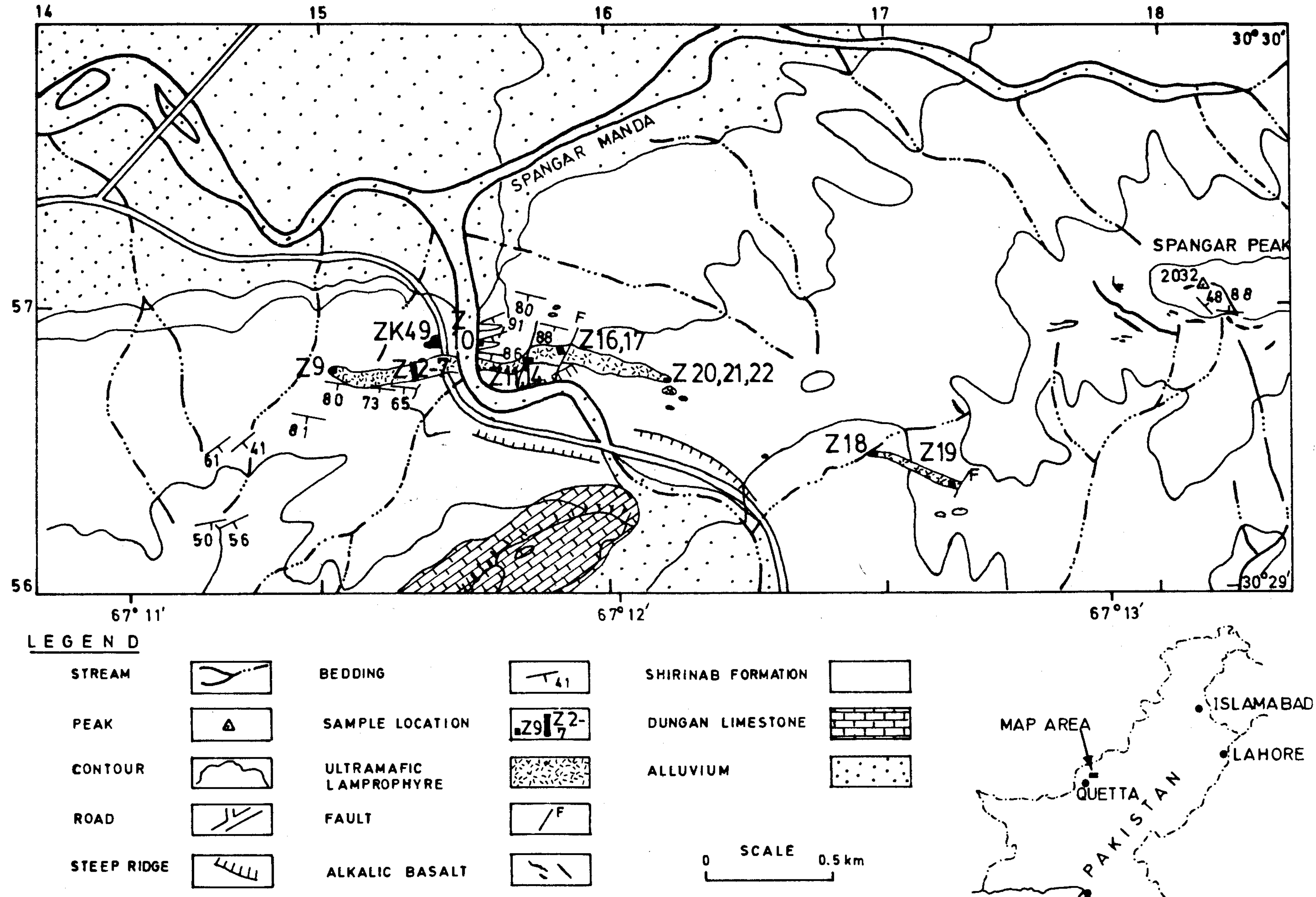


Fig. 2. Geological map of Spangar area with sample locations.

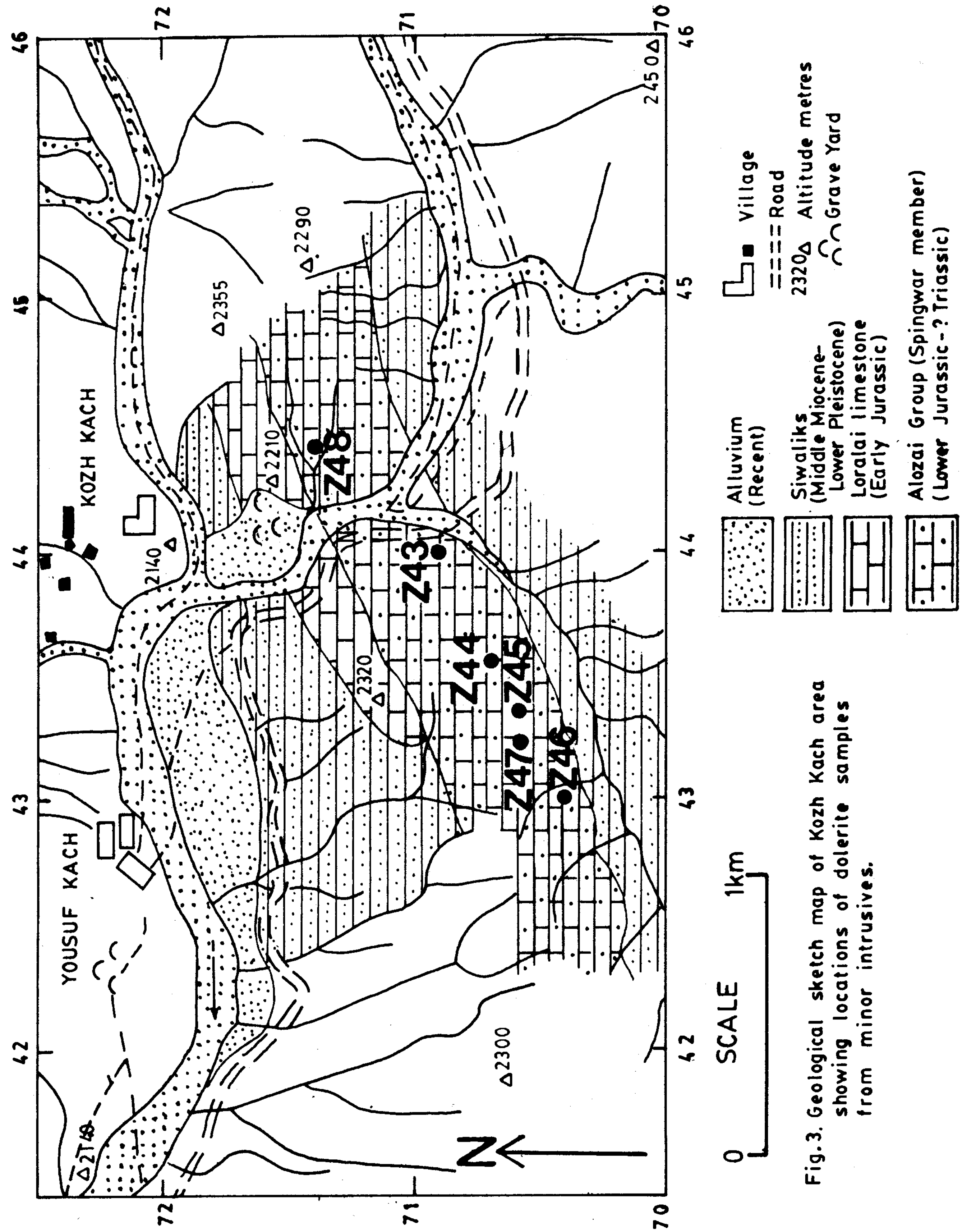


Fig. 3. Geological sketch map of Kozh Kach area showing locations of dolerite samples from minor intrusives.

Table 1. Composition of accessory chromian spinel from the kimberlitic rock (Z2) and associated alkali basalt (Z30) at Spangar.

Sample no.	Z2	Z30		Z2	Z30
SiO_2	0.34	0.12	Al	8.98	5.38
TiO_2	1.62	3.38	Cr	5.05	6.43
Al_2O_3	32.80	17.99	V	—	0.08
Cr_2O_3	27.49	32.03	Fe^{3+}	1.41	2.76
V_2O_3	—	0.37	Fe^{2+}	2.84	4.57
Fe_2O_3	8.06	14.44	Mn	0.03	0.05
Fe O	14.60	21.53	Mg	5.19	4.02
Mn O	0.13	0.22	Ni	0.05	0.02
Mg O	14.99	10.61	Ca	0.00	0.02
Ni O	0.27	0.10	100 Mg/ (Mg + Fe^{2+})	64.66	46.77
Ca O	0.00	0.07	100 Cr / (Cr + Al + Fe^{3+})	32.70	44.13
Z nO	—	0.01	100 Al/ (Cr + Al + Fe^{3+})	58.17	36.93
Total	100.30	100.87	100 Fe^{3+} / (Cr + Al + Fe^{3+})	9.13	18.94
Cations to 32 oxygens:			100 Cr/ (Cr + Al)	35.99	54.45
Si	0.08	0.03	Ti/(Ti + Cr + Al)	1.957	5.217
Ti	0.28	0.65	Fe^{2+} / Mg	0.55	1.14

rock is given by Ahmed & McCormick (1990). The assemblage varies in different parts of the outcrop and includes olivine of two generations, phlogopite, perovskite, monticellite, chlorite, calcite and very rare pectolite and nepheline. Melilite has been found in a small section of a sill near Garkai. Apart from the smaller outcrops; there is one outcrop of a bigger size. It contains rock that shows mafic and felsic patches indicative of some differentiation.

Inequigranular texture prevails at all outcrops of the rock. Macrocrysts are dominated by those of olivine and phlogopite. Enrichment in mica and other petrographic features resemble those of the "micaceous kimberlites" category rather than those of the "basaltic kimberlites". 'Books' of xenocrystal phlogopite are common. Monticellite is macrocrystal. Perovskite and chromian spinel are euhedral. Pegmatoidal patches with coarse phlogopite are present at places within the relatively bigger outcrop.

Microprobe analyses of the mineral phases are given by Ahmed & McCormick (1990). Olivine has a Fo content of 88.106 to 90.507%, with NiO < 0.37%, MnO<0.32% and CaO upto 1.46%. Phlogopite is magnesian with Mg/ (Mg+ Fe^{2+}) from 83.506 to 91.454%, but has lower SiO_2 and higher Al_2O_3 than most known kimberlitic and mantle-peridotitic phlogopites. In the discriminant plot after Scott-Smith & Skinner (1984), phlogopites plot in the kimberlitic field, away from the lamproitic field. Monticellite has low Mn, and Mg/ (Mg+Fe+Mn) is 79.541%. Perovskite lacks Na, REE, Th and Nb. It has low FeO that does not substitute for Ti and indicates formation under reducing conditions (Mitchell, 1972). It possesses high CaO and TiO_2 with little other substituents, in parallel with kimberlitic perovskites. The Cr-ceylonite, like kimberlitic spinels, has high MgO with increased Fe^{3+} + Ti content. Garnets are hydrous titanian andradites such as "andradite", "Ti-rich hydroandradite" and "hydromelanite" resembling garnets in alnöites (Rock, 1986). Apatite lacks REE.

The rock resembles kimberlites in some polymodal and irregular grain size distributions and in possessing rounded and corroded megacrysts. The rock differs from the usual ultramafic lamprophyres, as it does not show any gradation to carbonatites and the primary carbonates are not yet documented. Alkali feldspar and amphibole are absent; as are epidote, prehnite and sphene.

B. Alkalic Basalt:

Its frequent texture is prophyritic with intergranular to subophitic groundmass. The present mineral assemblage comprises kaersutite, plagioclase, clinopyroxene, chlorite, biotite, calcite, chromian spinel, pyrite, chalcopyrite, ilmenite, quartz, epidote, talc, garnet, magnetite, and titanomagnetite. Amygdale-rich outcrops are common.

These rocks exhibit through alteration to talc-carbonate or chlorite-carbonate rocks. Mildly altered rocks contain patches of carbonates with some chlorite, quartz, epidote, and secondary feldspar. Clinopyroxene often makes unaltered, zoned euhedral phenocrysts, but sometimes has anhedral margins. Some pyroxene phenocrysts are replaced by spherulitic chlorite. Pyroxene also makes fine groundmass grains which are partly chloritized. Plagioclase phenocrysts are sector-zoned and conspicuously twinnned. Twins are often penetrating. Feldspar also occurs as subophitic laths and as microlites in the groundmass.

Secondary carbonates may be abundant and patchy and may consist of calcite, dolomite or ankeritic dolomite; frequently seen as projecting euhedra inside globules made of radial chlorite. Quartz is secondary and occurs lining the carbonate patches with adjacent fresh rock in some rock samples only (e.g., Z30,Z81). Secondary veinlets may be made of carbonate and non-pleochroic chlorite that are, in turn, cut across by chloritized areas.

Microprobe analyses were performed using the Jeol Superprobe 733 instrument set up at the California Institute of Technology, Pasadena, U.S.A. Table 1 reports the representative chromian spinel from alkalic basalt (Z30). When compared to that from the associated kimberlitic lamprophyre, it has distinctly higher Cr and Fe and lower Al.

Fresh clinopyroxene analyses from three rock samples are given in Table 2. The quadrilateral plots are given in Fig. 4a. Their plots on the MnO-Na_2O - TiO_2 diagram after Nisbet and Pearce (1977) in Fig.4b show them to be representing within-plate alkali basalts. "The plot closely resembles that for the Gwanda Gwazi clinopyroxenes (McCormick, 1985).

The initial composition of clinopyroxenes crystallizing from a basic magma is linked to silica activity (Smith & Lindsley, 1971; Gibb, 1973). With increasing undersaturation of the magma (i.e., alkalinity), the initial clinopyroxene composition approaches the diopside-hedenbergite join on the pyroxene quadrilateral (Larsen, 1976). The initial composition of the pyroxenes from the Spangar alkali basaltic rocks (Fig 4a) demonstrates low silica activity of their magma and alkaline nature (cf. Asthana, 1991).

Table 3 gives the analyses from TiO_2-richer kaersutite and biotite from sample Z79. The sulphide analyses in Table 4 include those of pyrite from sample Z30 and Z81; and of chalcopyrite found in Z79. Analyses of feldspars (Table 5), chlorite (Table 6), Fe-Ti oxides (Table 7) and carbonates (Table 8) are mainly from samples of alkalic basalts (Z30, Z79 and Z81). The feldspar analyses assume total iron as trivalent. Calcic feldspar is abundant; mostly it is labradorite, but full range is from sodic bytownite to albite.

In chlorite analyses, total Fe is assumed to be Fe^{2+}, as the trivalent iron in most of the published chlorite analyses typically constitutes less than 5% of the total iron; and occurs only in the Fe-richer chlorites (e.g., Deer et al., 1962). The chlorites in the alkalic basalts are more magnesian than those in the sodic dolerite.

C. Kozh-Kach Sodic Dolerites:

The rocks possess coarse ophitic to subophitic texture. Secondary coarse calcite often fills veinlets. At a few locations amygdaloidal varieties occur. Primary minerals are clinopyroxene and plagioclase, but are often replaced. Chlorite showing anomalous interference colour in thin sections is spherulitic and may occur associated with non-spherulitic, green, flaky chlorite in the same samples. Epidote is also common. Amongst opaque minerals, pyrite, magnetite, ilmenite-magnetite intergrowths, titanomagnetite and rutile are present. The rocks may show severe alteration resulting in talc-carbonate or chlorite-carbonate rocks. Amygdales, when present, contain chlorite, calcite, feldspar laths; all with coarser grain size than that of the surrounding dolerite rock.

Mineral chemistry of sample Z48 is reported in the Tables 5 through 8. The feldspar is mostly

Table 2. Clinoproxene analyses from spangar alkali basalts.

Sp.no.	Z30	Z30	Z30	Z79	Z79	Z79	Z79	Z79	Z79	Z79	Z79	Z79	Z81	Z81	Z81	Z81	Z81	Z81	Z81	Z81
SiO_2	51.27	50.85	50.75	46.63	46.61	43.16	49.33	48.65	48.02	48.44	47.55	44.94	48.68	48.60	50.22	49.44	50.04	50.85	47.58	50.31
TiO_2	1.28	1.08	1.33	2.09	2.20	3.63	1.64	1.46	1.81	1.63	1.65	2.48	0.86	0.70	0.57	0.98	0.76	0.72	1.03	0.85
Al_2O_3	3.97	3.89	4.31	6.99	6.99	9.79	4.97	5.87	5.60	4.85	4.86	7.78	3.82	3.44	3.21	4.19	3.19	3.06	5.22	3.70
Cr_2O_3	0.76	0.93	0.75	0.00	0.58	0.00	0.37	0.22	0.00	0.01	0.00	0.04	0.52	0.86	1.04	0.49	0.73	0.36	0.80	0.35
Fe_2O_3	-	1.16	0.07	4.35	4.29	4.68	2.75	4.11	4.22	4.02	4.18	4.76	3.44	4.98	3.14	2.56	2.67	2.02	4.09	2.58
FeO	6.15*	4.49	5.98	2.57	2.25	4.66	3.19	1.56	2.76	2.76	2.95	2.66	1.31	0.16	1.93	2.87	2.20	2.84	0.09	2.68
MnO	0.10	0.15	0.12	0.11	0.14	0.17	0.12	0.04	0.18	0.09	0.15	0.11	0.12	0.10	0.15	0.12	0.03	0.09	0.06	0.07
MgO	14.75	15.31	14.63	13.50	13.92	10.83	14.76	14.76	14.02	14.44	14.29	12.95	15.78	16.36	16.62	15.72	16.27	16.34	15.18	16.03
NiO	0.06	0.05	0.06	0.04	0.01	0.01	0.01	0.08	0.00	0.03	0.03	0.00	0.06	0.12	0.07	0.00	0.01	0.06	0.02	0.05
CaO	21.81	22.12	21.93	22.82	22.78	22.61	23.00	23.30	23.10	23.00	22.27	22.29	22.08	21.88	21.55	21.47	21.92	22.01	23.03	22.21
Na_2O	0.31	0.29	0.32	0.34	0.28	0.37	0.29	0.34	0.32	0.28	0.26	0.33	0.22	0.24	0.25	0.31	0.26	0.24	0.23	0.23
ZnO	0.09	0.12	0.07	0.04	0.01	0.05	0.02	0.08	0.04	0.00	0.00	0.03	0.03	0.08	0.00	0.02	0.00	0.00	0.02	0.01
Total	100.55	100.45	100.32	99.49	100.06	99.96	100.45	100.47	100.07	99.55	98.19	98.37	96.93	97.52	98.75	98.17	98.08	98.60	97.36	99.07
Si	1.88	1.87	1.87	1.74	1.73	1.63	1.81	1.79	1.78	1.80	1.80	1.70	1.84	1.83	1.86	1.85	1.87	1.89	1.79	1.86
Al^{iv}	0.12	0.13	0.13	0.26	0.27	0.37	0.19	0.21	0.22	0.20	0.20	0.30	0.16	0.15	0.14	0.15	0.13	0.11	0.21	0.14
Al^{vi}	0.05	0.04	0.06	0.05	0.04	0.07	0.03	0.04	0.03	0.01	0.02	0.05	0.01	0.00	0.00	0.04	0.01	0.02	0.02	0.02
Ti	0.04	0.03	0.04	0.06	0.06	0.10	0.05	0.04	0.05	0.05	0.05	0.07	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.02
Cr	0.02	0.03	0.02	0.00	0.02	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.03	0.03	0.01	0.02	0.01	0.02	0.01
Fe^{3+}		0.03	0.00	0.12	0.12	0.13	0.08	0.11	0.12	0.11	0.12	0.14	0.10	0.14	0.09	0.07	0.08	0.06	0.12	0.07
Fe^{2+}	0.19	0.14	0.18	0.08	0.07	0.15	0.10	0.05	0.09	0.09	0.09	0.08	0.04	0.01	0.06	0.09	0.07	0.09	0.00	0.08
Mn	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Mg	0.81	0.84	0.80	0.75	0.77	0.61	0.81	0.81	0.78	0.80	0.80	0.73	0.89	0.92	0.92	0.88	0.91	0.91	0.85	0.89
Ca	0.86	0.87	0.87	0.91	0.91	0.91	0.91	0.92	0.92	0.92	0.90	0.90	0.90	0.88	0.86	0.86	0.88	0.88	0.93	0.88
Na	0.02	0.02	0.02	0.03	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
mg	81.04	85.86	81.35	90.34	91.67	80.56	89.19	94.41	90.06	90.31	89.62	89.68	95.55	99.45	93.89	90.72	92.97	91.11	99.66	81.44
Wo	46.27	47.14	46.71	52.32	51.88	54.73	49.97	51.72	51.61	50.83	50.10	52.59	49.00	48.87	46.66	47.10	47.37	46.87	52.08	47.66
En	43.54	45.39	43.35	43.07	44.11	36.47	44.62	45.58	43.58	44.40	44.73	42.51	48.73	50.85	50.08	47.99	48.93	48.41	47.76	47.86
Fs	10.19	7.47	9.94	4.61	4.01	8.80	5.41	2.70	4.81	4.76	5.18	4.89	2.27	0.28	3.26	4.91	3.70	4.72	0.17	4.48

* = Total iron as FeO. mg = 100 mg / (Mg + Fe^{2+}).

Table 3 . Analyses of kaersutite (1-4) and of biotite (5-7) from alkali basalt sample no. Z79. Fe O includes total iron.

	1	2	3	4	5	6	7
SiO_2	37.60	37.04	37.73	36.72	32.79	32.09	32.95
TiO_2	3.09	4.65	3.76	3.94	5.99	4.38	5.07
Al_2O_3	14.10	13.11	13.81	13.66	15.20	13.70	15.11
Cr_2O_3	–	–	–	–	–	0.01	0.04
V_2O_3	–	0.10	0.11	0.06	0.11	0.00	0.00
Fe O	17.03	21.97	19.89	21.89	23.52	26.26	28.02
Mn O	0.27	0.39	0.37	0.36	0.19	0.48	0.29
Mg O	8.27	5.89	7.05	5.30	7.88	5.69	5.40
Ni O	–	–	–	–	0.03	0.00	0.03
Ca O	12.43	11.20	11.05	11.34	0.08	0.16	0.51
Ba O	–	0.20	0.14	0.00	1.17	–	–
Sr O	0.00	0.12	0.03	0.00	0.18	–	–
Zn O	–	0.04	0.00	0.03	0.03	0.09	0.04
Na_2O	2.42	2.64	2.39	2.50	0.73	0.46	0.57
K_2O	1.56	1.50	1.60	1.68	8.00	7.33	7.25
P_2O_5	–	0.01	–	–	0.01	–	–
Cl	–	0.07	0.07	0.00	0.07	–	–
Total	96.77	98.82	98.00	97.48	95.98	90.65	95.28

Table 4. Sulphide analyses.

Sample no.	Z30	Z30	Z81	Z81	Z79
Si	0.12	0.04	0.03	0.04	0.50
Ti	–	–	0.02	0.14	0.06
Fe	48.93	49.02	48.12	48.59	35.73
Mg	0.05	0.01	0.01	0.01	0.10
Ni	0.09	0.13	0.01	0.07	0.21
Zn	0.07	0.07	–	–	0.02
Co	0.01	0.29	0.11	0.03	0.13
Cu	–	–	–	0.03	22.35
S	52.16	52.24	52.80	52.79	41.74
Total	101.43	101.80	101.10	101.70	100.84
Atomic percents:					
Fe	35.03	35.04	34.35	34.56	27.66
Cu	–	–	–	0.02	15.20
S	64.97	64.96	65.65	65.42	57.14

albite and calcic feldspar is not present in contrast to the feldspar compositions from alkali basalts (Table5). The Fe-Ti oxide analyses (Table 7) show that the sodic dolerites contain titanomagnetite and anatase/rutile in contrast to the ulvöspinel in alkalic basalt samples. The anatase/rutile is vanadium-bearing.

GEOCHEMISTRY

The major element oxides and trace elements of the whole-rock samples from the three groups of magmatic rocks were determined by the X-ray fluorescence technique. The samples were analyzed at the laboratory of the Department of Geological Sciences, University of Southern California, Los Angeles, California.

Table 5. Analyses of feldspars from mafic rock samples.

Anal. no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sp. no.	Z30	Z30	Z30	Z30	Z30	Z30	Z30	Z30	Z79	Z79	Z79	Z79	Z79	Z79	Z79
SiO_2	52.50	53.02	52.99	52.16	52.69	51.99	50.38	46.86	66.66	60.22	54.54	52.12	51.88	50.99	49.77
Al_2O_3	27.86	28.29	28.65	29.10	28.56	28.43	30.96	32.64	19.78	25.09	27.33	28.82	29.48	29.82	30.74
Fe_2O_3	0.80	0.80	0.79	0.84	0.78	1.00	0.71	0.61	0.15	0.35	0.36	0.46	0.46	0.51	0.49
MnO	0.00	-	0.02	-	-	-	0.02	-	0.01	0.01	0.00	0.02	0.00	0.00	0.00
MgO	0.10	0.12	0.13	0.14	0.12	0.15	0.19	0.13	0.00	0.01	0.01	0.05	0.06	0.04	0.08
CaO	11.99	12.08	12.21	12.61	12.69	12.87	14.55	17.03	0.14	7.15	9.83	11.22	12.47	12.89	13.91
BaO	0.05	0.00	0.03	0.01	0.01	0.00	0.02	-	0.00	0.18	0.16	0.04	0.00	0.04	0.01
SrO	0.00	0.18	0.13	0.33	0.20	0.28	0.36	-	0.01	0.29	0.38	0.28	0.00	0.37	0.11
Na_2O	4.60	4.56	4.50	4.28	4.19	4.20	2.79	1.92	11.97	6.23	5.65	4.83	4.13	3.87	3.48
K_2O	0.36	0.37	0.36	0.31	0.33	0.26	0.23	0.12	0.18	1.13	0.70	0.47	0.47	0.38	0.31
Total	98.26	99.42	99.81	99.78	99.57	99.18	100.18	99.31	98.90	100.65	98.93	98.31	98.95	98.91	98.90
Ab	40.13	39.73	39.18	37.37	36.69	36.58	25.41	16.83	98.39	57.03	48.95	42.60	36.45	34.42	30.61
An	57.80	58.15	58.75	60.85	61.41	61.94	73.22	82.48	0.64	36.17	47.06	54.68	60.82	63.36	67.60
Or	2.07	2.12	2.06	1.78	1.90	1.49	1.38	0.69	0.97	6.81	3.99	2.73	2.73	2.22	1.79

Anal. no	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Sp. no.	Z79	Z79	Z81	Z81	Z81	Z81	Z81	Z81	Z81	Z81	Z81	Z48	Z48	Z48	Z48	Z48
SiO_2	48.89	49.13	57.38	53.45	51.65	51.30	49.60	49.51	48.92	47.88	47.33	70.63	71.75	71.63	71.79	72.36
Al_2O_3	30.20	30.62	24.75	26.56	27.52	28.83	29.81	29.79	30.58	30.54	31.04	19.25	19.94	20.03	19.54	19.65
Fe_2O_3	0.50	0.58	1.13	0.76	0.92	1.23	1.43	1.33	0.92	0.95	0.84	0.24	0.18	0.28	0.11	0.33
MnO	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.04	0.01	0.04	0.00	0.02	0.00	0.02	0.00
MgO	0.07	0.07	0.17	0.07	0.08	0.14	0.13	0.11	0.14	0.15	0.20	0.01	0.00	0.00	0.01	0.00
CaO	13.79	14.16	7.26	9.45	10.29	11.89	13.21	13.43	14.09	14.33	14.99	0.03	0.04	0.04	0.07	0.11
BaO	0.03	0.05	0.00	0.12	0.03	0.04	0.00	0.00	0.05	0.01	0.05	0.00	0.00	0.05	0.02	0.03
SrO	0.22	0.04	0.00	0.00	0.22	0.22	0.14	0.01	0.00	0.10	0.00	0.00	0.00	0.05	0.00	0.09
Na_2O	3.34	3.33	6.69	5.57	5.18	4.35	3.87	3.74	3.26	3.29	2.82	9.70	5.82	5.53	7.34	6.40
K_2O	0.32	0.29	0.78	0.54	0.44	0.31	0.29	0.25	0.20	0.19	0.17	0.00	0.02	0.01	0.02	0.01
Total	97.36	98.27	98.16	96.53	96.33	98.32	98.49	98.17	98.20	97.45	97.48	99.86	97.77	97.62	98.92	98.98
Ab	29.90	29.35	59.64	49.96	46.44	39.10	34.07	33.03	29.17	29.03	25.14	99.76	99.40	99.48	99.30	98.96
An	68.22	68.97	35.77	46.84	50.98	59.05	64.26	65.54	69.66	69.87	73.85	0.17	0.38	0.40	0.52	0.94
Or	1.89	1.68	4.59	3.21	2.59	1.85	1.67	1.43	1.17	1.11	1.01	0.07	0.23	0.12	0.18	0.10

Table 6. Chlorite analyses from mafic rocks.

Anal. No.	1	2	3	4	5	6	7	8	9	10	11
Sp. No.	Z30	Z30	Z30	Z81	Z81	Z48	Z48	Z48	Z48	Z48	Z48
SiO_2	32.93	32.82	33.76	28.10	30.79	24.82	26.72	25.43	23.61	28.02	32.04
TiO_2	0.05	0.07	0.13	3.72	0.31	3.60	0.07	0.09	0.00	0.03	0.05
Al_2O_3	15.93	11.76	11.55	11.48	11.56	16.50	22.84	19.43	21.43	25.22	18.98
Cr_2O_3	0.02	0.48	0.92	0.00	0.19	-	-	-	-	-	-
V_2O_3	0.00	0.02	0.04	-	-	-	-	-	-	-	-
FeO*	2.37	26.62	23.49	26.19	24.80	27.86	28.27	29.85	33.28	24.22	26.09
MnO	0.00	0.14	0.03	0.00	0.05	0.13	0.09	0.07	0.06	0.16	0.09
MgO	34.77	15.85	15.99	10.81	12.79	9.52	10.28	10.20	8.49	9.42	10.33
NiO	0.18	0.00	0.00	0.23	0.25	0.06	0.02	0.00	0.00	0.03	0.01
CaO	0.05	0.31	0.62	4.40	3.54	1.39	0.17	0.77	0.04	0.11	0.16
ZnO	0.04	0.11	0.05	0.03	0.07	0.12	0.11	0.11	0.13	0.10	0.09
Na_2O	0.01	0.04	0.07	0.07	0.06	0.12	0.00	0.01	0.05	0.06	0.48
P_2O_5	0.02	0.00	0.00	-	-	-	-	-	-	-	-
Cl	0.09	0.00	0.00	-	-	-	-	-	-	-	-
Total	86.46	88.22	86.65	85.03	84.41	84.12	88.57	85.96	87.09	87.37	88.32
Cationic proportions calculated to 28 oxygens:											
Si	6.22	6.88	7.08	6.29	6.81	5.62	5.62	5.63	5.22	5.79	6.61
Al^{vi}	1.77	1.79	1.93	1.32	1.82	2.03	3.28	2.70	2.91	3.94	3.23
Fe	0.37	4.67	4.12	4.90	4.59	5.28	4.97	5.53	6.16	4.19	4.50
Mg	9.79	4.95	5.00	3.61	4.22	3.22	3.22	3.37	2.80	2.90	3.18
Ca	0.01	0.07	0.14	1.06	0.84	0.34	0.04	0.18	0.01	0.02	0.04
mg	96.32	51.49	54.82	42.39	47.90	37.86	39.33	37.86	31.26	40.94	41.38

The instrument used was RIGAKU X-ray fluorescence unit. Samples were made into glass-beads for analysis of their major elements, S and Cl; and into pressed powder pellets for trace element analyses. LOI was determined gravimetrically and expresses the total volatile content. Precisions of all determinations by XRF are better than 5%.

In selecting samples for analysis, every care was taken to include only the fesh material.

A. Kimberlitic Lamprophyre

Since the kimberlitic rock is not from diatreme facies and is mostly from hypabyssal facies, contamination by crustal xenoliths is negligible.

Analyses of samples from various parts of the intrusion are listed in Table 9 (Analyses 1-8; samples Z4, Z11, ZA17, Z19, Z21 & Z25).

Analyses 9 to 12 are different from analyses 1 to 8. The nature of variations seem to show that analyses 9 to 12 may represent either more evolved or crustal contaminated parts of rocks represented by analyses 1 to 8. Analyses 9 to 12 are less likely to represent alteration products because the differences are noticed even for the relatively immobile trace elements. Also, samples ZA17 and ZB17 are respectively, mafic and felsic parts of the same sample.

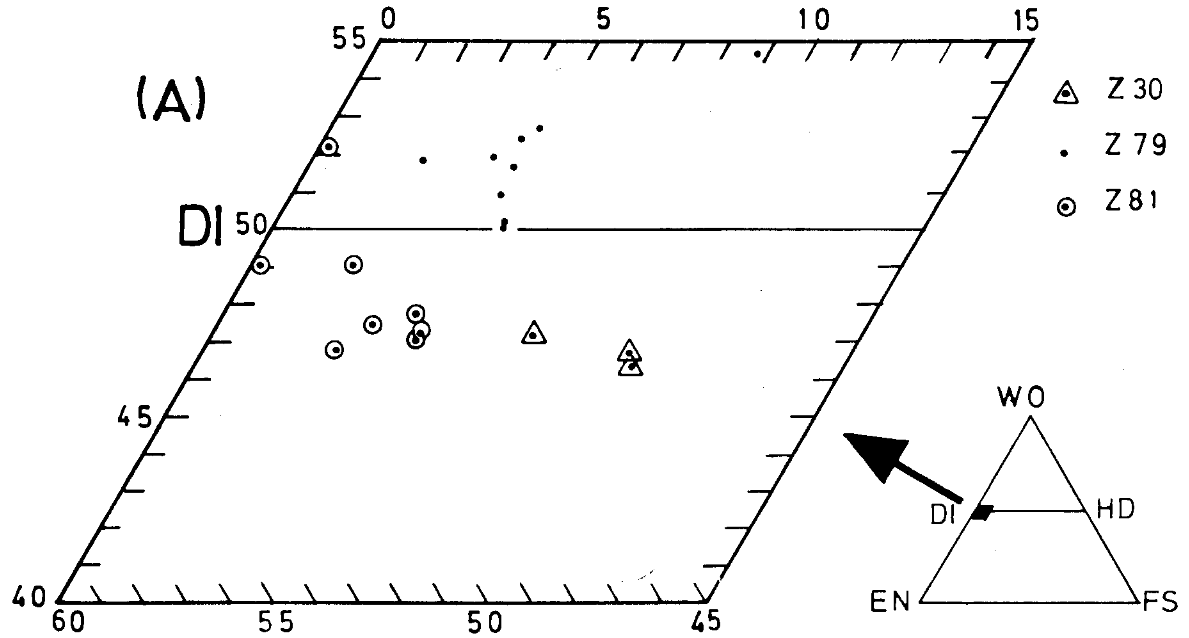
The major elements of the typical and freshest samples (e.g., Z4) show a typical kimberlite chemistry (Mitchell, 1989) such as high MgO, low SiO_2 and Na_2O with the exception of slightly higher $A1_20_3$ and CaO contents. It is strongly potassic rock. The higher $A1_20_3$ and CaO and lower SiO_2 of the rock resembles more like ultramafic lamprophyres than true kimberlites. On the MgO / CaO versus SiO_2 / $A1_2O_3$ plot after Hamilton & Rock (1990), the Spangar analyses ally more closely with the ultramafic lamprophyres.

Table 7. Fe-Ti oxide analyses from alkalic basalt (1-4) and sodic dolerite (5-8).

	1	2	3	4	5	6	7	8
Sp.No.	Z30	Z79	Z79	Z79	Z48	Z48	Z48	Z48
SiO_2	5.01	3.04	1.13	5.08	1.68	0.19	0.08	0.08
TiO_2	21.24	23.02	21.72	20.03	8.83	91.85	93.74	94.33
Al_2O_3	2.04	4.43	5.01	1.94	3.42	0.05	0.03	0.03
Cr_2O_3	-	-	-	-	0.13	0.01	0.02	0.06
V_2O_3	0.76	0.52	0.73	0.71	0.32	2.38	2.24	2.31
Fe_2O_3	45.21	43.62	49.96	46.14	40.16	-	-	-
FeO	24.26	22.29	19.77	22.07	39.39	-	-	-
FeO_T	-	-	-	-	-	0.54	0.47	0.41
MnO	0.57	-	0.07	-	-	-	0.06	0.00
MgO	0.59	0.58	0.13	0.37	0.24	0.02	0.00	0.01
NiO	-	-	0.06	0.01	-	0.03	-	0.01
CaO	0.15	0.19	0.18	0.26	0.09	0.11	0.63	0.43
ZnO	0.18	0.14	0.17	0.04	0.09	0.09	0.02	0.06
Na_2O	-	0.14	0.08	0.21	0.10	0.01	0.02	0.03
Total	100.01	97.97	99.01	96.86	94.45	95.28	97.31	97.76

Table 8. Carbonate analyses.

	1	2	3	4	5	6	7	8
Sp.No.	Z79	Z79	Z81	Z81	Z81	Z81	Z81	Z48
SiO_2	0.04	0.00	0.28	1.04	0.00	0.03	0.03	0.03
TiO_2	0.01	0.00	0.03	0.06	0.02	0.02	0.02	0.06
Al_2O_3	0.00	0.00	0.02	0.45	0.00	0.00	0.00	0.04
V_2O_3	0.01	0.05	0.00	0.01	0.00	0.00	0.01	0.01
FeO	2.10	36.99	7.76	7.94	31.86	38.21	50.12	0.94
MnO	0.11	0.45	0.16	0.31	0.67	0.54	2.30	0.51
MgO	21.85	16.63	16.16	15.78	23.92	18.36	4.47	0.14
NiO	0.00	0.06	0.00	0.05	0.00	0.05	0.00	0.00
CaO	29.76	4.44	34.85	34.15	0.59	0.72	0.99	51.40
BaO	-	-	0.02	0.03	0.00	-	-	-
SrO	-	-	0.00	0.00	0.00	0.11	-	-
ZnO	0.01	0.04	0.02	0.02	0.04	0.00	0.03	0.05
Na_2O	-	0.00	0.04	0.18	0.03	0.02	0.03	0.02
K_2O	-	-	0.00	0.07	-	-	-	0.01
P_2O_5	-	-	0.04	0.06	0.01	-	-	-
Cl	-	-	0.01	0.01	-	-	0.02	-
Subtotal	53.89	58.66	59.39	60.16	57.14	58.06	58.02	53.21



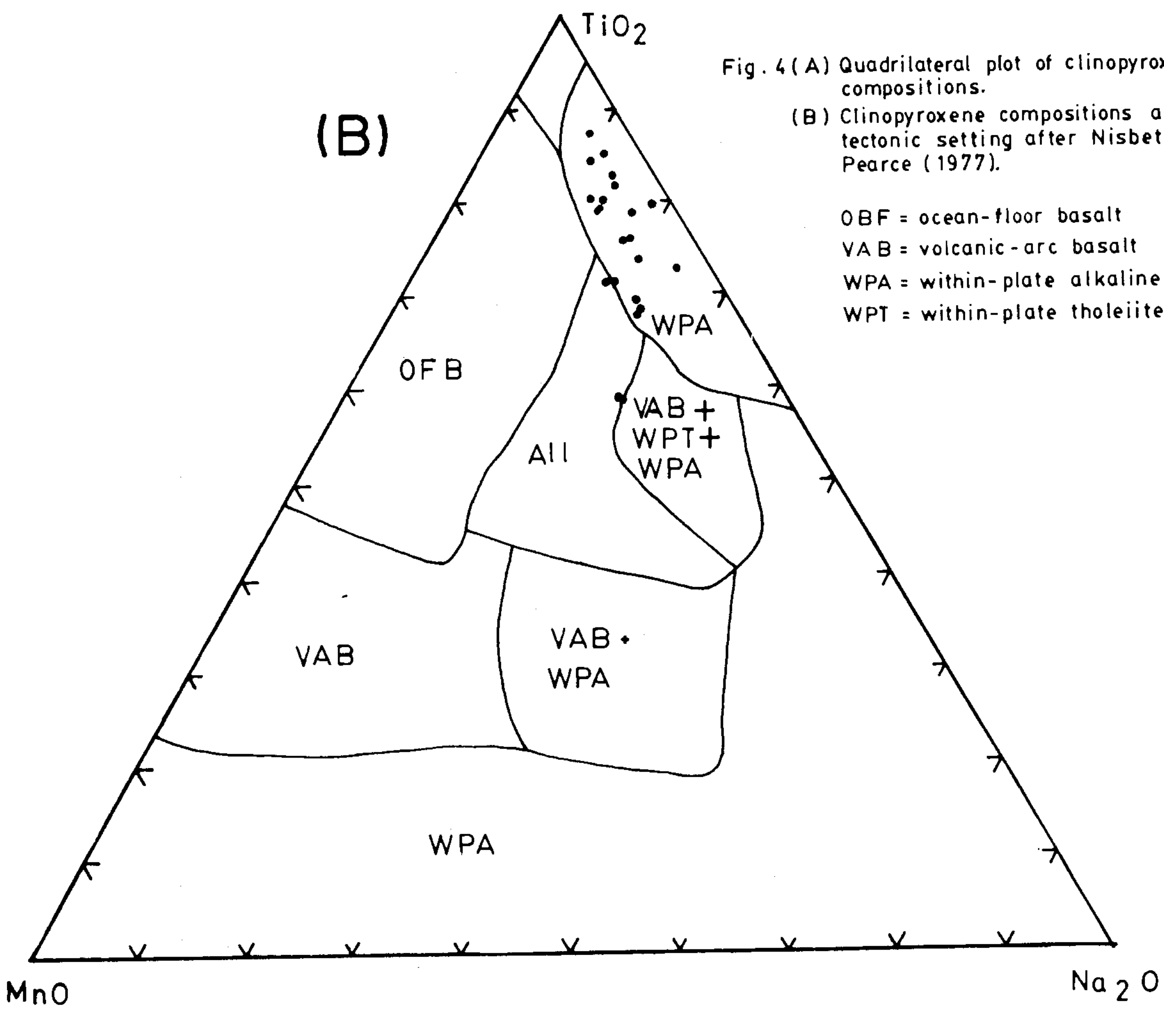
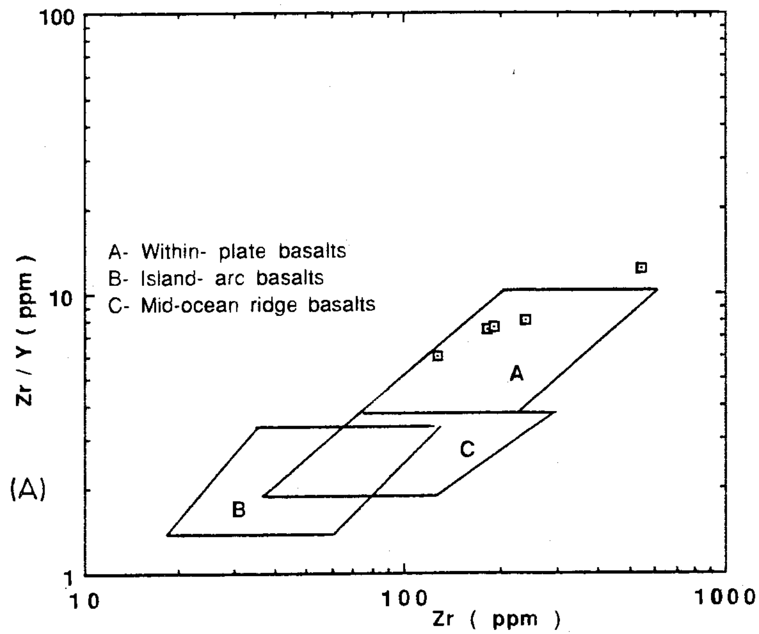


Fig. 4 (A) Quadrilateral plot of clinopyroxene compositions.
(B) Clinopyroxene compositions and tectonic setting after Nisbet & Pearce (1977).

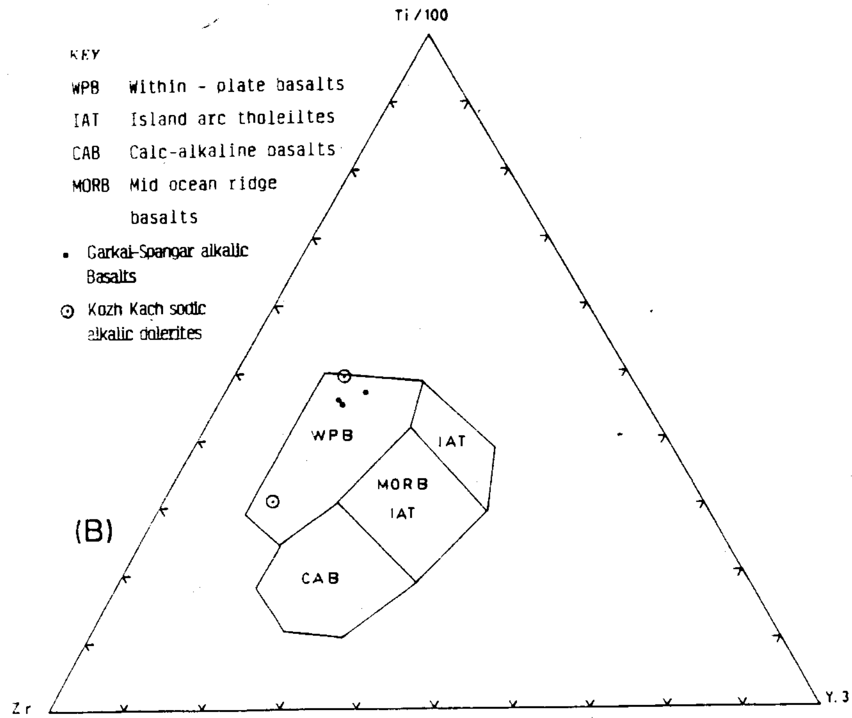
OBF = ocean-floor basalt
VAB = volcanic-arc basalt
WPA = within-plate alkaline
WPT = within-plate tholeiite

Table 9. Whole-rock analyses depicting variations in the Spangar kimberlitic rock (1-8), its evolved/contaminated parts (9-12), associated alkalic basaltic rocks (13-15) and the Kozh-Kach sodic dolerites (16-17). This Table also lists the average values for the ultramafic lamprophyres (18) and kimberlites (19) taken from Rock (1991) and average volatile-free alkali basalt (20) taken from Bergman (1987). Abbreviations: C.I. = crustal contamination index after Clement (1982) = (SiO_2 + Al_2O_3+Na_2O) / (MgO+$2K_2O$). Sp.no. = Sample number. -= Not determined.

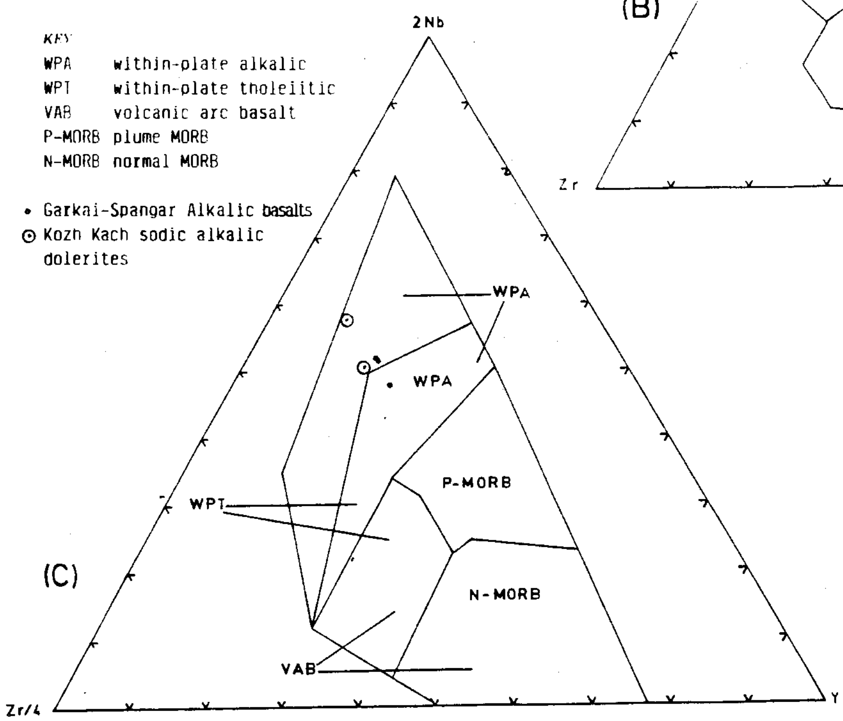
Anal.no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sp. no.	Z4	Z11	Z19	Z21	Z25	Z25C	Z26	ZA17	ZB17	Z18	ZC18	Z20	Z10	Z30	Z78	Z44	Z48			
SiO_2	33.40	34.10	33.63	32.72	34.52	-	33.21	33.51	33.63	30.79	30.70	32.03	42.21	45.82	43.65	44.05	42.93	32.3	38.4	46.5 ± 3.5
TiO_2	2.76	2.79	2.88	2.74	2.76	-	2.71	2.67	2.74	3.13	3.12	3.07	2.11	2.20	1.70	3.21	3.02	3.1	2.6	2.5 ± 1.0
Al_2O_3	7.76	8.90	8.51	9.20	11.52	-	7.43	13.07	12.05	13.23	13.22	10.30	14.67	15.29	13.18	15.72	16.80	6.7	4.7	14.9 ± 2.4
Fe_2O_3	11.10	10.20	10.46	10.66	10.28	-	10.62	9.89	7.61	9.81	9.82	8.91	9.98	10.55	9.94	12.80	15.14	13.6	12.4	12.5 ± 2.1
MnO	0.17	0.17	0.16	0.16	0.19	-	0.13	0.17	0.13	0.19	0.18	0.12	0.15	0.11	0.14	0.15	0.13	0.22	0.18	0.19 ± 0.11
MgO	21.21	16.88	18.09	16.53	18.25	-	18.39	16.83	11.88	11.18	11.20	9.18	4.63	5.81	7.15	4.25	3.80	15.0	28.7	7.4 ± 3.5
CaO	12.70	16.21	14.81	16.84	10.34	-	15.89	11.71	19.51	14.20	14.21	22.61	12.53	10.24	12.97	8.05	5.65	14.0	11.3	9.4 ± 2.4
Na_2O	0.24	0.90	0.05	0.23	0.45	-	0.05	0.57	1.07	2.44	2.52	0.92	3.31	2.98	2.46	5.38	4.95	1.0	0.5	3.3 ± 1.1
K_2O	1.90	2.49	2.47	2.43	4.29	-	2.10	4.05	2.94	1.18	1.18	2.90	0.23	0.56	0.30	0.02	0.06	1.9	1.4	1.4 ± 0.9
P_2O_5	0.98	1.23	1.30	1.37	1.01	-	1.14	0.86	1.27	2.15	2.13	2.86	0.33	0.34	0.22	0.39	1.48	1.0	0.9	0.6 ± 0.4
LOI	6.93	5.47	7.36	6.55	6.09	-	7.00	5.96	6.66	10.38	11.36	6.13	10.05	5.96	8.27	6.40	6.69			
Total	99.21	99.34	99.72	99.03	99.78	-	99.61	99.29	99.49	98.68	99.64	99.03	100.20	99.86	99.98	100.42	100.65	-	-	-
C.I.	1.655	2.008	1.832	1.971	1.733	-	1.801	1.891	2.632	3.431	3.425	2.887	-	-	-	-	-	-	-	-
Trace elements in parts per million :-																		-	-	-
S	2230	1110	490	270	290	290	-	240	210	530	-	300	420	730	2090	40	40	2000	-	-
Cl	170	110	60	50	60	60	-	160	30	130	-	90	40	40	60	80	120	350	202	-
Ba	412	2360	478	2413	2723	2709	-	2263	808	1216	-	2907	-	-	-	-	-	1100	1000	528
Rb	56	108	71	79	182	182	-	174	119	72	-	143	4.7	12.8	7.7	2.5	4.1	65	65	32
Th	11.1	11.3	12.0	10.2	9.3	8.9	-	9.4	8.9	-	-	2.7	2.5	2.4	1.9	2.8	12.5	10	16	3
Nb	121	141	117	129	136	134	-	136	170	130	-	169	37	39	25	45	121	120	110	69
Ta	2.3	1.2	1.8	2.4	1.5	2.5	-	1.1	0.8	0.8	-	0.6	0.9	0.5	0.4	1.8	1.9	9.5	9	19
La	91.6	98.9	116.6	91.1	123.2	115.6	-	111.9	114.0	67.0	-	101.2	24.9	43.5	9.5	65.1	185.3	125	150	54
Sr	489	799	557	767	380	377	-	354	406	4746	-	531	511	575	479	956	379	950	740	530
Zr	252	404	230	365	315	312	-	325	570	442	-	250	184	192	129	241	544	311	250	189
Hf	6.5	10.2	6.3	9.3	7.8	7.7	-	7.8	13.2	16.0	-	6.4	5.1	5.7	4.0	6.8	12.3	6.5	7	5
Zn	69	56	63	59	81	-	-	49	82	73	-	58	88	91	83	110	171	112	69	-
U	0.9	1.9	0.9	2.3	3.4	2.6		2.2	6.8	1.7	-	4.3	0.09	0.2	0.4	0.06	4.5	5	3.1	2.7
Y	27	33	28	33	30	28		30	28	39	-	42	24	26	22	30	44	26	22	33
Ga	17.6	14.4	16.7	15.3	18.9	18.8	-	14.0	11.6	10.5	-	12.5	19.9	20.9	15.1	26.5	31	15	5.7	-
Pb	4.2	5.4	4.8	5.6	4.4	6.7		5.5	6.8	10.1	-	6.9	4.5	5.2	3.0	6.9	6.1	7	15.3	-
Cu	41	20	37	65	86	-	-	103	128	169	-	45	71	76	87	60	27	65	93	-
Cr	1223	1208	846	1051	1284	1273	-	1182	746	58	-	222	378	242	544	21	36	480	1100	202
Ni	476	401	371	404	453	450	-	420	262	57	-	118	182	128	169	34	28	430	1050	145
V	293	327	313	261	297	308	-	316	301	352	-	333	251	308	232	474	536	250	120	213


100
10
1
10
100
1000
Zr / Y (ppm)
Zr (ppm)
A- Within- plate basalts
B- Island- arc basalts
C- Mid-ocean ridge basalts
A
B
C

(A)


Ti / 100
KEY
WPB Within - plate basalts
IAT Island arc tholeiites
CAB Calc-alkaline basalts
MORB Mid ocean ridge basalts
• Garkai-Spangar alkalic Basalts
⊙ Kozh Kach sodic alkalic dolerites
WPB
IAT
MORB
IAT
CAB
Zr
Y. 3

(B)


2Nb
KEY
WPA within-plate alkalic
WPT within-plate tholeiitic
VAB volcanic arc basalt
P-MORB plume MORB
N-MORB normal MORB
• Garkai-Spangar Alkalic basalts
⊙ Kozh Kach sodic alkalic dolerites
WPA
WPA
WPT
P-MORB
N-MORB
VAB
Zr/4
Y

(C)

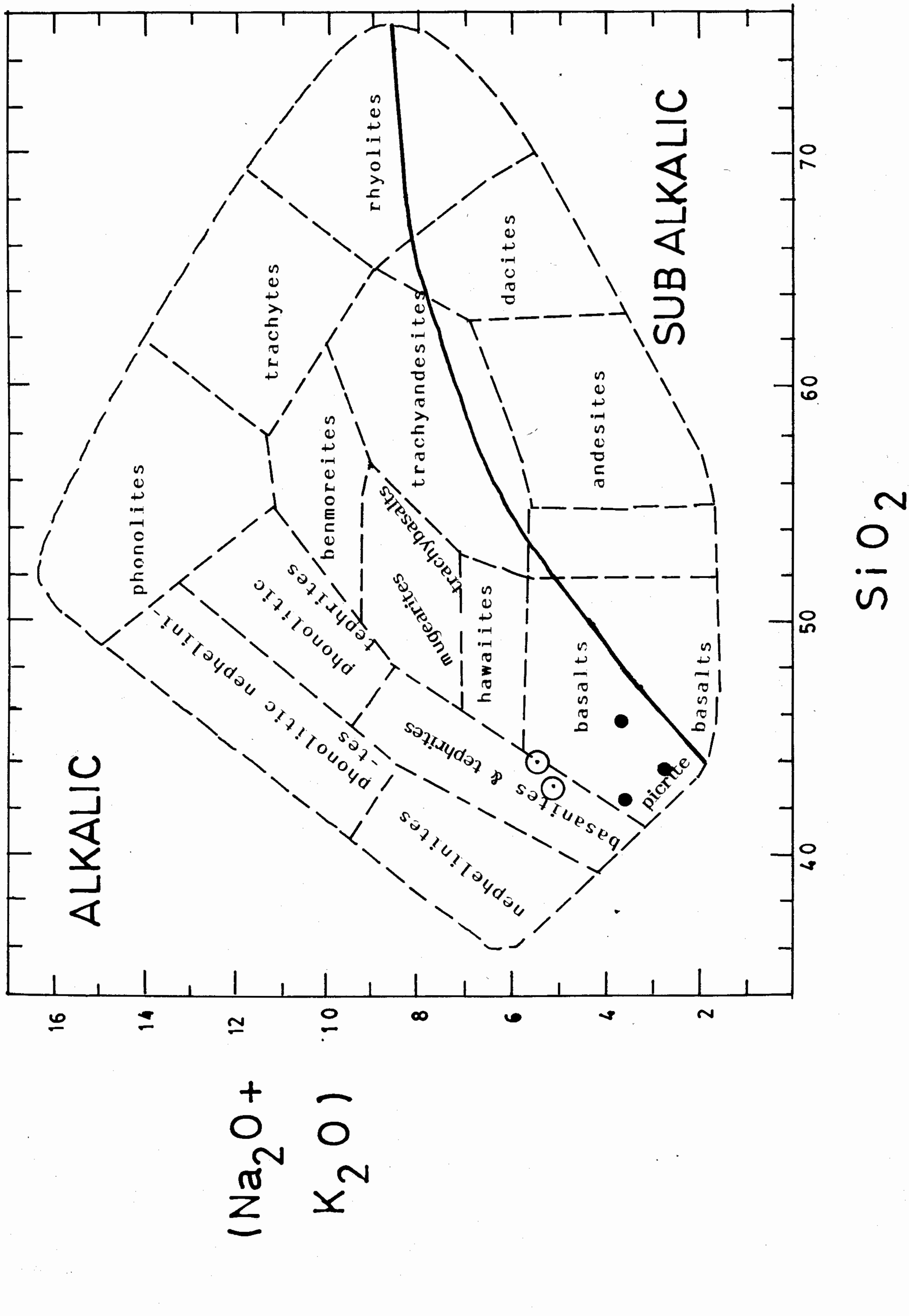


Fig.6. Alkali vs silica plot for rock samples from Garkai-Spangar area.

Comparison with average analyses from Smith et al. (1985) shows that the Spangar rock resembles Group IB kimberlites in its $Ti0_2$ / K_2O, CaO versus $A1_20_3$ and $Si0_2$ contents. Its K_2O is more like Group II (micaceous) kimberlites. K_2O ranges from 1.9% to 4.25% in the more primitive samples, and 1.18 to 2.94% in the more evolved parts, which are more sodic (Table 9). The excess of potash seems to be mainly contained in phlogopite or altered melilite. Only a few of the analyses from Spangar kimberlitic lamprophyre (Table 9) meet the requirements of continental "ultrapotassic" category (Foley et al., 1987); many samples contain < 3% K_2O and a few have K_2O / Na_2O < 3. Low Na_2 O distinguishes the rock from alnöites. On the MgO/CaO against Si_2O / Al_2O_3 plot (Rock, 1991), the analyses plot mostly in the ultramafic lamprophyres field.

In trace elements, V is higher, Ni is lower and all the rest (Table 9) fall within the range generally shown by kimberlites including comparatively high concentrations for certain compatible (Cr, Ni) and incompatible (Nb, Zr, Sr, La, Ba, Hf, Ta, Th, U) elements. In the compatible trace elements (Cr, Ni, V) and Mg/(Mg + Fe) values, the rock (especially its fresher samples like Z4) is similar to the primary magmatic rocks. Primary nature is also shown by the high Fo content of olivine (Ahmed & McCormick, 1990). Large-ion-lithophile element (K, Rb, Sr, Ba) contents are high, like the kimberlitic rocks and certain ultramafic lamprophyres.

The trace elements of the Spangar rock resemble those of the kimberlitic rocks as well as the ultramafic lamprophyres, on the discrimination plots such as those by Rock (1991, fig. 5.9). Rock (1987) has suggested inclusion of kimberlites as the fifth branch of lamprophyre clan. The features displayed by the Spangar rock necessitate it to be called "kimberlitic lamprophyre".

The Spangar rock has high content of LOI (H_2O and CO_2) and incompatible elements. High Nb (> 800 ppm) is in common with the rocks related to intraplate activity rather than those near subduction, in space and time (Thompson & Fowler, 1986). A metasomatized or enriched mantle source is indicated because of its strong incompatible trace element enrichment which appears to preclude partial melting of mantle peridotite. However, its other reason may be the disequilibrium melting involving a phase richer in REE (Rock, 1991).

Generally, the kimberlitic rock analyses may not represent their probable parent magma due to affects of their emplacement style, hybrid nature, crustal contamination, xenocryst content and amount of differentiation aggregates. The application of the contamination index of Clement (1982) and ratios Si/Mg and Mg/ (Mg + Fe) that point to contamination (Ilupin & Lutts, 1971; Fesq et al., 1975) show that the Spangar rock is variably contaminated or altered. Contamination by crustal rocks results in the addition of SiO_2, Al_2O_3 and Na_2O to kimberlites (Mitchell, 1989). Uncontaminated kimberlites are low in $A1_2O_3$ (< 5%), SiO_2 (25 - 35%) and Na_2O/K_2O ratios. The Spangar kimberlitic rock does possess high $A1_2O_3$ and CaO, but maintains its low SiO_2.

At places, segregation of the kimberlitic rock components into light - and dark - coloured bands is present. Chemical constituents of such bands from one sample are compared in Table 9.

Table 9 shows lower contamination indices for the analyses 1 to 8 compared to the analyses 9 to 12 which seem either evolved through magmatic differentiation or crustal contamination. The latter samples have relatively higher Na, Al, Ti, P, Ca, Pb values and lower Mg, Fe, Ni, Cr, Ta, Th, and Ga values. The light coloured and dark coloured parts from the same sample (ZA17 and ZB17, respectively) showed similar differences. However, Si has not increased and probably the variation does not represent crustal contamination.

B. Alkalic Basalts

These rocks are examplified by the samples Z30, Z78, Z79, Z80 and Z81. The analyses in table 9 show that they are olivine– and nepheline– normative; except sample Z30 which is only olivine–normative. Their normative feldspar compositions range from An_{48} to An_{55}. Normative nepheline contents and feldspar compositions of these rocks (analyses 13 – 15, Table 9) after Coombs & Wilkinson (1969), or their plot in the Si_2O vs (Na_2O + K_2O) diagram after Cox et al. (1979) names them as basalts, picrite basalts and basanites. The rocks are mildly alkaline, because they do not contain discrete alkali – rich phases like feldspathoids. High Mg, Cr, Ni contents indicate their primary nature. Nb / Y ration of > 0.67 indicates their alkaline nature (Winchester & Floyd, 1977).

On the tectonomagmatic discrimination plots based on relatively immobile trace elements, they plot in the "within-plate basalt" or "within-plate alkalic" fields. These plots are shown in Fig. 5b (after Pearce & Cann, 1973), 5c (after Meschede, 1986) and 5a (after Pearce & Norry, 1979).

The basalts are mildly alkalic with high Ti, La, Zr, and Nb contents and Zr / Y ratios and are lower in Sc and Al_2O_3 / TiO_2 ratios. Similar features are shown by continental rift basalts (e.g., Coish et al., 1991). They plot in a within-plate environment in the Ti-Zr-Y diagram after Pearce & Cann (1973).

C. Kozh Kach Sodic Dolerites

These rocks are examplified by samples Z44 and Z48 whose chemical analyses are given in Table 9. They contain normative olivine and nepheline; and the composition of normative plagioclase is about An_{30}, exhibiting soda enrichment.

Their trace element data plots in the "within-plate" fields in the tectonomagmatic discrimination plots (Fig. 5b,c). They also possess high Nb/ Y ratios (> 1) typical of alkaline rock suites (Winchester & Floyd, 1977).

The rocks mostly plot in the basanites field on the total alkalies versus SiO_2 diagram. They possess very high soda and low potash. They differ strongly from the Spangar alkali basalts in being higher in Ti, Al, Fe, Na, P, Cl, Zr, Ta, Hf, Zn, Th, La, Y, Nb, Ga, Pb and V (incompatible elements), and lower in Mg, Ca, K,S,Rb, Cu, Cr and Ni (compatible elements). The cause of this variation between the two may include: secondary alteration, mafic mineral fractionation, differences in source or in partial melting conditions. Since the differences are well-marked and include compatible elements, it seems likely that they are due either to their magma being more evolved, or their magma having been generated at a source different from that of the Spangar rocks. The sodic dolerites of Kozh-Kach may, therefore, be considered to make a rock suite which has marked primary geochemical differences from the Spangar alkalic rock suite.

DISCUSSION

The collision of Indian and Eurasian plates is supposed to have occurred about the lower Eocene - Paleocene time when the ophiolites in the northwest Pakistan were emplaced. The Spangar and Kozh Kach areas lie close to the western margin of the Indian plate that bears ophiolites. The volcanism of Spangar and Kozh Kach areas is, however, not related to this collision; because it seems to have occurred prior to the collision. It invades the lowermost Jurassic sediments. In Kozh-Kach area, the invaded rocks are limestone and shale of the early Jurassic Spingwar Member; but not the immediately overlying early Jurassic Loralai Limestone.

At Spangar, only the lowermost part of the Shirīnab Formation is invaded. The magmatism occurred before the basic volcanism of the adjoining Chinjan region (McCormick, 1985) and the Zhob Valley dykes and sills that occur in the Maastrichtian age Parh Limestone. The time of Spangar-Kozh Kach magmatism roughly corresponds to the time of detachment of the Indian plate from the Gondwanaland margin (Dewey, 1988; Sengör et al., 1988). The presence of potassic rocks is often regarded as evidence of intracontinental magmatism; the alkali basalts are often closely associated with rift structures.

The presence of both types of rocks at Spangar may indicate this magmatism to have been triggered by the onset of continental rifting and extension caused probably by a rising mantle plume or hot spot.

The rocks of Spangar are not from the oceanic islands that were proposed by McCormick (1985) to have formed the nearby Chinjan area volcanics. Rather, the Spangar rocks represent intracontinental plate magmatic activity.

The magmatic rocks at Spangar include kimberlitic rocks that occur in association with mild alkalic basalts. The activity is dominated by fissure type rather than central-vent type. The geochemistry supports its identification as a kimberlitic rock. It may be grouped with "ultramafic lamprophyres" (Rock, 1986), but it has more kimberlitic features than any other ultramafic lamprophyre. Moreover, the established criteria for the kimberlitic rocks (Mitchell, 1986, 1989) and for the ultramafic lamprophyres (Rock, 1986, 1989) greatly overlap; so much so that it has been convincingly suggested that kimberlites be considered a part of lamprophyres (Rock, 1989).

The Spangar kimberlitic rock is rich in incompatible elements like K, Ba, Rb, Sr, REE, P and Zr. It may have been derived from anomalous, enriched or metasomatized, source that laid either in the mantle within the subcontinental lithosphere; or just below it. The resemblances to the Group II (micaceous) kimberlites may be indicative of enriched mantle source in the subcontinental lithosphere, outside the asthenosphere.

Kimberlitic magmatism may be caused by source metasomatism (Bailey, 1985, 1987), diapiric upwelling (Le Roex, 1986), or passive tectonic disturbances associated with the propagation of deep lithospheric fractures (Haggerty, 1982).

Many workers relate the kimberlite magmatism to the rise of sublithospheric mantle plumes beneath ancient cratonic nucleii (England & Housemann, 1984; Le Roex, 1986). Such plumes or hot spots may provide the driving force for the intracontinental lithospheric thinning and rifting. Crough et al. (1980) and Crough (1981) have shown many post-Jurassic kimberlites to have formed closely above the known mantle hot spots.

The daipiric upwelling may have caused local tectonic disturbance that involved the deep lithospheric fractures. The Spangar alkalic basalts may have come up as a result.

It seems likely that Spangar kimberlitic magmatism occurred when a hot spot impinged on the base of Indian continental plate probably due to asthenospheric upwelling.

The potassic rocks may indicate a continental rift zone magmatism along zones of weakness in mobile belts. The kimberlites do not occur in young fold belts (Mitchell, 1986). The alkaline basaltic magmatism is common in the intracontinental plate rifts. However, generally, the continental rift zones contain much broader zones of uplift and magmatism than that exhibited by the Spangar area. The area seems to lie in a zone of weakness trending NE - SW. In the seismotectonic map of Pakistan (Kazmi, 1979) a major fault is shown traversing this area and trending NE to SW.

Coish *et al.* (1991) related chemistry of Vermont- New York basalts to progressive stages in the rifting of the ancient North American continent. The Spangar alkali basalts compare well with the early-stage rift basalts in their Ti and trace element contents.

The Indian continental plate began its pull apart from the Gondwanaland in Jurassic times perhaps because of a thermal mantle plume rising through the depleted asthenosphere; and magmas at this early stage may have been produced mainly from the melting of the enriched mantle by plume, to form enriched magmatic rocks like those of the Spangar area. This may have preceded the fragmentation of blocks of the lithospheric plates. Indian plate had begun to separate and drift apart in Jurassic between about 160 and 120 Ma ago (Norton & Sclater, 1979).

Although the Spangar - Kozh Kach magmatism had stopped by middle Jurassic; the same extension tectonics may have continued to provide channels for the basaltic volcanic and hypabyssal rocks that traversed the Maastrichtian age Parh Limestone in the Chinjan to Zhob tract. The Chinjan rocks were identified as "within-plate alkali basalts" by McCormick (1085). He found these rocks to have deposited simultaneously and / or alternately with limestone and marl. He suggested them to represent oceanic islands formed on the western side of the Indian plate as it passed over a hot spot and left the trace of its path as the Chagos-Laccadiv Ridge of the Indian Ocean. However, these rocks are different from the Spangar rocks where kimberlitic rock shows them to be intracontinental and not suboceanic.

The kimberlitic lamprophyre and the alkali basalts are both formed from relatively primitive magmas; as their evolved rock types, such as ijolite-carbonatites, phonolites, rhyolites, etc., are not presently found in the area described herein. Within the analyses of kimberlitic lamprophyres (1-12; Table 9), there are two groups: analyses 1 to 8 form one set and analyses 9 to 12 make the second set. The differences between the mafic and felsic groups are not due to secondary processes and may be either due to magmatic fractionation, or due to crystal contamination. Sample ZA17 is the mafic part of the sample with more felsic component ZB17. High Cr, Ni and Mg values for the kimberlitic lamprophyre analyses (1-8, Table 9) indicates a primary status for the magma (Rock, 1987). However, analyses 9 to 12 show that parts are either contaminated or fractionated. The rock shows features originating at deeper levels in the Earth's mantle.

CONCLUSIONS

In the northern part of the western margin of the Indian plate, the Spangar area was a centre of alkaline magmatism which might be a manisfestation of extensional tectonics within the continental plate. Here, a kimberlitic lamprophyre with associated alkalic basaltic magmatism is recognized invading the lowermost Jurassic sediments. The magmatism is dominantly of the fissure type rather than the central vent type. The magmatism was probably caused by deep mantle or asthenospheric upwelling during the extensional tectonics and break up of the Indian plate away from the Gondwanaland. The rocks are related to the splitting of the western margin of the Indian plate away from its position adjoining the part of Afro-Arabian plate near Somalia. Their emplacement was controlled by major fractures associated with the Jurassic rifting and continental break up. The source of the basalt was trace element enriched continental lithosphere. The kimberlitic lamprophyre displays geochemical and petrographic features that relate it to both the kimberlites and the ultramafic lamprophyres.

The sodic alkalic dolerites of the Kozh Kach area, although intruding the same Jurassic sediments, seems to belong to an episode of magmatism that differs from that of the Spangar area alkalic rocks. The differences between the two are clearly noticeable in the geological, petrographic, mineral chemical and geochemical features described in this communication.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the cooperation and assistance given by many individuals during various phases of field and laboratory studies. Many persons on the staff at the California Institute of Technology helped in sample preparation, microprobe analyses and computer work; J. Lawford-Anderson, Erik Bender and Vera Wilson of the University of Southern California cooperated for the XRF laboratory work, Patricia LeDell of San Marino, California, extended logistic support during the author's U.S. stay. The University Grants Commission, Pakistan, sponsored part of the field studies.

REFERENCES

AHMED, Z. (1986) Ophiolites and chromite deposits of Pakistan. In: Petraschek, W., Karamata, S., Karavchenko, G.G., Johan, Z., Economou, M. & Engin, T. (eds.) CHROMITES, UNESCO's IGCP 197 PROJECT "METALLOGENY OF OPHIOLITES". Theophrastus Publications, Athens (Greece), pp. 241-262.

——— **& McCORMICK, G.R. (1990)** A newly discovered kimberlitic rock from Pakistan. Min. Mag. **54**, pp. 537-546.

ASTHANA, D. (1991) Relict clinopyroxenes from within-plate metadolerites of the Petroi metabasalt, the New England fold belt, Australia. Min. Mag. **55** (381), pp. 549-561.

BAILEY, D.K. (1985) Fluids, melts, flowage and styles of eruption in alkaline ultramafic magmatism. Trans. Geol. Soc. S. Afr. **88**, pp. 449-457.

——— **(1987)** Mantle metasomatism — perspective and prospect. In: Fitton, J.G. & Upton, B.G.J. (eds.) ALKALINE IGNEOUS ROCKS. Geol. Soc. London Spec. Publ. **30**, pp. 1-13.

BERGMAN, S.C. (1987) Lamproites and other potassium-rich igneous rocks: a review of their occurrence, mineralogy and geochemistry. In: Fitton, J.G. & Upton, B.G.J. (eds.) ALKALINE IGNEOUS ROCKS. Geol. Soc. London Spec. Publ. **30**, pp. 103-190.

BILGRAMI, S.A. (1964) Mineralogy and petrology of the central part of the Hindubagh Igneous Complex, Hindu Bagh Mining District, Zhob Valley, West Pakistan. Records of the Geological Survey of Pakistan **10**, 28p.

CLEMENT, C.R. (1982) A comparative geological study of some major kimberlite pipes in the Northern Cape and Orange Free States. Ph.D. thesis (2 Volumes) Univ. Cape Town (Unpublished).

COISH, R.A., BRAMLEY, A., GAVIGAN, T. & MASINTER, R. (1991) Progressive changes in volcanism during Iapetan rifting: comparisons with the East African Rift - Red Sea system. Geology **19**, pp. 1021-1024.

COOMBS, D.S. & WILKINSON, J.F.G. (1969) Lineages and fractionation trends in undersaturated volcanic rocks from the East Otago Volcanic Province (New Zealand) and related rocks. J. Petrol. **10**, pp. 440-501.

CROUGH, S.T. (1981) Mesozoic hot spot epeirogeny in Eastern North America. Geology **9**, pp. 2-6.

———, MORGAN, W.J. & HARGRAVES, R.B. (1980) Kimberlites: their relation to mantle hot spots. Earth Planet. Sci. Lett. **50**, pp.260-274.

COX, K.G., BELL, J.D. & PANKHURST, R.J. (1979) THE INTERPRETATION OF IGNEOUS ROCKS. George Allen & Unwin, London.

DEER, W.A., HOWIE, R.A. & ZUSSMAN, J. (1962) ROCK-FORMING MINERALS. Vol. 3, Sheet Silicates, Longmans, London.

DEWEY, J.F. (1988) Lithospheric stress, deformation and tectonic cycles: the disruption of Pangaea and the closure of Tethys. In: Audley-Charles, M.G. & Hallam, A. (eds.) GONDWANA AND TETHYS. Geol. Soc. London Spec. Publ. **37**, pp. 23-40.

ENGLAND, P. & HOUSEMANN, G. (1984) On the geodynamic setting of kimberlite genesis. Earth Planet. Sci. Lett. **67**, pp. 109-122.

FESQ, H.W., KABLE, E.J.D. & GURNEY, J.J. (1975) Aspects of the geochemistry of kimberlites from the Premier Mine and other South African occurrences with particular reference to the rare earth elements. Phys. Chem. Earth **9**, pp.696-707.

FOLEY, S.F., VENTURELLI, G., GREEN, D.H. & TOSCANI, I. (1987) The ultrapotassic rocks: characteristics, classification and constraints for petrogenetic models. Earth Sci. Rev. **24**, pp. 81-134.

GANSSER, A. (1979) Reconnaissance visit to the ophiolites in Baluchistan and the Himalaya. *In*: Farah, A. & De Jong, K.A. (eds.) GEODYNAMICS OF PAKISTAN, pp. 193-213. Geological Surey of Pakistan, Quetta.

GIBB, F.G.F. (1973) The zoned clinopyroxenes of the Shiant Isles sill, Scotland. J. Petrol. **14**, pp. 203-230.

HAGGERTY, S.E. (1982) Kimberlites in western Liberia: An overview of the geological setting in a plate tectonic framework. J. Geophys. Res. **81**, pp. 10811-10826.

HAMILTON, R. & ROCK, N.M.S. (1990) Geochemistry, mineralogy and petrology of a new kind of ultramafic lamprophyres from Bulljah Pool, Nabberu Basin, Yilgarn craton, Western Australia. Lithos **24**, pp. 275-290.

HOFMANN, A.W. (1988) Chemical differentiation of the Earth: the relationship between mantle, continental crust and oceanic crust. Earth Planet. Sci. Lett. **90**, pp. 297-314.

ILUPIN, I.P. & LUTZ, B.G. (1971) The chemical composition of kimberlites and questions on the origin of kimberlite magmas. Soviet Geology **6**, pp. 61-73 (in Russian).

KAZMI, A.H. (1979) Preliminary seismotectonic map of Pakistan. Scale 1:2,000,000. Geological Survey of Pakistan, Quetta.

LARSEN, L.M. (1976) Clinopyroxenes and coexisting mafic minerals from the alkaline Ilimaussaq Intrusion, South Greenland. J. Petrol. **17**, pp. 258-290.

LE ROEX, A.P. (1986) Geochemical correlation between southern African kimberlites and south Atlantic hot spots. Nature **324**, pp. 243-245.

McCORMICK, G.R. (1985) Preliminary study of the volcanic rocks of the South Tethyan suture in Baluchistan, Pakistan. Acta Mineralogica Pakistanica **1**, pp. 2-9.

MESCHEDE, M. (1986) A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb- Zr- Y diagram. Chem. Geol. **56**, pp. 207-218.

MITCHELL, R.H. (1972) Composition of perovskite in kimberlite. Am. Mineral. **57**, pp. 1748-1753.

——— **(1986)** KIMBERLITES: MINERALOGY, GEOCHEMISTRY AND PETROLOGY. Plenum Publishing Corporation, New York.

——— **(1989)** Aspects of petrology of kimberlites and lamproites: some definitions and distinctions. In: Ross, J. *et al.* (eds.) KIMBERLITES AND RELATED ROCKS. Vol. 1. Their Occurrence, Origin and Emplacement. Geol. Soc. Australia Spec. Publ. **14**, pp. 7-45.

NISBET, E.G. & PEARCE, J.A. (1977) Clinopyroxene composition in mafic lavas from different tectonic settings. Contrib. Mineral. Petrol. **63**, pp. 149-160.

NORTON, I.O. & SCLATER, J.G. (1979) A model for the evolution of the Indian ocean and the breakup of Gondwanaland. Jour. Geophys. Res. 84 (B12), pp. 6803-6830.

PEARCE, J.A. (1983) Role of subcontinental lithosphere in magma genesis at active continental margins. In: Hawkesworth, C.J. & Norry, M.J. (eds.) CONTINENTAL BASALTS AND MANTLE XENOLITHS, pp. 230-249. Shiva, Orpington.

——— **& CANN, J.R. (1973)** Tectonic setting of basic volcanic rocks determined using trace element analysis. Earth Planet. Sci. Lett. **19**, pp. 290-300.

——— **& NORRY, M.J. (1979)** Petrogenetic implications of Ti, Zr, Y, and Nb variations in volcanic rocks. Contrib. Mineral. Petrol. **69**, pp. 33-47.

ROCK, N.M.S. (1986) The nature and origin and ultramafic lamprophyres; alnöites and allied rocks. J. Petrol. **27**, pp. 155-196.

——— **(1987)** The nature and origin of lamprophyres: an overview. In: Fitton, J.G. & Upton, B.G.J. (eds.) ALKALINE IGNEOUS ROCKS. Geol. Soc. London Spec. Publ. **30**, pp. 191-226.

——— **(1989)** Kimberlites as varieties of lamprophyres: implications for geological mapping, petrological research and mineral exploration. In: Ross, J. *et al.* (eds.) KIMBERLITES AND RELATED ROCKS, Vol. 1, Their Occurrence, Origin and Emplacement. Geol. Soc. Australia Spec. Publ. **14**, pp. 46-59.

SCOTT-SMITH, B.H.S. & SKINNER, E.M.W. (1984) A new look at Prairie Creek, Arkansas. *In*: Kornprobst, J. (ed.) KIMBERLITES 1: Kimberlites and Related Rocks, pp. 255-283. Elsevier, Amsterdam.

SENGÖR, A.M.C., ALTINER, D., CIN, A., USTAOMER, T. & HSU, K.J. (1988) Origin and assembly of the Tethyside orogenic collage at the expense of Gondwanaland. *In*: Audley-Charles, M.G. & Hallam, A. (eds.) GONDWANA AND TETHYS. Geol. Soc. London Spec. Publ. **37**, pp. 119-181.

SMITH, C.B., GURNEY, J.J., SKINNER, E.M.W., CLEMENT, C.R. & EBRAHIM, N. (1985) Geochemical character of southern Africa kimberlites: a new approach based on isotopic constraints. Trans. Geol. Soc. S. Afr. **88**, pp. 267-280.

SMITH, D. & LINDSLEY, D.H. (1971) Chemical variations in pyroxene and olivine from Picture Gorge baslt. Yearb. Carnegie Instn. Wash., **69**, pp. 269-274.

THOMPSON, R.N. (1982) Magmatism of the British Tertiary volcanic province. Scott. J. Geol. **18**, pp. 49-107.

——— **& FOWLER, M.B. (1986)** Subduction-related shoshonitic and ultrapotassic magmatism: a study of Siluro-Ordovician syenites from the Scottish Caledonides. Contrib. Mineral. Petrol. **94**, pp. 507-522.

WILKINSON, J.F.G. (1979) The mineralogy and petrography of alkali basaltic rocks. In: Sorensen, H. (ed.) THE ALKALINE ROCKS, pp. 67-95. John Wiley & Sons., Chichester.

WINCHESTER, J.A. & FLOYD, P.A. (1977) Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chem. Geol. **20**, pp. 325-343.

Manuscript received on April 20, 1991.
Accepted for publication on June 30, 1991.

ACTA MINERALOGICA PAKISTANICA
VOLUME 5 (1991) pp. 46-61.

REVISED NOMENCLATURE AND STRATIGRAPHY OF FEROZABAD, ALOZAI AND MONA JHAL GROUPS OF BALOCHISTAN (AXIAL BELT), PAKISTAN.

MUHAMMAD ANWAR, A.N. FATMI AND IQBAL H. HYDERI
Geological Survey of Pakistan, 16-G, Model Town, Lahore.

ABSTRACT: Stratigraphic studies of the various Mesozoic rock sequences of the Axial Belt lead to the conclusion that Balochistan can be divided into southern, central and northern parts on the basis of facies changes. In the light of these studies, a modified nomenclature has also been introduced for the Mesozoic sedimentary rocks in the 'Axial Belt'. These rocks are now divided into three groups: Ferozabad, Alozai and Mona Jhal. The Ferozabad Group consisting of Kharrari/Shirinab, Malikhore and Anjira Formations in the southern and central Balochistan and the Alozai Group consisting of Wulgai, Spingwar and Loralai Formations in northern Balochistan range in age from Triassic to Middle Jurassic. The Mona Jhal Group consisting of Sembar, Goru, Parh and Mughal Kot Formations ranges in age from Late Jurassic to Cretaceous.

Some new fauna is collected from different areas during field investigations and is identified to fix the age limits of the formations. An attempt is made to correlate the formations within Balochistan and the formations of Upper Indus Basin deposited during Mesozoic times. About 20 detailed sections were measured to establish the lithostratigraphic units in Balochistan. The oldest rock unit, Permian outcrop of Alozai group within the Triassic shale, spotted in the Wulgai area, is not in situ. Some new fossil horizons are also located within Balochistan (Axial Belt).

INTRODUCTION

Mesozoic rocks are widely exposed in Balochistan. The existing knowledge on the biostratigraphy and sedimentology of these rocks is imperfect. An enormous thickness of Mesozoic marine sediments is developed in Balochistan, but hardly any attempt has been made to establish precise time boundaries. Very few of the time-stratigraphic boundaries of the Mesozoic strata are well-defined. These have been described as undifferentiated Mesozoic lithostratigraphic units of various formations. To describe the stratigraphy of the Mesozoic rocks of Balochistan, under a project of the Geological Survey of Pakistan entitled "stratigraphic and sedimentological studies of Mesozoic rocks of Pakistan", the authors carried out special studies of the rock sequences in different areas of Balochistan. Under these studies about 20 stratigraphic sections were measured in detail in the southern, central and northern Balochistan.

In southern Balochistan two new groups, namely the Ferozabad Group with three formations (Kharrari, Malikhore and Anjira) and the Mona Jhal Group with four formations (Sembar, Goru, Parh and Mughal Kot) are being introduced for the Late Jurassic-Cretaceous rocks.

In central Balochistan the Shirinab Formation of Hunting Survey Corporation (1961) has been accepted as a facies equivalent of the Khairari Formation of the southern Balochistan, but the Chiltan limestone of Hunting Survey Corporation is proposed to be replaced by three new formations, the Malikhore, Anjira and Chiltan Limestone. Two new groups, the Ferozabad and Mona Jhal, introduced in southern Balochistan are also considered valid for the Mesozoic rocks of central Balochistan.

The nomenclature used by Hunting Survey

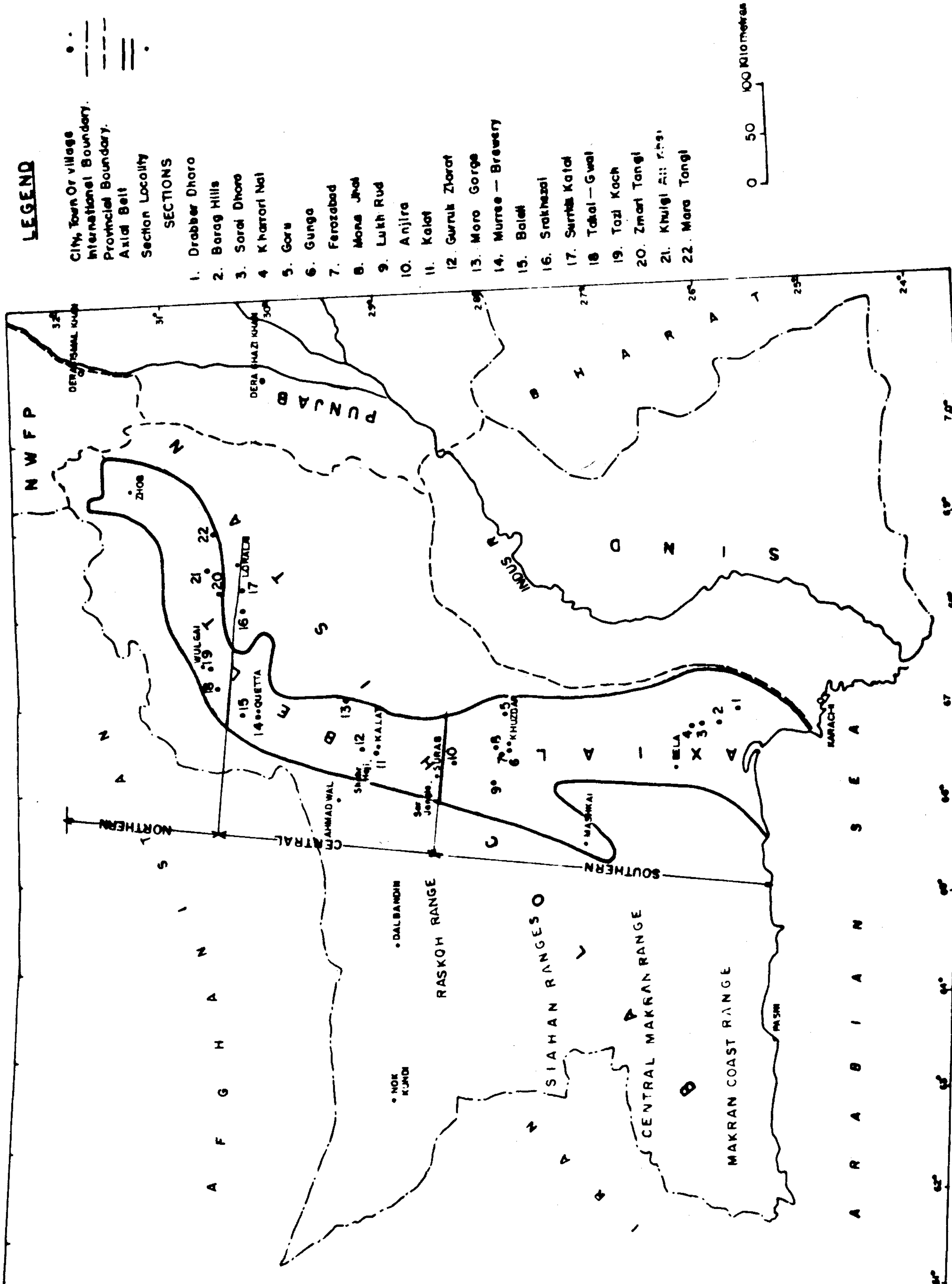


FIGURE. I. MAP SHOWING SECTION LOCALITIES IN BALOCHISTAN (AXIAL BELT)

Corporation (1961) and Williams (1959) for the Jurassic rocks in northern Balochistan is accepted as such (Alozai Group and Wulgai, Spingwar and Loralai Formations). On the other hand a new group called Mona Jhal Group comprising four formations (Sembar, Goru, Parh and Mughal Kot) is being introduced for the Late Jurassic-Cretaceous rocks.

The present work specifically describes the stratigraphy of the Mesozoic sequence of Windar, Uthal, Khuzdar, Kalat, Quetta, Khanozai, Sanjawi and Loralai areas. The lithological variations are described on the basis of detailed study of stratigraphic sections and an attempt is made to propose a more precise nomenclature for the lithostratigraphic units of Mesozoic rocks in Balochistan. The fossils reported in this paper were collected by us jointly and identified by one of us (A.N. Fatmi).

A very sketchy information on the lithostratigraphy and sedimentology of the Mesozoic rocks of Balochistan based on the unpublished reports of oil companies' geologists was available till 1959. Although the presence of fossils from Late Triassic, Toarcian, Callovian and Late Cretaceous has been mentioned in the literature but very little is monographed (Noetling, 1897; Vredenburg, 1909; Hunting Survey Corporation, 1961; Fatmi, 1969). Williams (1959) divided the Mesozoics into three formations called Spingwar, Loralai limestone and Anjira in Balochistan.

Hunting Survey Corporation (1961) introduced different nomenclature for the Jurassic rocks in Balochistan. It described these rocks under the caption of Windar group and Zidi formation in southern Balochistan; Shirinab formation and Chiltan Limestone in central Balochistan and Alozai group and Loralai limestone in northern Balochistan. Hunting Survey Corporation also introduced Parh group or serie to represent the Cretaceous rocks of Balochistan.

This presentation is based on a comprehensive study of the Mesozoic rocks of Balochistan made during 1984-88. Two new groups, Ferozabad comprising three new formations (Kharrari, Malikhore and Anjira) and Mona Jhal consisting of four formations (Sembar, Goru, Parh and Mughal Kot) are introduced in the southern Balochistan (approved by the Stratigraphic Committee of Pakistan). These two groups with above mentioned formations except Kharrari Formation is being introduced in central Balochistan. The Shirinab Formation replaces the Kharrari Formation in central Balochistan which is a facies equivalent of it. The Mona Jhal Group is also being introduced in northern Balochistan.

STRATIGRAPHY

For the description of Mesozoic rocks, Balochistan basin can be divided into three parts, i.e., southern, central and northern Balochistan, on the basis of remarkable facies changes in Jurassic rocks (Fig. 1). The southern Balochistan covers the area from Gadani to Anjira, the central Balochistan from Anjira to Gwal and the northern Balochistan from Gwal to Zhob (Gul Kach) in the Axial Belt. The nomenclature used in this study is after Fatmi et.al. (1986) and Hunting Survey Corporation (1961). Some new names are proposed to replace the names used by Hunting Survey Corporation. The stratigraphic sequences of Mesozoic rocks in Balochistan are tabulated in Table 1. An attempt is made to correlate the different formations within Balochistan basin (Figs. 2 & 3).

UPPER TRIASSIC-MIDDLE JURASSIC

(A) SOUTHERN BALOCHISTAN (WINDAR-LASBELA-KHUZDAR-ANJIRA AREAS)

Ferozabad Group

The name Ferozabad Group as approved by the Stratigraphic Committee of Pakistan (Farhat, 1988), was introduced by Fatmi et al. (1990). This name is derived after Ferozabad village (35 I/9), 13 km west of Khuzdar. This group includes the following three formations in ascending order:

3.	Anjira Formation	Early to Middle Jurassic
2.	Malikhore Formation	Early Jurassic
1.	Kharrari Formation	Triassic to Early Jurassic

Kharrari Formation:

The name Kharrari Formation approved by the Stratigraphic Committee of Pakistan was

Era	Period	Epoch	Stage	Balochistan (Axial Belt, this report): Southern		Central		Nothern		Upper Indus Basin: Shaikh Budin Hills		Surghar Range		Western Kohat	
MESOZOIC	CRETACEOUS	LATE	MAASTRICHTIAN		PAB Ss.		MORO FM								
			SENONIAN: COMPANIAN	MONA JHAL GROUP	MUGHAL KOT FM.	MONA JHAL GROUP	MUGHAL-KOT FM.	MONA JHAL GROUP	MUGHAL KOT FM.					KAWAGARH FM	TSUKHAI TSUK MEM.
			SENONIAN: SANTONIAN		PARH Ls.		PARH Ls.		PARH Ls.						CHOLAR SILLI MEM.
			SENONIAN: CONIACIAN												
			TURONIAN												
			CENOMANIAN		GORU FM.		GORU FM.		GORU FM.						
		EARLY	ALBIAN												
			APTIAN							SURGHAR GROUP	LUMSHIWAL FM.	SURGHAR GROUP	LUMSHIWAL FM.	SURGHAR GROUP	LUMSHIWAL FM.
			NEOCOMIAN: BARREMIAN		SEMBAR FM.		SEMBAR FM.		SEMBAR FM.		CHICHALI FM.		CHICHALI FM.		CHICHALI FM.
			NEOCOMIAN: HAUTERIVIAN												
			NEOCOMIAN: VALANGINIAN												
			NEOCOMIAN: BERRIASIAN												
	JURASSIC	LATE	TITHONIAN												
			KIMMERIDGIAN												
			OXFORDIAN												
		MIDDLE	CALLOVIAN							BAROCH GROUP	SAMANA SUK FM.	BAROCH GROUP	SAMANA SUK FM.		
			BATHONIAN			FEROZABAD GROUP	CHILTAN Ls.							BAROCH GROUP	SAMANA SUK FM.
			BAJOCIAN	FEROZABAD GROUP	ANJIRA FM.		ANJIRA FM.	ALOZAI GROUP	LORALAI FM.		SHINAWARI FM.		SHINAWARI FM.		SHINAWARI FM.
		EARLY	AALENIAN												
			TOARCIAN												
			PLIENSBACHIAN		MALIKHORE FM.		MALIKHORE FM.		SPINGWAR FM.		DATTA FM.		DATTA FM.		DATTA FM.
			SINEMURIAN		KHARRARI FM.		SHIRINAB FM.								
			HETTANGIAN												
	TRIASSIC				Base not exposed		Base not exposed		WULGAI FM.	MUSA KHEL GROUP	KINGARIALI FM. / TREDIAN FM. / MIANWALI FM.	MUSA KHEL GROUP	KINGARIALI FM / TREDIAN FM. / MIANWALI FM.		

Drafted by: Zafar Ahmed. Data based on field investigations by Fatmi, Anwar and Hyderi. Prepared by: Muhammad Anwar.

TABLE NO.1. PROPOSED STRATIGRAPHIC NOMENCLATURE OF MESOZOIC ROCKS OF BALOCHISTAN (AXIAL BELT) AND CORRELATION WITH UPPER INDUS BASIN.

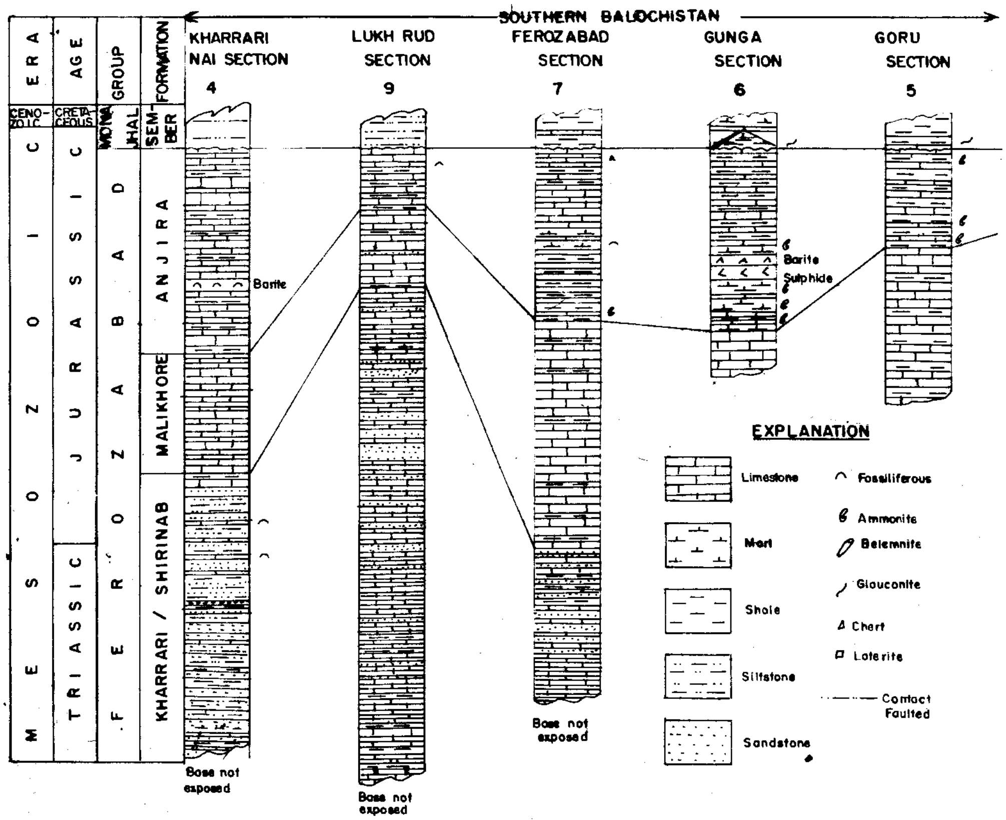
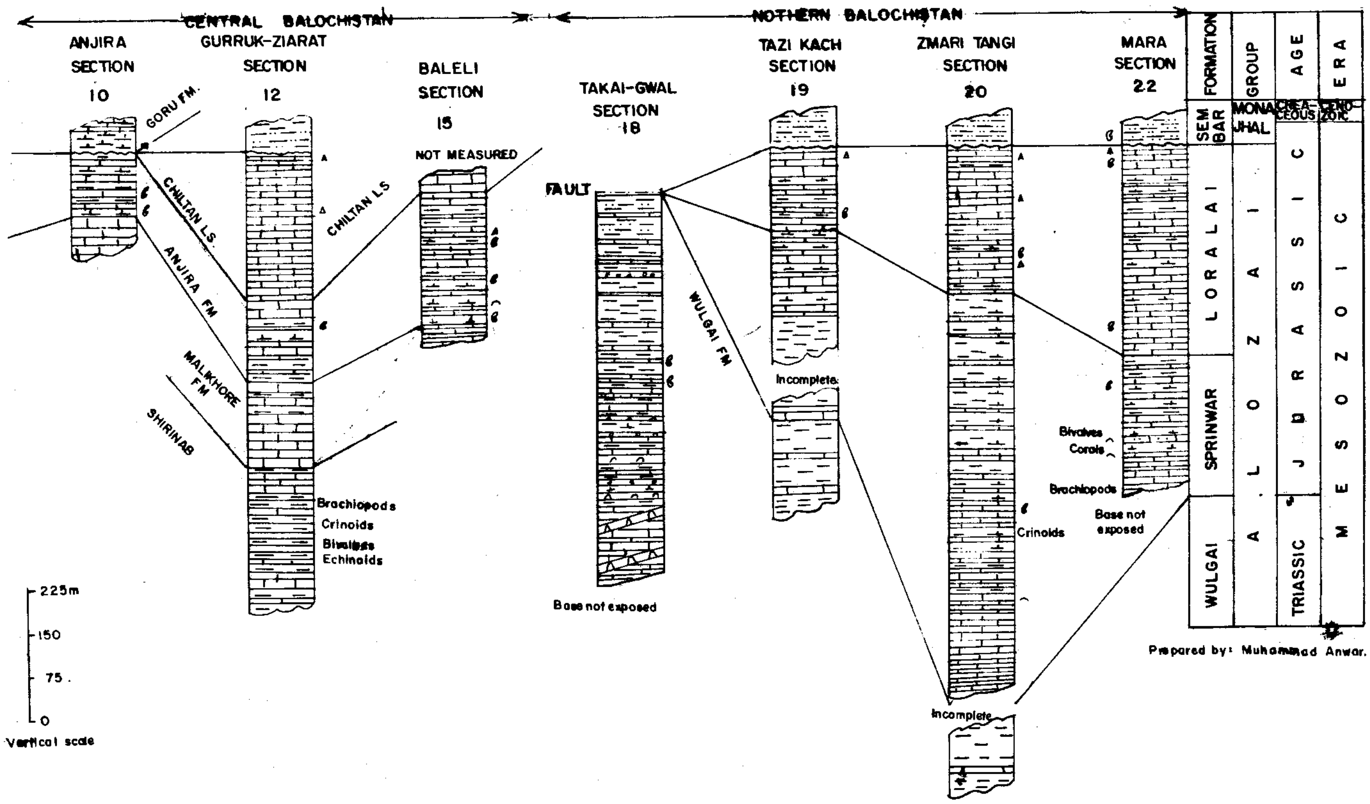


FIGURE 2. COLUMNAR SECTIONS OF FEROZABAD



AND ALOZAI GROUPS IN BALOCHISTAN (AXIAL BELT).

introduced by Fatmi et al. (1990) to separate a mixed clastic carbonate facies which was included previously in "Windar group" and "Zidi formation" by Hunting Survey Corporation (1961). This name was derived from Kharrari Nai (Mor Range, 35K/16) in Windar area that drains Uthal territory.

The formation consists of limestone, dolomite, sandstone, siltstone and shale in the type locality. The sandstone is gray, light gray, purplish brown, weathers brownish gray, thin to medium bedded, fine to medium grained, well-sorted, quartzose, micaceous, gritty, cross-bedded, fragmentary and friable. The limestone is gray to brownish gray, weathers brown, laminated to thin-bedded, flaggy, micritic and unfossiliferous. The siltstone is grenish gray to brownish gray and weathers brown. The shale is black to greenish gray, weathers brownish gray, sandy, soft flaky to hard fissile and platy. It is micaceous and silty at places.

In the Khuzdar area the limestone with minor shale intercalations is common in the lower part; sandstone and limestone interbeds in the middle part and limestone with sandstone and marl/shale intercalations in the upper part. At places the limestone is pelletal, silty, argillaceous, mottled, biosparitic and fragmentary in the upper part. Coquina beds are common.

The base of the formation is not exposed. Its thickness in the type locality is more than 464 m. Moreover, it is more than 248 m thick in the Ferozabad section and 824 m in the Lukh Rud section. Its contact with the overlying Malikhore Formation is transitional.

Lower Toarcian ammonite fauna was collected from the Anjira Formation. No Pre-Toarcian ammonites were seen in the Malikhore and Kharrari Formations except bivalves, brachiopods, corals, gastropods, etc. But keeping in view the thickness of the Malikhore and Kharrari Formations, it is presumed that the Kharrari Formation, though mainly of Early Jurassic age, may extend into the Triassic.

Malikhore Formation

The name Malikhore Formation approved by the Stratigraphic Committee of Pakistan was introduced by Fatmi et al. (1990) to distinguish the middle, massive to thick-bedded carbonate unit of Windar group and "Zidi formation" of Hunting Survey Corporation (1961). This name is derived after the village Malikhore (35 I/9), 27 km west-northwest of Khuzdar.

In the type locality the formation is mainly composed of thick-bedded limestone with subordinate calcareous shale/marl as thin partings. The limestone is gray to grayish brown, weathers brown, thick-bedded to massive, biomicritic, hard, pelletal, oolitic, coquinoidal and shelly with frequent bioturbated mottled beds. The shale is dark gray to greenish gray and calcareous. In the Kharrari Nai and Lukh Rud sections, the shale is black, fissile and carbonaceous. The formation is highly resistant which forms steep slopes or cliffs.

The formation is widely distributed throughout southern Balochistan. It is 387 m thick in the type locality, 204 m in the Kharrari section and 136 m in the Lukh Rud section. Its contacts with the underlying Kharrari Formation and overlying Anjira Formation are transitional.

No cephalopods have been reported from the formation except abundant fragmentary gastropods, bivalves (*Pecten, Weyla, Gervillea*), crinoids (*Isocrinus*), brachiopods (*Spiriferina* sp.), corals, etc., from different levels. The age is considered to be Early Jurassic. The sediments were deposited in shallow marine environments as indicated by mottling, bioturbation and wavy bedding.

Anjira Formation

The name Anjira Formation approved by the Stratigraphic Committee of Pakistan, the uppermost formation of the Ferozabad Group, was introduced by Williams (1959). This name is derived from the Anjira village (34 L/7) with type locality, 12 km east of Anjira.

The formation consists of thin- to thick-bedded limestone interbedded locally with partings of marl and calcareous shale. The limestone is gray to dark gray, weathers brownish gray, and is lithographic and fossiliferous. It is marly, shelly, mottled and muddy at places. The marl is gray to greenish gray, weathers brownish gray, soft, flaggy and nodular. The shale is creamy or gray and soft.

A mineralized zone occurs stratigraphically below the highest Early Jurassic (Upper Toarcian) and the lower part of Middle Jurassic (Lower Bajocian) strata in the Gunga section near Khuzdar where the formation consists of marl and marly limestone with green shale intercalations and contains ammonites and other fossils. The upper part is composed of limestone interbedded with shale and is unfossiliferous. The barite deposit (20 m thick) in the Kharrari Nai section occurs 224 m below the unconformable contact with the basal glauconitic siltstone beds of Sembar Formation. Its stratigraphic position is approximately 20 m above the *Protogrammoceras* sp. - bearing well-bedded dark gray limestone of Lower Toarcian age. The difference between the Gunga and Kharrari barite deposits is that the Gunga deposit (20 m thick) occurs 180 m below the topmost beds and a sulphide zone (23 m thick) also occurs below it, but in the Kharrari Nai the barite deposit is 224 m below the upper unconformable contact with the Sembar Formation. The stratigraphic position of mineralized zone is similar in both areas.

The formation is distributed widely in the southern Balochistan. It is 110 m thick at the type locality, 168 m in the Goru section, 312 m in the Ferozabad section, 100 m in the Lukh Rud section and 352 m in the Kharrari section. The lower contact with the Malikhore Formation is transitional. The upper contact with the Sembar Formation is disconformable in all measured sections except in the type locality where it is overlain disconformably by the Goru Formation. Laterite is developed at this contact.

The fossils picked up from the Anjira section include *Trigonia* sp., *Spirferina* sp., *Terebratula* sp., gastropods, *Polyplectus* sp., *Bouleiceras nitescens*, *Bouleiceras cf. arabicum*, *Fuciniceras* sp., *Tachylytoceras* sp., *Grammoceras*, *Protogrammoceras*, *Hammatoceras* sp., *Phylsiogrammoceras* sp. *aff. dispansum* (Upper Toarcian) and *Dumorlieceras menaghini*. *Protogrammoceras* sp. (Lower Toarcian), *Hammatoceras* sp. (Upper Toarcian) and *Nanolytoceras* (Bajocian) were collected from the Gunga section. The fauna found from the lower part of the formation from the Ferozabad section were brachiopods, (*Spiriferina, Terebratula*), corals (*Montlivaltia* sp.) and other molluscan including Lower Toarcian ammonoids and nautiloids (*Bouleiceras, Protogrammoceras, Dactylioceratids, Cenoceras*, etc.). From the Kharrari Nai section *Protogrammoceras* sp. *aff. madagascariense* (Lower Toarcian), *Fuciniceras* sp., *Dactylioceras* sp., *Spiriferina* sp., *Zeilleria* (*Terebratula*) and *Lobothyris* sp. have been recorded by the authors. *Protogrammoceras* sp. and *Lytoceras* sp. have been reported from the Sarai Dhoro section in the Uthal area. In the Sarai Dhoro and Drabber Dhoro sections, the uppermost beds of the formation contain belemnites. The uppermost beds in the north of Sand and Pir Bukkar (Windar Nai area) have yielded additional Bajocian cephalopods including poorly preserved large Phylloceratids and Lytoceratids. From 5 to 10 m below this top Bajocian horizon occurs the lower Toarcian *Bouleiceras*, *Dactylioceras* and small brachiopods (Spiriferinids) in marly limestone beds. In Goru section, the lower part contains Upper Toarcian grammoceratid ammonites (*Hammatoceras, Phymatoceras, Phylsiogrammoceras*, etc.). Higher up a single *Graphoceras* was picked indicating a Lower Bajocian age. Some crushed Stephonoceratid ammonite (? *Cadomites* or ? *Skolikostephanus*) and fragments of *Belemnopsis* from the topmost beds (2m) of Anjira Formation in the Mona Jhal section indicate that the age of the formation may not exceed over Bajocian. On the basis of fauna, the age is considered to be Toarcian to Middle Bajocian. The formation is correlated with the Shinawari Formation of Shaikh Budin Hills, Surghar Range and Western Kohat (Samana Range) on the basis of ammonite (*Bouleiceras*).

The deposition of the carbonate sequence appears to have been in a shallow, fluctuating marine environment with a variable intermittent influx of fine clastic material from the source area.

(B) CENTRAL BALOCHISTAN (KALAT-QUETTA REGION)

Ferozabad Group

The name Ferozabad Group (already approved by the Stratigraphic Committee of Pakistan in southern Balochistan) is being extended into central Balochistan with three formations, namely Shirinab, Malikhore and Anjira. The Shirinab

Formation is considered as stratigraphic facies equivalent to the Kharrari Formation of the southern Balochistan and Spingwar Formation of northern Balochistan. The overlying Chiltan limestone is kept a separate unit due to its prominent development with massive limestone ridges in Kalat, Mastung and Quetta and are the oldest rock units developed in areas south and east of Axial Belt in the Sulaiman and Kirthar Provinces where it is overlain by Mazar Dirk formation of Lower Callovian age and unconformably by Mona Jhal Group.

Shirinab Formation

The name Shirinab Formation was introduced by Hunting Survey Corporation (1961) for the oldest rocks in central Balochistan from Shirinab River that drains the Chapper, Mungochar and Shirinab valleys, northwest of Kalat.

The formation consists of limestone with subordinate marl and shale. The limestone is light gray to dark gray, ash gray, weathers rusty brown to brownish gray, thin to thick bedded, mottled, sublithographic, micritic to biomritic with shelly, oolitic, pelletic and pisolitic interbeds. It is also crinoidal, platy, flaggy, dolomitized and argillaceous at places. Coquina beds are common. The marl is greenish gray and nodular. The shale, dominant in the upper part, is buff, maroon, greenish gray to brown, calcareous and ranges from soft flaky to hard fissile.

The base of the formation is not exposed. Its thickness is more than 1000 m in the Kalat section, and 230 m was measured (base not exposed) in the Gurruk-Ziarat section. Its contact with the overlying Malikhore Formation is transitional.

The age of the formation is Pre-Toarcian. Hunting Survey Corporation (1961) and Vredenburg (1909) reportd the presence of Permian fossils in the Shirinab Formation, 11 km southwest of Sar Jangal and 3 km west of Shahr Haji in the Surab-Kalat areas, respectively, but Japanese-Pakistani Research Group (1989) and the authors were unable to locate any Permian outcrops in the area. The present studies indicate that a dark gray, crinoidal, medium- to thick-bedded limestone is underlain by medium-bedded limestone with marl intercalations containing spiriferinids terebratulids and cephalopods including *Harpoceratids* of Early Jurassic (Upper Pliensbachian) age, 3 km west of Shahr Haji. The fossils collected from the Gurruk-Ziarat section include *Rhynchonella* sp., *Terebratula* sp., *Spiriferina* sp. and bryozoans. From Sar Jangal area, middle Liassic ammonite *Oxynoticeras* has been collected. But keeping in view the enormous thickness of the formation, it is believed that it may extend into the Triassic.

Malikhore Formation

The name Malikhore Formation as introduced in southern Balochistan is being extended in central Balochistan to replace the lower part of massive carbonate unit of Chiltan limestone of Hunting Survey Corporation (1961).

The formation is mainly composed of limestone with calcareous shale as partings in the upper part. The limestone is light gray to brownish gray, weathers palish brown. It is thick-bedded to massive, sugary textured, hard, fractured, crystalline and occasionally mottled. It is lithographic to sublithographic, sparitic, shelly and oolitic. Chert is present in the form of nodules. Calcite veins are present in the lower part.

The massive limestone is highly resistant and forms some of the highest ridges within the central Balochistan. The beds dip steeply and the erosion surface has commonly produced a dog-tooth or saw-edge pattern.

The formation is 145 m thick in the Gurruk-Ziarat section. The lower and upper contacts with the Shirinab and Anjira Formations are transitional. It has not yielded any cephalopods but has some poor molluscan fauna (fragmentary gastropods, bivalves, brachiopods, corals, etc.) at different levels. The age is considered to be Early Jurassic. Mottling, bioturbation and wavy bedding indicate that the sediments were deposited in a shallow water carbonate environment.

Anjira Formation

The name Anjira Formation was introduced by Williams (1959) and the Stratigraphic Committee of Pakistan has approved this name for southern Balochistan. Hunting Survey Corporation has mapped it as a part of Chiltan limestone. But the authors have proposed it as the upper formation of the Ferozabad Group.

The formation consists of thin- to thick-bedded limestone interbedded with marl and/or subordinate shale. The limestone is gray to dark gray, weathers brownish gray. It is thin-to thick-bedded, pelletal, hard, fractured, marly, medium grained, biosparitic and shelly. It contains chert nodules and shell fragments at places. The marl is gray, soft, nodular and fossiliferous. The shale is dark gray to greenish gray and calcareous.

The formation is measured to be 135 m in the Gurruk-Ziarat section and 225 m in the Baleli section. Its lower contact with the Malikhore Formation is transitional and is placed where interbeds of limestone and marl/shale start. The upper contact with the Chiltan Limestone is conformable.

The formation is highly fossiliferous. It has yielded *Rhynchonella* sp., *Terebratula* sp., *Spiriferina* sp., Bryozoans, *Bouleiceras* sp., *Nejdia* sp. and *Protogrammoceras* sp. The fossils collected from the Baleli section include *Rhynchonella, Fuciniceras* sp. (Lower Toarcian), *Grammoceras, Dumortieria menaghini, Polyplectus* and *Phymatoceras* sp. (Upper Toarcian). The fauna indicates an Early Jurassic (Toarcian) age. The formation is correlated with the Shinawari Formation of Shaikh Budin Hills, Surghar Range and Western Kohat (Samana Range).

Chiltan Limestone

The name Chiltan Limestone introduced by Hunting Survey Corporation (1961) is accepted as such in central Balochistan which is derived after the Chiltan Range southwest of Quetta (34 J/16).

The Chiltan Limestone can be divided into two parts, the lower and the upper. The lower part consists mainly of limestone which is gray to dark gray, brownish gray, weathers dark brownish gray, fine grained, thin to thick bedded, flaggy, flaky, argillaceous, sublithographic to lithographic and fossiliferous with oolitic, shelly and bioturbated beds. Chert is present along bedding planes as well as in nodular form within limestone (Kalat area). The upper part consists of massive to thick-bedded limestone. It is dark gray to black, weathers dark gray to brown, oolitic, pelletal and crinoidal with dolomite and biohermal units (Lak Pass-Ziarat Nala). It contains hardly any shale and marl intercalations.

The formation is measured to be 260 m (lower part) in the Gurruk-Ziarat section. The lower contact with the Anjira Formation is gradational whereas its upper contact with the Sembar Formation is sharp and disconformable but it is faulted near Kalat. The formation is hard, highly resistant and forms the highest ridges in Kalat and Quetta areas in central Balochistan.

The Chiltan Limestone has yielded poorly preserved fragmentary remains occasionally. But its stratigraphic position above the Anjira Formation suggests the age to be mainly Middle Jurassic. It correlates with the Samana Suk Formation of the Upper Indus Basin. The formation was deposited in a shallow water carbonate environment.

(C) NORTHERN BALOCHISTAN (GWAL-WULGAI-ALOZAI-MARA KILI AREAS)

Alozai Group

The name Alozai group introduced by the Hunting Survey Corporation (1961) is accepted in northern Balochistan. This name is derived from the village Alozai (39 B/10) in the Zhob Valley. The rocks belonging to this group are widely exposed in a long strip in the northern Balochistan between Loralai and Zhob Valley. This Group is recognizable close to Quetta-Ziarat Road section. It is, however, proposed that the undifferentiated Alozai Group should include the following formations:

Loralai Formation	Early to Middle Jurassic
Spingwar Formation	Early Jurassic to Upper Triassic
Wulgai Formation	Triassic

The stratigraphic studies of the Alozai group were carried out in four different sections, i.e., Gwal, Wulgai Nala, Zmari Tangi and Mara Tangi. A normal sequence of rocks from Early Jurassic to Early Cretacerous age is exposed in the Zmari Tangi and Mara Tangi sections. The presence of Permain fossils in the limestone deposited within the shaly horizon of Triassic age suggests the development of an olistolith in Wulgai nala. This body is a few hundred metres in length and caps a small ridge in the upstream of Wulgai Nala (Japanese-Pakistani Research Group, 1989).

A terrain of low relief is developed by the Alozai group for its soft weathering Triassic and Early Jurassic rock units. This character becomes a distinction in recognizing it from the overlying ridge forming Loralai Formation.

The thickness of the group is more than 900m in the Gwal and Wulgai areas, 665m in the Zmari Tangi section (type locality) and 215m in the Mara Tangi section. This group is the oldest rock unit in Balochistan. Its base is not exposed but its upper contact with the Sembar Formation is unconformable and sharp. On the faunal basis the age of the group is considered to be Triassic to Middle Jurassic.

Wulgai Formation

The name Wulgai Formation introduced by Williams (1959) is adopted for the Triassic rocks and is derived after the village Wulgai near Khanozai (34 J/6).

The formation may be divided into the following two Members:-

2.	Upper Member	Upper middle Triassic
1.	Lower Member	Lower Triassic

Lower Member

It consists of shale with micritic limestone intercalations. The shale is black, greenish gray, maroon, silty, non-calcareous, fissile and contains ammonite fossils. The limestone is dark gray to black, weathers brown, fine grained, thin- to medium-bedded, platy and hard. It is dolomitized and sandy at places with some calcite veins.

Upper Member

It consists of shale with limestone and siltstone interbeds. The shale is purple, brownish gray to greenish gray, silty, non-calcareous, siliceous, laminated, fissile and contains calcite veins along the bedding planes. Pencil-shaped weathering is common. It contains *Daonella* and *Halobia*. The limestone is gray to dark gray and weathers brownish gray. It is thin- to medium-bedded, platy, siliceous, micritic, hard and, at places, recrystallized and sparitic with occasional siltstone beds.

The two members are separated by a conglomeratic bed (Middle Triassic?) in the Takai-Gwal section. The complete stratigraphic sections of Triassic formation (Wulgai Formation) could not be measured in a proper way in the Gwal and Wulgai areas due to the complicated structure. The thickness of the formation is more than 900m in the Gwal and Wulgai areas.

The presence of Permain fossils in the dark gray to black, brecciated, fusulinid limestone occurring as an olistostrome, suggests a Permian age. The olistostrome occurs within Triassic shale. On faunal basis the age of the formation is considered to be Triassic. The fossils include brachiopods, conodonts, radiolaria, and *Daonella* from the Wulgai Nala and *Daonella, Halobia* and some ammonites (*Meekoceras, Paranorites, Anakashmirites, Owenites*, etc.) from Gwal area.

Spingwar Formation

The name Spingwar Formation was introduced by Williams (1959) for the Lower Jurassic strata with a type section at Spingwar, north of Zmari Tangi, about 35 km northwest of Loralai.

The formation is mainly comprised of limestone, marl, siltstone and shale. The limestone is dark gray to black and weathers light gray to brownish gray. It is thin- to thick-bedded, platy, lithographic, argillaceous in the lower part, fine to medium grained and fossiliferous. The shale is greenish gray, maroon and purple, silty, calcareous, flaky and fissile. The limestone bands are developed at intervals within shale. The marl is greenish gray, pale gray and splintery.

The formation can be divided in to lower and upper parts. The lower part mainly consists of micritic limestone with occasional dark shale and very pale orange marl beds. The upper part consists of greenish gray, soft-weathering marl and shale with subordinate limestone and calcareous sandstone. The limestone is dark gray, thin-bedded and marly.

The thickness of the formation is more than 665 m in the Zmari Tangi section, 215 m in the Mara Tangi section and 140m in the Tazi Kach section. It is underlain transitionally by the Wulgai Formation of Triassic age and is overlain by the Loralai Formation of Early to Middle Jurassic age. Its age is considered to be Early Jurassic on the basis of fossils and its stratigraphic position. The fossils include ammonites, brachiopods, bivalves, crinoids, corals and shell fragments.

Loralai Formation

The name Loralai Formation was introduced by Hunting Survey Corporation (Williams, 1959) after the town of Loralai (39 B/11). Zmari Tangi, 3 km northeast of Ahmaqzai Killi (39 B/6) is proposed as type locality.

Loralai Formation consists mainly of well-bedded limestone with shale and marl interbeds in the lower part. The limestone is dark gray to black, weathers brownish gray, thin- to thick-bedded, hard, argillaceous, fine grained, sublithographic and breaks with conchoidal fracture. Chert lenses are developed along the bedding planes. In the upper part, it contains oolitic, pisolitic and pelletal beds at places. The shale is black, gray, splintery, papery and calcareous. The marl is greenish gray and soft.

In many localities the formation can be divided into the lower and upper members. The lower member consists of dark gray, micritic and argillaceous limestone interbedded with shale and/or marl. Some beds are mottled and contain Toarcian ammonites. The shale is abundant in this part. The upper member is mainly thin- to thick-bedded, micritic limestone with minor shale/marl as thin partings. The limestone is oolitic and pelletic at places.

As the Loralai Formation is more resistant and harder than the Alozai group and Sembar Formation, it forms prominent ridges in the area.

The thickness of the formation is 250m in the Zmari Tangi section, 360m in the Mara Tangi section and 150m in the Tazi Kach section (Khanozai area). Its lower contact with the Spingwar Formation is transitional and is placed at the base of the main limestone unit, above the uppermost thick beds of greenish gray marl/shale whereas its upper contact with the Sembar Formation is sharp and disconformable.

The Loralai Formation is rich in radiolaria. The age assigned by Williams (1959) and Woodward (1959) is Early Jurassic but Hunting Survey Corporation (1961) and Japanese-Pakistani Research Group (1989) have recorded Toarcian fossils from the lower part of it. During present field investigations some Toarcian ammonites were collected from this part in the Loralai area (*Nejdia* sp. and *Protogrammoceras* sp. from the Khulgai Ali Khel section and *Phymatoceras* sp. from the Mara Tangi section). Some poorly preserved ammonites were also found from the upper part of the Loralai Formation of the Zmari Tangi and Mara Tangi sections. The lower age limit is clearly Late Liassic but the upper limit as considered by the authors may extend upto Bajocian (Middle Jurassic). Thin-bedded, radiolarian and micritic limestone suggests the low energy conditions. Its stratigraphic position is similar to that of the Anjira Formation in southern Balochistan.

LATE JURASSIC - CRETACEOUS

Mona Jhal Group

The name Mona Jhal Group as approved by the Stratigraphic Committee of Pakistan was introduced by Fatmi et al. (1990) from the Mona Jhal anticline (35 I/9), 13 km north of Khuzdar. It is subdivided into the following four formations in ascending order:

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

This group is developed throughout Balochistan and has the same characteristics for the southern, central and northern Balochistan. Hence, it is being proposed to replace Parh group or series of Hunting Survey Corporation (1961) in central and northern Balochistan. In this paper only Sembar Formation is described on the basis of lithological and paleontological studies carried out by the authors.

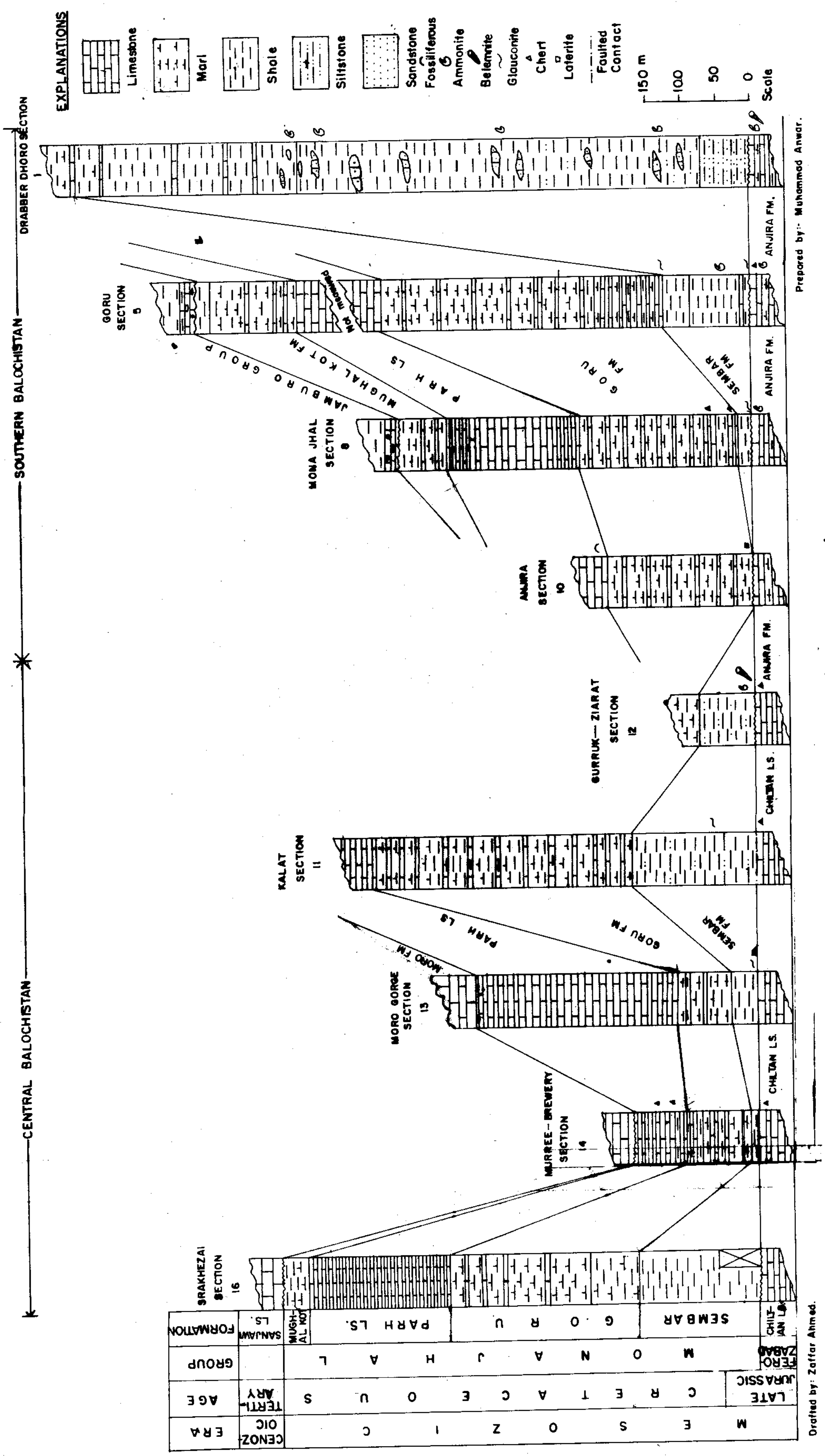


FIGURE 3. COLUMNAR SECTIONS OF MONA JHAL GROUP IN BALOCHISTAN (AXIAL BELT)

Sembar Formation

The name Sembar Formation approved by the Stratigraphic Committee of Pakistan was introduced by Williams (1959) after Sembar Pass (39 C/9).

In southern Balochistan the Sembar Formation consists of dark greenish gray, silty shale, nodular siltstone, rusty-weathering sandstone beds and concretions with occasional glauconite. In the Khuzdar area, the shale is olive green, calcareous, splintery, silty, sandy, fossiliferous and glauconitic at the base with calcareous sandstone and sandy limestone interbeds. In the Windar Nai area, the formation is divisible into lower, middle and upper members. The lower member consists of siltstone, silty shale and sandstone with barite nodules. The middle member is composed of purple, green, silty shale containing siltstone beds and concretionary lenses. Four ammonite zones have been determined. The upper member comprises gray to green, calcareous shale with lenticular marly limestone beds and calcite veins.

In central Balochistan the formation consists mainly of shale. It is yellowish green to dark green and weathers light green to brown. It is glauconitic, silty, fissile to blocky, ferruginous, calcareous and flaky. In the Moro Gorge section, the formation is sandy and non-calcareous with glauconitic sandstone beds and laterite at the base. In the Surrkh Kattai section, northeast of Sanjawi, the lower part of the formation contains shale and sandstone interbeds. The sandstone is purplish gray and weathers brown. It is hard, medium bedded, calcareous, fine grained, micaceous and contains ferruginous concretions. It is gypsiferous at places.

In northern Balochistan the formation mainly consists of shale and siltstone with minor sandstone. The shale is gray to greenish gray, olive green, soft, non-calcareous, splintery and fissile with occasional silty bands. The siltstone is gray and chocolate brown.

The thickness of the formation is 965 m in the Drabber Dhoro section, 126 m in the Goru section and 20 m in the Mona Jhal section in southern Balochistan whereas it is not developed at the Anjira section. In central Balochistan, it is measured to be 178 m in the Kalat section, 80 m in the Gurruk-Ziarat section (east of Purduzai village), 37 m in the Moro Gorge section, 12 m in the Murree-Brewery section and 174m in the Srakhezai section. It is 245 m thick in the Takai-Gwal section in northern Balochistan. The lower contact is with the Anjira Formation in southern Balochistan, with the Chiltan Limestone in central and with the Loralai Formation in northern Balochistan. The contact is disconformable and sharp, marked by a change in lithology. In the Kalat section, it is faulted with the Chiltan Limestone. The upper contact with the Goru Formation is transitional throughout Balochistan.

The basal part of the formation has yielded *Laevaptychus* and some belemnites (*Belemnopsis* and *Hibolithes*) particularly from the Goru and Mara Tangi sections and *Metahoploceras* and *Streblites* sp. (Lower Kimmeridgian) from the Mona Jhal section indicating a Late Jurassic age. Higher up in the middle part, abundant Valanginian fauna collected from the Surrkh Kattai section includes *Phylloceras* sp., *Neolissoceras* sp., *Olcostephanus* sp., *Duvalia* sp. and *Hibolithes*. From the Goru section *Phylloceras* sp., *Bochianites* sp., *Olcostephanus* sp. and *Neohoploceras* sp. have been recorded which indicate Early Cretaceous (Neocomian) age. The middle part in the Barag Hills section (35 K/13) is rich is fauna. Fossils include *Aspidoceras* sp., *Katroliceras* sp., *Lithacoceras* sp., *Ptychophylloceras* sp., *Pachysphinc-tes* and *Hybonoticeras*. The age is considered to be Late Jurassic to Early Cretaceous on the basis of fauna. The formation is correlated with the Chichali Formation of the Shaikh Budin Hills, Surghar Range and Western Kohat.

The Late Jurassic marine transgression in Balochistan appears to be fairly widespread depositing a thick marine sequence of clastic rocks (shale, siltstone and fine sandstone) which become more calcareous in the Early Cretaceous with deepening of the basin. A continuity of sedimentation from Late Jurassic to Early Cretaceous is evident. The thinning of the formation around Khuzdar, Quetta and Ziarat suggests that these areas may not have completely submerged till about Neocomian (Fatmi, 1986).

CONCLUSIONS

The present stratigraphic investigations in the Axial Belt (Balochistan) have resulted in some new information on the nomenclature, age, environments and contact relationship of the rocks of the Ferozabad, Alozai and Mona Jhal Groups in the Axial Belt. Some important conclusions are summarized as under:

1. Two new groups, the Ferozabad Group with three formations (Kharrari, Malikhore and Anjira) and the Mona Jhal Group with four formations (Sembar, Goru, Parh and Mughal Kot), are introduced in southern Balochistan which have been approved by the Stratigraphic Committee of Pakistan.

2. The same groups can be recognised in central Balochistan except that Kharrari Formation is not developed and is replaced northward by the Shirinab Formation of Hunting Survey Corporation (1961) which appears to be a facies equivalent of Kharrari Formation in the south.

3. Mona Jhal Group with four formations is also recognisable in northern Balochistan.

4. The undifferentiated Alozai Group of Hunting Survey Corporation (1961) is considered to include two formations, the oldest being the Spingwar Formation (a name introduced by Williams, 1959) and the youngest being Loralai Formation. The Alozai Group overlies Triassic Wulgai Formation with apparent conformable relationship. This is because of recent find of Hettangian ammonites in Kozh Kach area near Khanozai from the lower part of Alozai Group. Definite Wulgai (Trassic) equivalent is not recognised from southern Balochistan though some oil company geologists reported Upper Triassic shale from Juner section (not visited). The Spingwar Formation is a facies equivalent to the Kharrari and Malikhore Formations. While the Anjira Formation is equivalent to the Loralai Formation.

5. The Permian occurrence in the Wulgai area is an olistolith within Triassic shales and thus there is no outcrop of Permian in situ underlying the Triassic in any locality.

6. There are no Permian outcrops in the Kalat-Surab areas as described by Hunting Survey Corporation (1961) from Shahr Haji and by Vredenburg (1909) from Sar Jangal.

7. Toarcian (Early Jurrasic) fauna has been collected from the lower parts of the Anjira and Loralai Formations and the two thus are time equivalent and not one over the other as contended in Stratigraphy of Pakistan (Fatmi, 1977).

8. Middle Bajocian cephalopods and belemnites have been identified from the topmost beds of the Anjira Formation in the Windar Nai area to fix the upper age limit in southern Balochistan.

9. Mineralized barite- and sulphide-bearing Zones occurs stratigraphically between the Upper Toarcian and the Lower Bajocian strata in the Gunga section. This age is determined on the basis of collected fauna which includes *Hammatoceras* (Upper Toarcian) and *Nanolytoceras* (Lower Bajocian).

10. *Laevaptychus* and some belemnites (*Belemnopsis* and *Hibolithes*) from basal part of Sembar Formation indicate a Late Jurassic age. There is a faunal break from Bajocian to Oxfordian in southern Balochistan. If Chiltan Limestone depositionally showsthickening, a lesser time gap between Chiltan Limestone and Sembar Formation is anticipated and perhaps the deposition continued till Late Bathonian in Kalat area.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. Farhat Hussain, Director General, Geological Survey of Pakistan for the encouragement of these investigations. Thanks are due to Dr. Aftab A. Butt, Institute of Geology, Punjab University and Mr. M. Akram Bhatti, Geological Survey of Pakistan, for the critical review of the paper. The help and cooperation of M/S. Zia Ullah Ch., IER, Punjab University, M. Afaq Khan and M.K. Pasha, Geological Survey Pakistan, to finalize the paper is much appreciated.

REFERENCES

BLANDFORD, W.T. (1879) The geology of Western Sind. Geol. Surv. India. Mem. **17**, pp. 1-196.

FARHAT, H. (1988) Minutes of the 13th meeting of the Stratigraphic Committee of Pakistan. Report, 14p. (Unpublished).

FATMI, A.N. (1969) Lower Callovian ammonites from Wam Tangi, Nakus, Balochistan. Geol. Surv. Pakistan Mem. **8**, pp. 1-14.

——**(1977)** Mesozoic of Pakistan: *In:* Shah, S.M.I. (ed.), Stratigraphy of Pakistan. Mem. Geol. Surv. Pakistan. **12**, pp. 29-56.

——**(1984)** Stratigraphy and stratigraphic problems of the Jurassic rocks of Pakistan. Internat. Symp. Jurassic Stratigraphy, Erlangen (Germany), Vol. **3**, pp. 653-660.

——**(1986)** Lower and Middle Jurassic ammonites from "Windar group" in Phusi Jhal (Kanrach) and Sand (Windar Nai) sections of Lasbela Balochistan, Pakistan. Mem. Geol. Surv. Pakistan. **16** (parts 1,2), 28 + 25p.

——**, HYDERI, I.H., ANWAR, M. & MENGAL, J.M. (1986)** Stratigraphy of "Zidi formation" (Ferozabad Group) and "Parh group" (Mona Jhal Group), Khuzdar District, Balochistan, Pakistan. Rec. Geol. Surv. Pakistan **75**, 32 p.

——**, HYDERI, I.H., ANWAR, M., MENGAL, J.M., HAFEEZ, A. & KHAN, M.A. (1990)** Stratigraphy of Mesozoic rocks of southern Balochistan, Pakistan. Rec. Geol. Surv. Pakistan. (In press).

HUNTING SURVEY CORPORATION (1961) Reconnaissance geology of part of West Pakistan (Colombo Plan Cooperative Project). Toronto, Canada, 550p.

JAPANESE-PAKISTANI RESEARCH GROUP (1989) Preliminary report of general survey on the geology of Balochistan: *In:* Okimura, Y. & Fatmi, A.N. (eds.) Tectonics and sedimentation of the Indo-Eurasian colliding plate boundary region and its influence on the mineral developments in Pakistan. Hiroshima University, pp. 2-31.

NOETLING, F. (1897) Fauna of the Upper Cretaceous (Maastrichtian) beds of the Mari Hills, Baluchistan. Mem. Geol. Surv. India Paleont. Indica, ser. **16**, 1, 3, pp. 1-79.

OLDHAM, R.D. (1892) Report on the geology of Thal Chotiali and part of the Mari country. Rec. Geol. Surv. India, **25,** (1), pp. 18-29.

VREDENBURG, E. (1909) Report of the geology of Sarawan, Jhalawan, Makran and the State of Lasbela. Rec. Geol. Surv. India **38** (pt.3), pp. 189-215.

WILLIAMS, M.D. (1959) Stratigraphy of the Lower Indus Basin, West Pakistan. World Petroleum Congr. 5th, New York, Proc. Sec. 1, Paper **19,** pp. 377-390.

WOODWARD, J.E. (1959) Stratigraphy of the Jurassic System, Indus Basin. Stand. Vacum. Oil Co., pp. 2-13 (unpublished report).

Received on April 19, 1991.
Accepted for publication on May 31, 1991.

ACTA MINERALOGICA PAKISTANICA
VLUME 5 (1991) pp. 62 - 69.

USE OF RESISTIVITY METHOD IN GROUNDWATER STUDIES OF MAULI AND TUTAK VALLEYS, BALOCHISTAN, PAKISTAN.

UMAR FAROOQ & NASIR AHMAD
Institute of Geology, Punjab University,
Quaid-e-Azam Campus, Lahore-54590, Pakistan.

ABSTRACT: The geology and the groundwater conditions in the area are briefly described. Geophysical investigations, using electrical resistivity method, with Schlumberger configuration AB/2=400m were undertaken at most of the V.E.S. locations. The data from 29 Schlumberger soundings have been analyzed. The interpreted geoelectric sounding results have been compared with bore hole sections wherever available. It has been found that in Tutak Valley there is considerable scope of obtaining large quantities of water from the subsurface groundwater storage through shallow wells as well as tubewells.

INTRODUCTION

Like other parts of Balochistan, the project areas suffer from water shortage both for agriculture and domestic purposes. This is primarily because of insufficient rainfall, large run-off and limited water percolation into the ground. The area is covered with consolidated sediments ranging in age from Jurassic to early Eocene, and unconsolidated sub-Recent to Recent alluvium of Quaternary age. The thickness of this alluvial fill is unknown. The surface layer of valley floor is constituted by gravelly loam. The subsurface material expected is coarser in piedmont area and grades finer towards the centre of valley floor. Water is stored within this unconsolidated fill, and is the main source of groundwater in the area. From the point of view of groundwater investigations, the problem is to determine the thickness of the water-bearing horizons, total groundwater storage within sounding depth, and the safe limit of yield for such aquifers.

The usefulness of the resistivity method in geological mapping depends to a considerable extent on the resistivity contrast. The contrast may exist due to discontinuity of rock formation or change in physical condition. So the resistivity method can be successfully employed for groundwater investigations, where a good electrical resistivity contrast exists between the water-bearing formations and the underlying rocks (Zohdy et al., 1974).

In general, the matrix minerals in rocks are insulators. In rocks containing fluids, current is conducted electrolytically by the interstitial fluids and resistivity is controlled by porosity, water content as well as quality of water. Clay minerals, however, are capable of storing electrical charges and current conduction in clay minerals is electronic as well as electrolytic (Zohdy *et. al.*, 1974). Thus, unconsolidated sediments, when water-bearing, show low values of resistivity as compared to high resistivity values for dry sediments (Bose et al., 1973).

In order to meet the acute shortage of water in the valleys, geophysical investigations, using electrical resistivity method, have been carried out in collaboration with the Directorate of Hydrology, WAPDA, Quetta, under USAID programme; and are discussed in this paper. The locations of project areas are shown in Figs. 1 and 2.

GEOLOGY

The valleys lie within the Axial Belt in close association with the Khuzdar Syntaxis ("Khuzdar Knot" of Jones, 1960). The Khuzdar Knot is formed

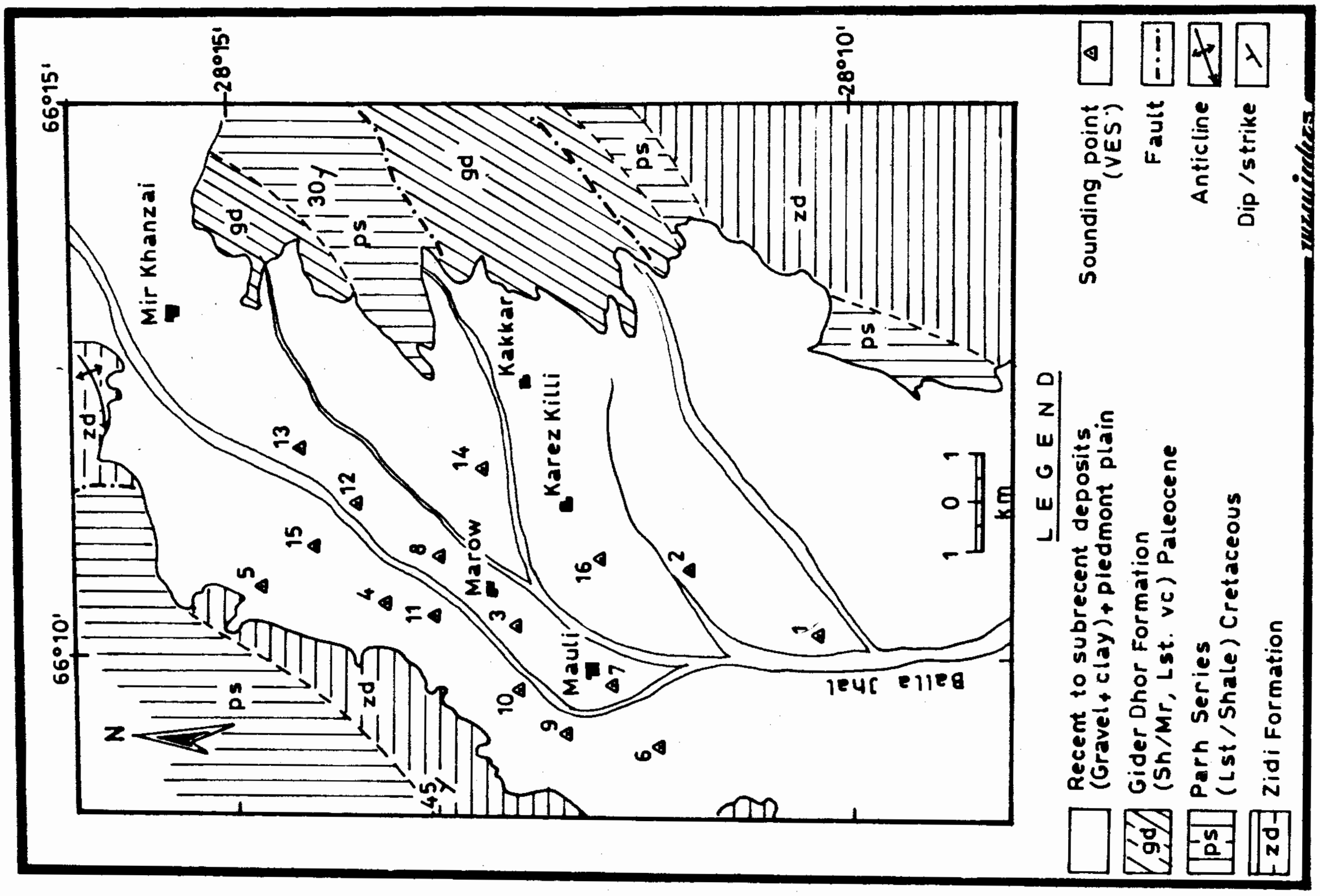


FIG. 1. GEOLOGY OF THE MAULI AREA AND LOCATION OF SCHLUMBERGER SOUNDING (VES) POINTS.

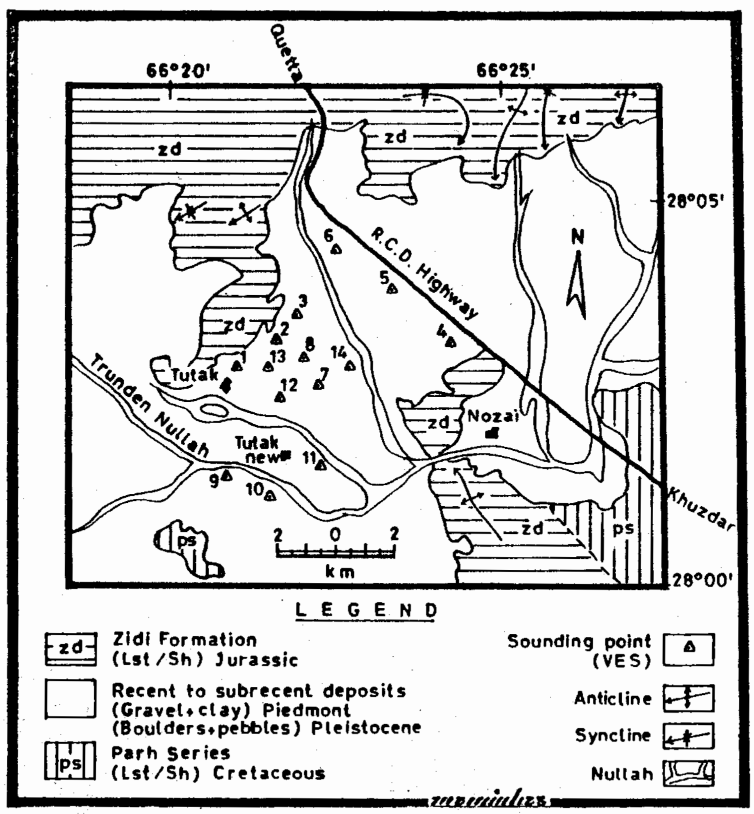


FIG. 2. GEOLOGY OF TUTAK AREA AND LOCATION OF SCHLUMBERGER SOUNDING (VES) POINTS.

mainly in the Mesozoic rocks, by two successive changes in the fold trends. The consolidated rocks range in age from Jurassic to late Cretaceous (early Eocene) and their distribution is shown in the geological map of the area (Figs. 1,2). The formations exposed in the catchment largely consist of limestone and shale, with minor component of sandstone. These older formations are not described, and they are of little importance for the development of groundwater resources in the valleys.

From viewpoint of development of groundwater resources in the valleys (Aslam, 1977), the sub-Recent to Recent deposits of valleys are far more important and they make the piedmont alluvium and valley floor. The piedmont alluvium starts from the base of mountain highland and merges into the central part of undulating surface and abundant flood plains. It is an area of intermediate slope and relatively uneven surface. The piedmont alluvium constitutes one of the main deposits for groundwater recharge in the area and is composed of the debris brought down by the streams (nalas) from the catchment area. The piedmont plain is dominantly developed in eastern and southern part of both Mauli and Tutak valleys respectively.

The valley alluvium constitutes the central part of the project areas which start from the lower limit of the piedmont plain. It is characterized by the flat but graded topography. The valley alluvium is largely composed of silty material, including thin stringers of pebbles and gravels down to a depth of 30 feet.

HYDROGEOLOGY

The climate in the area is of arid type. Average annual precipitation is 20 cm / year. About 55% of the annual precipitation occurs during the months of January, July and August. Winters are cold and summers are moderate (Table 1).

Streamflow, a very important factor in water supply of the project area, is entirely dependent on precipitation that falls within the drainage basin. Precipitation in the basin occurs completely in the form of rainfall. No perennial streams of any significant size enter the Tutak valley except Tutak Karez, originating from a spring near old Tutak village Nargise seepage is located near Nargise Jhal in western corner of the valley. Water seeps through unconformity plane between Parh Series and Recent deposits. Mauli valley is completely recharged by non-perennial streams. Hydrogeologically, the unconsolidated alluvial fill is by far the most important in the area. It constitutes water aquifers, and is the main source of groundwater in the area.

FIELD INVESTIGATION

All resistivity observations were performed with Heinrich type geohmeter consisting of resistivity sender MK 2A and receiver MK 3. Thick mild-steel rods were used for transmitting the current into the ground and porous pots with saturated copper sulphate solution, with copper rods dipped into them, served as potential electrodes. Power was supplied from power generator of 5 Ampere capacity.

In order to get an idea of geological sequences and the associated resistivity values, altogether 29 Schlumberger soundings (Zohdy, 1969) were taken from above-mentioned areas. The location of sounding points is shown in Figs. 1 and 2. Soundings were taken with AB/2=m, subject to the limitation of accessibility. For Schlumberger soundings, apparent resistivity values (a) were plotted against half current electrode separation (AB/2) on transparent double log graph paper of modulus 62.5mm, and a smooth curve was drawn for each of the V.E. Soundings. The field curves were interpreted by partial curve-matching technique using the auxiliary point methods of electrical sounding interpretation (Koefoed, 1960, 1979). This interpretation was later confirmed by RESIST 87 computer programme for V.E.S. data interpretation.

Results of Resistivity Survey of Mauli Valley

The geoelectrical section prepared on the basis of results of V.E. Soundings (Fig. 1) corresponds to a longitudinal section PQ running almost parallel to the Sar Mauli nala. This section is shown in Fig. 3b. The section shows the extent and thickness of different geoelectrical layers in terms of inferred geology.

The topmost layer throughout the traverse is found to be thin (2-8m). This is considered to be dry gravelly loam having resistivity from 128 to 380 ohm-m. The second layer, overlain by surface layer, continues down to a depth of 15m to 48m from the surface. The resistivity values of this layer vary from 106 to 330 ohm-m. Such high resistivity probably represents gravel and boulder beds of old stream. This high resistivity layer is underlain by third layer resistivity values from 52 to 90 ohm-m which may be due to gravel with intercalation of clay (mixture of gravel and clay). Resistivity section indicates that this horizon gradually thickens from SW to NE direction through V.E.S 10 and V.E.S. 11 and attains maximum thickness at V.E.S. 12 (upto 200m deep below the surface).

It can be seen from the resistivity cross-section that the resistivity of the fourth (last) layer is very low (13-28 ohm-m) all along the traverse which may be due to clay/shale layer appearing at deeper depths. This layer continues down to the maximum explored depth as shown in the section and may indicate the bedrock.

Comparison of Results of V.E.S 4 of Mauli Area with a Testhole Profile

The results of V.E. Sounding station 4 have been compared with the geological section obtained from Text-hole 2, which acts as control point. Comparison is shown in Fig. 4. The thickness of the surface layer as obtained from the interpretation of sounding curve is, for all practical purposes, in good agreement with the test-hole section. It has been found that the interface between surface layer and second layer occurs a little bit at higher level than that interpreted from the sounding curve.

The interpretation of Schlumberger sounding station 4 indicates that the second layer is probably gravel and third one gravel with interclations of clay. The boundary between second layer and the third layer of V.E. Sounding is not so well brought out by the borehole section. On geological section these two geoelectrical layers merge into one. The interface between fourth layer and third layer of sounding curve is, however, in very good agreement with the geological section of testhole no.2.

Results of Resistivity Survey of Tutak Valley

In order to facilitate interpretation of the resistivity data, the subsurface sediments have been categorized into three resistivity zones and the continuation and correlation of these zones in depth, alongwith two resistivity sections, have been discussed. The location of the sounding points is shown in Fig.2. Two geoelectric sections along line AB and LM, prepared on the basis of Schlumberger sounding results, are shown in figs. 5b and 6. The resistivity section along AB is comprised of V.E. Soundings 1,2 and VES 3. The sounding stations are near to the Tutak village (old) in the north-western part of the valley. It can be seen from the sounding results that the top soil layer has a maximum thickness of about 5m and varies in resistivity from 40 to 154 Ohm-m. The resistivity of the second layer has been found to be high (100-231 Ohm-m) all along the geoelectric section which may be due to gravel. The maximum depth of this gravelly layer has been found to be about 46m from the surface at VES 2. This high resistivity layer is underlain by a layer whose resistivity varies from 42 to 78 Ohm-m. The variation in resistivity value of this horizon is probably due to the variation of fine sediments content in it. The lithology assigned to this layer may be admixture of gravel and clay. The third layer continues down to a depth of 42-70m from the surface.

Futhermore, the geoelectric section indicates that the fourth layer is sandwitched between two layers of moderate resistivity values, overlain by third layer and underlain by fifth layer. The resistivity values of this layer vary from 17-33 Ohm-m. This is a prominent clay / shale layer which attains maximum thickness of about 130m at VES 2. The last layer has resistivity value from 42 to 82 ohm-m and continues down to the maximum explored depth. This layer is possibly gravel with interclation of clay.

The resistivity-section along LM through VES 9, 10 and 11 is shown in Fig. 6. The V.E. sounding stations in this section are located in the southern part of valley. The section is across the Trunden nala near Tutak village (new). This zone largely consists of high resistivity layers. The medium resistivity layers are of very limited extent. It may therefore, be concluded that southern part of Tutak valley is probably underlain by a considerable thickness of gravel/boulder beds.

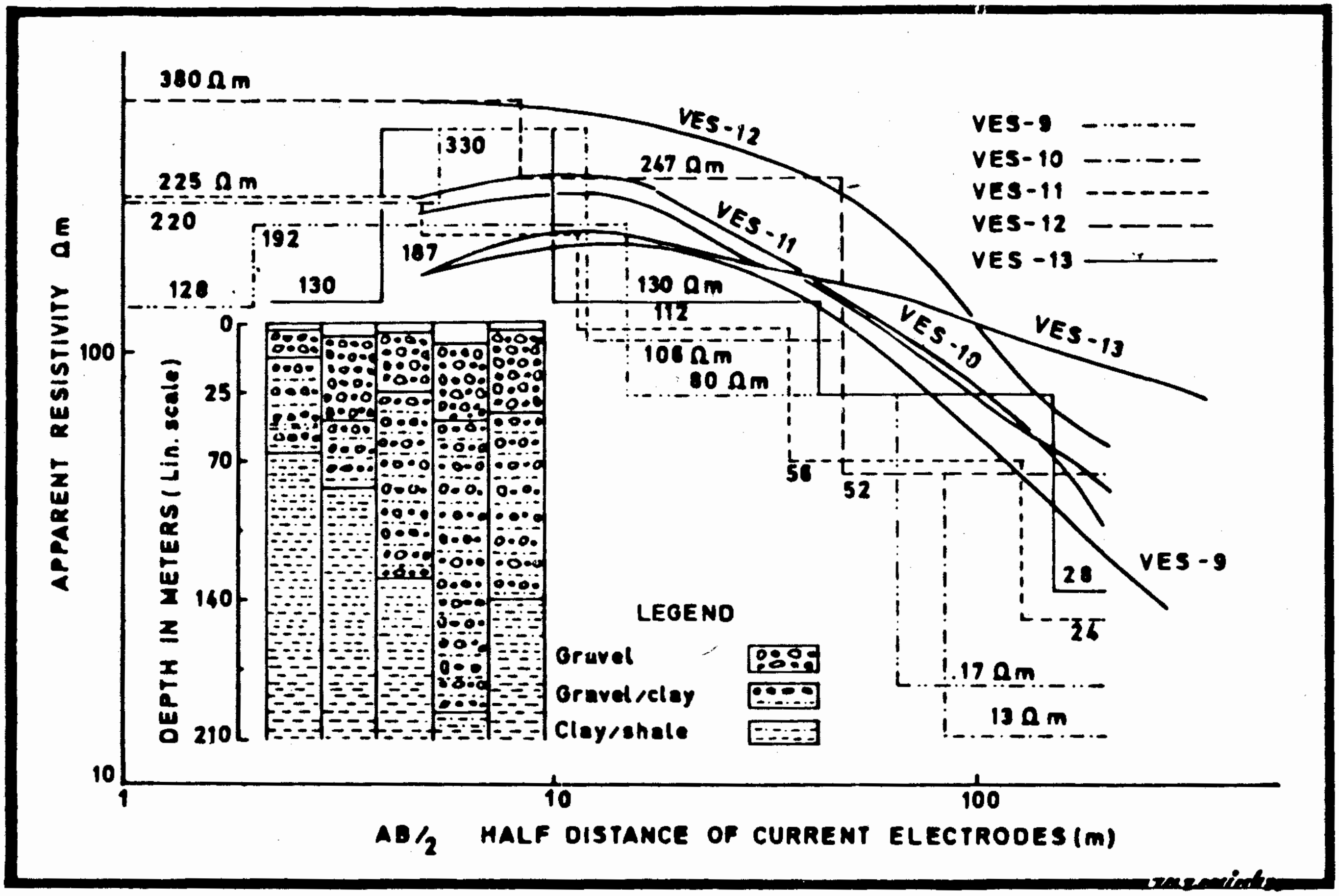


FIG. 3a. SCHLUMBERGER V.E.S CURVES OF MAULI AREA REPRESENTING SECTION 'PQ'

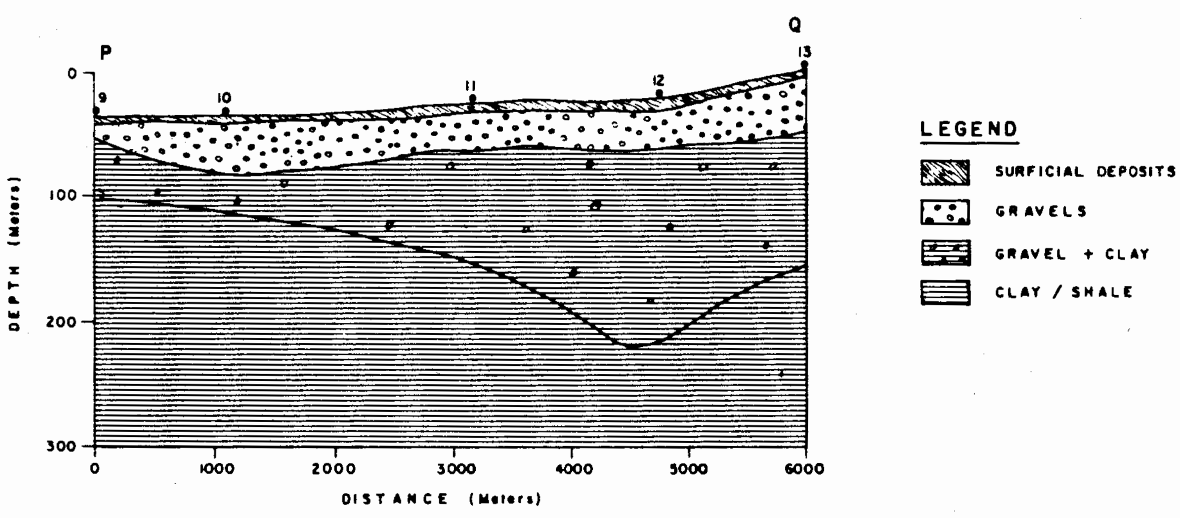


FIG. 3b. GEOLOGICAL SECTION ALONG PQ PREPARED FROM THE INFORMATION GIVEN IN 3a

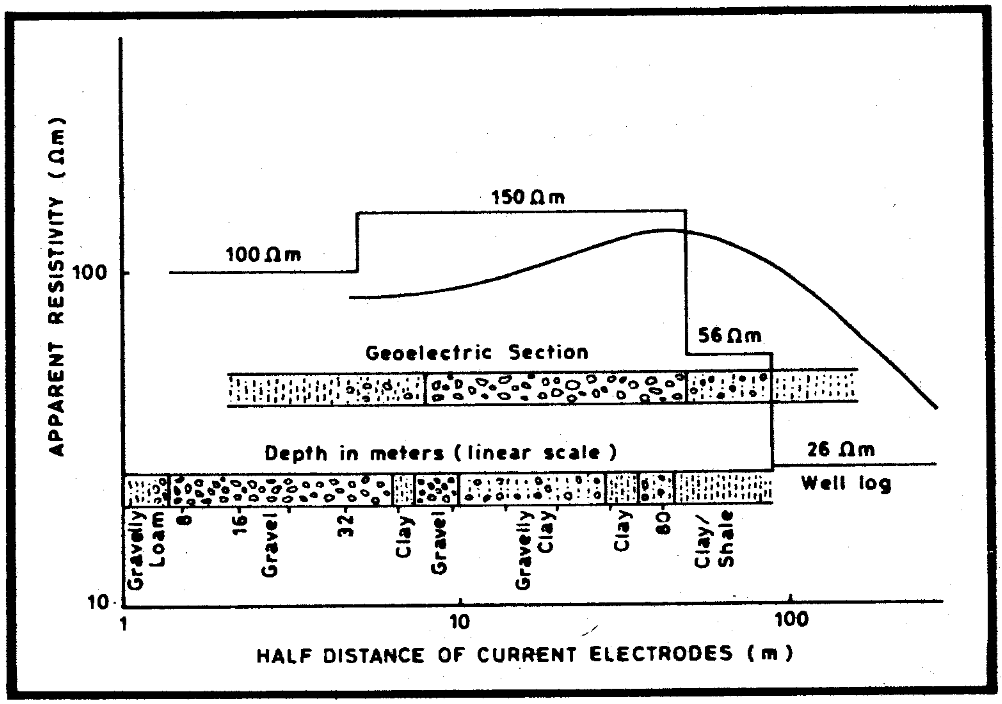


FIG.4. WELL PROFILE AND RESISTIVITY CURVE (VES4) AT MAULI KILLI

CONCLUSIONS

The geophysical studies of the area indicate the presence of 3 to 4 layers in almost all the cases. The first layer invariably corresponds to the soil cover (surface layer). This is underlain by coarser debris, possibly gravel and boulder beds underneath which mixture of coarser and finer sediments and / or fine sediments alternate.

The southern part of Tutak valley (near new Tutak) appears to be filled with coarser deposits, probably gravel/boulder beds. These beds gradually disappear towards northern, north-western (Tutak old) and northeastern parts of valley at deeper depths. However, it is observed that a layer of coarser debris may exist at shallow depths, overlain by top layer, in both Mauli and Tutak areas. It has also been found that a prominent clay/shale layer, possibly the bed rock, appears at deeper depths throughout the Mauli Valley, and may be identified in test-holes.

Therefore, in Tutak Valley there is considerable scope of obtaining large quantities of water from the subsurface groundwater storage through shallow wells as well as tubewells. Southern part of the valley may be recommended for heavy duty tubewells, while in rest of the Tutak valley and throughout the Mauli valley, fair quantities of water may be obtained from shallow depths by means of light-duty tubewells and open wells.

ACKNOWLEDGEMENTS

The authors are thankful to Prof. Dr. Shafeeq Ahmad, Director of the Institute, and Dr. Aftab Ahmad Butt for their useful discussions. Thanks are also due to Mr. Nadeem Ahmad for his help in typing the manuscript.

REFERENCES

ASLAM, M. (1977) Hydrogeological reconnaissance survey report of Mauli and Tutak areas, Baluchistan. Hydrogeological Directorate of WAPDA, Quetta. (Unpublished Report).

BOSE, R.N., CHATTERJEE, D. & SEN, A.K. (1973) Electrical resistivity surveys for groundwater in Aurangabad subdivision. Geoexploration, Bihar, India. **11**, pp. 171-181.

JONES, A.G. (ed.), (1960). RECONNAISSANCE GEOLOGY OF PART OF WEST PAKISTAN; A Colombo Plan Cooperative Project: Govt of Canada, Toronto, **550** p.

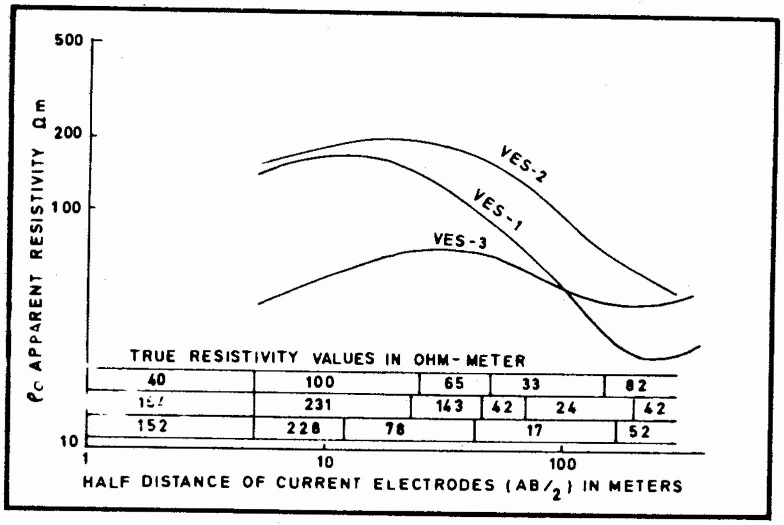


FIG. 5a SCHLUMBERGER V.E.S. CURVES OF TUTAK AREA REPRESENTING SECTION 'AB'

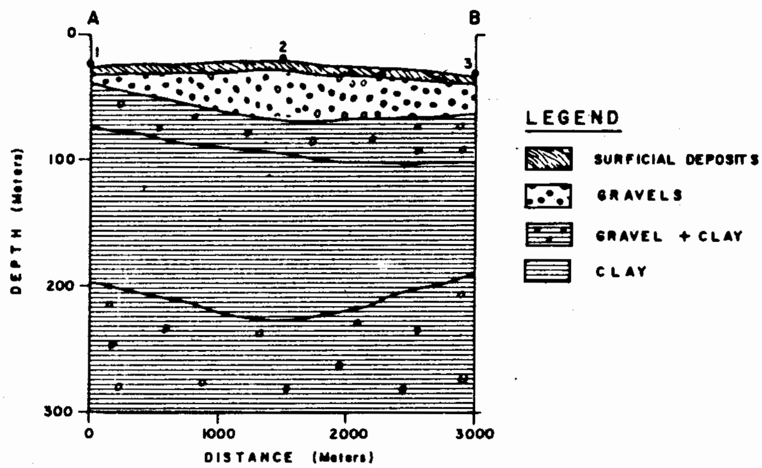


FIG. 5b.
GEOLOGICAL SECTION ALONG AB PREPARED FROM THE INFORMATION GIVEN IN 5a

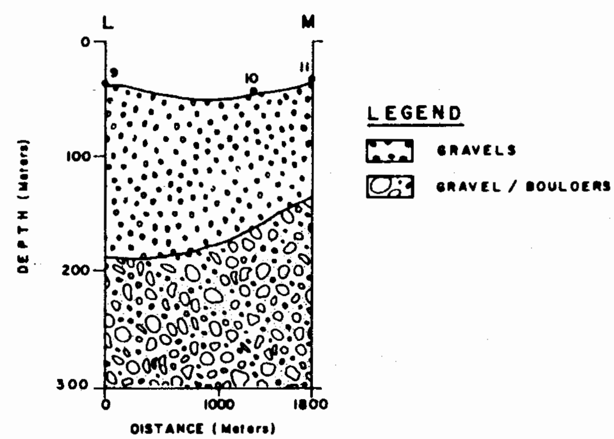


FIG. 6.
GEOLOGICAL SECTION ALONG LM BASED UPON TRUE RESISTIVITY VALUES OF VE SOUNDINGS 9,10 & 11 OF TUTAK AREA

KOEFOED, O .1960. A generalized Cogniard graph for the interpretation of geoelectrical sounding data. Geophys. Prospect. **8**, pp. 459-469.

——— **1979.** GEOSOUNDING PRINCIPLES, 1: RESISTIVITY SOUNDING MEASUREMENTS. Elsevier, Amsterdam.

ZOHDY, A.A.R., & JACKSON, D.B. (1969). Application of deep electrical soundings for groundwater exploration in Hawaii. Geophysics **34**, pp. 584-600.

——— **, EATON, G.P. & MABEY, D.R. (1974)** Application of surface geophysics to groundwater investigations. Techniques of Water-Resources Investigations of the United States Geological Survey. Book 2, Chapter D1. U.S. Geological Survey, Washington, D.C.

Manuscript received on April 20, 1991.
Accepted for publication on June 30, 1991.

ACTA MINERALOGICA PAKISTANICA
VOLUME 5 (1991) pp. 70 -76.

GEOCHEMISTRY OF SALINE LAKES FROM SOAN-SAKESAR VALLEY, KHUSHAB DISTRICT, PAKISTAN.

SHAFEEQ AHMAD,
Institute of Geology, Punjab University, Lahore, Pakistan.
MOHAMMAD FAROOQ
Directorate of Land Reclamation, Mughalpura, Lahore, Pakistan.
&
FAYAZ UR REHMAN
P.C.S.I.R. Laboratories Complex, Ferozepur Road, Lahore, Pakistan.

ABSTRACT: Surface water samples were collected from three lakes from Soan-Sakesar valley; namely Uchhali, Khabbaki and Jahhlar and their adjoining wells/seepages/springs. These samples were analyzed for major cations and anions. The weight ratio of Na/(Na + Ca) as a function of TDS (Gibbs boomerang-shaped envelope) shows that the chemistry of these lakes is mainly controlled by an evaporation-crystallization process with minor contribution of dissolved salts continuously adding from the sub-merged seepages/springs of hard/soft waters emerging from underlying sedimentary rocks. Uchhali lake is highly saline; while Jahhlar and Khabbaki lakes are moderate and less saline lakes, respectively. The Uchhali wells have not shown to be affected by the lake water, while Khabbaki wells are moderately affected by the lake water with respect to SO_4.

INTRODUCTION

Lakes are beautiful physiographic features found worldwide. They are important to the scientists in understanding the chemical/biological processes occurring in these natural laboratories. Recently, a lot of work has been done by different research workers in understanding the chemistry of these lakes; see for example, Comin & Alonso (1988), Hurlbert & Chang (1988), Schmid (1988), Stumm & Lerman (1989) and Kilham (1990). Many have studied these lakes for the distribution, history, abundance and tolerance of the biota, i.e., the biological aspect; see for example, Bowen et al. (1988), Colburn (1988), Williams & Kokkinn (1988) and Wood & Talling (1988). The present study aims at the origin, water chemistry, salinity problems and process that controls the chemistry of three lakes from Soan-Sakesar valley and their surrounding wells/springs/seepages.

MATERIAL AND METHODS

Fifty surface water samples were collected from the three lakes and their adjoining wells, streams and springs in March 1986. Water samples were obtained in 1-litre polyethylene bottles and were stored at 4°C. The pH and EC of the water samples were measured in the field. Standard analytical procedures were adopted from Richards (1968) for the determination of major and minor ions in the water samples, and are summarized as follows: sodium and potassium by flame photometry; calcium and magnesium by compleximetric titration against ethylenediaminetetra-acetic acid (EDTA) using ammonium purporate and eriochrome black T as indicators; alkalinity (bicarbonate and carbonate) by titration to 8.5 and 4.5 end-point; chloride by titration against silver nitrate; sulphate by back titration with barium chloride.

GEOLOGY AND GEOGRAPHY

The Soan-Sakesar valley starts at the extreme north of Khushab District (Punjab Province, Pakistan) surrounded by the two parallel east-west longitudinal ridge systems. The average elevation of this area is around 2500 feet and the highest point besides this area is the Sakesar-top at 4992 feet above sea level. The area is covered by sedimentary rocks (clastic and non-clastic), mainly

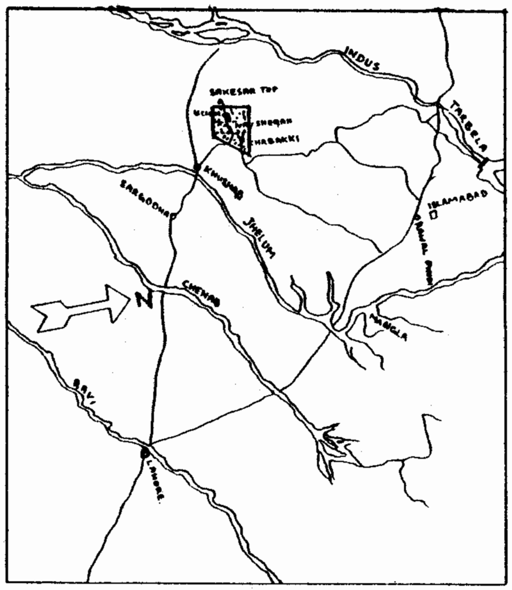


Fig 1. Location map of the studied area.

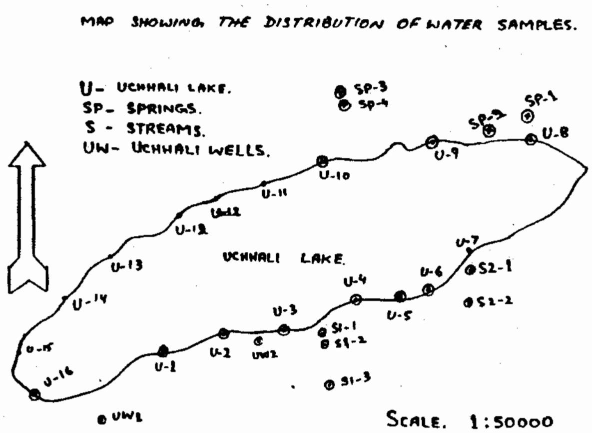
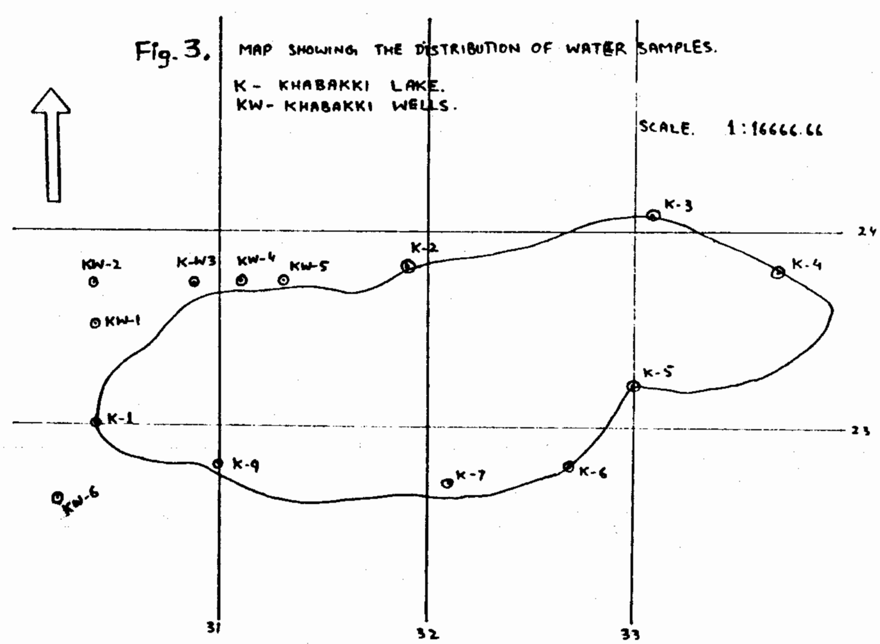


Fig 2. Map showing the distribution of water samples of Uchhali lake and its surrounding wells/springs/seepages.



of Tertiary age. Three lakes have been reported in the area namely; Uchhali, Khabbaki and Jahhlar having 14, 4 and 2.5 km^2 areas respectively (Fig. 1). These lakes were developed in the synclinal structures formed by the folding of Eocene rocks. The area is mainly exposed by Sakesar Limestone of Eocene age. The upper part of the Sakesar Limestone shows unconformable contact with Murree Formation. The lower contact with the Nammal Formation is gradational as observed in the working mine at Uchhala village. A brief description of these lakes is given below:

Uchhali lake

The Uchhali lake is situated near Uchhali village having an area of about 14 km^2. It is elliptical in shape. The origin and age of the lake is uncertain. However, the size of the lake has sufficiently increased as reported by the locals and the old aerial photographs. Like Khabbaki lake, it also has an internal drainage system. Four active streams/ seepages are continuously adding water to its southern side. One major seepage in the mid-way to Kufri and Anga is also contributing from the eastern side. Six springs of hard/soft water at northern side are the major source of input. The northern part of the lake is directly in contact with Sakesar limestone, while the other sides of the lake are with alluvial plains. Structurally, Uchhali lake forms a synclinal feature. The water level of Uchhali lake has also been arisen for the last few years, which causes a great many changes in the physiographyof the area, e.g., an old metalled road from Uchhali to Chitta and much of the cultivated land has been eaten by the lake. Fourteen surface water samples from the lake, and its adjoining wells/springs/seepages were collected for water analysis. The distribution of these samples is shown in Fig. 2.

Khabbaki lake

It is also elliptical in shape, with longer axis in E-W direction. The eastern flank of the lake touches the village Khabbaki, hence the name. According to the local information, the Khabbaki lake had appeared before 1950 as a small pond having its enclosed internal drainage system. The lake is recharged by two springs at its northern bank, which are now submerged. The lake is directly in contact with Sakesar limestone at its northern flank. Now for the last few years, the water-level of Khabbaki lake has gone up unexpectedly, which caused great disasters in the area, for example, a metalled road, three Dhoks (small residential places), and a nearby fruit garden, and surrounding wells and cultivated land were perturbed by the lake water. Eight surface-water samples from lake and its surrounding wells/ springs were collected for analysis. The distribution of these water samples is shown in Fig. 3.

Jahhlar lake.

The Jahhlar lake is located near Jahhlar village, at a distance of about 5 km in the south of Kufri. It is a bowl-form depression, surrounded by high hills. Five surface-water samples were collected from lake for analysis.

RESULTS AND DISCUSSION

The geochemical data for the three lakes and their surrounding wells/seepages/springs alongwith their averages is given in Table 1. It can be seen from Table 1 that the data does not show a significant variation in the chemistry of surface water. Therefore, the average data for the three lakes can be used for the discussion/comparison purposes.

Three natural mechanisms are said to control the chemistry of lakes and rivers: atmospheric precipitation, rock dominance and the evaporation-crystallization process (Gibbs, 1970; Kilham, 1990). Furthermore, the waters on the Earth's surface can be distinguished from each other on the basis of both their total ionic contents (salinity) and the mutual proportions (ionic ratios) in which various ions are present (Chester, 1990). Therefore, the relative importance of each mechanism can be evaluated by plotting the weight ratio of Na/ (Na + Ca) as a function of total dissolved salts. Gibbs (1970) showed that if the three mechanisms are of equal importance then a boomerang-shaped envelope of the data is observed. The end-member formed by the atmospheric precipitation is mainly characterizesd by the low weathering intensity and high rates of evaporation (upper diagonal arm); while rock-dominance end-member is characterised by high weathering intensity and low rates of evaporation (middle); and an evaporation-crystallization end-member is characterized by high weathering intensity and high rates of evaporation (bottom arm), as shown in Fig. 4(i).

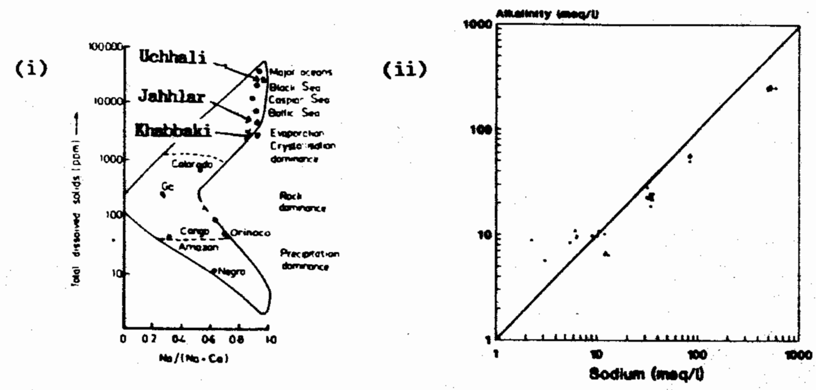


Fig. 4 . (i) Variation of Na/(Na + Ca) as a function of total dissolved salts (modified from Chakrapani and Subramanian, 1990). (ii) Total alkalinity (mainly CO_3 + HCO_3) vs Na for the waters of Soan-sakesar valley.

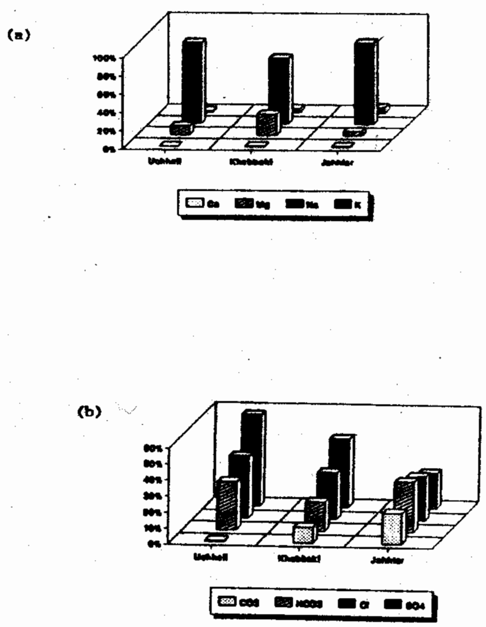


Fig. 5. Average chemical composition of major ion concentrations in the water samples of three lakes from Soan-sakesar valley. (a) Major cations. (b) Major anions.

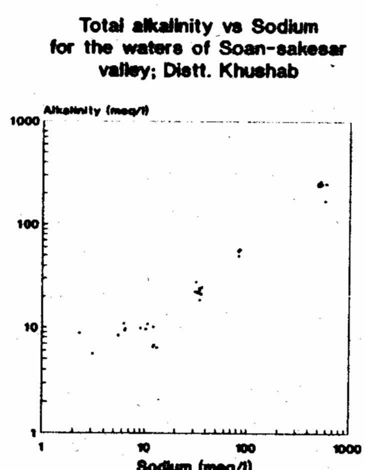


Fig. 6.

Table 1. Chemical composition of surface water samples from Uchhali, Khabbaki and Jahhlar lake (Soan-Sakesar Valley; District Khushab, Punjab), in units meq/1.

	S.No.	pH	EC	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	TDS
Uchhali	U-1	> 11	40000	tr	61	489	10.2	2.0	23.0	220	316	25600
lake	U-2	"	40000	tr	46	491	8.2	1.0	18.9	221	319	25600
	U-3	"	42000	tr	30	491	11.5	–	18.0	218	349	26880
	U-4	"	40000	tr	61	533	8.9	1.6	18.6	231	309	25600
	U-5	"	41000	tr	40	491	7.7	2.4	16.0	226	326	26240
	U-6	"	43000	tr	61	489	7.7	4.2	16.4	235	345	27520
	U-7	"	44000	tr	43	520	8.9	5.0	16.2	226	381	28160
	U-8	"	44000	tr	60	511	7.7	5.6	17.2	230	377	28160
	U-9	"	42000	tr	64	489	8.2	6.6	20.7	227	331	26880
	U-10	"	40000	tr	41	511	8.2	4.4	18.8	230	307	25600
	U-11	"	42000	tr	65	520	7.7	5.6	20.9	240	318	26880
	U-12	"	42000	tr	86	491	8.2	2.4	16.4	233	333	26880
	U-13	"	41000	tr	50	509	11.3	2.6	20.8	230	319	26240
	U-14	"	46000	tr	85	587	8.2	13.4	10.8	239	417	29440
	Average	> 11	41929	–	56	509	8.8	4.1	18.1	229	339	26834
Uchhali	S1-1	8.2	2500	5.9	8.9	10.5	0.9	0	10.1	0.6	15.5	1600
seepages	S1-2	8.5	2600	5.8	8.7	11.9	0.8	2	5.8	0.7	18.7	1664
springs	S1-3	8.1	2575	5.2	8.7	12.2	0.8	0	6.1	0.7	20.1	1648
wells	S2-1	7.8	1850	0.9	6.8	12.0	0.6	0	9.6	0.5	10.2	1184
	S2-2	8.0	1950	1.3	6.5	13.1	0.8	0	5.6	0.8	15.3	1248
	Sp-1	8.2	4600	4.8	14.5	31.5	1.1	0	25.2	2.7	24	2944
	Sp-2	8.1	4600	4.2	10.5	35.9	0.8	0	22.4	2.2	26.8	2944
	Sp-3	7.5	975	0.8	6.5	2.3	0.6	0	8.5	0.3	1.4	624
	Sp-4	7.3	800	0.8	4.0	3.1	0.4	0	5.2	0.4	2.7	512
	Uw-1	7.5	1400	-	7.04	6.94	0.4	0.9	3.0	0.4	8.99	896
Khabakki	K-1	8.5	4000	0.3	10.8	30.9	2.2	5.0	9.5	13.0	17.5	2560
lake	K-2	8.5	4300	0.3	10.5	35.5	2.0	3.6	8.2	13.0	23.7	2752
	K-3	8.5	4200	0.3	10.6	34.1	2.2	4.2	5.6	13.0	24.7	2688
	K-4	8.6	4200	0.2	10.7	34.3	2.0	5.0	8.6	14.5	19.2	2688
	K-5	8.5	4100	0.2	10.8	32.4	2.3	5.4	8.2	14.0	18.4	2624
	K-6	8.6	4000	0.4	10.2	32.2	2.0	4.8	9.4	12.5	18.3	2560
	K-7	8.6	4200	0.3	11.2	33.8	2.0	5.0	9.6	14.5	18.4	2688
	K-8	8.6	4200	0.3	10.5	34.5	2.1	5.2	8.0	13.5	20.8	2688
	Average	8.5	4150	0.29	10.7	33.5	2.1	4.8	8.4	13.5	20.1	2656
Khabakki	KW-1	7.8	1280	1.5	4.5	5.5	1.3	-	4.4	4.0	3.1	768
wells	KW-2	7.8	1300	1.2	3.6	6.4	1.8	-	5.2	4.5	1.5	832
	KW-3	8.4	1400	1.0	4.4	6.2	2.4	2.0	6.4	4.5	1.1	896
	KW-4	8.4	2200	1.4	5.4	9.0	7.7	2.0	6.8	3.0	11.7	1408
	KW-5	8.0	1700	2.0	4.8	10.1	0.6	-	5.6	4.0	7.3	1088
	KW-6	8.0	1600	1.2	8.1	6.3	0.6	-	7.8	1.5	6.6	1024
	Average	8.1	1580	1.4	5.1	7.3	2.4	0.7	6.0	3.6	5.2	1003
Jahhlar	J-1	9.0	7800	0.8	4.4	84.7	3.1	18.0	31.4	25.0	18.6	4992
lake	J-2	9.0	7800	0.7	4.2	82.4	5.7	17.2	28.6	26.0	21.2	49992
	J-3	9.0	7800	0.6	4.0	82.7	5.7	16.6	31.8	25.5	19.1	4992
	J-4	9.0	7700	0.6	4.3	82.4	5.7	21.6	24.0	25.5	21.9	4928
	J-5	9.0	7700	0.5	4.8	81.3	6.4	16.4	30.0	25.0	21.6	4928
	Average	9.0	7760	0.6	4.3	82.7	5.3	18.0	29.2	25.4	20.5	4966

EC = Electric Conductivity; units μ S/ca. TDS = Total Dissolved Salts; units μ g/ml. tr = Traces.

The average weight ratio of Na/(Na + Ca) of the these lakes is, therefore, plotted on a boomerang-shaped envelope of Gibbs (1970), as a function of total dissolved salts - (Fig. 4, i). At a first glance, it appears that the chemistry of the three lakes is mainly controlled by an evaporation-crystallization process.

The examination of Na and total alkalinity (CO_3 + HCO_3) also strengthens the idea of evaporation-crystallization end-member (Fig. 4, ii). A more or less linear relation between Na and total alkalinity indicates the precipitation of CaCO3 as calcite during evaporation-crystallization process. However, in the framework of Gibbs's ideas of boomerang-shaped envelope, one can not ignore the possible contribution of dissolved salts from ground water brines/evaporites or leaching of old sedimentary/metamorphic rocks, as first pointed out by Feth (1971) and Stallard & Edmond (1983). Chester (1990) pointed out this process as evaporite end-member. In the present study the contribution of dissolved salts from the underground ancient sedimentary rocks is evident by the presence of hard/soft water springs/- seepages which are continuously adding to these lakes (Kausar &Shams, 1987). Similar scenario has been produced by Kilham (1990), for the African lakes and rivers. He concluded that apart from the evaporation-crystallization end-member, many of the lakes in Africa, appearing on the top arm of the boomerang-shaped envelope having >1000 μg/ml of total dissolved salts (TDS) are dominant by salt from either the ocean or ancient sedimentary deposits.

From the above discussion, it may be concluded that the chemistry of the three lakes from the Soan-Sakesar valley is mainly controlled by an evaporation-crystallization process. In addition to this, a recharge from the hard/soft water springs present in the area is an important process. These springs/seepages contribute a fair amount of dissolved salts rich in Cl and SO_4, leached from underground sedimentary rocks.

The Uchhali lake (~27 g/1 TDS) can be defined as 'saline lake' under the classification of Wood & Talling (1988) as it contains excess of 3 g/1 of total dissolved salts. Colburn (1988) categorised the saline waters of Death Valley, USA, as: low saline (2-8 g/1), moderately saline (10-20 g/1) and highly saline waters (>25 g/1). Khabbaki and Jahhlar lakes show the early stage of saline condition having ~3 and ~5 g/1 of TDS, respectively. The order of salinity-decrease in the three lakes is:

Uchhali > Jahhlar > Khabbaki

A comparison of the chemistry of the three lakes from Soan-Sakesar valley, as sum total percentage of each cation and anion is presented in Fig. 5(a and b). It can be seen from Fig. 5a that among the major cations, Na is the highest in all three lakes, pointing out same mode of occurrence. The Khabbaki lake is slightly rich in Mg as compared to the other two lakes of the area.

The major trend of anions in the three lakes varies slightly. However, the hierarchy, in which, each of the anion is present is same in two of the lakes, i.e., Uchhali and Khabbaki. This indicates that similar kind of processes control the chemistry of these two lakes with SO_4 being the highest. It is interesting to see that the distribution of major anions in Jahhlar lake is also important in having high alkalinity, i.e., CO_3 + HCO_3. Lerman & Stumm (1989) described that the higher alkalinity values in lake waters can be obtained through biological productivity, carbonate-mineral dissolution, reduction reactions in water and sediments, or input of chemical bases. In the case of Jahhlar lake, the higher values of CO_3 and HCO_3 could be from the addition of Na-carbonates or bicarbonates leached from the surrounding ancient sedimentary rocks.

It may be concluded, therefore, that the chemical trend in major cations and anions of the two lakes, i.e., Uchhali and Khabbaki are similar while Jahhlar shows a slightly different trend with respect to alkalinity and SO_4, probably due to the input of chemical bases.

The geochemistry of both Khabbaki lake and its surrounding wells shows a similar pattern. The wells show a great deal of SO_4 contamination due to the uprising of water level in the lake during the last few years and hence, the water is not good for drinking purposes (see Table 1). However, the data for Uchhali wells suggests that they are equally good for both drinking and irrigation purposes due to low pH (7.5) and EC (1400 μ S/cm).

CONCLUSIONS

The chemistry of the three lakes from Soan-Sakesar valley is mainly controlled by an evaporation-crystallization process and the contribution of dissolved salts from the nearby active springs/seepages of soft/hard water cannot be ignored. Uchhali lake falls in the category of highly saline lakes; while Jahhlar is saline and Khabbaki is in the early stages of saline conditions. Uchhali wells are equally good for both irigation and drinking purposes; while Khabbaki wells are contaminated with respect to SO_4 due to the uprising of water-level during the last few years and therefore, are not good for drinking purposes.

ACKNOWLEDGEMENTS

We are thankful to Professor F.A. Shams, former Director, Institute of Geology, Punjab University, Lahore, for his valuable suggestions and arrangements for the field work. We are grateful to Dr. A.Q. Qureshi, Managing Director, Ittehad Chemicals, Kala Shah Kaku, for sincere cooperation in water analyses.

REFERENCES

BOWEN, S.T., BUONCRISTIANI, M.R. & CARL, J.R. (1988) Artemia habitats: Ion concentrations tolerated by one super species. Hydrobiologia **158**, pp.201-214.

CHAKRAPANI, G.J. & SUBRAMANIAN, V. (1990) Preliminary study on the geochemistry of the Mahanadi river basin, India. Chem. Geol. **81**, pp.241-253.

CHESTER, R. (1990) MARINE GEOCHEMISTRY. Unwin Hyman Ltd. London.

COLBURN, E.A. (1988) Factors influencing species diversity in saline waters of Death Valley, USA. Hydrobiologia **158**, pp.215-226.

COMIN, F.A. & ALONSO, M. (1988) Spanish salt lakes: Their chemistry and biota. Hydrobiologia **158**, pp.237-245.

GIBBS, R.J. (1970) Mechanisms controlling world river water chemistry. Science **170**, pp.1088-1090.

HURLBERT, S.H. & CHANG, C.C.Y. (1988). The distribution, structure, and composition of ice deposits in Bolivian salt lakes. Hydrobiologia **158**, pp.271-299.

KILHAM, P. (1990) Mechanisms controlling the chemical composition of lakes and rivers: Data from Africa. Limnol. Oceanogr., **35**(1), pp.80-83.

KAUSAR, T. & SHAMS, F.A. (1987) The changing agro-economic pattern of Khabbaki in Soan Sakesar valley, district Khushab, Punjab, Pakistan. Geol. Bull. Punjab Univ. **22**, pp. 125-135.

LERMAN, A. & STUMM, W. (1989) CO_2 Storage and alkalinity trends in lakes. Wat. Res. **23**(2) pp.139-146.

RICHARDS, L.A. (1968) DIAGNOSIS AND IMPROVEMENT OF SALINE AND ALKALI SOILS. Oxford & IBH (Indian Edition).

SCHMID, R.M. (1988). Lake Torrens brine. Hydrobiologia **158**, pp.267-269.

WILLIAMS, W.D. & KOKKINN, M.J. (1988) The biological affinities of the fauna in episodically filled salt lakes: A study of Lake Eyre South, Australia. Hydrobiologia **158**, pp.227-236.

WOOD, R.B. & TALLING, J.F. (1988) Chemical and algal relationship in a salinity series of Ethiopian inland waters. Hydrobiologia **158**, pp.29-67.

Received on May 3, 1991.
Accepted for publication on June 20, 1991.

ACTA MINERALOGICA PAKISTANICA
VOLUME 5 (1991) pp. 77-82.

AN OCEANIC ISLAND BASALT FROM PIR UMAR, KHUZDAR DISTRICT, PAKISTAN.

ZULFIQAR AHMED
National Centre of Excellence in Mineralogy, University of Balochistan,
G.P.O. Box 43, Quetta, Pakistan

ABSTRACT: A small isolated outcrop of basalt with well developed pillow structure, occurs near Pir Umar (27° 39' 30" N, 66° 37' E), Khuzdar District, Pakistan; emplaced tectonically in the Jamburo Group (Palaeocene – Oligocene). The geochemical evidence shows it to have an oceanic island origin. The suprasubduction zone rocks belonging to the Bela Ophiolite, emplaced in lower Eocene, outcrop about 20 km westwards from Pir Umar basalt. Pir Umar basalt may represent a recycled oceanic lithosphere brought up by diapiric upwelling.

INTRODUCTION

At a distance of 24 km southwards from Khuzdar town, on the Khuzdar - Karachi highway, a minor structural slice of pillowed basalt outcrops (Fig.1). It is emplaced into the upper part of the Jamburo Group rocks of Palaeocene to Oligocene age. The rocks in the vicinity are all sediments. Linkage of the basalt to other igneous activity in the region is not known.

This paper presents geochemical data and attempts to characterize the rock referred in this paper as Pir Umar basalt (PUB). The data indicates an oceanic island origin which does not tally with the supra-subduction zone basaltic rocks of the Bela ophiolite whose principal outcrop lies only 20 km west of Pir Umar. This tectonic setting of this rock is not easy to deduce because of its small outcrop area, tectonic contacts and absence of more evolved rock types related to PUB.

GENERAL GEOLOGY

The pillowed basalt outcrops only 2 km north of the Pir Umar Rest House in the Khuzdar District. The location has a latitude 27° 39' 30" N and longitude 66° 37' E. The area is covered by the 1:50,000 scale topographic sheet no. 35 I/10 of the Survey of Pakistan.

The rock outcrops of the area are dominated by sedimentary rocks which consist of basal Shirinab Formation (Jurassic) overlain by either or both of the Sembar and Guru Formations (Jurassic); overlain in turn, by the Parh Formation (Cretaceous). This appears to grade upwards into the Jamburo Group rocks which are of Palaeocene to early Oligocene age as described by the Hunting Survey Corporation (1961). The Nari Formation of Oligocene to early Miocene age lies conformably above the Jamburo Group. Nari Formation is composed of darkish shales and sandstones. PUB lies inside the limestone of Jamburo Group close to its upper contact with the Nari Formation. Total thickness of the Jamburo Group ranges from 1500 to 2500 feet, made of shallow- water deposits of shale, marl, limestone and subordinate sandstone.

PETROGRAPHY AND MINERAL CHEMISTRY

Samples numbered Z1481 and Z1734 are collected from the cores of pillow lobes.

The rock displays pilotaxitic and intergranular textures. Rarely, microphenocrysts of silicate minerals are present. Slender laths of fresh feldspar make up about half the rock volume. Fine-grained chlorite is present in matrix. Opaque minerals include long ilmenite plates (> 10%), sometimes intergrown with magnetite; and tiny equant grains of magnetite (5 %). Presence of ulvöspinel is indicated by microprobe. Secondary calcite fracture fillings are less than 3%. The calcite does not contain significant $MgCO_3$ or $FeCO_3$.

Chlorite is probably largely a secondary product. Spherulitic chlorite is abundant. Four microprobe analyses of chlorite are reported in

Table 1. Chlorite analyses from PUB.

	1	2	3	4
SiO_2	34.93	37.99	38.12	33.02
TiO_2	0.08	0.14	0.15	3.43
AL_2O_3	16.87	16.60	16.45	14.87
V_2O_3	0.01	0.03	0.02	0.09
FeO	16.48	14.72	15.66	21.70
MnO	0.24	0.20	0.26	0.14
MgO	18.23	15.65	16.50	15.32
NiO	0.08	0.04	0.00	0.00
CaO	0.28	0.38	0.77	0.46
BaO	0.01	0.01	0.00	0.02
SrO	0.00	0.00	0.32	0.00
ZnO	0.07	0.13	0.06	0.04
Na_2O	0.19	0.15	0.88	1.58
K_2O	0.76	2.16	1.04	0.08
P_2O_5	0.04	0.03	0.25	0.14
ZrO_2	0.04	0.03	0.01	0.02
Total	88.31	88.26	90.49	90.91

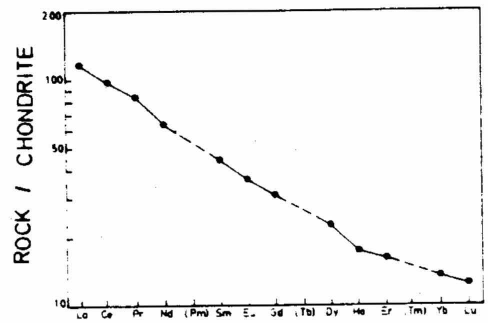


Fig.2. Chondrite-normalized REE abundances for PUB sample Z 1734.

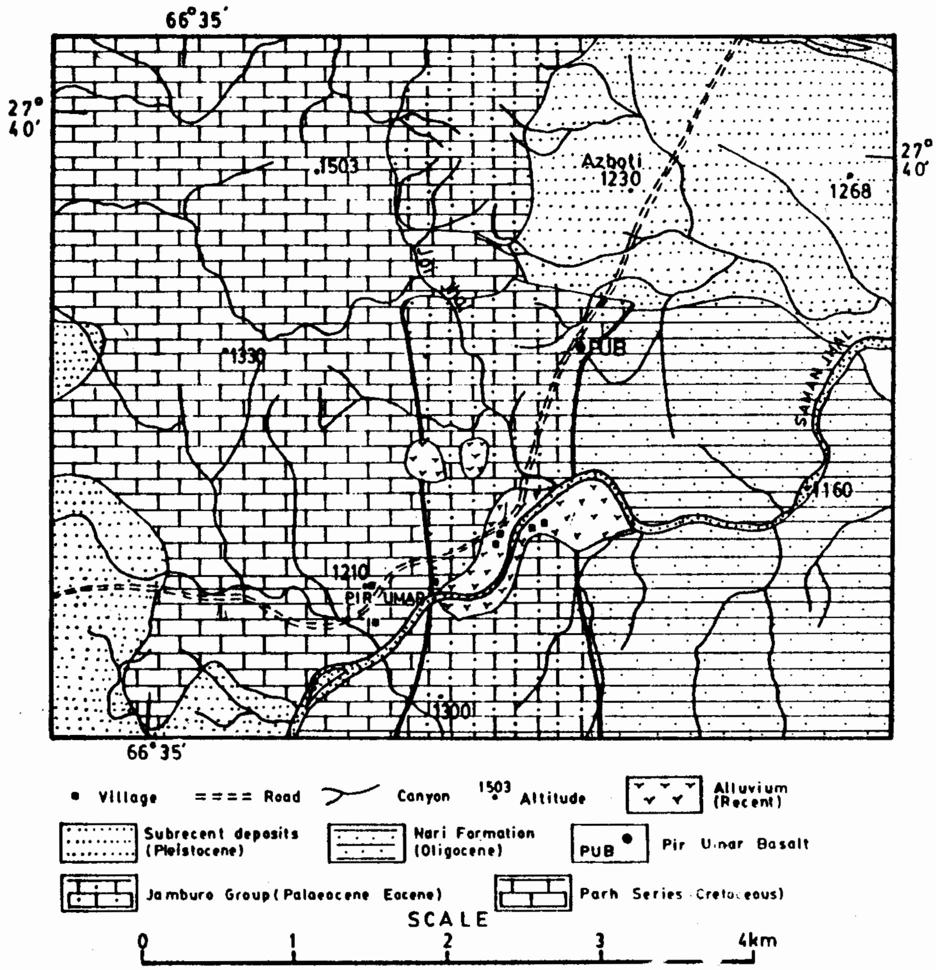


Fig.1. Geological sketch map of Pir Umar area.

Table 1. One of the analyses shows chlorite with lower SiO_2, Al_2O_3, and MgO, but with higher FeO than the rest.

WHOLE ROCK GEOCHEMISTRY

The whole-rock analyses for the major and trace elements of two samples from the pillowed basalt were carried out using X-ray fluorescence spectrometer unit set up at the Department of Geological Sciences, University of Southern California, Los Angeles, U.S.A. The rare-earth elements of the same samples were determined employing the inductively coupled plasma spectrometry carried out at the Department of Geology, Royal Holloway and Bedford New College, University of London, England. The accuracy as well as precision for these determinations are estimated to be better than 5% based on the repeat analyses and values for the standards. The standard rock powders KC11, KC12 and KC13 at the ICP laboratory were used for controlling the rare earth determinations in addition to the blank and fixed- composition solutions.

Major- trace - and rare earth - element data are presented in Table 2.

The compositions differ greatly from that of MORB in many respects. TiO_2, Na_2O and K_2O are higher than MORB as are trace elements like Sr, Rb, Zr and Nb. MgO and CaO are lower than MORB. The rock is depleted in Cr and Ni relative to MORB. Very high Nb contents (Table 2) resemble those of the within-plate basalts.

The ratios Zr/Nb and Y/Nb resemble those of oceanic island basalts (OIB) as reported by various workers (e.g., Weaver, 1991; Wilson, 1989, figs. 9.18 & 9.19). Other trace element ratios are also like those for OIB as compiled by Weaver (1991) and are given in Table 3.

Rare Earth Elements

The chondrite-normalized REE pattern for the PUB rock is shown in Fig. 2. The enrichment in light REE is conspicuous and considerable, just like that of the oceanic island basalts. The fractionated heavy REE abundances are like OIB, and unlike P-type MORB which is also light REE enriched. PUB is strongly enriched in light REE in comparison with the N-type MORB which is usually regarded a result of derivation from relatively undepleted mantle source. The steeper slope in Fig.2 shows an enrichment of light REE even more than that of the oceanic tholeiites and is more like that displayed by the alkali basalts. The absence of negative Eu anomaly is usually considered to indicate less fractionation of plagioclase.

Trace Elements

Fig. 3 is a spiderdiagram showing the geochemical pattern normalized to N-type MORB and drawn after Pearce (1982) and Pearce et al. (1984). The patterns differ from those shown by the supra-subduction zone basalts (Pearce et al., 1984, fig.1). This strongly humped pattern for PUB seems to lack the effects of subduction and resembles that of the oceanic islands. All elements from Sr to Ti are enriched, whereas Y and Yb retain abundances close to unity. However, Cr is exceptionally low (Table 2). The pattern appears to have been drawn from the incompatible - element enriched portion of mantle such as that associated with mantle plumes. As observable in other areas of within-plate basalts (Pearce, 1982), the degree of enrichment of the elements may be related to its incompatibility relative to garnet lherzolite. Thus, the most incompatible elements Rb, Th, Nb, are more enriched. However, Ta is slightly lower, but still is enriched. Ti plots high relative to Y and Yb. The Cr values (Table 2) are much lower than the often observed values close to unity (Pearce, 1982). This may be because Cr is compatible with the mafic phases, whereas Y and Yb show little change as they are compatible with garnet.

In the spiderdiagram with incompatible element abundances normalized to primordial mantle values (Fig. 4) after Sun (1980), the PUB pattern shows trough at K and peak at Nb. This behaviour is generally observed in the OIB as well as the plume-type MORB. However, the pattern resembles that of alkalic oceanic island basalt (e.g., Wilson, 1989, fig. 9.22) which possesses distinctly higher concentrations of the elements plotted than those exhibited by the P-type MORB. The positive Nb anomaly relative to Th and La on this plot indicates non-arc alkaline signatures (cf. Jenner et al., 1991).

Table 2. Whole - rock analyses of PUB samples.

Sp. No.	Z1481	Z1734		Z1481	Z1734
SiO_2	45.53	46.65	*C.I.P.W*	*Norms:*	
TiO_2	2.81	2.92	or	2.80	3.79
$A1_2O_3$	16.02	16.19	ab	35.19	38.68
FeO	9.69	9.91	an	15.09	16.36
MnO	0.19	0.17	ne	8.73	5.50
MgO	5.02	3.91	di	6.38	5.61
CaO	5.54	5.66	ol	16.85	15.30
Na_2O	6.06	5.77	il	5.34	5.55
K_2O	0.47	0.64	ap	1.70	1.82
P_2O_5	0.72	0.77	D.I	46.72	47.98
LOI	7.49	7.44	Plagioclase	23.28	25.48
Total	99.54	100.03			
Trace elements in p.p.m. :			*REE in p.p.m. (by ICP–AES) :*		
S	40	110			
C1	60	60	La		38.00
Ba	–	–	Ce		84.30
Rb	14	19	Pr		10.07
Th	1.64	4.9	Nd		40.00
Nb	61.4	62.8	Sm		8.91
Ta	0.7	1.4	Eu		2.78
La	59	–	Gd		8.42
Sr	339	294	Dy		7.78
Zr	315	324	Ho		1.32
Hf	7.9	7.9	Er		3.63
Zn	125	123	Yb		3.00
U	0.2	0.3	Lu		0.42
Y	39	40.9	Th/La	0.03	0.13
Ga	20	20.8	Zr/Nb	5.137	5.162
Pb	2.7	3.6	Y/Nb	0.638	0.652
Cu	5.9	6.1	Th/Nb	0.078	0.027
Cr	6.1	6.6	La/Nb	0.96	0.61
Ni	3.9	5.5	Rb/Nb	0.225	0.3015
V	344	355	K/Nb	64	85

Table 3. Incompatible trace element ratios in PUB compared to those from major chemical reservoirs (mantle & crust) and end-members of OIB, compiled by Weaver (1991).

		Zr/Nb	La/Nb	Rb/Nb	K/Nb	Th/Nb	Th/La
1.	Primordial mantle	14.8	0.94	0.91	323	0.117	0.125
2.	Normal MORB	30	1.07	0.36	296	0.071	0.067
3.	Continental crust	16.2	2.2	4.7	1341	0.44	0.204
4.	Z 1734 (PUB)	5.16	0.61	0.302	85	0.078	0.129
5.	Z 1481 (PUB)	5.14	0.96	0.225	64	0.027	0.028
6.	Saint Helena OIB	4.5	0.69	0.38	179	0.078	0.112
7.	Rurutu OIB	5.0	0.77	0.38	179	0.078	0.107
8.	Gough OIB	6.8	0.97	0.99	432	0.105	0.110
9.	Upolu, Samoa, OIB	4.5	1.09	0.76	254	0.133	0.122

DISCUSSION

OIB are characteristically enriched in incompatible trace elements compared to basalts erupted at plate margins. This reflects their derivation from an enriched mantle source, as the trace elements are generally considered not to have fractionated during OIB genesis. The enriched mantle source of OIB magmas is distinct from the upper mantle source for MORB. Assuming insignificant fractionation of trace elements during OIB genesis, the trace element data in Table 3 may be compared to the values given by Weaver (1991) for identification of OIB end members. The lower PUB values for La/Nb and LILE/Nb compare well with the OIB, and Nb–Ta depletion related to subduction–zone processes (Weaver, 1991) is not found. In resemblance to his HIMU OIB magmas, and the model proposed by Weaver (1991), the PUB trace elements may have resulted by a subduction-zone processed, dehydrated ancient basaltic oceanic crust, recycled into the mantle and subsequently remelted. The subduction zone processing didn't entrap a pelagic or terrigenous sediment component, as indicated by differences in trace element ratios of PUB and the EMI or EMII OIB end-members of Weaver (1991). This model is further supported by the field occurrence of PUB inside much younger strata than those surrounding the nearby Bela ophiolite. In view of this model, it is possible that the basaltic component from the same ancient oceanic lithosphere source as that for the Bela ophiolite was dehydrated during subduction-zone processes, was recycled into the mantle and remelted to produce source magma for the PUB.

The occurrence of within-plate basalts in the seamounts associated with the suprasubduction zone volcanic environment has been documented from the Tonga arc-trench zone in the SW Pacific by Zlobin et al. (1991). Such within-plate magmatic activity originates from deep, undepleted, probably metasomatically-enriched mantle, which melts due to upwelling of deep mantle plume caused by diapir development. Since such upwelling is supposedly pre-subduction (Zlobin et al., 1991); such model seems not applicable to PUB because its emplacement is younger than the associated Bela ophiolite.

CONCLUSIONS

An isolated minor outcrop of pillowed basalt occurs near Pir Umar in Khuzdar District and is referred here as PUB. It does not make a part of the Bela ophiolite rocks which outcrop a few km westwards from PUB. PUB lacks geochemical signatures of supra-subduction zone basaltic rocks or MORB. The trace and rare-earth element data suggests that PUB is an alkaline ocean island basalt. Based on the trace element data and the OIB genetic model proposed by Weaver (1991), it may be considered possible that PUB source was the same ancient oceanic lithosphere from which the Bela ophiolite was derived. The basaltic crustal part underwent subduction-zone processes and dehydration before it was recycled into the mantle and remelted to produce the source magma for PUB. The PUB magmatic event may have occurred during the northward movement of the Indian plate from its position in the Gondwanaland when it may have passed over a hot-spot.

ACKNOWLEDGEMENTS

Mahmood A. Chaudhry at the California Institute of Technology helped in sample preparation. Dr. J. Lawford-Anderson, Erik Bender and Vera Wilson of the University of Southern California assisted in the XRF work. USAID's Pakistan Participant Training Program provided funding for the author's U.S. stay. The British Council's Link Programme made possible the rare-earth element determinations which were conducted at the RHB New College, University of London.

REFERENCES

HUNTING SURVEY CORPORATION (1961) RECONNAISSANCE GEOLOGY OF PART OF WEST PAKISTAN. Toronto, Canada.

JENNER, G.A., DUNNING, G.R., MALPAS, J., BROWN, M. & BRACE, T. (1991) Bay of Islands and Little Port complexes, revisited: age, geochemical and isotopic evidence confirm suprasubduction-zone origin. Can. J. Earth Sci. **28**, pp.1635-52.

McCORMICK, G.R. (1985) Preliminary study of the volcanic rocks of the South Tethyan suture in Baluchistan, Pakistan. Acta Mineralogica Pakistanica **1**, pp.2-9.

PEARCE, J.A., (1982) Trace element characteristics of lavas from destructive plate boundaries. *In*: Thorpe, R.S. (ed.) ANDESITES, pp. 525-48. John Wiley & Sons, Chichester.

———, LIPPARD, S.J. & ROBERTS, S. (1984) Characteristics and tectonic significance of supra-subduction zone ophiolites. *In*: Kokelaar, B.P. & Howells, M.F. (eds.) MARGINAL BASIN GEOLOGY. Geol. Soc. London Spec. Publ. **16,** pp. 77-94.

SUN, S.–S. (1980) Lead isotopic study of young volcanic rocks from mid-ocean ridges, ocean islands and island arcs. Phil. Trans. R. Soc. London **A297,** pp. 409-45.

WEAVER, B.L. (1991) Trace element evidence for the origin of ocean island basalts. Geology **19,** pp. 123-6.

WILSON, M. (1989) IGNEOUS PETROGENESIS. Unwin Hyman, London.

ZLOBIN, S.K., KOLESOV, G.M. & KONON KOVA, N.N. (1991) Development of within-plate magmatism on the landward and offshore slopes of the Tonga Trench. Ofioliti **16** (1), pp.17-35.

Manuscript received on April 30, 1991.
Accepted for publication on September 20, 1991.

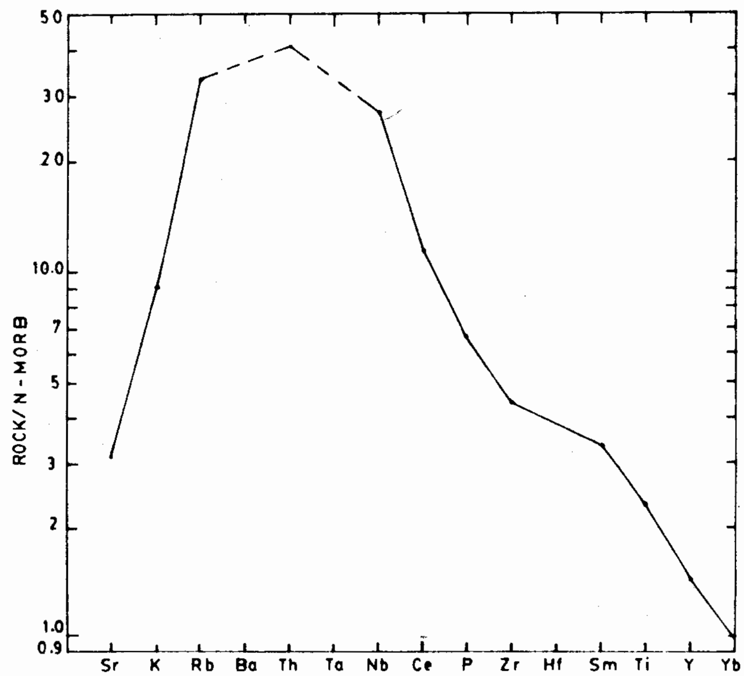


Fig. 3. Geochemical pattern for the sample Z 1734 normalized to an average N-type MORB after Pearce (1982) and Pearce et al. (1984).

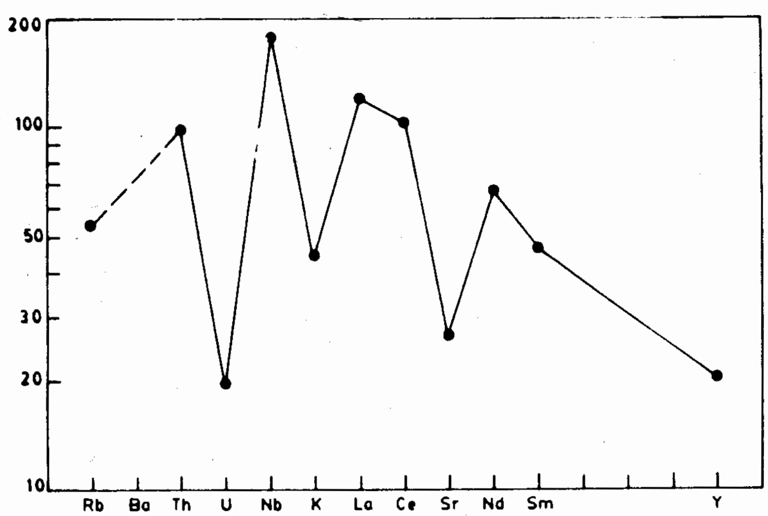


Fig. 4. Incompatible element abundances in sample Z 1734 normalized to primordial mantle values (Sun, 1980).

ACTA MINERALOGICA PAKISTANICA
VOLUME 5 (1991) pp. 83 - 98.

BASALT GEOCHEMISTRY AND THE SUPRA-SUBDUCTION ZONE ORIGIN OF THE BELA OPHIOLITE, PAKISTAN.

ZULFIQAR AHMED

National Centre of Excellence in Mineralogy, University of Balochistan, G.P.O. Box 43, Quetta, Pakistan.

ABSTRACT: The most complete and the largest ophiolite of Pakistan, the Bela ophiolite, has a crustal section more developed than its mantle section. The well-developed pillowed and non-pillowed basalts have been analyzed for their major-, trace-, and rare-earth elements. All the analyzed basalts lack signatures of N-type MORB. A supra-subduction zone origin for these rocks is evident. A composite geochemistry prevails; dominated by the marginal-basin basalts. Presence of a proximal island arc is also indicated. At a few localities, oceanic-island type geochemistry indicates some diapiric upwelling as well.

INTRODUCTION

Volcanic rocks, especially basalts, are important in providing evidence for the tectonic environments of igneous regions (e.g., Wilson, 1989). The Bela ophiolite in south-western Pakistan outcrops for a length exceeding 400 km in a north-south direction on the western marginal region of the Indian continental plate.

The hitherto unknown tectonic environment of the Bela ophiolite alongwith the geochemical characterization of the basalts forms the main aim of this study. Evidence has been collected from field relations, petrography, mineral chemistry and the major-, trace- and rare earth-elemental whole-rock contents of the basalts from Bela ophiolite. The coarser grained rocks such as dolerites and gabbros; and the rocks with more felsic compositions, are omitted from this compilation and will be discussed in a separate communication.

GEOLOGY

The Bela ophiolite is spread over a vast area in the region comprised of the Districts of Bela and Khuzdar (Fig.1). The north-south trending outcrop length of the ophiolitic rocks exceeds 400 km. It stretches between 25° N and 27° 52' N latitudes. The width is variable from 10 to 15 km.

Relatively less disturbed calcareous rocks of the Nal Limestone of Eocene age overlie the Bela ophiolite unconformably.

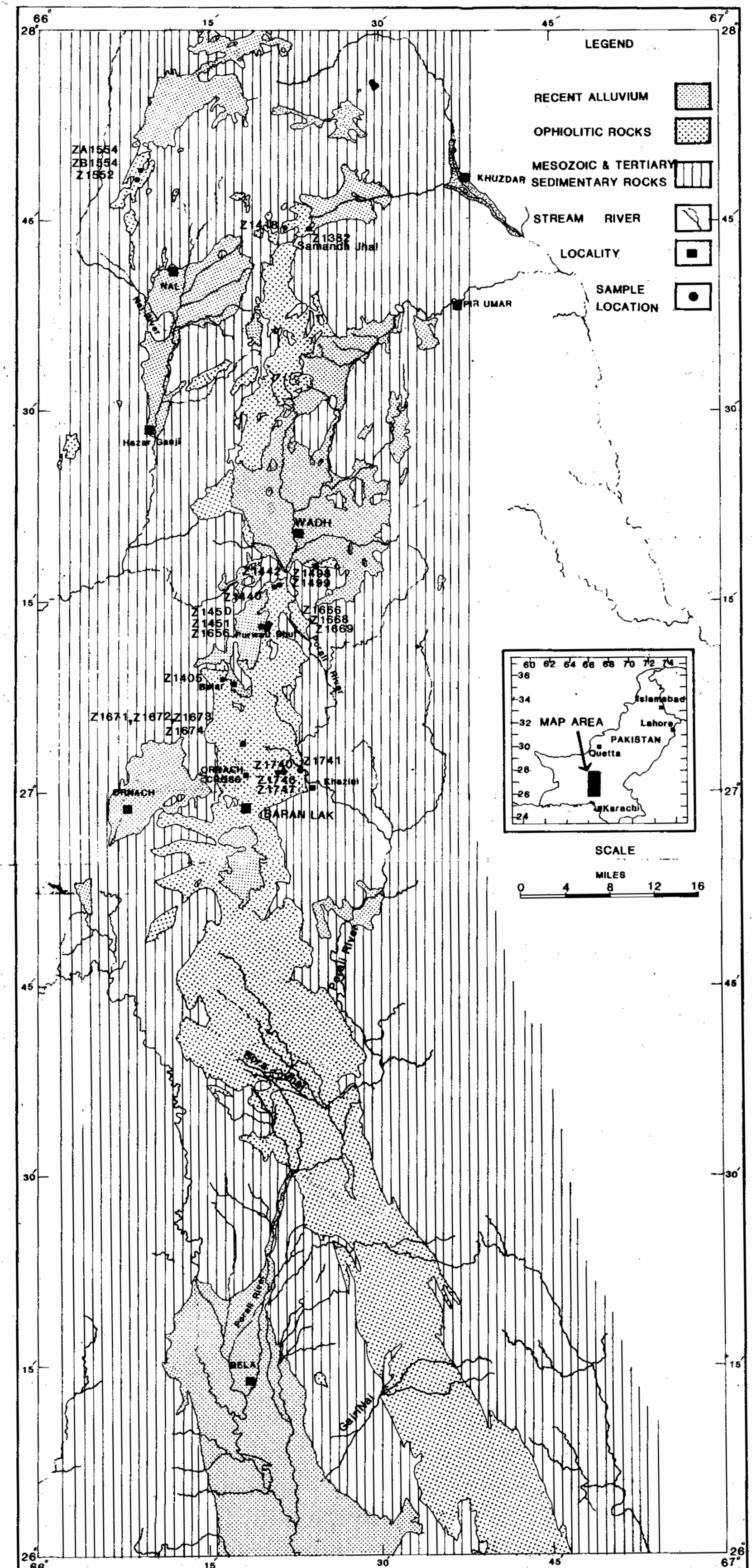
All the principal components of an ophiolite sequence are developed. The mantle tectonite consists predominantly of harzburgite with a small proportion of lherzolite. The layered ultramafic rocks consist predominantly of dunite, but some wehrlite and pyroxenite are also developed. The layered gabbroic cumulates overlie ultramafic cumulates. One such transition is seen to the north and east of Ornach-Cross.

The mafic rocks from the crustal sequence show much greater development and thickness as compared to the ultramafic rocks of mantle affinity. The basalts predominantly show pillow structure. However, basalts lacking such pillows are also present. At least at two locations the pillow structure and the pahoehoe lava outcrops are developed very closely - within a distance of < 10 metres from each other. (e.g., Fig.2).

GEOCHEMISTRY

Analytical Techniques:

The major and trace elements are analyzed by the X-ray fluorescence (XRF) method employing standard procedures at the Department of Geological Sciences, University of Southern California,


LEGEND
RECENT ALLUVIUM
OPHIOLITIC ROCKS
MESOZOIC & TERTIARY SEDIMENTARY ROCKS
STREAM RIVER
LOCALITY
SAMPLE LOCATION
KHUZDAR
PIR UMAR
WADH
BARAN LAK
ORNACH
BELA
Samanda Jhal
ZA1554
ZB1554
Z1552
Z1382
Z1740
Z1741
Z1671, Z1672, Z1673
Z1674
MAP AREA
PAKISTAN
Islamabad
Lahore
Quetta
Karachi
SCALE
MILES
0 4 8 12 16
66°
67°
28°
27°
26°

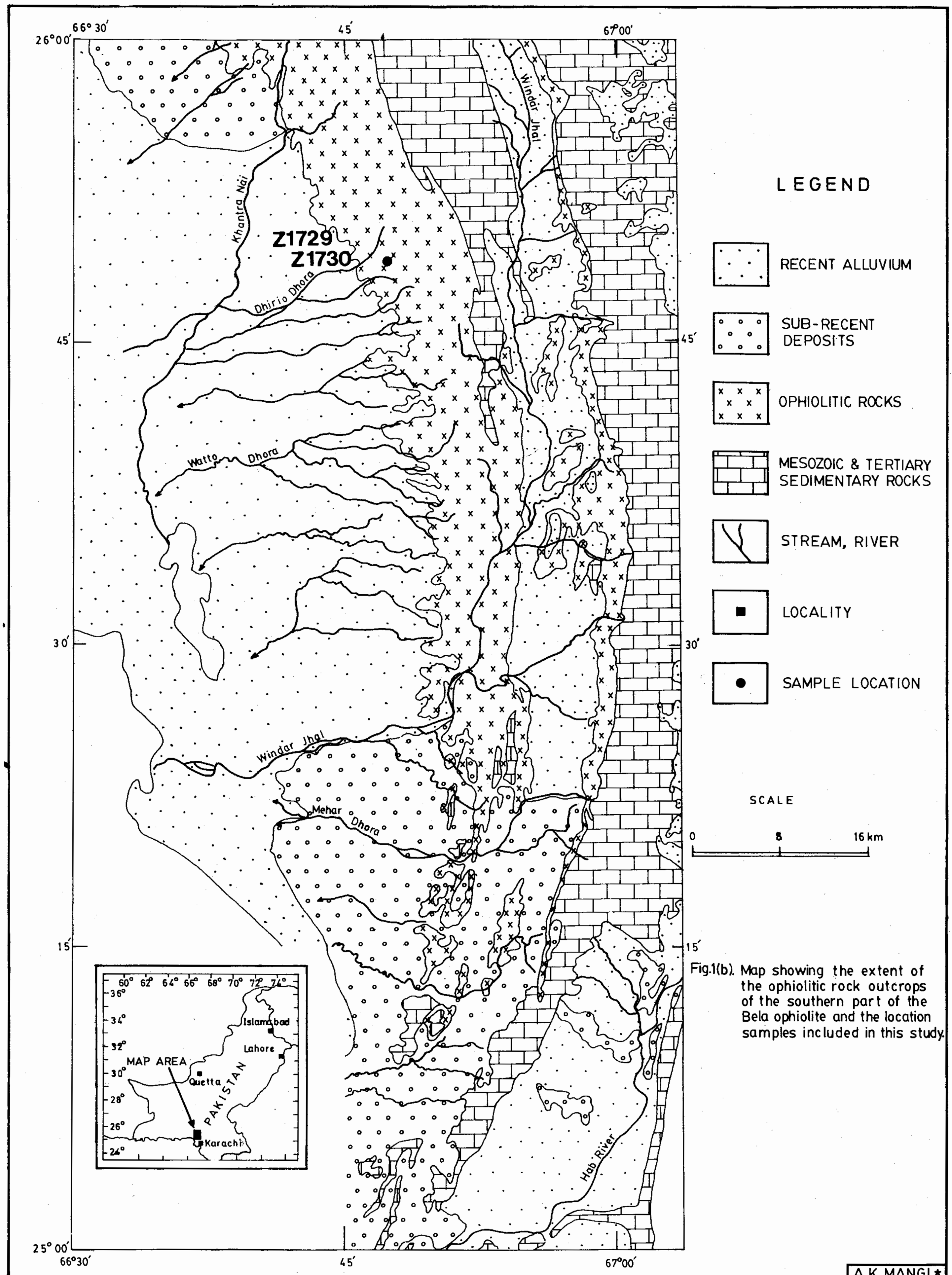


Fig.1(b). Map showing the extent of the ophiolitic rock outcrops of the southern part of the Bela ophiolite and the location samples included in this study.

A.K. MANGI *

Table 1. Location and description of the basalt samples from Bela ophiolite.

Sample No.	latitude & Longitude	Locality	Description
Z1489	lat. 27° 15' 36"N long. 66° 21' 27"E	7 km south of Wadh town.	Basalt
Z1521	lat. 26° 31' 37"N long. 66°24'45"E	Hur Murad Shank, near Porali River	Basalt dyke in gabbro.
Z1546	lat. 26° 12' 55"N long. 66° 36' 21"E	Junction of Khinar Dhora and Gajri Nai streams.	Porphyritic basalt.
Z1549	lat. 27° 45' 16"N long. 66° 08" 21"E	West canyon, off Karku Jhal.	Pillowed basalt, green in outcrop colour.
Z1550	lat. 270 45' 16"N long. 66° 08" 21"E	West canyon, off Karku Jhal.	Pillowed basalt black in outcrop colour.
Z1578	lat. 27° 42' 15"N long. 66° 11' 02"E	near Nal town	Pillowed amygdaloidal basalt with cupriferous chert in interlobe space.
Z1587	lat. 26° 36' 21"N long. 66° 19' 20"E	Hund Jhal.	A mélange block, (?), 100 m **X** 50 m in outcrop, brown weathered, mildly pillowy with chert developed in joints.
Z1590	lat. 26° 35' 54"N long. 66° 19' 42"E	East bank of Hund Jhal	Pillowed basalt with Cu-stained chert in the inter-lobe space.
Z1593	lat. 26° 38' 06"N long. 66° 18' 50"E	Kohan Jhal; 20ms of the old Mn mine.	Basalt
Z1594	lat. 26° 38' 20"N long. 66° 39' 14"E	In-between Bora Jhal & Kohan Jhal.	Black coloured basalt at limestone contact.
Z1600	lat. 26° 39' 10"N long. 66° 19' 37"E	Yangru Jhal	Bosalt flow lying conformably over a dark grey shale bed.
Z1602	lat. 26° 38' 22"N long. 66° 19' 49"E	East of Bora Jhal 2 km SW of Shahni.	Basalt.
Z1604	lat. 26° 42' 07"N long. 66° 18' 13"E	North of Kargazi peak.	Pahoehoe lava basalt.
Z1635	lat. 26 32' 59"N long. 66° 18' 28"EDin.	Mikki Jhal, off-Sor Dir	Basalt
Z1643	lat. 26° 49' 22"N long. 66° 17' 46"E	Gharmas.	Pillowed basalt.
Z1704	lat. 26° 38' 45"N long. 66° 22' 10"E	East bank at junction of Hinar Ping Jhal & Diria Ping Jhal streams	Pillowed basalt.
Z1706	lat. 26° 30' 25"N long. 66° 23' 19"E	1.2 km. east of Usman Bent.	Basalt.
Z1714	lat. 26° 30'49"N long. 66° 24'22"E	Haji Mohammad Khan Bent	Crust of pillow-lobe of basalt
Z1715	lat. 26° 30' 49" N long, 66° 24' 22"E	Haji Mohammad Khan	Core of the same pillow-lobe as for sp. Z1714
Z1724	lat. 26° 18' 12"N long. 66° 33' 53"E	Wattawari Dhora.	Basalt.
Z1728	lat. 28° 18' 07"N long. 66° 33' 28"E	Gajri Nai	Pillowed basalt with chrysocolla developed in interlobe space.
Z1730	lat. 25° 49' N long. 66° 47' 07"E	Uthal, Harer Dhora.	Core of pillow lobe of basalt.
Z1777	Approximate: lat. 27° 32' N long. 66° 24'E	Goth Shafi Mohammad	Pillowed basalt occurs 10 m from from a pahoehoe lava outcrop.

(A)

(B)

Fig.2(A). Typical pillowed basalt outcrop from Bora Jhal (lat. 26°38′36″N, long. 66°18′46″E).

(B). Photograph of ropy surfaced pahoehoe lava basalt with associated pillow-basalt outcrop from near Goth Shafi Mohammad (approximate lat. 27°32′N, long. 66°24′E).

Table 2. Major and trace element analyses of basalts from the Bela ophiolite.

Anal.no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Sp.no.	Z1730	Z1724	Z1728	Z1546	Z1714	Z1715	Z1521	Z1635	Z1704	Z1706	Z1590	Z1593	Z1594	Z1587	Z1602	Z1600	Z1604	Z1643	Z1578	Z1549	Z1550
SiO_2	48.45	48.53	47.78	51.04	48.74	49.64	48.74	48.32	49.36	46.70	49.73	49.36	49.80	47.62	49.31	50.95	50.41	48.18	54.41	46.50	41.98
TiO_2	2.23	2.14	3.25	2.69	2.26	2.21	1.15	2.41	2.18	3.58	1.94	2.55	2.01	3.20	3.00	2.12	2.15	2.28	0.77	1.00	1.83
Al_2O_3	13.92	14.31	12.94	14.27	14.71	14.24	15.39	14.56	13.84	13.51	14.61	13.59	16.89	14.17	13.07	13.99	13.88	14.93	14.97	15.03	13.69
FeOt	12.59	11.53	14.21	8.77	11.49	11.68	7.85	11.68	11.09	13.63	10.76	12.78	9.88	13.46	13.39	11.34	10.59	11.53	10.50	5.91	7.64
MnO	0.17	0.18	0.21	0.14	0.16	0.16	0.13	0.16	0.17	0.21	0.16	0.32	0.15	0.24	0.21	0.19	0.23	0.16	0.20	0.16	0.15
MgO	5.95	7.07	5.14	4.87	5.45	5.69	6.65	6.19	5.70	5.87	6.33	5.99	3.89	5.13	5.48	6.30	6.93	5.33	4.14	7.85	2.63
CaO	8.51	10.08	9.67	7.35	10.97	10.03	10.58	11.12	8.88	7.40	7.83	10.60	6.43	8.87	9.79	9.09	8.25	11.49	5.45	13.27	13.22
Na_2O	3.19	2.84	2.36	3.19	2.71	3.03	3.64	2.25	3.59	3.41	4.22	2.35	4.41	3.05	2.87	3.05	4.08	2.14	4.62	3.57	4.30
K_2O	1.34	0.13	0.43	4.13	0.48	0.24	0.86	0.23	0.07	1.20	0.76	0.13	1.33	0.98	0.24	0.65	0.21	0.41	1.49	0.30	2.13
P_2O_5	0.25	0.22	0.54	0.59	0.26	0.26	0.19	0.27	0.24	0.61	0.21	0.31	0.91	0.48	0.45	0.26	0.23	0.26	0.16	0.16	0.40
LOI	2.05	1.74	1.52	1.93	1.51	1.93	4.15	1.32	3.44	2.57	2.81	0.62	4.03	1.81	2.02	1.29	2.45	1.80	3.19	6.23	12.41
Total	98.66	98.78	98.05	98.97	98.74	99.11	99.33	98.52	98.56	98.69	99.36	98.57	99.74	99.01	99.82	99.25	99.39	98.48	99.90	99.97	100.39
D.I.	34.92	24.84	22.94	49.82	25.76	27.04	33.20	20.40	30.79	35.92	39.75	21.32	45.20	31.58	25.71	29.62	35.75	20.50	47.86	24.96	32.60
Trace elements in p.p.m. :																					
S	70	40	110	40	80	40	20	900	60	1270	70	930	40	70	30	140	100	70	50	20	120
Cl	60	40	50	80	20	10	190	30	50	100	80	30	80	20	30	110	300	10	30	30	20
Rb	44	3.8	7.6	102	12	4.78	13	5.65	2.93	52	12	3.65	23	38	5.87	16	3.09	11	20	9	41
Sr	389	346	275	1118	237	221	243	310	494	314	411	314	646	264	254	344	209	246	243	533	295
Ba	24	-	-	865	-	-	-	-	-	-	-	-	161	-	-	92	-	-	13	-	-
Zr	139	128	289	412	158	154	95	132	143	192	181	194	351	272	257	197	124	147	46	84	140
Ta	0.32	0.99	0.4	0.95	0.66	0.18	0.57	0.5	-	0.25	1.25	1.4	0.5	1.74	0.52	0.53	0.11	0.36	0.11	0.79	0.20
Hf.	3.95	3.77	7.02	11	4.38	4.27	2.95	3.76	4.28	4.94	4.86	5.04	8.83	6.83	6.36	5.23	3.48	4.14	2.07	3.06	4.03
Zn	115	87	111	80	43	117	77	113	117	133	49	130	100	126	153	111	72	122	100	53	81
Th	0.71	0.16	1.36	8.95	0.61	-	-	1.15	0.78	-	-	0.21	4.52	0.58	0.50	0.98	-	1.11	0.48	0.59	-
U	0.56	0.08	0.12	1.57	1.32	0.09	0.2	0.1	0.07	0.66	0.17	0.8	1.57	0.49	0.1	0.3	0.07	0.38	0.28	0.35	0.53
La	30	24	8.48	92	31	22	0.53	14	-	9.08	21	16	73	20	38	35	30	19	8.05	-	31
Y	33	30	57	31	35	34	30	31	32	34	35	41	36	56	51	37	29	35	27	19	40
Nb	7.77	8.2	17	81	8.83	8.62	8.67	7.64	7.9	17	11	9.9	70	15	14	13	7	8.53	-	15	18
Ga	20	22	22	20	20	20	15	20	17	25	24	23	17	25	24	22	18	21	16	12	14
Pb	3	3.77	3.69	11	2.67	2.20	0.86	1.29	2.93	3.35	1.07	2.76	5.5	3.8	3.21	3.81	4	1.68	2.35	2.07	2.75
Cu	114	90	68	51	6.43	104	58	98	101	82	20	102	16	68	100	103	92	102	73	72	53
Cr	126	218	120	146	187	181	288	180	187	96	104	138	12	132	127	172	212	202	26	691	129
Ni	74	99	60	68	84	86	124	86	91	73	74	72	6.72	67	66	84	93	87	18	255	29
V	388	319	517	379	255	424	211	418	404	498	329	378	211	522	443	347	380	380	302	161	190
Zr/Nb	18	16	17	5	18	18	11	17	18	11	16	20	19	18	18	15	18	17	-	6	8

D.I. = Differentiation Index.

Los Angeles, U.S.A. However, the initial steps of sample preparation were done at Caltech, Pasadena, where fresher parts of the rock samples were separated by cutting and then were powdered by the jaw-crusher and tungsten-carbide swing-mill grinder, avoiding all possible contamination. Representative fractions from the rock powders were made out into glass discs to measure the major elements and into pressed powder pellets to measure the trace elements. The XRF spectrometer used was the RIGAKU System 3070, wavelength-dispersive automatic unit. The tube voltage employed was 40 kV, 30 mA for the major element runs, and 55 kV, 40 mA, for the trace lement runs. Analytical precision is better than ± 5%.

The analyses for the rare-earth elements (REE) were performed at the inductively coupled plasma atomic emission spectrometry (ICP - AES) laboratory of Dr. J.N. Walsh, at the Department of Geology, RHB New College, University of London, England. The measurements on the ICP were caliberated against the fixed-composition solutions as well as the reference standards KC10, KC11, KC12 and KC13. These standards were analyzed to assess the accuracy of REE abundances which is better than 5% for La, Ce, Eu, Yb and Lu and better than 15% for Nd, Sm, Gd and Tb. The precision of these analyses is estimated to be better than 5%, based on the duplicate analyses and the analyses of standards.

Analytical Results

Results of the geochemical whole-rock analyses are listed in Table 2, and illustrated in Figs. 3 to 7. This study is based solely on basalt samples characterized by the aphyric textures and the 'basic' silica content (45 to 52%).

In their major element contents, the basalt samples do not show very large variations (Table 2). Compared to the basalt chemistry, the magmatic water content is relatively high. The H_2O and CO_2 are included in the LOI values which are below 4.15% except for two of the samples with LOI at 6.23% and 12.41%, respectively. K_2O is abnormally high in one of the samples (Z1546).

The pertinent studies regarding mobility of elements during the process of alteration and low grade metamorphism (e.g., Harte, 1970; Harte et al., 1974; Hellman et al., 1979; Dungan et al., 1983) suggest that the following elements show little mobility: P, Ti, Y, Zr, Nb, Hf, Ta, Th, REE, Sc, V, Cr, Co and Ni. The variations in these elements are therefore, attributed largely to magmatic processes.

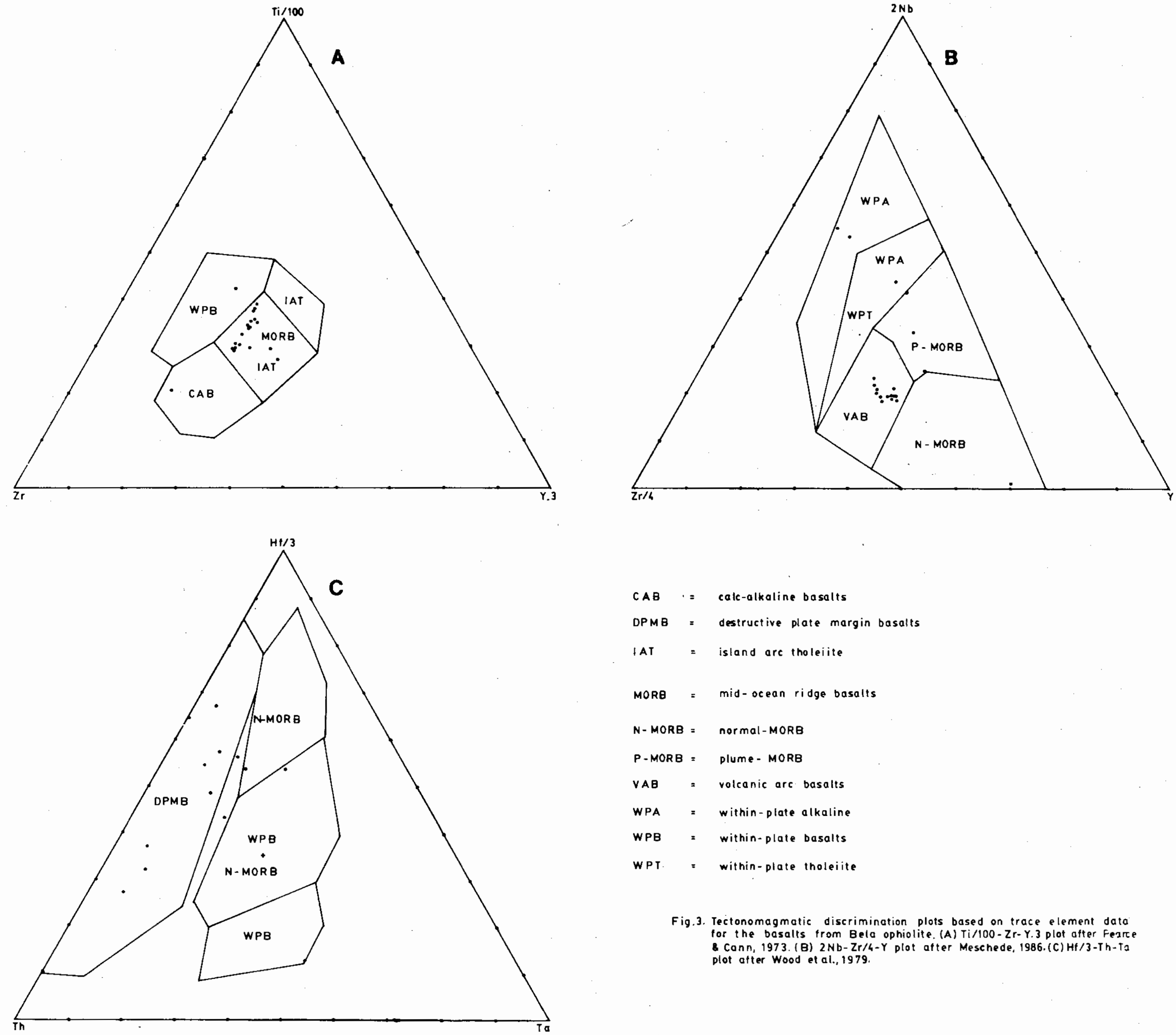
The large-ion-lithophile elements (or LILE) comprise Cs, Rb, K, Ba, Sr, Th, U, Pb, La and Ce. Some of these (Cs, Rb, K, Sr and U) can be highly mobile during alteration of sea-floor basalts by seawater (Harte, 1971). Sr is mobile during epidotization of sea-floor basalts (Humphris & Thompson, 1978). Sr and Rb may show erratic behaviour due to alteration. Sr may also show irregular behaviour due to plagioclase fractionation. Table 2 shows that sample Z1546 is exceptionally enriched in all the LILE compared to the rest of the samples. The strong enrichment of LILE in sample Z1546 cannot be explained by strong seawater alteration because its content of certain immobile elements, i.e., Th, Nb, Hf and Zr (Saunders & Tarney, 1984) is also high.

The very high Nb content of two samples, Z1546 and Z1594, resembles that of the non-arc, within-plate alkalic basalts.

For tectonomagmatic discrimination, the triangular plots are shown in Fig.3 utilizing the basalt analyses of Table 2. Fig. 3A plots Ti/100 - Zr - Y.3 (after Pearce & Cann, 1973). It shows that all except 4 of the 21 analyses given in Table 2, plot in the combined field "island arc tholeiites & mid-ocean ridge basalts". Sample Z1594 plots in the calc-alkaline basalt field, Z1706 plots in the within-plate basalt and calc-alkaline basalt fields. Sample Z1578 plots just outside the islandarc tholeiite field.

Fig. 3B plots 2Nb - Zr/4 - Y (after Meschede, 1986). Many of the analyses are clustered in the volcanic-arc basalt field. Sample Z1546 and Z1594 plot in the "within-plate alkalic" field. Three samples plot in the field of plume-type MORB. The only point in the N-type MORB field is that of sample Z1578, which may be due to analytical uncertainty as it does not tally with its plot outside of MORB in Fig. 3A.

During the present study, none of the basalt



CAB	=	calc-alkaline basalts
DPMB	=	destructive plate margin basalts
IAT	=	island arc tholeiite
MORB	=	mid-ocean ridge basalts
N-MORB	=	normal-MORB
P-MORB	=	plume-MORB
VAB	=	volcanic arc basalts
WPA	=	within-plate alkaline
WPB	=	within-plate basalts
WPT	=	within-plate tholeiite

Fig.3. Tectonomagmatic discrimination plots based on trace element data for the basalts from Bela ophiolite. (A) Ti/100-Zr-Y.3 plot after Pearce & Cann, 1973. (B) 2Nb-Zr/4-Y plot after Meschede, 1986. (C) Hf/3-Th-Ta plot after Wood et al., 1979.

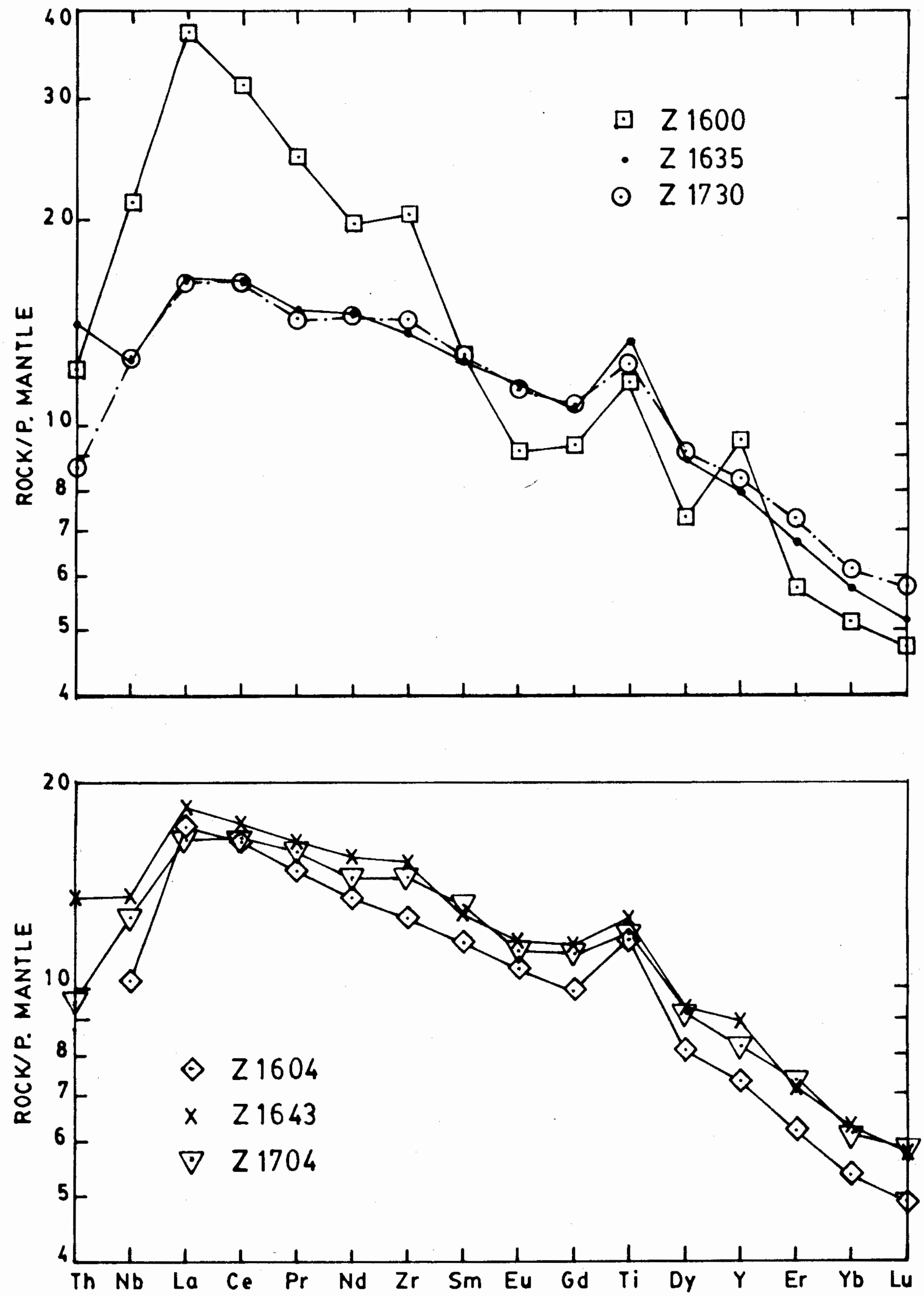


Fig. 4. Primitive – mantle normalized abundances of Th, REE, and HFSE in basaltic volcanics of the Bela ophiolite. Individual samples are identified by separate symbols and sample number. Normalizing values from Hofmann (1988).

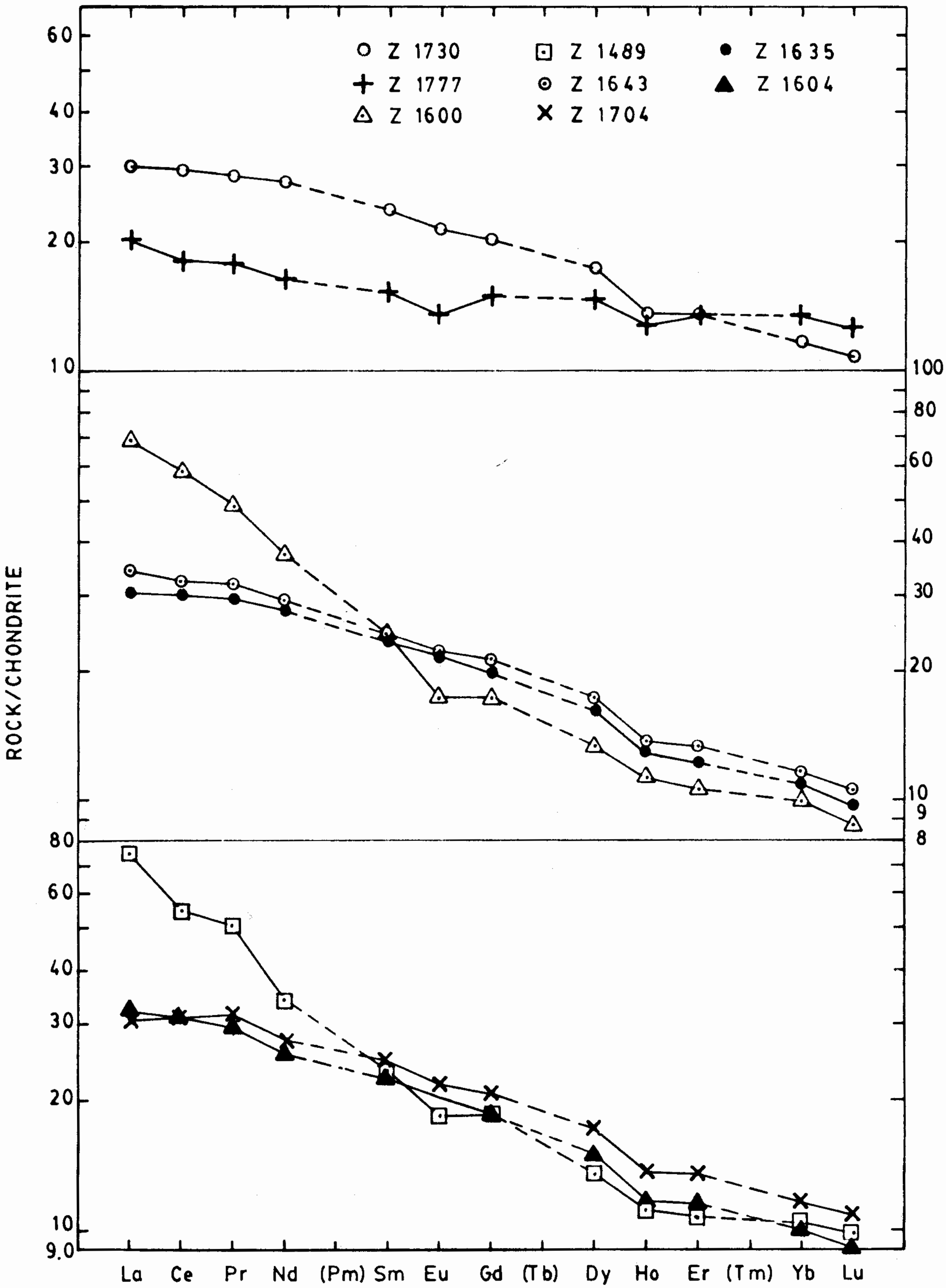


Fig. 5. Chondrite-normalized rare earth elements plots for the basalts of Bela ophiolite.

Table 3. Rare-earth element abundances in p.p.m. for basalts from the Bela ophiolite.

Sp.no.	Z1777	Z1730	Z1635	Z1704	Z1604	Z1643	Z1600	Z1489
La	6.70	9.90	10.00	10.20	10.60	11.30	22.90	24.90
Ce	15.70	25.80	26.00	27.00	26.90	28.10	50.50	48.10
Pr	2.20	3.48	3.61	3.87	3.61	3.92	6.03	6.16
Nd	10.20	17.30	17.50	17.40	16.20	18.50	23.70	21.60
Sm	3.08	4.88	4.78	5.06	4.54	5.00	4.93	4.75
Eu	1.05	1.67	1.69	1.69	1.56	1.72	1.34	1.44
Gd	4.12	5.59	5.48	5.72	5.05	5.84	4.86	5.17
Dy	5.05	5.87	5.63	5.88	5.14	5.95	4.68	4.65
Ho	0.98	1.04	0.99	1.05	0.90	1.06	0.85	0.84
Er	3.03	3.01	2.79	3.02	2.58	3.01	2.40	2.46
Yb	2.92	2.55	2.39	2.56	2.21	2.58	2.14	2.28
Lu	0.43	0.37	0.33	0.37	0.31	0.36	0.30	0.33

samples showed an N-type MORB geochemistry. To determine whether the basalts possess an island arc - suprasubduction zone geochemical signatures, that is, negative Nb relative to Th and La on the primitive-mantle normalized plots, patterns of 6 basalt samples are shown in Fig.4. Sample Z1635 shows a negative Nb anomaly with respect to Th and La. Nb of sample Z1643 plots distinctly lower than La but at similar level as Th. For samples Z1604 and Z1730, Th values were not determined, but their Nb values plot distinctly lower than La. Samples Z1600 and Z1704 show a smooth progressive increase in Th, Nb and La concentrations. The geochemical characteristics of the six basalt samples show a spectrum from well-developed arc through transitional signatures to non-arc, which may be compared to those shown for the Bay of Islands ophiolite by Jenner et al. (1991).

Certain other samples (no. Z1537, Z1578, Z1580 and Z1590) not plotted on Fig. 4 possess negative Nb with respect to Th and La when normalized to the primitive mantle values.

The rare-earth element abundances in the samples are assumed to reflect the original contents. It is generally accepted that the rare-earth element concentrations are not much affected by secondary processes in rocks such as metamorphism, hydrothermal alteration and weathering, unless these processes are severe (Sun & Nesbitt, 1978).

The rare-earth element analyses for the basalts from the Bela ophiolite are given in Table 3. The concentrations are normalized to chondritic meteorites (Nakamura, 1974) in Fig. 5. REE analyses for eight samples only are plotted, avoiding overlapping plots. The pattern of a typical pillowed basalt from Bela ophiolite is demonstrated by samples such as Z1635, Z1643 and Z1704. These show a mild enrichment in light REE which are about 15 to 35 times chondritic values. The heavy REE vary from 8 to 15 times chondritic abundances. The heavy REE concentrations of such samples may suggest absence of garnet in the source. None of the studied samples shows a pattern depleted in light REE. Thus, a normal (or N-type) MORB is not present in the Bela ophiolite. This conclusion is also supported by certain other criteria. For instance, the range of SiO_2 content of volcanic rocks is not narrow, which is a typical feature of the mid-ocean ridge segments (SiO_2 =47 to 51%) and more silicic differentiates are also abundantly present. The samples are not depleted in the large low-valency cations (Cs, Rb, K, Ba, Pb and Sr). The larger ions are not depleted than the smaller ions and the element ratios K/Rb, K/Ba and Sr/Ba are not as high as those of N-type MORB. The Zr/Nb ratio which is, 30 for the N-type MORB (Wilson, 1989) ranges from 5 to 20 for the analyses listed in Table 3. There seems no tendency for the LREE or the other incompatible elements' depletion in the Bela ophiolite samples. Unlike the N-type MORB, the chondrite-normalized La/Sm ratio is more than unity for all the studied samples. Negative Eu anomalies are not common. In Fig.5 which plots 8 samples, only one (Z1730) shows a small negative Eu anomaly.

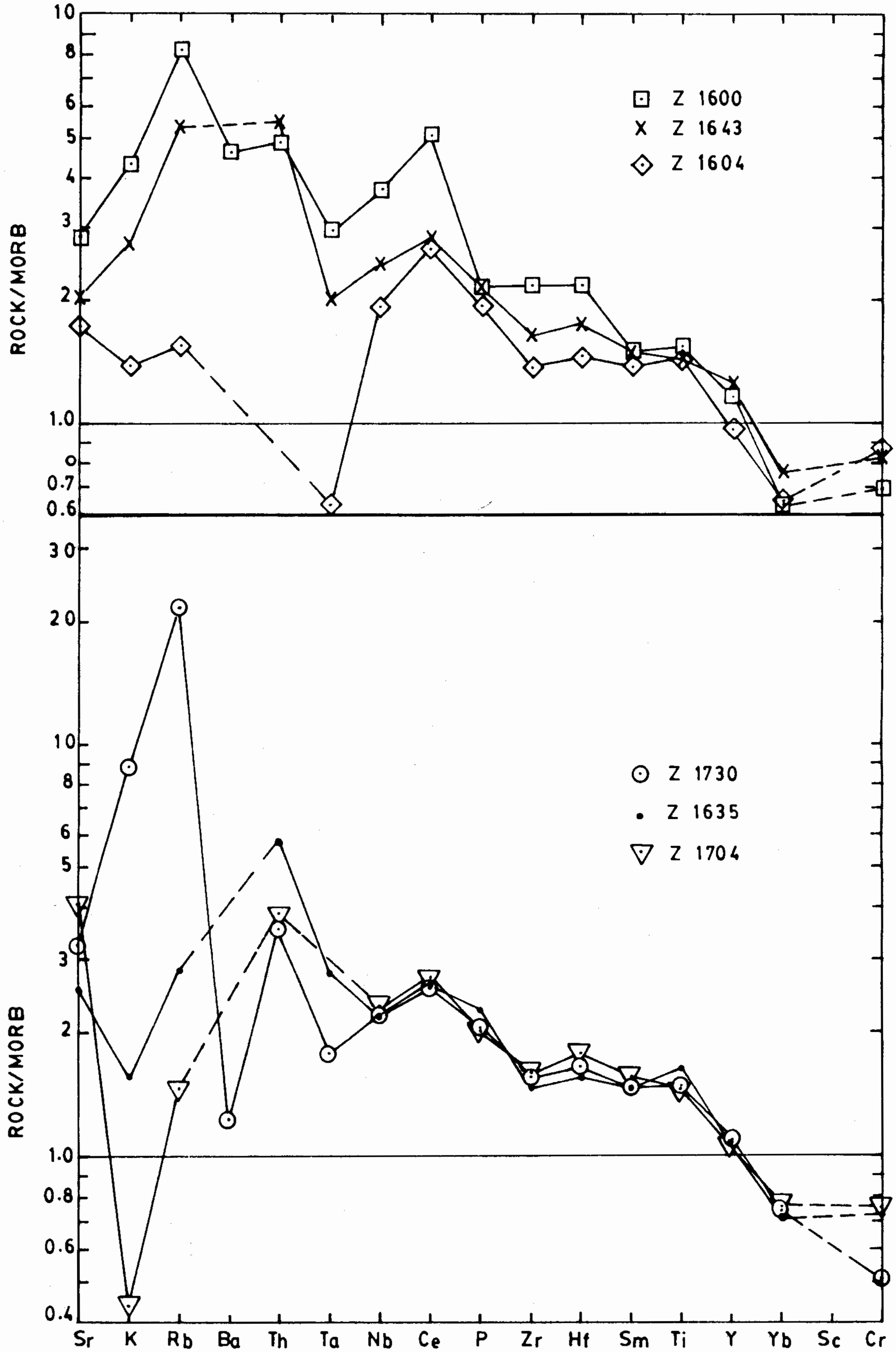


Fig.6. Mid-ocean ridge basalt-normalized trace elemement patterns for some basalts from the Bela ophiolite. Normalizing value after Pears (1982).

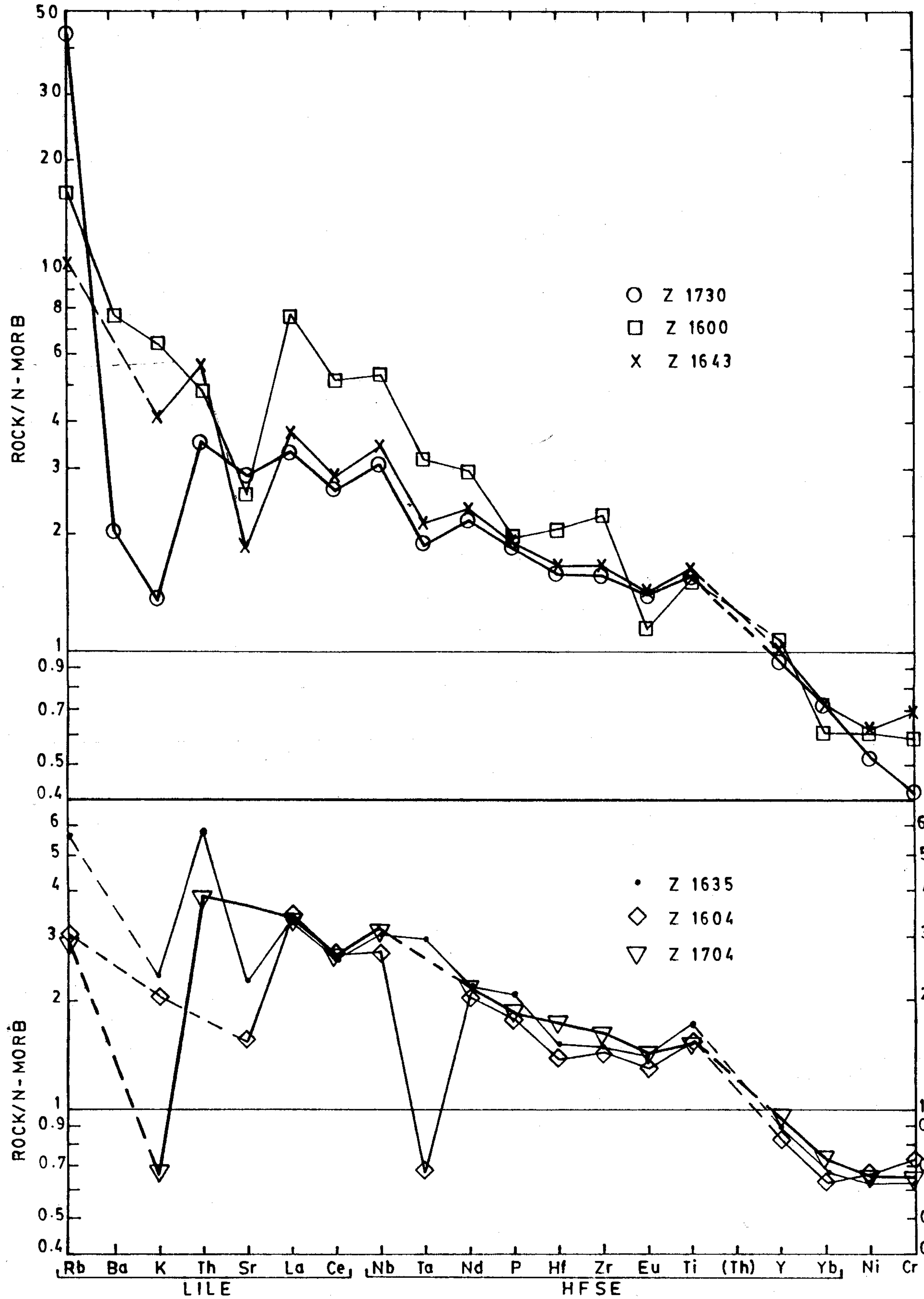


Fig. 7. Basalt analyses plotted after normalization against fresh N-type MORB after Saunders & Tarney (1984).

The LREE enrichment seen in the samples is similar to that shown by the mafic rocks from plume-type MORB, oceanic island basalts, island-arc basalts and marginal basin basalts. The flatter patterns such as those shown by samples Z1730, Z1635, Z1643, Z1604 and Z1704, at 10 to 30 times chondrite, resemble the marginal basin basalts patterns. They do not show a negative Eu anomaly. In this respect, they are more like the back-arc basin basalts rather than the arc basalts. Sample Z1777 exhibits even flatter pattern at 12 to 20 times chondrite, but it shows a small negative Eu anomaly which is unlike the marginal basin basalts (Wilson, 1989). Some samples such as Z1600, Z1489, show patterns indistinguishable from those of the oceanic island basalts.

The presence of plagiogranites in the region (Ahmed, 1991) may point towards an ensialic, rather than ensimatic, marginal basin. However, such basins are rare, and the basalt geochemistry discussed herein is more like an ensimatic marginal basin, affected by a nearby subduction slab.

The suprasubduction zone ophiolites carry a geochemical component from an underlying subduction zone. Mid-ocean ridge ophiolites lack this component. In Fig. 6, MORB-normalized basalt patterns for 6 samples are drawn after Pearce et al. (1984). Typically, Yb, Sc and Cr plot below MORB, but Y and Ti are above MORB values. The patterns do not completely resemble the oceanic non-SSZ patterns shown by Pearce et al. (1984); but the presence of SSZ component is revealed in the lowered curves in the Nb-Ta region. Fig.6 shows the trace elements in basalts normalized to a typical MORB after Pearce (1982) and Pearce et al. (1984). In Fig.6, comparatively high abundance of incompatible elements (Rb, K, Th, Ce) relative to the other less incompatible species (Zr, Hf, heavy REE) is observed. The use of K, Rb, and probably Ba, Sr and Th in evaluating primary magmatic geochemistry may not be reliable for altered basalts (Saunders & Tarney, 1984, Fig.1). The variety of the patterns displayed in Fig.6 differs from the patterns typical of within-plate basalts which, according to Pearce (1982) are characterized by an enrichment in all elements from Sr to Ti (Fig. 6) and a value close to unity for Y, Yb, Sc and Cr. The samples in Fig.6 also differ from transitional to enriched - MORB pattern which is characterized by a high degree of enrichment of most incompatible elements (Ba, Th, Ta, Nb) relative to the moderately incompatible elements (P, Zr, Hf, Sm); and also by the negligible Ti enrichment relative to Y and Yb (Pearce, 1982).

The pattern with generally low abundances shown by the sample Z1604 resembles those of the island-arc tholeiites. This sample is from a pahoehoe lava basalt with ropy surface. However, this sample differs from arc samples in terms of Fig. 5.

In Fig.7 (after Saunders & Tarney, 1984), a distinct degree of LIL element enrichment is displayed. Some of this enrichment may be due to secondary alteration; but high Th values are probably primary. Th is considered less mobile at least during low grade alteration of basalts (Saunders & Tarney, 1984). The enrichment is similar in extent to that in certain back-arc basins (e.g., the Mariana Trough) but not as strong as that found in island arcs and remnant arcs (Saunders & Tarney, 1984). The basalts in the Bela ophiolite are dominated by samples which possess a chemical transition between mid-ocean ridge and island-arc basalts.

The enriched or E-type MORB shows LILE enrichment coupled with enhanced abundances of Nb and Ta (e.g., Saunder & Tarney, 1984). The basalts from Bela ophiolite do not show Nb and Ta abundances for a few samples. The island-arc and continental margin calc-alkaline magmas are characteristically enriched in LILE and depleted in HFSE relative to N-type MORB. The basalt of Bela do show LILE enrichment, but in Figs. 6 & 7, the HFSE (except Yb) depletion below that of the N-type MORB is not observed.

In Fig. 7 the form of data curves shows that the enrichment in LIL elements relative to HFS elements, is a little higher than that for certain back-arc basins, e.g., the Mariana Trough and the East Scotia Sea. Saunders & Tarney (1984) have shown that the degree of LILE enrichment in back-arc basalts depends on the maturity of the adjacent subduction zone in addition to the evolutionary state of the basin and contemporaneous arc.

A comparison with the total range of LILE enrichment displayed by the back-arc basins given by Saunders & Tarney (1984) shows that the marginal basin basalts from Bela were associated with a moderately mature subduction zone. The localized LILE and water enrichment of the source of these basalts by fluids derived from the subducted dehydrating slab is suggested. The moderate LILE / HFSE enrichment may indicate that such fluids were probably not derived from an earlier episode of subduction.

CONCLUSIONS

Pillowed basalts are a well-developed component in the Bela ophiolite. Minor outcrops and dykes of non-pillowed basalt also occur. Rare pahoehoe lava outcrops occur in proximity to the pillowed basalts. The basalts show a omposite geochemistry and there is no simple predictable pattern of the basaltic magmatism. However, all the samples analyzed in this study lacked the N-type MORB signatures. The basalts show supra-subduction zone geochemical signatures. Marginal basin basalts are abundantly developed. At a few locations basalts with oceanic island geochemistry are developed.

REFERENCES

AHMED, Z. (1991) A supra-subduction zone origin of the Bela ophiolite indicated by the acidic rocks of Khuzdar District, Pakistan. (This Volume).

ARCULUS, R.J. & POWELL, R. (1986) Source component mixing in the region of arc magma generation. J. Geophys. Res. **91,** pp. 5913 - 5926.

DUNGAN, M.A., VANCE, J.A. & BLANCHARD, D.P. (1983) Geochemistry of the Shuksan greenschists and blueschists, North Cascades, Washington: Variably fractionated and altered metabasalts of oceanic affinity. Contrib. Mineral. Petrol. **82**, pp. 131-146.

JENNER, G.A., DUNNING, G.R., MALPAS, J., BROWN, M. & BRACE, T. (1991) Bay of Islands and Little Port complexes revisited: age, geochemical and isotopic evidence confirm suprasubduction- zone origin. Can. J. Earth Sci. **28,** pp. 635-652.

HART, R.A. (1970) Chemical exchange between seawater and deep ocean basalts. Earth Planet. Sci. Lett. **9,** pp. 269-279.

HART, S.R. (1970) K, Rb, Cs, Sr and Ba contents and Sr isotope ratios of ocean floor basalts. Phil. Trans. R. Soc. London **A-268,** pp. 573-587.

———, ERLANK, A.J. & KABLE, E.J.D. (1974) Sea floor basalt alteration: some chemical and Sr-isotopic effects. Contrib. Mineral. Petrol. **44,** pp. 219-230.

HELLMAN, P.L., SMITH, R.E. & HENDERSON, P. (1979) The mobility of the rare earth elements: evidence and implications from selected terrains affected by burial metamorphism. Contrib. Mineral. Petrol. **71,** pp. 23-44.

HOFMANN, A.W. (1988) Chemical differentiation of the Earth: the relationship between mantle, continental crust and oceanic crust. Earth Planet. Sci. Lett. **90,** pp. 297-314.

HUMPHRIS, S.E. & THOMPSON, G. (1978) Trace element mobility during hydrothermal alteration of oceanic basalts Geochim. Cosmochim. Acta **42,** pp. 127-136.

MESCHEDE, M. (1986) A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram. Chem. Geol. **56,** pp. 207-218.

NAKAMURA, N. (1974) Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. Geochim. Cosmochim. Acta **38,** pp. 757-775.

PEARCE, J.A. (1982) Trace element characteristics of lavas from destructive plate boundaries. *In*: Thorpe, R.S. (ed.) ANDESITES, pp. 525-548. John Wiley & Sons, Chichester.

——— & CANN, J.R. (1973) Tectonic setting of basic volcanic rocks determined using trace element analysis. Earth Planet. Sci. Lett. **19,** pp. 290-300.

PEARCE, J.A., LIPPARD, S.J. & ROBERTS, S. (1984) Characteristics and tectonic significance of supra-subduction zone ophiolites. *In*: Kokelaar, B.P. & Howells, M.F. (eds.) MARGINAL BASIN GEOLOGY. Geol. Soc. London Spec. Publ. **16,** pp. 77-94.

SAUNDERS, A.D. & TARNEY, J. (1984) Geochemical characteristics of basaltic volcanism within back-arc basins. *In* : Kokelaar, B.P. & Howells, M.F. (eds.) MARGINAL BASIN GEOLOGY. Geol. Soc. London Spec. Publ. **16,** pp. 59-76.

SUN, S. - S. & NESBITT, R.W. (1978) Petrogenesis of Archean ultrabasic and basic volcanics: evidence from rare earth elements. Contrib. Mineral. Petrol. **65,** pp. 301-325.

WILSON, M. (1989) IGNEOUS PETROGENESIS -- A GLOBAL TECTONIC APPROACH. Unwin Hyman, London.

Manuscript received on June 25, 1991.
Accepted for publication on September 12, 1991.

ACTA MINERALOGICA PAKISTANICA
Volume 5 (1991) pp. 99 - 108.

URANIUM MINERALS FROM PAKISTAN : A REVIEW

M.A. RAHMAN
Karachi Nuclear Power Training Centre, KANUPP, P.O. Box 3183,
Karachi, Pakistan.

ABSTRACT : In Pakistan, at least fourteen U- Th-bearing mineral species occur widely distributed in sandstone, granite, pegmatite, carbonatite, and graphite schist rocks. The primary minerals are mainly associated with the acid intrusives, carbonatites and graphite schists showing the disseminated type of occurrence. Invariably, the mineralizations are associated with minor concentration of uraniferous limonite due to oxidation by weathering. Secondary U mineralization indicates wider distribution and is mainly associated with the fluviatile sandstone of Upper Miocene age. The nature of U-mineralizations and their petrogenetic significance are discussed.

INTRODUCTION

The first uranium mineral tentatively identified as metatyuyamunite was encountered by the Geological Survey of Pakistan near the village Rakhimunh in District Dera Ghazi Khan in May, 1959 (Asad & Schmidt, 1962). In 1962, the Pakistan Atomic Energy Commission (PAEC) initiated a radiometric survey programme in this District which resulted in the discovery of a uranium deposit at Baghalchur. Furthermore, widespread occurrences of uranium mineralization were located in the Middle Siwalik sandstone outcrops in Dera Ghazi Khan area. An intensive programme undertaken by the Atomic Energy Minerals Centre, Lahore, has helped to locate several U-mineral species distributed in various rock formations. Uranium mineralizations located in different areas were studied for its field relations and to provide laboratory data. This paper describes briefly the nature of uranium mineralization hosted in different rock types. A classification of uranium bearing minerals and their description is presented to discuss their petrogenetic significance.

DISTRIBUTION OF URANIUM IN ROCKS

Uranium occurs as an exyphile element in an average concentration of 2.8 ppm in continental areas (Phair & Gottfried, 1964). It is intimately associated with thorium. Uranium occurs in three isotopes, ^{238}U, ^{235}U and ^{234}U out of which ^{238}U is over 99 per cent abundant in nature. Uranium is present in varied geological environments. Uranium minerals amount to over 100 species, Geochemical factors governing the distribution of uranium are as follows : (a) Its isomorphism. (b) Wide stability range of uraninite. (c) Oxidation of U^{+4} to U^{+6}.

The isomorphism of uranium is demonstrated by the substitution of uranium by Th, Zr, Fe and rare-earth elements and is present in numerous minerals in the form of oxides, complex oxides, phosphates, silicates and organic complexes.

Uraninite is stable over a wide range of temperature in its composition from UO_2 to U_3O_8. Under low temperature conditions, uraninite is precipitated by epigenetic processes either in structure-controlled traps or under highly reducing conditions favourable for the reduction of U^{+6} to U^{+4}. Examples of such behaviour of uranium can be cited from the Colorado Plateau and Wyoming type deposits. In the high temperature forms, uranium is notably concentrated in pegmatites and hydrothermal veins. The behaviour of uranium to oxidize readily forming highly soluble uranyl ion $(UO_2)^{+2}$ enables uranium to be easily mobilized and redistributed under ordinary weathering conditions. Hence, secondary uranium minerals are derived from the primary mineralizations forming carbonates, phosphates, vanadates, silicates and sulphates. Uranium mineralizations associated with different rocks in Pakistan can be divided into the following rock types : (1) Sandstones (2) Pegmatites (3) Granites (4) Carbonatites (5) Graphite Schists.

NATURE OF URANIUM MINERALIZATIONS

In Pakistan uranium minerals occur in sandstones, granitic rocks, pegmatites, carbonatites and in graphite schists. The distribution of uranium in these rocks is shown in Fig.1. Various types of occurrences are described below.

SANDSTONE TYPE

Uranium mineralization hosted in sandstones occur in three areas : (a) Dera Ghazi Khan area; (b) Kohat-D.I. Khan area; (c) Bhimbar area.

Dera Ghazi Khan Area

The mineralization consists of a major zone of uranium mineralization at Baghalchur and numerous smaller zones widely distributed throughout a narrow stratigraphic thickness in the area (Ashraf & Rahman, 1963, 1964; Aslam & Rahman, 1964; Rahman et al., 1966; Rahman, 1972). The mineralization occurs in the sandstone of the Middle Siwalik formation of Upper Miocene age. The sandstone is grey, fine to medium grained, porous and friable. It consists of quartz, oligoclase, microcline, biotite, muscovite and hornblende with minor amounts of tourmaline, epidote, chlorite, garnet, magnetite, ilmenite and limonite. Fine argillaceous material as well as calcite forms the matrix of the sandstones. Based on the modal analyses, the sandstones were classified as impure arkose (Rahman, 1972).

The uranium mineralization in the area is in the form of both primary and secondary minerals. The primary minerals are present as fine grained uraninite and coffinite in the sandstone below the water table.

The secondary mineral tyuyamunite is wide spread in the surficial zones of the sandstone. The mineral occurs mainly as thin coatings on the detrital constituents and is irregularly mixed with the matrix. The mineralization occurs in the form of pockets and thin lenses upto 6 in length. Layers, 1-10 cm thick, follow the bedding and cross bedding in the sandstone along a narrow stratigraphic zone in the Middle Siwalik formation. The geological exploration work delineated about 100 surface showings of the mineralization containing uranium in the range of 0.05 to over 0.5% U_3O_8 (Moghal, 1974).

The origin of uranium deposits in the Dera Ghazi Khan District has not been clearly understood so far. Earlier studies on the secondary mineralization suggested that the tyuyamunite deposits indicate a syngenetic sedimentary origin (Rahman, 1972). Subsequent mineralogical investigations on the drilled cores revealed the presence of uraninite and coffinite associated with the detrital constituents of the sandstone (Basham & Rice, 1974). It was suggested by Basham and Rice (1974) that these minerals are of authingenic origin and that the ground water behaviour played an important control on mineralization resulting in uranium enrichement subsequent to sedimentation.

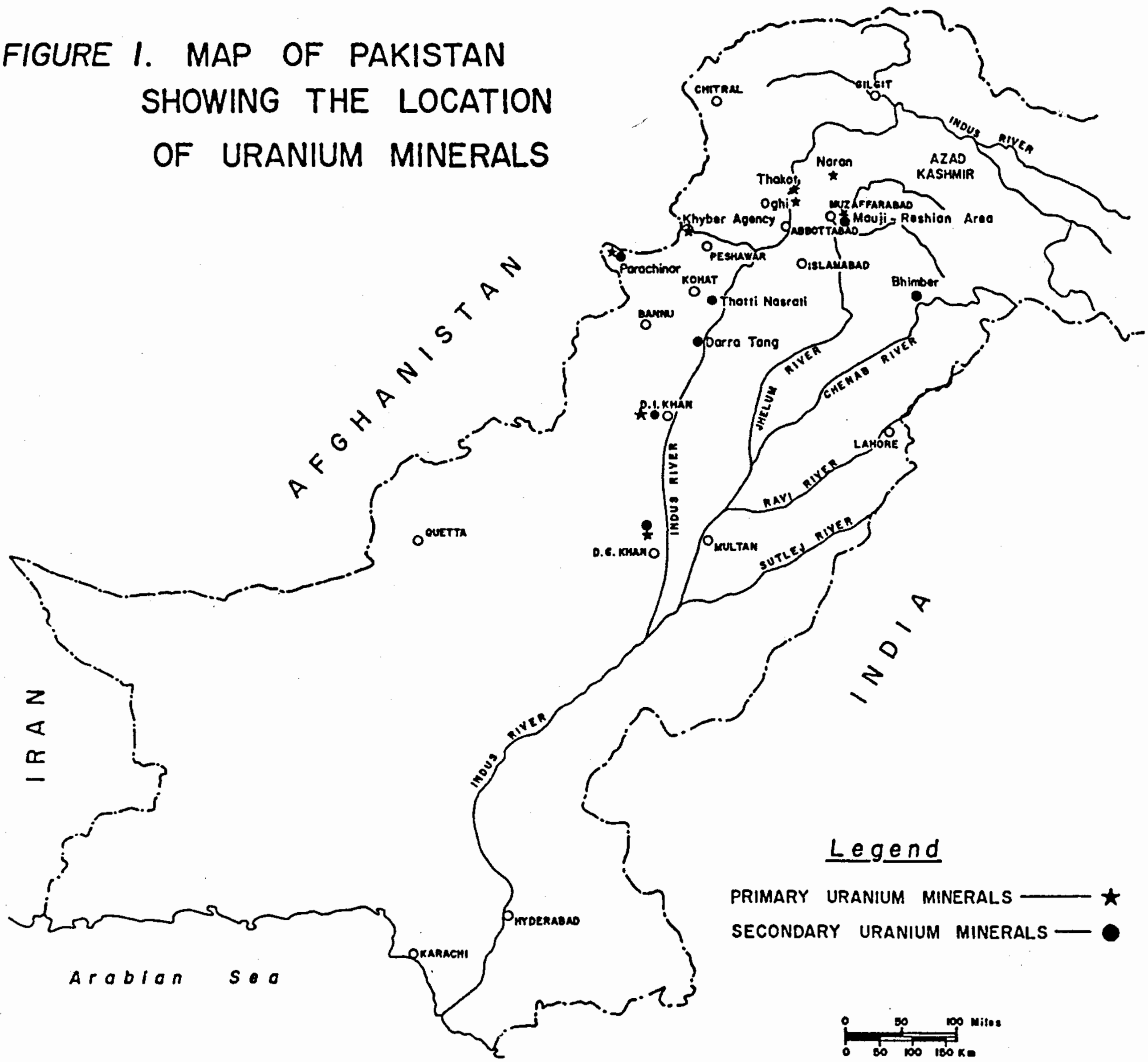
Kohat and D.I. Khan Areas

Secondary uranium mineralization located in this area occurs in the sandstones of Middle Siwalik formation. The host rocks in this area are in continuation to the type area of Siwalik formation in Potwar. The minerals include carnotite (Baig et al., 1978) and uranophane (Basham & Rice, 1974). Both occur separately along the same stratigraphic sequence. Carnotite and uranophane occur in the sandstone as coating on clay balls, in pockets and along short layers following the bedding. Comparing the field relations, the mineralization in Kohat - D.I. Khan area indicates similarity to that of Dera Ghazi Khan area.

Bhimber Area

Uranium mineralization is present in sandstone rocks forming extension of Middle Siwalik formation in Bhimber, Azad Kashmir.

FIGURE I. MAP OF PAKISTAN SHOWING THE LOCATION OF URANIUM MINERALS



The uranium mineral occurs as uranophane (Basham & Rice, 1974) in the surficial zones in the sandstones.

PEGMATITE TYPE

Radioactive minerals occur in two major pegmatite bodies separately located near village Bagarian in District Mansehra and the other at Naran in Kaghan Valley.

Bagarian Pegmatite, District Mansehra

About one mile NE of village Bagarian is a pod-like pegmatitie body, 60 m long and 25 m wide enclosed in a granite gneiss which is grouped under the Susal Gali (Shams, 1961). The pegmatite contains a radioactive mineral, tentatively identified as uraninite (?) from its physical properties. This mineral occurs as an accessory mineral in the pegmatite. Ashraf (1974) has provided data on the petrogenesis of the Bagarian pegmatite and has indicated that this is a complex pegmatite with four zones developed from border zone to the quartz core, each zone with a different mineralogical composition. It is suggested that this pegmatite has been replaced by pneumatolytic fluids near the intermediate zone with the development of beryl, columbite, microcline, perthite, uraninite (?), muscovite and garnet (Ashraf, 1974).

Naran Pegmatite, Kaghan Valley

A fairly large pegmatite body near Naran in Kaghan Valley contains a radioactive mineral. The pegmatite consists mainly of quartz, feldspar with irregularly distributed pockets of muscovite. The radiocative mineral is of refractory type. Based on physical properties, it is identified as samarskite (?), being similar to Bagarian pegmatite.

GRANITE TYPE

There is a widespread occurrence of uranium associated with acid intrusive bodies. The mineralization is weakly disseminated. Uranium mineralizations associated with granitic rocks occur in Thakot area, District Mansehra and in Parachinar area, N.W.F.P. which are briefly described below.

Thakot Area

The mineralization is hosted in granitic rocks and associated pegmatites showing banded structure. Pegmatites are present as lenticular bodies often exhibiting vein-like form along the foliation in the gneisses. The radioactive zones in pegmatites and granitic gneiss are characterised by high degree of metamorphism associated with tectonic activity. The mineralization is characterised by the presence of metamict zircon irregularly disseminated in pegmatite and granitic gneiss as an accessary mineral (Rahman, 1976). Subsequently field and laboratory investigations showed the presence of vein-type mineralization containing fine- to coarse-grained uraninite and pyrite irregularly disseminated in the granitic and pegmatitic rocks (Rahman, 1978). Further field studies on this area have indicated that the mineralization is structurally controlled and is present along shear joints probably deposited by hydrothermal solution (Butt & Khalid, 1980).

Parachinar Area

The radioactive anomalies in the granitic rocks of Parachinar area show the presence of uraninite as discretely disseminated together with allanite and radioactive epidote. These minerals are of primary nature and occur as accessory constituents in medium grained granitic as well as pegmatitic parts of the migmatised rocks. These minerals are characterised by metamictization. Secondary uranium mineralization is also present as uraniferous limonite and goethite concentrated in minor fractures and fillings in pyrite pseudomorphs. This form of uranium enrichment is localised depending upon the mobility of uranium and iron in solution by weathering processes (Butt & Mahmood, 1986; Rahman & Jaseemuddin, 1978).

Carbonatite

The radioactive anomalies that occur in a carbonatite body at Loe Shilman in Khyber Agency showed the presence of a radioactive mineral. The rock is fine-to medium-grained consisting mainly of calcite and dolomite with minor amounts of apatite, phlogopite, biotite, amphibole and sphene. Petrographic studies on the carbonatite have indicated the presence of three different mineralogical types of carbonatites classified into amphibole phlogopite carbonatite, apatite carbonatite and biotite carbonatite which represent separate intrusions (Majid, 1976).

Based on the microscopic and x-ray diffraction work on the radioactive mineral as well as data obtained by electron probe microanalysis of the mineral (Syed, 1975), the mineral is classified by the writer as betafite. It occurs as coarse-grained irregular disseminations in the carbonatite body. This identification has been contested by Butt (1981) who has classified the mineral as pyrochlore on the basis of x-ray powder diffraction pattern and Nb-Ti ratio rather than Nb-Ta ratio considered by Rahman (1980). The pyrochlore, identified in Leo-Shilman carbonatite ranges from totally metamict through partially metamict to nonmetamict mineral species.

Graphite Schists

The graphite schists of the Salkhala Series rocks in Azad Kashmir, hosts uranium mineralization associated with thorium and other minerals. The mineralization occurs mainly at Mauji and Reshian in District Muzaffarabad, Azad Kashmir. The graphite schist rocks are very fine grained, dark grey to black and finely schistose to somewhat hard and massive. The rock shows small-scale folding and jointing characterised by high degree of brecciation. Shearing in the graphite schist is a common feature. The shear zones range in thickness from 30 cm to 2 m. The graphite schists of the Mauji and Reshian areas essentially consist of quartz, sericite and carbonaceous material in varying proportions. Minor amounts of rutile , shorlite, apatite, epidote and goethite are also present.

Mineralogical work on the uranium mineralization in Mauji-Reshian area, indicated the presence of uranium minerals, brannerite and uraniferous goethite, with xenotime as a thorium-bearing mineral. The mineralization in the graphite schists is associated with pyrite, graphite, rutile, chalcopyrite, marcasite, sphalerite, covellite, pyrrhotite, tetrahedrite and galena. Goethite is widely distributed as a secondary mineral predominantly in the surficial zone (Rahman, 1976 a).

Brannerite as primary uranium mineral alongwith xenotime is irregularly disseminated in the graphite schist showing preferred orientaition parallel to the schistosity. Texture and structural relations show that both the brannerite and xenotime are of pretectonic origin. The presence of uranium in the area is closely associated with that of thorium. Uranium concentration ranges from 3 to 106 ppm and thorium from 31 to 281 ppm (Rahman, 1976a).

CLASSIFICATION AND DESCRIPTION OF URANIUM MINERALS

In Pakistan, uranium minerals occur in a variety of compounds distributed in different rock types. Radioactive minerals containing uranium and thorium as essential constituents as well as minor amounts are enlisted in Table 1.

The identification of the mineral species is based on the mineralogical data invariably supported by chemical analyses of the radioactive rock samples from different localities in Pakistan showing uranium associated with thorium. To date fourteen mineral species have been identified from different localities. Uranium minerals of Pakistan have been classified into two broad categories :

(1) Primary uranium minerals.
(2) Secondary uranium minerals.

The minerals listed under the primary groups have tetravalent uranium and are generally characterized by the dark colours and higher specific gravity. The minerals listed under the secondary group are the minerals having hexavalent uranium and are characerised by brilliant colours and low specific gravity. Data relating to mineral species, respective host rocks and localities are given in Table 1.

The mineralogical characteristics of various uranium-bearing minerals and their associations are briefly described below.

(1) Allanite : $(Ca, Ce)_2$ $(Fe^{+2}\ Fe^{+3})$ Al_2O_3 OH $(Si_2O_7)(SiO_4)$

Allanite occurs as prismatic to irregularly shaped grains. The mineral is characterised by yellowish colours. Overgrowths of allanite on epidote grains are present indicating its development as an alteration product of epidote.

Table 1. Uranium and thorium bearing minerals from Pakistan.

Minerals	Composition	Locality
Primary Minerals:		
Allanite	$(Ca,Ce)_2(Fe^{+2},Fe^{+3})Al_2O_3OH(Si_2O_7)(SiO_4)$	Parachinar
Betafite	$(U,Ca)_{2-x}(Nb, Ti, Ta)_2O_{6-x}(HO)_{1+x}$	Khyber Agency
Brannerite	$(U, Th, Ca)(Ti, Fe)_2O_6$	Mauji, Reshian, A.K.
Coffinite	$U(SiO_4)_{1-x}(OH)_{4x}$	D.G. Khan
Radioactive Zircon	$ZrSiO_4$	Thakot, Mansehra
Radioactive Epidote	$CaFe^{+3}Al_2O.OH(Si_2O_7)(SiO_4)$	Parachinar
Samarskite	$(Y, Fe, U)(Nb, Ti, Ta)_2(O.OH)_6$	Naran, Kaghan Valley
Uraninite	UO_2	Mansehra, D.G. Khan, Thakot
Xenotime	YPO_4	Mauji, Reshian, A.K.
Monazite	$(Ce, La, Th, U)PO_4$	Musa Mena, Malakand Agency
Secondary Minerals:		
Carnotite	$K_2(UO_2)_2(VO_4)^2.1\text{-}3H_2O$	Kohat
Tyuyamunite	$CaO.2UO_3.V_2O_5.8H_2O$	D.G. Khan
Uranophane	$Ca(UO_2)_2(SiO_3)_2(OH)_2.5H_2O$	D.I. Khan
Uraniferous Goethite	α - FeO.OH	Mauji, Reshian, A.K. Parachinar.

Allanite occurs as discretely disseminated grains distributed in granitic gneiss and pegmatite bodies in Parachinar area. It occurs in association with a radioactive epidote.

(2) Betafite: $(U, Ca)_{2-X}(Nb, Ti, Ta)_2O_{6-x}(OH)_{1+x}$

Under polarized light, the mineral shows anomalous colours distributed in colour zones with reddish brown margins and dark brown middle parts of the grains. It is nonpleochroic with n=1.960. Also, it is isotropic indicating very weak anisotropism and reddish brown internal reflection. Based on the available chemical data, the radioactive mineral was identified as betafite. Betafite occurs as coarse grains disseminated in carbonatite of Khyber Agency.

(3) Brannerite: $(U, Th, Ca)(Ti, Fe)_2O_6$

This mineral occurs as irregularly prismatic shaped grain upto 50 µm in size. It is grey (in air) to dark grey (in oil) with low reflectivity (15 to 17%). The mineral is completely isotropic probably due to its metamict state but shows faint brown and grey internal reflection. It occurs in association with rutile and pyrite (Rahman, 1976a).

Brannerite occurs as fine disseminated grains together with the xenotime grains in the graphite schist in Mauji-Rashian area in District Muzaffarabad, Azad Kashmir. Mineralogical and textural features suggest that these minerals are of pre-tectonic origin.

(4) Coffinite: $U(SiO_4)_{1-x}(OH)_{4x}$

Coffinite occurs in association with uraninite as minute granules less than 1 µm in size in aggregates showing colloform texture. The mineral is mainly associated with the detrital constituents of sandstones in the zone of non-oxidized mineralization at Beghalchur, Dera Ghazi Khan. Basham and Rice (1974) have suggested an authigenic origin for these uranium minerals.

(5) Radioactive Zircon: $ZrSiO_4$

Radioactive zircon occurs as fine-grained crystalline grains of about 40 µm size. It is reddish brown in colour and is characterised by the presence of zoning, irregular fractures and birefringence masked by the colour of the mineral. This is a metamict zircon and is irregularly distributed as an accessory mineral in pegmatites and granitic gneiss in Thakot area, District Hazara (Rahman & Jaseemuddin, 1976).

(6) Radioactive Epidote: $CaFe^{+3}Al_2O.OH (Si_2O_7) (SiO_4)$

The radioactive epidote is characterised by yellowish green colour and distinct weak pleochroism. Interference colours are generally anomalous and strongly bireflectant. The mineral occurs as disseminated grains in granitic gneiss and pegmatite in association with allanite in the Parachinar area (Rahman & Jaseemuddin, 1976).

(7) Samarskite (?): $(Y, Fe, U) (Nb, Ti, Ta)_2 (O.OH)_6$

The mineral occurs as coarse grained crystals irregularly disseminated in the pematite body. The mineral is metamict as it does not give an x-ray pattern. The mineral was tentatively identified as samarskite. The mineral occurs in a pegmatite body lying near Naran in Kaghan Valley, in District Hazara.

(8) Uraninite: UO_2

The mineral occurs as an accessory mineral in the Bagarian Pegmatite in District Mansehra. Uraninite is found in the intermediate zone of pegmatite in association with beryl, columbite and garnet (Ashraf, 1974). The mineral is found to be metamict by x-ray diffraction work.

Uraninite mineralization is also hosted in the unoxidized zone of the Middle Siwalik sandstone at Baghal Chur in District D.G. Khan and in the pegmatoid rocks at Thakot, District Mansehra. Uraninite occurs as aggregates of fine grains of uraninite less than 1 µm in size in sandstone, showing colloform texture. The mineral is associated with detrital constituents of sandstone in the unoxidized zone of the uranium mineralization in District Dera Ghazi Khan. In Thakot, uraninite occurs as fine to coarse grained mineral associated with pyrite irregularly disseminated along veins in pegmatiod rocks (Butt & Khalid, 1980).

(9) Xenotime: YPO_4

Xenotime is present as equant grains which are generally brecciated or show slight deformatin along schistosity in the graphite schist. Inclusions of pyrite and rutile are commonly present. Xenotime grains are upto 200 µm in size. Mineragraphic studies indicate that the mineral is grey with weak but distinct bireflectance and very low reflectivity (about 7%). It is weakly anisotropic showing grey and brown colours (Rahman, 1976a). The mineral shows strong internal reflection showing grey, brown and reddish brown colours.

(10) Carnotite: $K_2 (UO_2)_2 (VO_4)_2 1\text{-}3H_2O$

Carnotite occurs as yellow coloured powdery coatings on detrital clay balls as well as detrital constituents and interstitially in sandstone. The mineralization is present as thin layers and lenses in medium to coarse grained sandstone. Carnotite is frequently associated with reddish brown iron oxide.

The carnotite mineralization lies in the Middle Siwalik sandstone in the vicinity of the Thatti Nasrati town in District Kohat (Baig et al., 1978). The nature of the carnotite occurence is similar to the tyuyamunite occurrence at Baghalchur in District Dera Ghazi Khan. Both occurrences are in the sandstone of Upper Miocence age.

(11) Tyuyamunite: $CaO_2 . UO_3V_2O_5 8H_2O$

Tyuyamunite occurs as greenish yellow minerals with very fine crystalline aggregates showing moderate pleochroism from colourless to greenish yellow and strong interference colours. It occurs as thin irregular coatings on detrital constituents as well as interstitially with the matrix (Rahman, 1972). The mineralization occurs in lenses and layers following the bedding and cross bedding in the arkosic sandstone as well as in grit and conglomerate along narrow stratigraphic zone in the Middle Siwalik formation. Tyuyamunite occurs as a secondary mineral in the oxidized zone whereas the unoxidized zone contains uraninite and coffinite. Field and textural features related to the secondary tyuyamunite deposits have indicated a syngenetic origin. Further work has, however, indicated evidence of uranium enrichment subsequent to sedimentation comparable to sandstone uranium deposits in the U.S.A. (Basham & Rice, 1974).

(12) Uranophane: $Ca (UO_2)_2 (SiO_3)_2 (OH)_2.5H_2O$

Uranophane occurs as greenish yellow mineral. It shows acicular to hair-like form and occurs in aggregates. On the basis of the crystal habit, refractive indices and x-ray diffraction work, the mineral is identified as uranophane (Butt, 1979).

Uranophane occurs as disseminations and as layers in the sandstone at Derra Tang in District D.I. Khan. It is secondary and is probably derived as an alteration product of primary uranium mineral.

(13) Uraniferous Goethite: α - FeO.OH

In uraniferous goethite, uranium is present in association with goethite. It occurs as filling of fractures and voids in the zone of oxidation in the graphite schists in Mauji and Reshian area, Azad Kashmir. It also forms matrix in the graphite schist breccia within the graphite schist rocks. The distribution of secondary uranium mineralization as uraniferous geothite in graphite schist can be explained by the leaching of very fine possible urano-organic complex phase by removal of uranyl ion in solution. This probably took place simultaneously with the oxidation of pyrite under the oxidizing conditions due to the climatic factors (Rahman, 1976b).

Uraniferous goethite also occurs in the granitic gneiss and pegmatite in the Parachinar area, N.W.F.P. The presence of secondary mineralization in the granitic rocks in Parachinar is present in minor fractures and as fillings of pyrite pseudomorphs in the surficial zones.

(14) Uranium - bearing monazite: (La, Ce, Th, U)PO_4

An occurrence was described by Ahmed (1985) from near Musa Mena near Dargai, NWFP.

PETROGENETIC SIGNIFICANCE

The uranium mineralization is predominantly associated with the sandstones of fluviatile origin belonging to Upper Miocene age. The mineralization is characterized by uranium-rich minerals which are deficient in thorium.

The presence of secondary minerals in sandstones, such as tyuyamunite in Dera Ghazi Khan, carnotite and uranophane in Kohat D.I. Khan areas indicate that these minerals were made of hexavalent uranium and vanadium. Uraninite and coffinite present in the unoxidized zone in Dera Ghazi Khan area are found to be of authigenic origin indicating that the ground water behaviour played an important control on mineralization resulting in uranium and vanadium enrichment subsequent to sedimentation (Basham & Rice, 1974).

Uranium minerals in the igneous rocks are preferentially hosted in igneous intrusive rocks of acidic composition such as pegmatites and granites. Minerals occurring in these rocks are allanite, radioactive zircon, radioactive epidote, samarskite (?) and uraninite of primary types. These minerals occur as irregular grain disseminations, as accessory constituents of these intrusions. The uraninite mineralization is associated with sulphides in structurally controlled veins which is suggested to be emplaced by hydrothermal solutions related to the late stage crystallization (Butt & Khalid, 1980). Uraninite(?) also occurs in a pegmatite body in Hazara.

The uranium mineralization associated with the granitic rocks has rarely indicated the presence of secondary uranium minerals. Such mineralization is associated with minor concentrations of uraniferous limonite and goethite. This form of uranium enrichment is very localised and is mainly dependent on the mobility of uranium by weathering processes.

Betafite occurs as primary uranium mineral in carbonatites in Khyber Agency. This mineralization is characterized by disseminated type of distribution. Brannerite and xenotime as primary minerals in the graphite schist at Mauji and Reshian area, are finely disseminated in the schist showing preferred orientation parallel to the schistosity. The graphite schist was originally of sedimentary character indicating it to be of black shale origin. The nature of brannerite and xenotime suggest a detrital character (Rahman, 1976a; b). In Mauji-Reshian area, secondary uranium mineralization is present as veins and as matrix in the graphite schist breccia present in shear zones. The origin of this secondary uranium is suggested to be a urano-organic complex probably occurring in unoxidized zone of the graphite schist. The presence of the urano-organic complex in Mauji-Reshian area is similar to that as suggested for black shales in Vastergotland and Narke District in Sweden, Chattanooga shale in USA and in Vosges mountain, France (Swanson, 1961; Bowie, 1979).

CONCLUSIONS

Thirteen uranium and thorium mineral species, both of primary and secondary types occur in sandstones, granites, pegmatites, carbonatites and graphite schist rocks. Primary minerals range in composition from simple oxide of uranium to complex oxides invariably with the association of thorium and rare-earth elements. These minerals occur mainly in intrusive rocks as well as in graphite schists with associated mineralizations. Secondary minerals occur as hydrated oxides and vanadates in the sandstones of fluviatile origin belonging to the Upper Miocene age. The uranium mineralization in the sandstone indicates wider distribution and is likely to be of greater economic significance.

ACKNOWLEDGEMENTS

The author is grateful to Mr. Mohammad Aslam, Project Manager, BC-1 Project, formerly Director, Atomic Energy Minerals Centre, Lahore for his support in the establishment and organisation of modern mineralogical laboratory facilities at the AEMC, Lahore, in 1974 where the present work was undertaken on significant uranium occurrences of Pakistan. The author is thankful to Dr. K.A. Butt, Head, Hard Rock Division, Atomic Energy Minerals Centre, Peshawar, for critical reading of the manuscript and useful suggestions. The author is indebted to Mr. Aziz Ahmad Siddiqui, Director, KNPTC for his support in the publication of this paper.

REFERENCES

AHMED, Z. (1985) A new occurrence of uranium-bearing thorian monazite, northwestern Pakistan. Acta Mineralogica Pakistanica **1,** pp. 27-33.

ASAD, S.A. & SCMIDT, R.G. (1962) Uranium mineralization near Rakhimunh village, Dera Ghazi Khan District, West Pakistan. Geol. Surv. Pakistan Mineral Inform. Circular **5.**

ASHRAF, M. (1974) Geochemistry and petrogenesis of acid minor bodies of Manshera and Batgram area, Hazara District. Ph.D. thesis, University of the Punjab, Lahore (Unpublished).

ASHRAF, M. & RAHMAN, M.A. & HASSAN, S.M. (1963) Radiometric reconnaissance survey of uranium mineralization near Rakhimunh, D.G. Khan District, West Pakistan. Pakistan Atomic Energy Minerals Centre Report **AE/Geo-2.** (Unpublished).

ASHRAF, M., RAHMAN, M.A. & HASSAN, S.M. (1964) Radiometric survey of Zinda Pir, and Rakhimunh areas, D.G. Khan, West Pakistan. Pakistan Atomic Energy Minerals Centre Report **AEC/Geo-4.** (Unpublished).

ASLAM, M. & RAHMAN, M.A. (1964) Short note on the subsurface exploration of uranium mineralization in the Baghalchur area, D.G. Khan District, West Pakistan. Pakistan Atomic Energy Mineral Centre Report **AEC/Geo-3.** (Unpublished).

BAIG, M.A.S., AKRAM, M.S., MAZHAR, F., AHMED, F. & KHAN, J.A. (1978) Carnotite mineralization at Thatti Nasrati area, Kohat. Pakistan Atomic Energy Minerals Centre Report **AEMC/Geo-22.** (Unpublished).

BASHAM, I.R. & RICE, C.M. (1974) Uranium mineralization in Siwalik sandstone from Pakistan. Proc. IAEA Symp. Vienna, pp. 405-417.

BOWIE, S.H.U. (1979) World uranium deposits. Proc. IAEA Symp. Uranium Exploration Geology, Vienna, pp. 23-33.

BUTT, K.A. (1979) Identification of yellow mineral from Darra Tang area. Pakistan Atomic Energy Minerals Centre Report. (Unpublished).

BUTT, K.A. & KHALID, M. (1980) Uraninite bearing minor veins and associated alteration in Thakot area, District Mansehra, Pakistan. PAEC Sem. Uranium Exploration Lahore. (Unpublished).

BUTT, K.A. (1981) Pyrochlore group minerals in carbonatite from Loe-Shilman, Khyber Agency, NWFP. Geol. Bull. Univ. Peshawar **14,** pp. 111-122.

BUTT, K.A. & MAHMOOD, K. (1986) Unit cell dimensions of uraninites from various geological environments in Pakistan. Acta Mineralogica Pakistanica **2,** pp. 47-52.

MAJID, M. (1976) Mineralogy and petrology of the Shilman carbonatite complex, Khyber Agency, NWFP. Infor. Rel. Geol. Deptt. Univ. Peshawar **7.**

MOGHAL, M.Y. (1974) Uranium in Siwalik sandstones, Sulaiman Range, Pakistan. Proc. IAEA Symp. Vienna **183/41**, pp. 383-403.

PHAIR, G. & GOTTFRIED, D. (1964) The Colorado Front Range, Colorado, USA as a uranium and thorium province. *In*: Adams, J.A.S. & Lower, W.M. (eds.) NATURAL RADIOACTIVE ENVIRONMENT. Chicago University Press, Chicago.

RAHMAN, M.A. (1972) Sedimentary tyuyamunite deposits in the D.G. Khan District, West Pakistan. The Nucleus, PAEC, Islamabad, **9**, pp. 33-38.

(1976 a) Mineralogical investigations on uranium mineralization in District Muzaffarabad, Pakistan. Pakistan Atomic Energy Minerals Centre Report **AEMC/Geo-6.** (Unpublished).

——— **(1976 b)** Geology and petrogenesis of host rocks of uranium mineralization in Mauji and Reshian areas, Azad Kashmir, Pakistan. Pakistan Atomic Energy Minerals Centre Report **AEMC/Geo-7.** (Unpublished).

——— **(1978)** Results of the detailed mineralogical examination of radioactive samples from Thakot area. *In*: Baig, M.A.S. (ed.) Report on the discovery and preliminary investigations of Thakot anomalous zone. Pakistan Atomic Energy Minerals Centre Report **AEMC/Geo-16.** (Unpublished).

——— **& JASEEMUDDIN, M. (1976)** Preliminary mineralogical investigations on radioactive occurrences in Thakot area, District Hazara, Pakistan. Pakistan Atomic Energy Minerals Centre Report **AEMC/Geo-8.** (Unpublished).

—— & —— **(1978)** Nature of uranium-thorium mineralization in Parachinar area, NWFP, Pakistan. Pakistan Atomic energy Minerals Centre Report **AEMC/Geo-13**, 39p. (Unpublished).

RAHMAN, M.A., KHAN, A.N., HASSAN, S.M. & MOGHAL, M.Y. (1966) Radiometric checking in the northern and southern areas of D.I. Khan District, West Pakistan. PAEC Direc. Nucl. Minerals Lahore, Report **DNM-9.** (Unpublished).

SHAMS, F.A. (1961) A preliminary account of the geology of the Mansehra area, District Hazara, West Pakistan. Geol. Bull. Univ. Punjab **1**, pp. 57-63.

SWANSON, V.E. (1961) Geology and geochemistry of uranium in marine black shales, a review. U.S.G.S. Prof. Pap. **356-C.**

SYED, S.A. (1975) Mineralogy and petrology of Loe Shilman uranium ore body, Khyber Agency, NWFP. Pakistan Atomic Energy Minerals Centre Report AEMC. (Unpublished).

Manuscript received on September 25, 1991.
Accepted for publication on November 21, 1991.

ACTA MINERALOGICA PAKISTANICA
VOLUME 5 (1991) pp. 109 - 120 .

FACIES OF JURASSIC ROCKS IN THE SURGHAR RANGE, PAKISTAN.*

H. MENSINK
Institute of Geology, Ruhr University, Bochum, Federal Republic of Germany.
D. MERTMANN
Institute of Geology, Ruhr University, Bochum, Federal Republic of Germany.
A. SARFRAZ
Institute of Geology, Punjab University, Lahore, Pakistan.
& FAIZ AHMAD SHAMS
Institute of Geology, Punjab University, Lahore, Pakistan.

ABSTRACT: The Jurassic sediments of the Surghar and Salt Range show a variety of microfacies-types. It is possible to distinguish 12 different rock facies. Furthermore the sections contain many discontinuities. The sedimentary history can be divided into 5 subsequent phases between the Upper-Trias and Neocomian.

INTRODUCTION

The main region of our investigation lies in the Surghar Range (Fig. 1). In this region, the most complete Jurassic sections of the entire area are situated. In the Salt Range, where we picked up only one profile, the Upper Jurassic is missing due to Tertiary erosion. The studied sediments of the other 4 sections —— Miranwal Nala, Baroch Nala, Gulakhel and Chichali Pass —— are part of the relativey thin cover of the old Indian plate.

Uptil now the geological and paleontological treatment referred only to a macroscopical division of rocks and a description of the ammonite fauna. Prsently the Jurassic sequence is divided into 4 formations (Fig. 2). In the first, rare ammonites are found at the base of the Shinawari Formation. These are *Bouleiceras* and *Cenoceras* of the Lower Toarcian. Younger ones date from the highest part of the Samana Suk Formation, in the research area being Middle-Callovian. In the Chichali formation ammonites are more plentiful. This covers a period from the Upper Oxfordian to the Valanginian. Two breaks of sedimentation, one at the Triassic/Jurassic boundary, and the other at the middle/upper Jurassic boundary are present and the rock sequence is without any gaps. Only the upper discontinuity is proved by ammonites. Therefore, the stratigraphic framework of the Jurassic sections in the Surghar Range is relatively widely spaced in comparison to the others, e.g. European areas.

FACIES INTERPRETATION

The sections studied are given in Fig.3.

Microfacies analysis is more or less unknown for the Jurassic rocks of the Surghar Range. We studied about 120 thin sections and could distinguish 12 facies types as described below.

1. Dolomite facies (Fig. 4a)

Section	:	Gulakhel (E)
Formations	:	Kingriali-, Datta-
Samples	:	E 1, 2, 3, 5, 6.

Description: The rocks are composed of extremely fine-grained dolomite. Sometimes bird-eyes occur. Debris of ostracods and gastropods as well as detrital quartz grains can be abundant. Clasts of echinoderms are seldom.

Environment: On account of their grain size, their internal structures and their fossil content, these dolomites developed syndiagenetically in an intertidal to lagoonal environment along a flat coastline through the vaporization of sea and pore water in an arid climate.

2. Sandstone Facies (Fig. 4b)

Section	:	Gulakhel (E), Baroch Nala (D)
Formation	:	Data-, Shinawari-
Samples	:	D 20, 31, 32, E7, 10, 11, 13

Description: Characteristic are sandstones, siltstones, sandy marls and clays. Cross-bedding is common, flaser bedding is less common. Mud craks, scolithos burrows, horizons of drifted wood and from time to time soils are intercalated. Shelly limestone beds occur only in the upper part of the Datta-formation.

The sandstone contains about 55% to 97% quartz. Its grain size varies between 0.25 - 0.40 mm. It is well graded.

*Presented at the First Pakistan Geological Congress, held from October 27 to 31, 1984, at the Institute of Geology, Panjab University, Lahore, Pakistan.

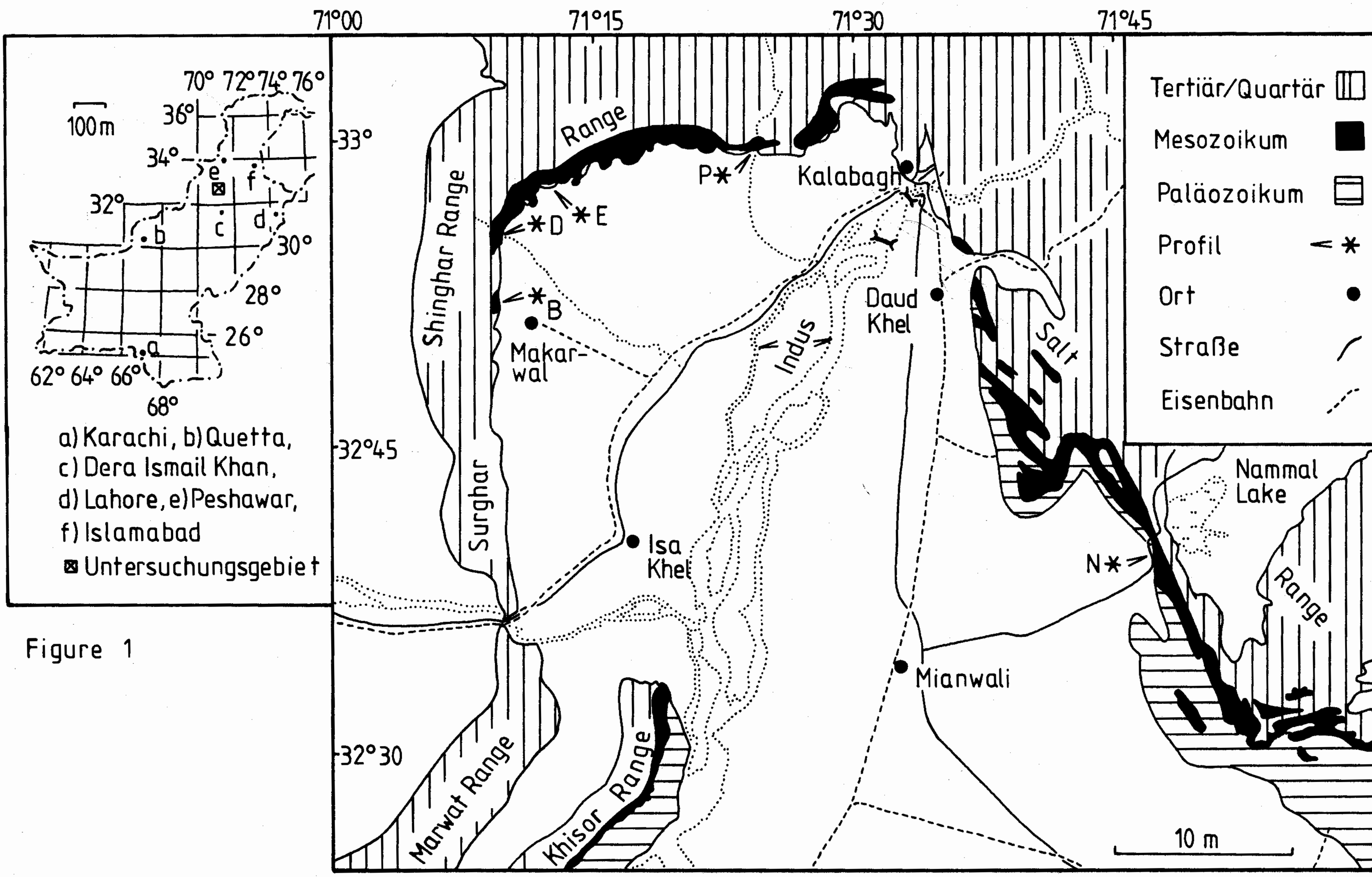


Fig. 1. Localities in the Surghar and Salt Ranges. Scale in miles. B = Miranwal Nala, D = Baroch Nala, E = Gulakhel, P = Chichali Pass, N = Nammal gorge.

Division (FATMI, 1974)	Stages	New Subdivision
Chichali-Formation	Valangian Upper-Oxfordian	Chichali-Formation
— discontinuity —		— discontinuity —
Samana Suk-Formation	Middle-Callovian ?Lower-Callovian ?Bathonian	Makarwal-Formation — discontinuity — Samana Suk-Formation
Shinawari-Formation	?Bajocian Lower-Toarcian	Shinawari-Formation
Datta-Formation	?Lower-Lias	Datta-Formation
— discontinuity —		— ? —
Kingriali-Formation	?Upper-Triassic	Kingriali-Formation

Fig. 2. Formations of the Jurassic and their attributed stages after Fatmi) 1972, 1975); the proposed new subdivisions.

The shape of grains is subangular to well-rounded. The matrix is a calcitic micrite.

Environment: It has been shallow marine to intertidal, in times a supratidal coastal area in the neighbourhood of a very active massif. It supplies periodically a high amount of quartz detritus.

3. Fe-oolithic Limestone Facies (Fig. 4c).

Sections	:	Baroch Nala (D), Gulakhel (E)
Formation	:	Shinawari-
Samples	:	D 11, 16, E 15.

Description: In awashed, sparitic matrix with small parts of micrite pelecypods, gastropods, echinoderms, ostracods, foraminifers and bryozoans can be found. Detrital quartz is sub-angular to poorly rounded and finer than 1 mm. Ooides are radially structured. The Fe-ooids are irregularly shaped up to 3 mm thick. Their nuclei consist of iron-stained siltstones, lithoclasts, quartz, ooids or bioclasts. Polyooids are seldom found. Other minor components of these facies are intra- and extra-clasts.

Environment: In a shallow marine area, presumably near a coast with a tidal flat in its neighbourhood, from time to time intensive currents and wave action led to reworking, transportation and, with reduced sedimentation, to the genesis of the Fe-ooids. Transitions to the intraclast limestone-facies can be shown.

4. Sandy Limestone Facies.

Section	:	Baroch Nala (D)
Formation	:	Shinawari-
Samples	:	D 13, 15.

Description: In a poorly washed, micritic matrix, quartz grains are comon (40%). The other components, like Fe-ooids, ooids, pellets, intraclasts and bioclasts, account together for not more than 25% and are sometime allochthonous.

Environment: The sedimentation took place under coastal, shallow marine conditions in the neighbourhood of tidal flat areas.

5. Intraclast Limestone Facies (Fig. 5a, b)

Section	:	Gulakhel (E), Miranwala Nala (B) Baroch Nala (D)
Formations	:	Shinawari-, Samana Suk-, Chichali-
Sample	:	E 13, 23, 24, B4-1, D 12, 34.

Description: In a mostly micritic matrix different lithoclasts of different limestone types like micritic, oolitic limestones, pelletal limestone or a bioclastic limestone, characteristic ironstained clasts, sometimes with mud cracks or algal structures, occur. All lithoclasts could be drilled. Accessory components are bioclasts, pellets, ooids, Fe-ooids and quartz.

The think section B4-1 shows many gastropod- and pelecypod shells together with agglutinative foraminifers in an entirely micritic matrix. Quartz is missing. The drilled lithoclasts consist of micritic limestones or bioclastic limestone. The drillholes are formed like amphoras. Below ledges, small areas of dripstone cement occur.

Environment: The frequent lithoclasts point to a coastal area with gaps in sedimentation, reworking, transportation and wave action. B4-1 originated in a tidal flat area. The sediments were lithified synsedimentary, reworked and drilled, perhaps during periods of emersion. Together with the overlying sandy bioclastic limestone it indicates a slow transgression above the discontinuity of the Middle-Callovian/Upper-Oxfordian.

6. Oolithic Limestone Facies (Fig. 4d).

Sections	:	Gulakhel (E), Baroch Nala (D)
Formations	:	Shinawari-, Samana Suk-
Samples	:	D 5, 10, 13, 21, 22, 51, 54, E 19.

Description: In a micritic to sparitic matrix upto 70% ooids occur. They are constantly radially structured, formed like their nuclei, and moderately graded. Gastropods and pelecypods are frequent, quartz, lithoclasts and Fe-ooids may be present.

Environment: In a temproarily agitated water the ooids originate in a marginal marine area. The fauna is therefore specialized and adapted to the tidal flat.

7. Biogenous Limestone Facies

Sections	:	Gulakhel (E), Baroch Nala (D), Chichali Pass(P)
Formations	:	Shinawari-, Samana Suk-
Samples	:	E 18, 20, D 6, 19, 45, P4.

Description: This facies combines different limestone types: each of them contains a special monomict fauna.

a) One of them is a coral-limestone. All internal structures are recrystallized. From a macroscopical point of view it might be a boundstone. The external shape of the colonies is preserved.

b) Another is a limestone with a variety of well preserved gastropods in a micritic matrix with pellets.

c) The last one (D 6, 19, 45, P4) is a limestone with abundant shells of pelecypods and brachiopods. Enchinoderms are only distributed as accessories.

Environment: It is different for different limestone-types.

a) The coral-limestone originated in a warm shallow marine area. It seems to be distributed in patches on a platform near a coast. The thickness is about 2 m in the section Gulakhel and only a few colonies exist in the Baroch Nala section.

b) The gastropod-limestone points to a reduced, mostly unagitated water circulation on a tidal flat.

c) The sedimentation of the shelly limestone took place in open marine, shallow lagoons or bays on a carbonate platform.

8. Bioclastic-pelletal Limestone Facies (Plat 3-b)

Section	:	Miranwal Nala (B), Gulakhel (E), Baroch Nala (B) Chichali Pass (P)
Formations	:	Shinawari-, Samana Suk-
Samples	:	P1, 2, 3, 5, B2, 3, 4, E21, 25 D67, 70, 69, 64.

Description: In a partly micritic, bioturbated matrix exists an abundant marine fauna with echinoderms, foraminifera, brachiopods, pelecypods and more seldom bryozoans, gastropods and serpulas. Pellets are frequent.

Environment: The conditions were open marine and sub-tidal on a carbonate platform.

9. Micrite Facies (Fig. 5c)

Sections	:	Baroch Nala (D), Miranwal Nala (B)
Formations	:	Shinawari-, Samana suk-
Samples	:	D1, 2, 8, 24, 27, 29, 39, 46, 65, 68, 61, 55, 53, 49, 48, 46, 42, 43, 40, B1.

Description: These are mostly very homogenous micrites, partly micrites with upto 5% fossils and quartz and very seldom micrites with 20% of shells of gastropods, ostracods or agglutinated foraminifera. Bird-eyes or stromatactis-structures occur as well as small algal buildings.

Environment: It has been a tidal flat area with reduced water circulation in a marginal platform position.

10. Pelletal Limestone Facies (Fig. 6a)

Sections	:	Baroch Nala (D), Gulakhel (E), Miranwal Nala (B)
Formations:		Shinawari-, Samana Suk-
Samples	:	D9, 17, 35, 37, 38, 40, 56, 57, 62, 63, E22, B1.

Description: The rock components are mainly closely packed. It is difficult to distinguish between components and matrix. Some ostracod fragments and algal structures are preserved.

Environment: This limestone was built up in an intertidal to very shallow subtidal sea with periodically agitated water.

11. Pelletal Sparitic Limestone Facies (Fig. 5d)

Section	:	Baroch Nala (D)
Formations	:	Shinawari-, Samana Suk-
Samples	:	D3, 4, 14, 18, 21, 22, 23, 33, 40, 49, 50, 51, 52, 53, 54, 58, 59, 66.

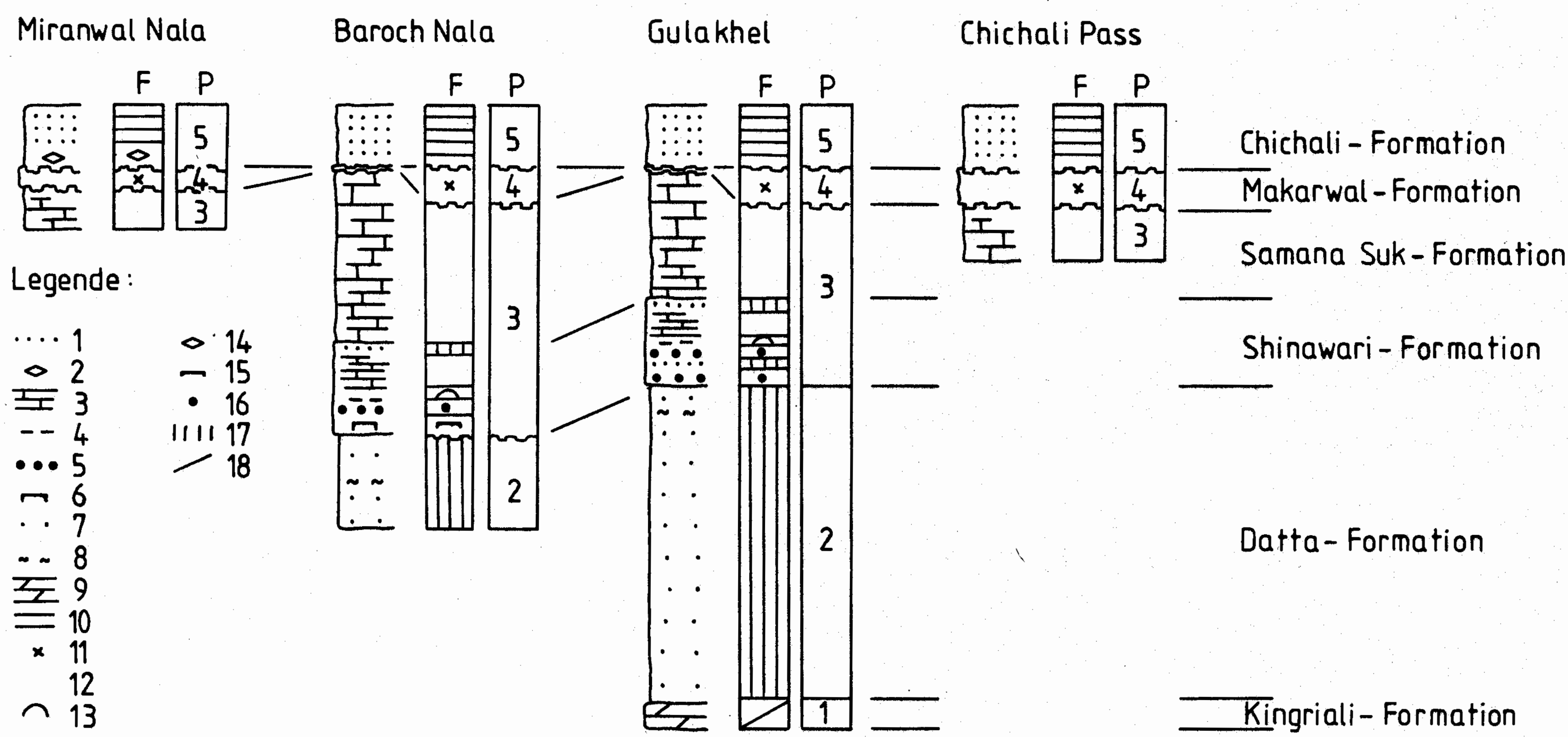


Fig. 3. Sketch of the studied sections, their facies (F) and their paleogeo-graphical phases (P). 1 = glauconitic sandstones. 2 = intraclast limestones. 3 = micritic limestones. 4 = coral limestones. 5 = Fe-oolitic and intraclast limestones. 6 = biogenous pelletal limestones. 7 = sandstones. 8 = soil horizons. 9 = dolomite. 10 = Facies 12. 11 = Facies 8. 12 = Facies 6, 9, 10, 11. 13 = Facies 7b 14 = Facies 5 15 = Facies 7c, 11 16 = Facies 3, 5 17 = Facies 218 = Facies 1 Scale of the sections: Miranwal Nala and Chichali Pass: 1 cm = 5 m; Gulakhel and Baroch Nala 1 cm = 100 m.

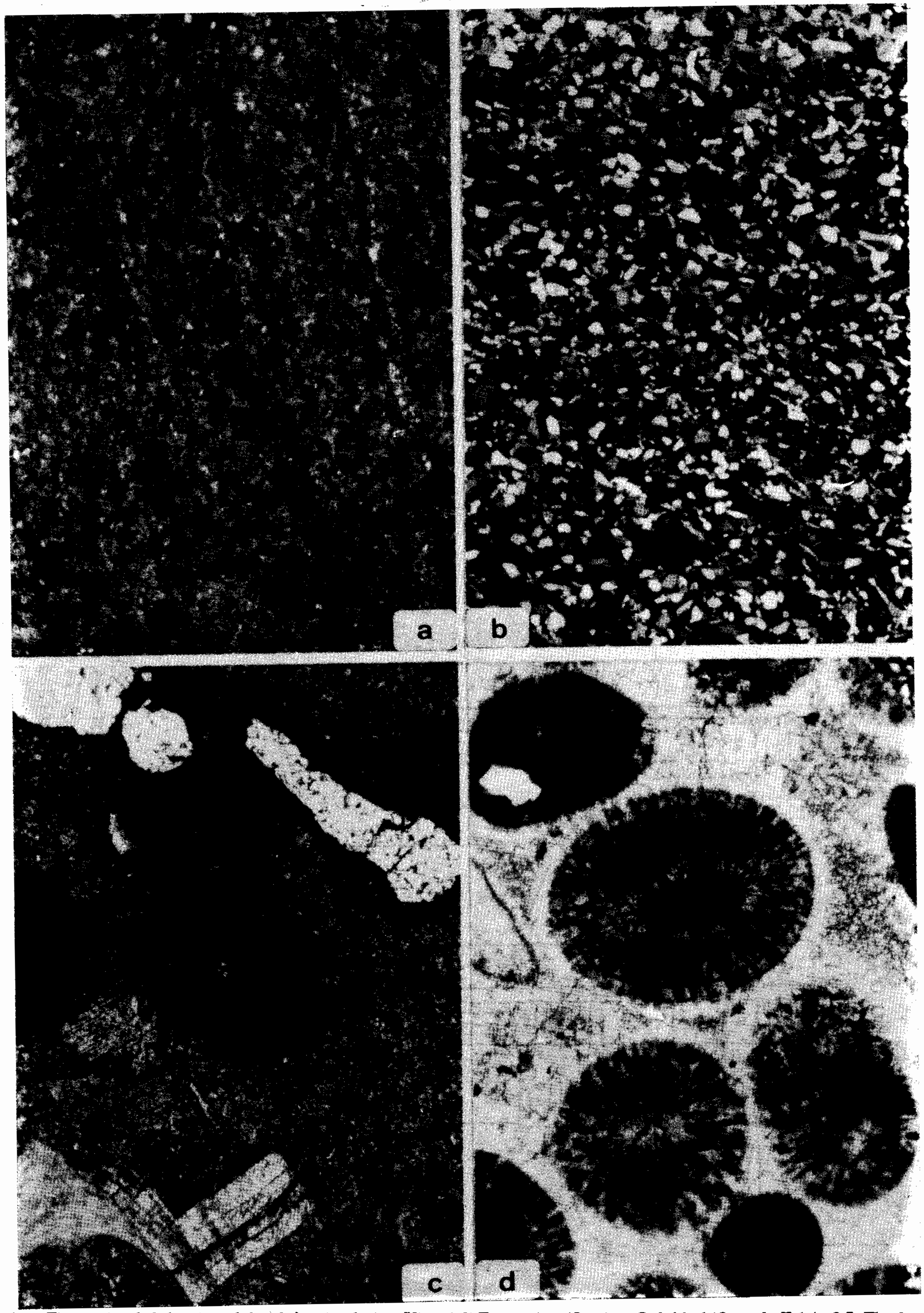


Fig. 4 **a-** Finegrained dolomite of the dolomite-facies. Kingriali Formation/Section Gulakhel/Sample E 1/x 2,5. The length of photomicrograph is 5 cm. b- Sandstone of the Sandstone-facies. Datta Formation/Section Gulakhel/Sample E 10/crossed nicols. The length of photomicrograph is 5 cm. C- Fe-ooids of the Fe-oolitic limestone facies with quarts and shells. Shinawari formation/ Section Baroch Nala/Sample D 16. The length of photomicragraph is 1.25 cm. D- Radially structured ooids of the Oolitic limestone-facies. Shinawari Formation/section Baroch Nala/Sample 25/x 10. The length of photomicrograph is 1.25 cm.

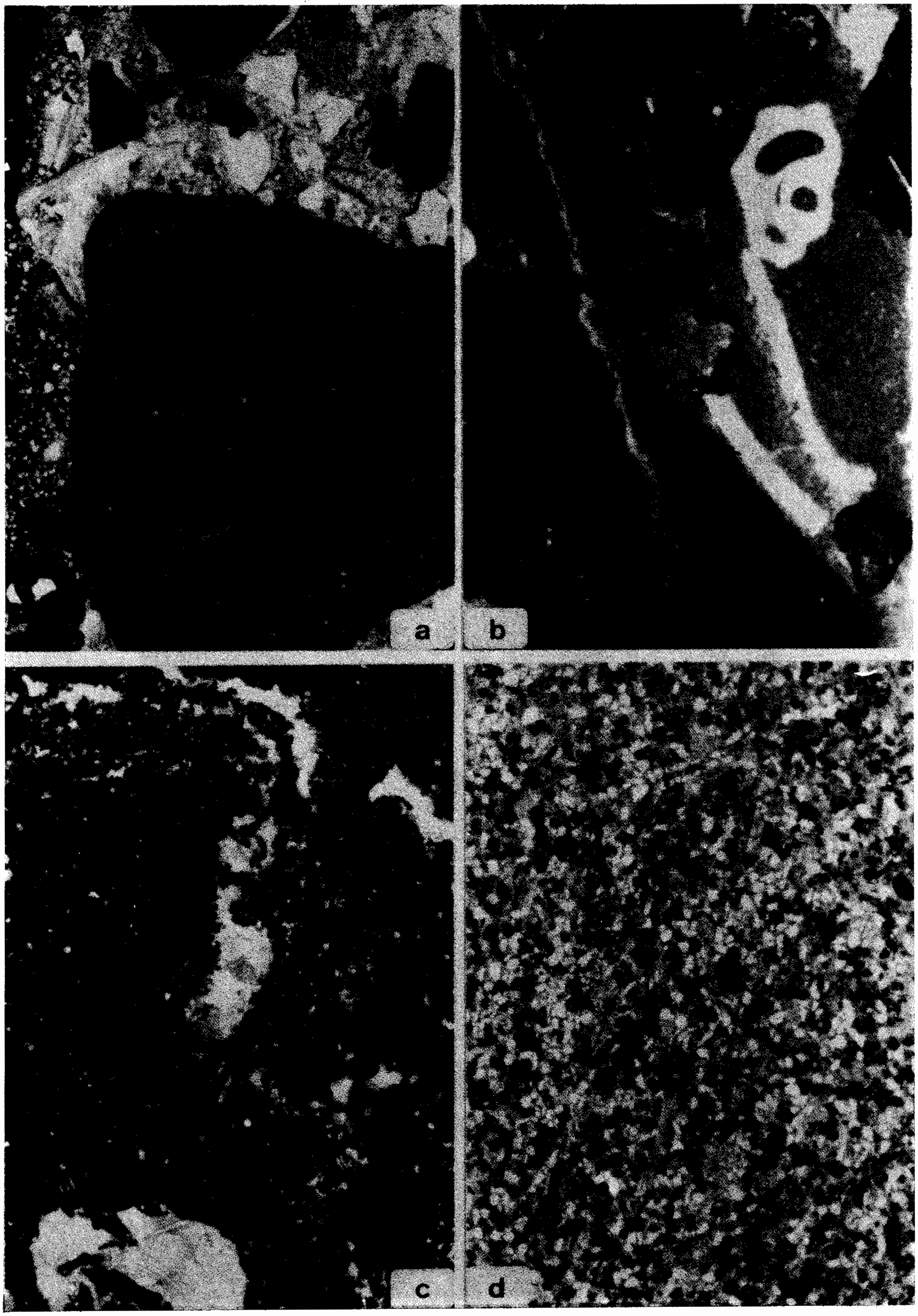


Fig. 5. Photomicorgraphs from Surghar Range samples. Each view is 5 cm in length. A- Iron stained lithoclast with mud cracks of the Intraclast limestone-facies. Shinawari Formation/section Baroch Nala/Sample D 12 **B**- Carbonate intraclasts in a micritic matrix together with gastropods, foraminifera and shells of the intraclast limestone-facies. Chichali formation/Section Miranwal Nala/Sample B 4-1 C- Pelletal micrite with bird-eyes structures of the micrite-biomicrite-facies. Shinawari Formation/section Baroch Nala/Sample D 29 D- Sandy pelletal limestone of the pelletal sparitic limestone facies. Shinawari Formation/Section Baroch Nala/Sample D 22.

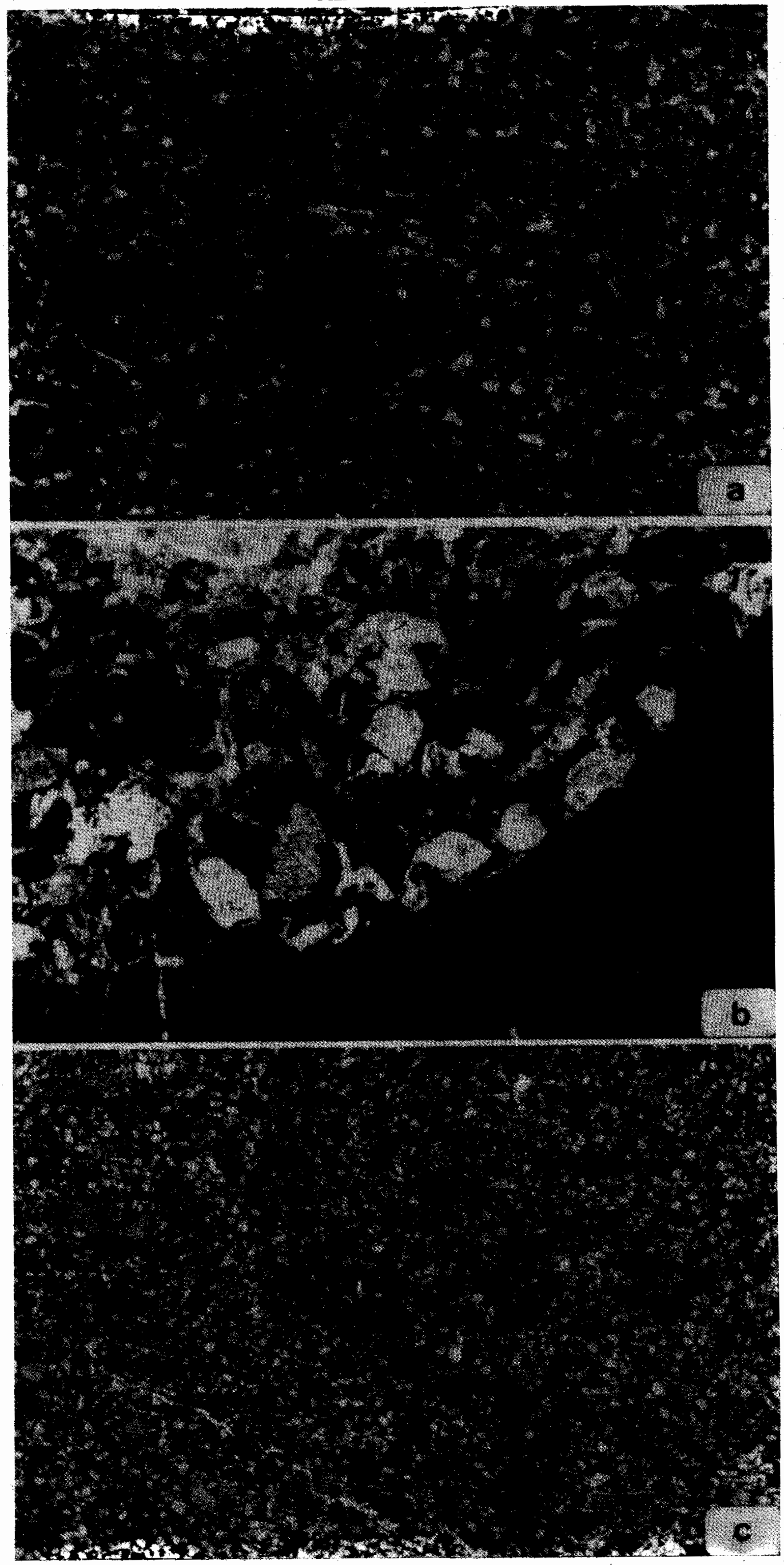


Fig. 6. Photomicrographs from Surghar Range samples. Each view is 5 cm in length. A- Pelletal limestone of the pelletal limestone facies. Samana Suk formation/Section Baroch Nala/Sample D 35/. B- Discontinuity on top of the Samana Suk formation. It is a hardground with drillholes. They are filled by the bioclastic-pelletal limestone facies of the Makerwal Formation. Samana Suk-, Shinawari Formation/ section Chichali Pass/Sample P. C- Glauconite-sandstone-facies. Chichali Formation/Section Chichali Pass/Sample P 8.

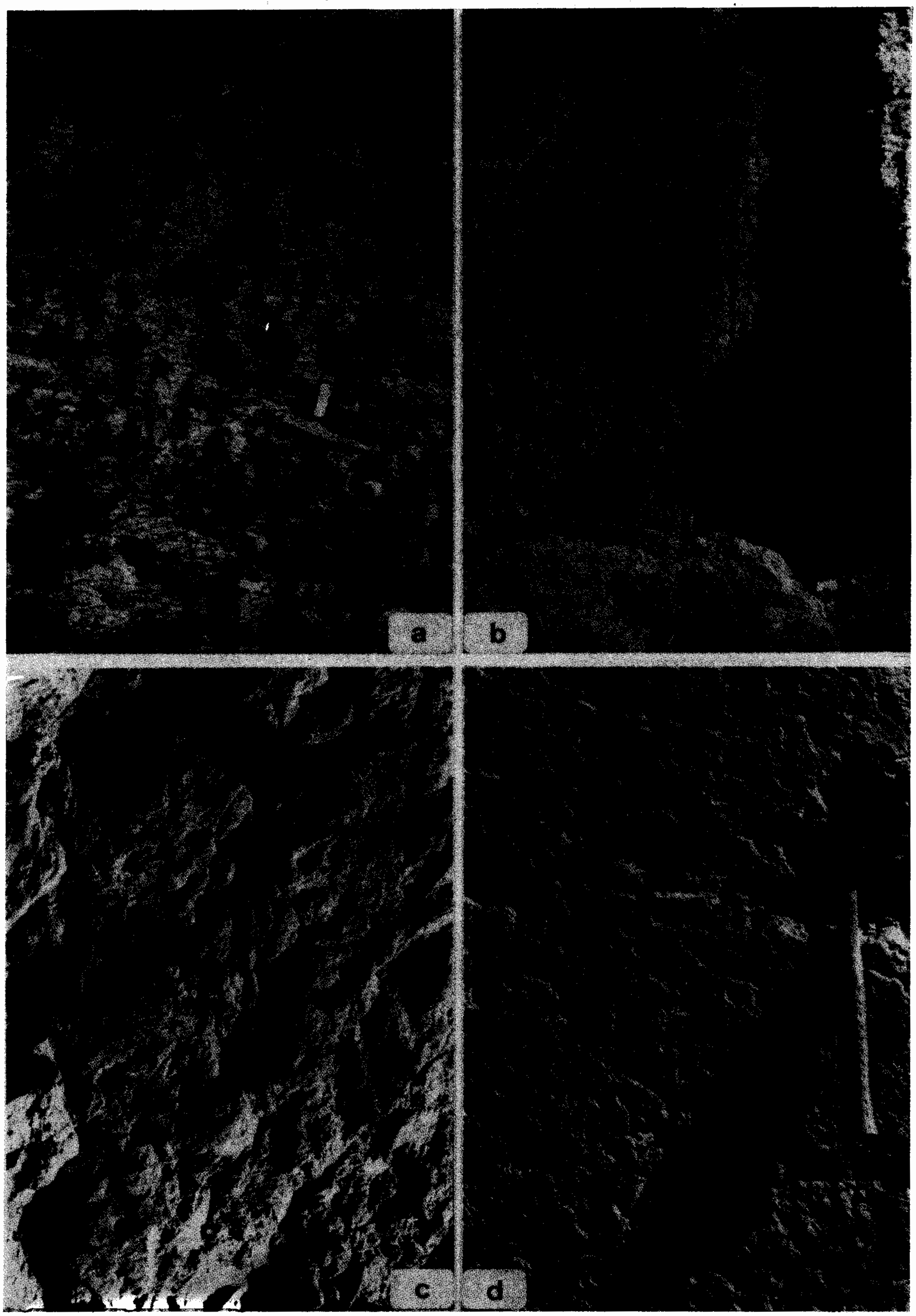


Fig. 7. A- Soil horizon in siltstones of the Datta Formation. Section Baroch Nala. b- Mud crack horizon in the Samana Suk Formation. Section Baroch Nala. c- Drilled hardground on top of the Samana Suk Formation. Section Baroch Nala. d- Eroded and drilled hardground on top of the transgressive Makarwal Formation. Section Baroch Nala.

Description: In a sparitic matrix, abundant (50%) poorly sorted pellets are characteristic. Quartz can reach an amount of 20%, bioclasts like shells, echinoderms, foraminifera and gastropods make upto 40%. Ooids and lithoclasts may occur.

Environment: The rocks originated in a shallow, subtidal area. Times of reduced water circulation changed with those of highly agitated water. Then a connection to the open marine subtidal platform was established.

12. Glauconite Sandstone Facies (Fig. 6c)

Section	:	Chichali Pass (P), Miranwal Nala (B)
Formation	:	Chichali-
Samples	:	P6, 8, 14, 18, B6.

Description: Beneath a changing amount of quartz (20-75%), a fine grained, pale green, well preserved glauconite (30%) is characteristic for this facies type. Micas are constantly present. Secondary iron is frequent in thin sections 14 and 18. The matrix is a sparry Fe-calcite or more often a micritic carbonate. The fossil content consists of pelecypod-, brachiopod, and gastropod shells, belemnites and ammonites.

Environment: The glauconitic sandstones developed in marine environment under slightly redued conditions by normal salinity. The depth ranges between shelf and upper continental slope. This deltaic sedimentation was periodically delayed.

DISCONTINUITIES

Out of the Jurassic sections of the Surghar and Salt Range, two discontinuities have been described so far.

Our new field work showed that there are many more discontinuities in the sequence. Their formation and position may be important for the interpretation of the facies and the paleogeographical setting of the sections.

1. It is not certain, whether the succession from the Kingriali Formation (? Upper Triassic) to the Datta Formation is separated by a marked discontinuity. Fatmi et al. (1987) described an onlap relationship of Datta Formation over the Triassic from western Salt Range (Lalumi-Chidru section). In the sections Gulakhel and Nammal Gorge, we found a transitional change from the dolomite facies to the sandstone facies. Locally bedding planes are covered with Fe-crusts, but primary, Jurassic origin is doubtful.

2. During the sedimentation of the Datta Formation, only local mud cracks and soil horizons (Plate 4-a) developed. Near the turn to the Shinawari Formation in the Baroch Nala section a hardground is well preserved. The change from a sandstone facies to different carbonates of the Shinawari Formation marks the beginning of the Toarcian transgression with *Bouleiceras*.

3. Presumably a much wider distribution is connected with the discontinuities of the Shinawari Formation. This applies especially to the Fe-ooid and intraclast limestone facies. They ended with a hardground which is the basement of the following transgressive coral limestone. The uppermost sandstone horizon originated in another regression phase in a coastal area.

4. The Samana Suk Formation is often truncated with firmgrounds, hardgrounds and mud cracks (Plate 4-b). They are only of local interest.

5. A new thin unit of limited extent at the top of Samana Suk Formation is recognized and proposed to be called "Makarwal Formation". This is bounded by two well marked hardgrounds, both with a number of boreholes and covered with thin Fe-crusts (Plate 4-c, 4-d). In between lies an open marine, bioclastic pelletal limestone (Facies 8) of the? Lower to middle-Callovian. The later discontinuity (Plate 4-d) is connected with an omission period from the middle Callovian to the Upper Oxfordian (Fatmi 1972). We lean towards assigning the lower discontinuity (Plate 4-c) to the Lower Callovian.

6. The Chichali Formation is very thin in comparison to the covered time period (Fatmi 1972). It is possible, that a reduced and stagnant sedimentation took place for a long time.

PALEOGEOGRAPHIC DEVELOPMENT

The facies types and the discontinuities prove that the studied area has been at first a shore to shallow marine platform in the vicinity of a periodically active massif. A superposed transgression led to an open marine, deeper subtidal sea.

The paleogeographical development took place in 5 phases:

1. Sabkha phase/Kingriali Formation/? Upper Triassic.

A sabkha area developed north of an emerged land mass at the end of the Upper-Triassic. Through early diagenesis a fine grained dolomite was created in an arid climate.

2. Sandy tidal flat phase/Datta Formation/? Lower-Lias.

On a flat shore of the southern massif, thick, often cross-bedded sandseries were deposited. Driftwood horizons, mud cracks and scolithos burrows show an intertidal environment. Soils developed in temporarily emerged areas. Open marine influences are missing.

3. Carbonate Platform phase/Shinawari- and Samana Suk Formations/Toarcian? Lower Calovian.

With a marked transgression at the beginning of the Shinawari Formation, a wide carbonate platform was built up. Changes between sediments of marine lagoons and tidal flats are characteristic.

The Shinawari Formation presents a superposed cycle from a more marine time to a tidal flat with sand sedimentation in an intertidal milieu at the very end. From then on during the whole Samana Suk Formation, the studied area remained a very shallow sea with limited temporarily open marine influences. Internal cycles are frequent in the Samana Suk Formation but they also occur in the Shinawari Formation. One example is the small regressive phase with Fe-ooid- and intraclast limestone and the transgressive coral limestone in the middle part of the Shinawari Formation.

The more or less tidal facies of the Samana Suk Formation end with the first rocky seashore with many drill-holes. During a possible longer period of omission it was covered with an iron crust.

4. Open marine subtidal phase/Makarwal Formation/Middle Callovian

Above the hardground is a transgressive bioclastic pelletal limestone with many brachiopods and ammonites of the Middle Callovian. Its thickness in the Surghar Range varies between 0.80 m and 3.10 m. This open marine horizon differs extremely from the underlying and overlying rocks and therefore it has been separated as a new unit. It ends with the second drilled, iron-stained hardground. No sediments are preserved between the Middle Callovian and Upper Oxfordian. Overlying clasts of drilled micrite with dripstone cement indicate that the hardground be interpreted as a rocky seashore.

5. Deltaic phase/Chichali Formation/Upper Oxfordian/Cretaceous.

Glauconitic sands with a rich neritic fauna are typical. A wide transgression took place and the deepest sedimention area was established. The rate of sedimentation remained low. The southern land mass showed a renewed activity with the input of quartz material.

CONCLUSIONS

Sediments from four sections, namely Miranwal Nala, Baroch Nala, Gulakhel and Chichali Pass have been analysed to determine the facies development during Jurassic in the Trans Indus Range. All of these sections are located within the Surghar Range area, Punjab. The microfacies development is discernible in five subsequent phases. Starting from a dolomitic stage of the Kingriali Formation, and then a subsequent sand sedimentation of the Datta Formation deposited in a sub- to intertidal environment. The transgression from Lower Toarcian through Callovian of Shinawari and Samana Suk Formations marked the existence of shallow subtidal carbonate platform. The transgressive Makarwal Formation is boarded by two distinct discontinuities.

The younger Chichali Formation lasted from the upper Oxfordian to Neocomian. This rock unit was formed in a transgressive subtidal sea. The glauconitic sandstone of the Chichali Formation contains a rich neritic fauna. The carbonate unit near the top of Samana Suk Formation (named here as Makarwal Formation) is bordered by two distinct discontinuities.

ACKNOWLEDGEMENTS

The present investigations developed in cooperation between the Geological Institutes of the University of the Punjab, Lahore and the Ruhr-University, Bochum.

We wish to express our thanks to the Coal Mining Section of Makarwal, PMDC, who arranged the fieldwork with their Geologist Mr. Qureshi, and with the Geological Sampler, Mr. Spin Gul. The Deutsche Forschungsgemeinschaft subsidized the studies with a grant.

REFERENCES

ARKEL, W.J. (1956) JURASSIC GEOLOGY OF THE WORLD. Edinburgh, London. 806 p.

DRAWFORD, A.R. (1974)The Salt Range, the Kashmir syntaxis and the Pamir Arc. Earth Planet. Sci. Lett. **22**, pp. 371-379.

DANIL CHIK, W. (1961) The iron formation of the Surghar and western Salt Range, Mianwali District, West Pakistan. U.S. Geol. Surv. Prof. Pap. **424D,** pp. 228-231.

FATMI, A.N. (1972a) Stratigraphy of the Jurassic and Lower Cretaceous rocks and Jurassic ammonites from northern areas of West Pakistan. Bull. (Geol.), Brit. Mus. Nat. Hist. **20 (7),** pp. 297-380.

——— (1972b) Some recent evidences on the age of Samana Suk Formation, Samana Range, Kohat. Geonews, Geol. Surv. Pak. Quetta **2(1),** pp. 38-41.

——— (1972c) A note on the ages of limestone outcrops near Gadani and Chalara, Lasbela District. Geonews, Geol. Surv. Pak. Quetta **2 (2),** pp. 37-38.

——— (1973) Late Jurassic and early Cretaceous (Berriasian) ammonites from Shaikh Budin Hills, Dera Ismail Khan district, N.W.F.P., Pakistan. Rec. Geol. Surv. Pak. **21 (2),** pp. 1-38.

———(1974) Lithostratigraphic Units of the Kohat-Potwar Province. Indus Basin, Pakistan. Mem. Geol. Surv. Pak. **10,** pp. 1-80.

——— (1974) Some problems of Mesozoic stratigraphy in Hazra and Baluchistan. Genews, Geol. Surv. Pak. Quetta **4,** pp. 35-42.

——— **& CHEEMA, M.R.** (1972) Early Jurassic cephalopods from Khisor-Marwat Ranges (Shaikh Budin Hills) Dera Ismail Khan District, N.W.F.P., Pakistan. Rec. Geol. Surv. Pak. **3,** pp.

——— **& HOLDER, H.** (1975) A new Lower Jurassic ammonite genus *Kohaticeras* from the Shinawari formation, Kohat Tribal Belt, Pakistan. Palaeont. Zeitsch. Stuttgart **49 (1/2),** pp. 35-43.

——— **& HYDRI, I.H.** (1986) Disappearance and reappearance of some Mesozoic units in Lalumi section, western Salt Range ——— a stratigraphic riddle. Acta Mineralogica Pakistanica **2,** pp.53-59.

———**, HYDERI, I.H. & ANWER, M.** (1990) Occurrence of the ammonite genus *Bouliceras* from Surghar with a revised nomenclature of the Mesozoic rocks of the Salt Range and Trans Indus Ranges (Upper Indus Basin). Geol. Bull. Punjab Univ. **22,** pp.

FUGEL, E. (1978) MIKROFAZIELLE UNTERSUCHUNGSMETHODEN VOK KALKEN. Berlin - Heidelberg-New York. 454p.

FUCHTSBAUER, H. & MULLER, G. (1977) SEDIMENT PETROLOGIE I: Sedimente und Sedimentgesteine. Stuttgart. 784p.

HALLAM, A. (1975) JURASSIC ENVIRONMENTS. London - New York - Melbourne, 269p.

HOLDER, H. (1964) HANDBUCH DER STRATIGRAPHISCHEN GEOLOGIE - Vol. **4,** Jurassic. Stuttgart. 603 p.

HOLCOMBE, C.J. (1977) Intraplate wrench deformation in Iran, Afghanistan and Western Pakistan. Geol. Rundschau **67 (1),** pp. 37-48.

MALIK, S.A. (1983) A note on the Tredian Formation. Geological Gazette for the Baluchistan Geological Society **6(1),** pp. 6-10.

MENSINK, H. (1984) Sedimentationszyklen auf der "Iberischen Platte" in der Jura Zeit - Auswirkungen von Meeresspiegel - schwankungen im Vordriftstadium, 17p. (in Vorb).

SHAH, S.M.J. (1980) Stratigraphy and economic geology of Central Salt Range. Rec. Geol. Surv. Pak. **52,** pp. 1-104.

WOLFART, R. & WITTEKINDT, K. (1980) GEOLOGIE VON AFGHANISTAN. Berlin-Stuttgart. 500 p.

Manuscript received on October 20, 1991.
Accepted for publication on December 21, 1991.

ACTA MINERALOGICA PAKISTANICA
VOLUME 5 (1991) pp. 121 - 128.

BIOSTRATIGRAPHY OF THE UPPER CRETACEOUS PARH LIMESTONE FROM QUETTA REGION, PAKISTAN.

THIERRY AUBRY,
National Centre of Excellence in Mineralogy, University of Balochistan, Quetta,
KHADIM H. DURRANI
Geology Department, University of Balochistan, Quetta,
&
MEHRAB K. BALOCH
National Centre of Excellence in Mineralogy, University of Balochistan, Quetta.

ABSTRACT: This work concerns the biostratigraphy of upper Cretaceous in Balochistan. Samples chosen from ten measures sections are studied paleontologically and petrographically. Results obtained permit to describe new lithologic facies of the upper Cretaceous and to propose a new biostratigraphic correlation between different regions of Balochistan.

INTRODUCTION

A review of the literature on the upper Cretaceous formations in Balochistan reveals that most of the information consists of lithological descriptions and concern few sections (Butt, 1986; 1988; Hunting Survey Corporation 1960).

Data concerning paleontology of sections are scarce and do not permit precise correlation (Allemann, 1979).

The present work based on measured and sampled sections from Quetta region (Fig. 1), deals with the biostratigraphy of different lithological units of upper Cretaceous in Balochistan. Two other sections (Khuzdar and Loralai) were also studied for comparison.

PREVIOUS WORK

LITHOLOGICAL UNITS CLASSIFICATION

The name Parh limestone for the principal lithological unit of the upper Cretaceous in Balochistan was introduced by Blandford (1879) and remained in vogue till Shah (1977). The type section is located in the Parh Range of the upper reaches of Gaj River. Hunting Survey Corporation (HSC) in 1960 described that the limestone is typically porcellaneous or sublithographic. The beds are characteristically regular, smooth-faced and tabular ranging from 10 to 60 cm in thickness.

This lithological unit is only one part of the Parh series which contains many kinds of rocks. The field determination of lower contacts between Parh limestone and Goru Formation which consists of shale and marl has been a problem for mapping by Hunting Survey Corporation. The lithologic boundary chosen is drawn at the base of limestone strata (HSC, 1960). However, the authors found that the boundary between Parh limestone and Goru Formation is subject to great variation and is transitional.

The Parh limestone is overlain uncomformably by the Mughal Kot Formation. In Quetta region, the contact is vaguely described.

The term Fort Munro limestone has been used by Williams (1959) and was elevated to the status of `formation' by Shah (1977). It is equivalent of Brewery limestone of HSC (1960). According to Shah the formation conformably overlies the Mughal Kot Formation. However, Allemann (1979) described a "sharp, unconformable contact against dolomicrite of under lain formation" that we have confirmed in the Murree-Brewery sections.

Moro Formation has been mapped as a unit wherever it is thick. It presents a basal conglomerate in the Bolan Pass-Moro River region which marks a disconformity with the Parh limestone (HSC, 1960).

The Cretaceous series are dominated by the volcanic rocks in some part of the Axial Belt. These have been mapped as Bela Volcanics Group by HSC(1960). Kazmi (1979) in northeastern Balochistan referred to these rocks as Bibai Formation. Recently the Bibai Formation has been studied petrographically by Kazmi (1984) and McCormick (1985).

BIOSTRATIGRAPHY

Synthesis of upper Cretaceous in Pakistan has been done by Butt (1986, 1988). The part concerning Balochistan is mainly based on the work of Allemann (1979) on Murree-Brewery section. Allemann established a sequence of distinct biozones, but he did not refer to the stratigraphic classification used in Pakistan. According to his lithologic description of Murree-Brewery section, the limit of Goru Formation and Parh limestone is between late Turonian and Coniacian. While the top of the pelagic sediments is upper Santonian or lower Campanian. Fort Munro Formation, which contains layers of accumulated *Orbitoides* species at its base and *Omphalocyclus macroporus* at the top, is dated as upper Maastrichtian.

LOCATION OF SECTIONS STUDIED

Ten sections representing the upper Cretaceous were studied from different areas (Fig. 1). Four sections, extending in south-west direction, (Goru Formation to Fort Munro limestone) are located in the Murree-Brewery gorge near Quetta.

Hanna section is located about 1.5 km north-west of Hanna Lake, near Quetta; and the Spin Karez section 3 km SW of Spin Karez Lake. Two other sections are located near Ahmadun village, 5 miles NE of Kach; and Gogai village, 3 miles E of Ahmadun.

Spezand Railway Station section located 16 km south of Quetta was described but not measured.

Furthermore, two more sections from different geographical locations are described for comparison. One section is incomplete near Loralai town —— has no upper or lower contacts —— while the other section is complete and located near Chashma Murad Khan, about 24 km south of Khuzdar.

METHODS OF STUDY

All the sections were measured and described in the field, bed by bed. The different lithological facies were noted alongwith the presence and position of flint nodules within the beds. Also, 67 thin-sections prepared from 97 collected samples were studied petrographically and paleontologically.

RESULTS

Lithological description of sections are shown in Fig. 1.

PETROGRAPHY

The following lithological units are differentiated on the basis of petrography and field relations.

micrite and Fossiliferous Micrite (Parh estone Unit)

This type of limestone, following Folk's classification (Folk, 1959, 1962) is the widespread facies in the different sections studied. Its field appearance has been described in previous works (HSC, 1960; Shah, 1977). In Quetta region, the common colour is light grey which weathers to yellowish grey. Pink and red samples are present in Ahmadun and Gogai sections. In Khuzdar area. the colour is olive green.

Thin-sections show a wackstone structure according to Dunham's classification (Dunham, 1962), with a matrix composed of micrite. Allochems in the form of foraminifera are generally more than 10%. The paleontological aspects are given under biostratigraphy.

Secondary fractures are common and generally filled by sparry calcite and iron xoide (Fig. 2).

Isolated rhombs of dolomite ranging from 0.1 to 0.2 mm are present in a quarter of the samples (Fig. 1 & 3). They occur as euhedral rhomb-shaped crystals, sometimes replacing part of fossils (Fig. 2, no 7), and reveal a neomorphic fabric. However, their concentration in some cases along fissures and association with iron oxide suggest recent processes of infiltration.

Two lithological variations have been noted within Parh limestone:

(1) Dolomite: in the field at four locations we observed pink coloured, soft beds variable in thickness. At Hanna lake and Spezand R.S. sections the thickness is about 2 m (sample Hanna, B), at Spin Karez it is 1 m (sample C & D) and at Brewery section the thickness ranges upto 20 cm. These beds have the appearance of sandstone but thin section study revealed them to be dolomite. The original texture of limestone is not preserved and has been completely replaced by

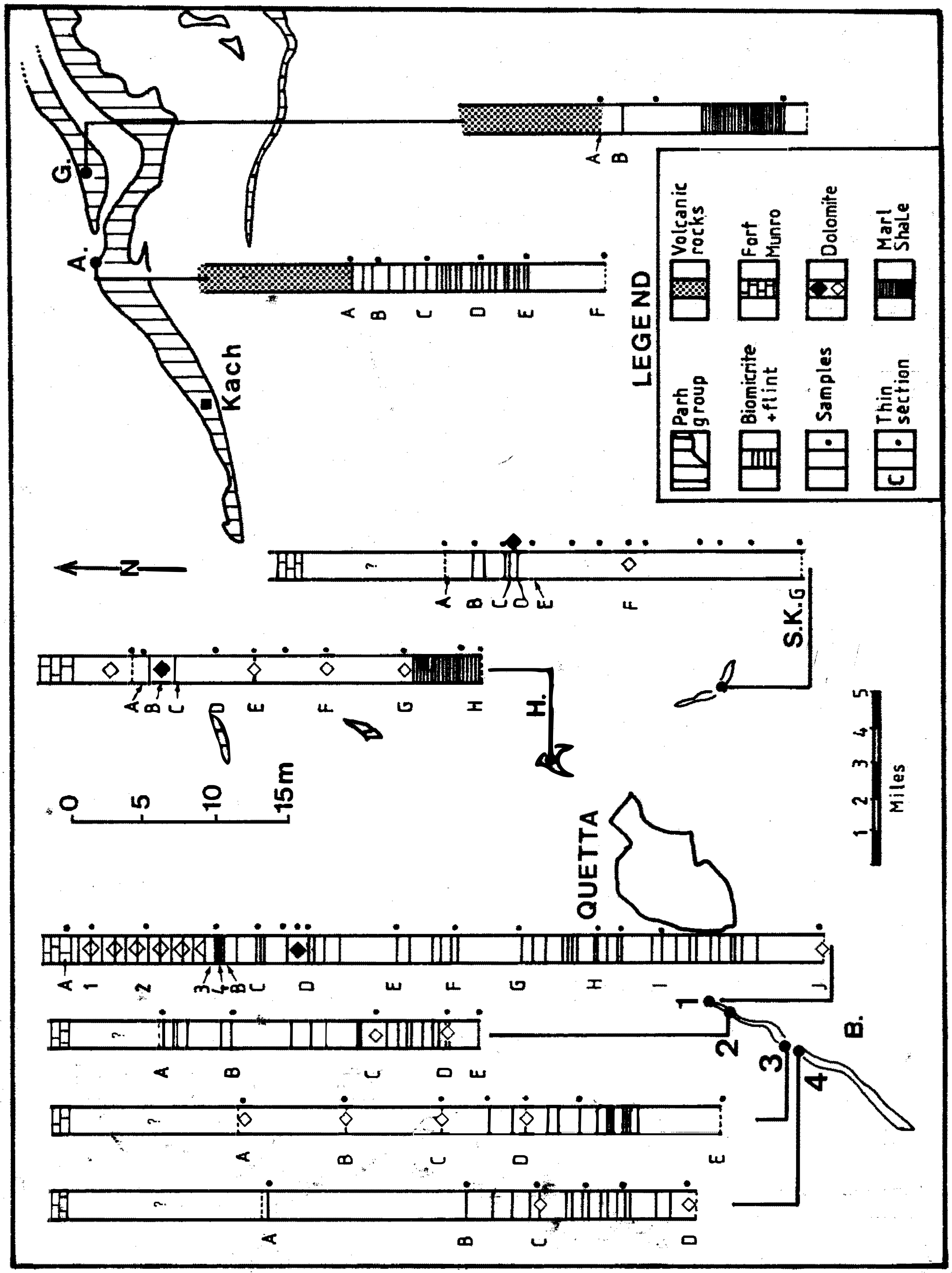


Fig. 1- Location map and lithological description of section studied near Quetta.
B. Murree-Brewery, H.Hanna, S.K. Spin Karez, A. Ahmadun, G. Gogai.

dolomite. The matrix is composed of soft iron oxide or micrite. The crystal size ranges from 0.05 (Murree-Brewery) to 0.2 mm (Hanna). In Ziarat Nala section this dolomite appears as lenses replacing biomicrite on average about 20 m wide.

(2) Silicification in Biomicrites:- Silicification in the form of flint nodules and continuous layers is common in this unit, especially in the lower part (Figs. 1 & 3). Section analyses indicate that the number of silicified layers in sections is a function of compaction. Petrogenetic aspect of silicification from Murree-Brewery, Kach and Loralai was studied previously (Aubry et al., 1988).

Peloids matrixed by iron oxide

One sample collected near the upper contact with Parh limestone in section B shows peloids matrixed by iron oxide material. Few intraclasts of microsparite without fossil are present. Interpretation of this facies is presented in the section on "contact relationships".

Microsparite

This homogeneous microsparite facies is associated with peloids and continues in Brewery section. No fossil has been observed in the thin sections studied. This facies as well as biodolomicrite overlying it are strongly fractured and brecciated, probably due to some faulting along bedding plane of unconformity.

Biodolomicrite

This facies was sampled at its base near the top of Parh limestone and at its top where it has contact with Fort Munro Formation (Section B, Fig. 3). It is the chronological equivalent of Mughal Kot Formation.

Hand specimens are grey to dark grey and coarse grained. Occurrence is not regular as it is highly fractured, making it more susceptible to alteration.

Thin-section examination reveals replacement by subhedral dolomite crystals of original rounded allochems. The micritic matrix has been partially replaced by finely crystalline dolomite. Organisms are present in the form of algae and foraminifera. Preservation of organisms does not allow precise determination.

Biosparite

This unit described locally as Fort Munro limestone (Shah, 1977) or Brewery Limestone (HSC, 1960) has been studied in previous work for Murree-Brewery section (Allemann, 1979). It consists of thick dark grey bioclastic limestone containing abundant layers of *Orbitoides apiculata*.

BIOSTRATIGRAPHY

All thin sections have been described according to their fossil content. Biomicrite facies reveal planktonic foraminifera especially *Globotruncana* species. Recent works and world-wide distribution of *Globotruncana* permit precise foraminifera zonation for upper Cretaceous (Harland et al. 1982; Kent and Gradstein, 1985).

Data concerning biostratigraphy of upper Cretaceous about all Pakistan have been collected by Butt (1986, 1988). The part on Balochistan of his paper is mainly based on the work of Allemann in Murree-Brewery section. The zones proposed by Allemann have been recognised in different sections of this paper. However, lithological precisions have been observed. Campanian *Globotruncana* species are not present in all the sections studied from Murree-Brewery suggesting differential erosion at the top of the Parh limestone. Silicification is also seen in the lower part of biomicrite facies corresponding to *G. shneegansi*, *G. sigali* and *G. renzi* assemblage zone.

Data concerning *Globotruncana* species noted in different thin sections and petrographic observations are depicted in figs. 2 and 3. *Globotruncana linneiana* and *lapparenti* are present in the majority of thin-sections, but we have not considered them as they range from Coniacian to Maastrichtian.

CONTACT RELATIONSHIPS

Contact Between Goru Formation and Parh Limestone

The upper contact of Goru Formation with the Parh limestone is transitional and is considered at the last interbedded shale (Shah, 1977). However, we have already mentioned the difficulty

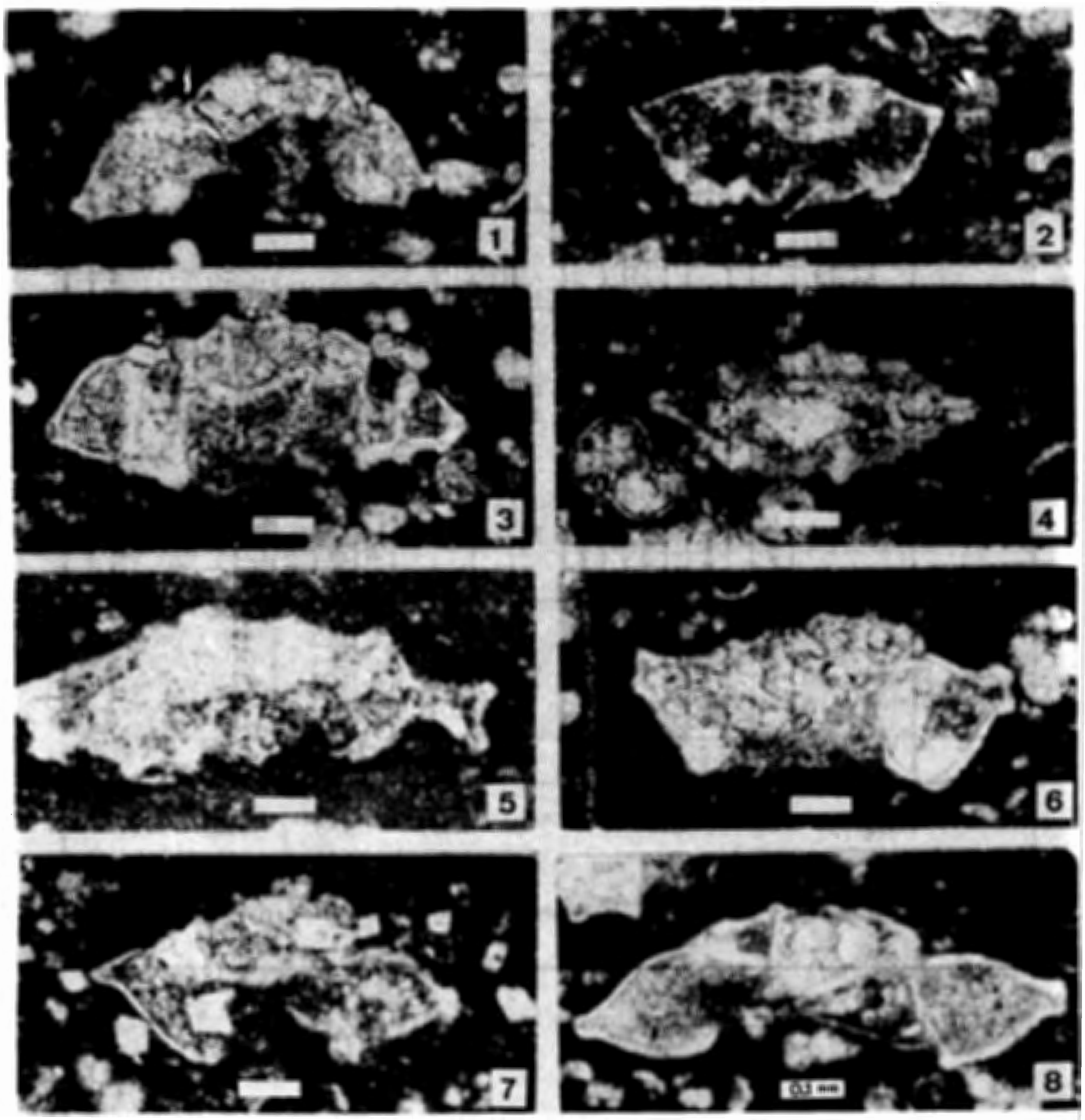


Fig.2:- Photomicrograph of Globotruncana species, bearing scale bars are 0.1mm. 1.G. fornicata from sample B(2) A.2,G.ventricosa from S.M. 13-3.G. arca from S.K.A, 4.G stuartiformis from S.K.A, 5.G coronata from B(1) H-6.G concavata from B(1).C,7.G shneegansi from B(4) D,8.G sigali from A(1). B.

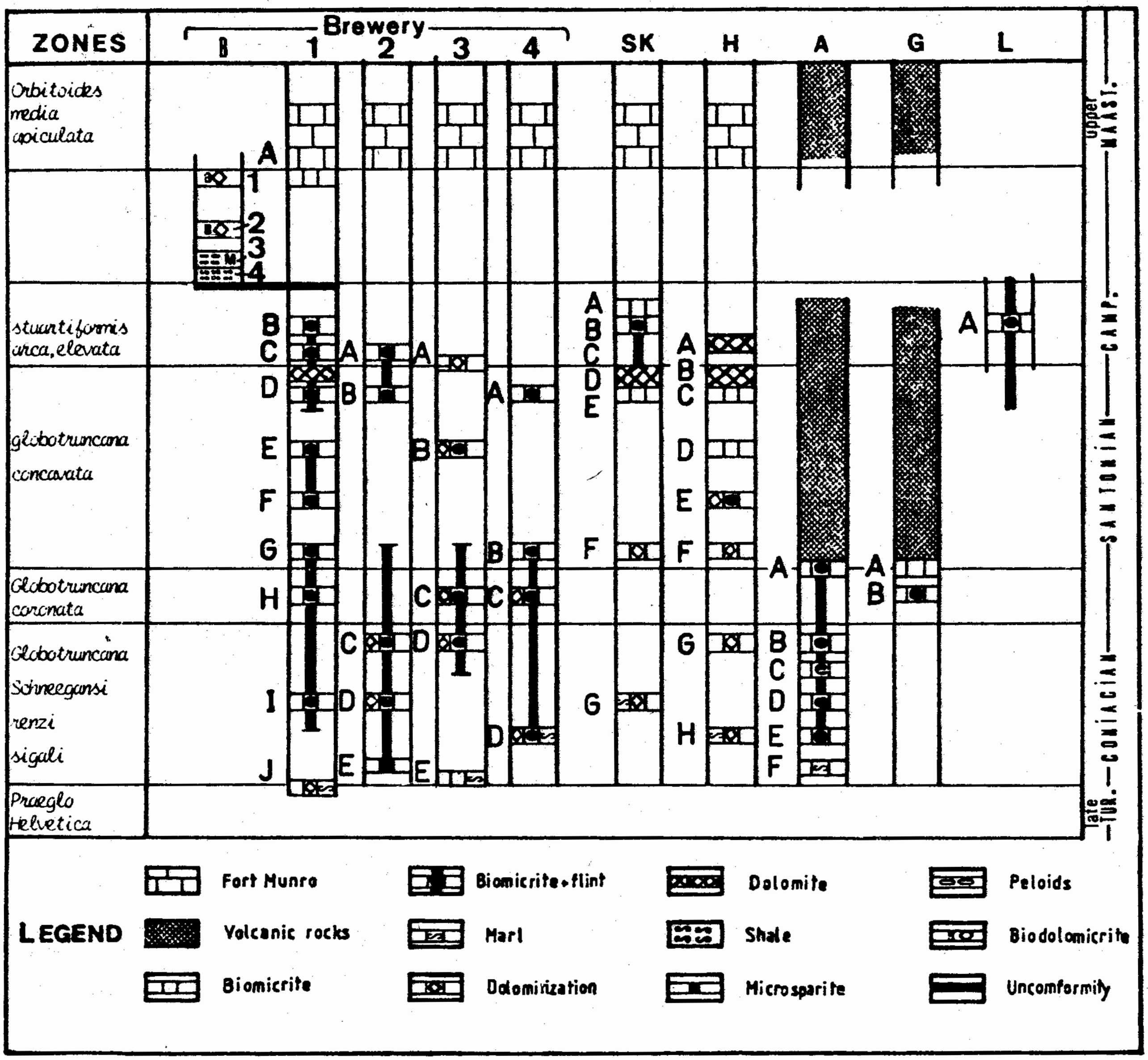


Fig.3- Biostratigraphic correlation of the different sections studied.

encountered by the Hunting Survey Corporation in determining the boundaries within the Parh series.

The correlation between the different sections on the basis of *Globotruncana* zonation suggests lateral lithological variations for the base of *G. shneeganzi, renzi* and *sigali* assemblage zone (Fig. 3). We propose the beginning of this biozone as the base of the Parh limestone.

Upper Contact of the Parh Limestone

In the sections close to Quetta (Murree-Brewery, Hanna and Spin Karez) the contact is not exposed, and to our knowledge has not been described. Topography suggests a soft material between the two limestone ridges (Parh and Fort Munro). To resolve this problem we dug a trench near the section B1 which permits description and sampling of new lithological facies. Red gypsiferrous shale occur on about 20 cm at the contact with Parh limestone. This unit is overlain by 2 m of peloids matrixed by iron oxide and microsparite. These facies suggest a change in depositional environment and weathering of the top of Parh limestone.

Time of Deposition of Bibai Formation

In the Kach area (70 km NE of Quetta) a thick succession of volcanic ashes, tuffs, agglomerates and basaltic lavas overlie the Parh limestone. These rocks have been studied petrographically and referred to as Bibai Formation by Kazmi (1979, 1984). The contact according to Kazmi is transitional. Some lenses of Parh limestone are interbedded with volcanics (Mc Cormick, 1985, Durrani et al., 1985).

These lenses of Parh limestone contain *G. linneana* which indicates only Coniacian to Maastrichtian age according to biozonations.

Samples from Ahmadun section permit to put the limit of the *Globotruncana shneeganzi, renzi, sigali* assemblage zone and *G. concavata* zone between samples A and B, while the thin-sections of sample A from Gogai section show *G. concavata* mixed with *G. shneeganzi.*

This suggests, that the clastic volcanic rocks associated with bedded shales and conglomerates were deposited in these two sections contemporaneously with pelagic carbonates in Quetta region. In the light of data from these two sections it can be considered of an older age than previously thought for the beginning of volcanism in the other areas i.e., late Coniacian to Early Santonian. Fossils observed by Kazmi at the top of Bibai Formation indicate an upper Maastrichtian age.

CONCLUDING REMARKS

Data collected during precise measurement of sections and laboratory appraisal revealed new information concerning the existence of upper Cretaceous Formations in Quetta region. Thickness of Parh limestone, according to the definition proposed in this article, ranges from 25 to 40 m around Quetta. It shows low rate of sedimentation in comparison with other areas of Khuzdar, i.e. 240m (190m according to Fatmi et al., 1986) and Loralai (25m for Campanian and Santonian). The biomicrite facies underlying volcanic rocks are about 15m in Ahmadun section in comparison to the sedimentation rate of the lower part of Parh limestone in Murree-Brewery section.

The different rocks, overlying the Parh limestone and underlying the Fort Munro Formation, show variation in sedimentary facies. The first facies indicates alteration of older deposits. Carbonate rocks follow this facies. The lower part is strongly fragmented as a result of their involvement in tectonism due to faulting along the unconformity where mainly gypsiferous shales were deposited. Biodolomicrite present in more than 8m contain foraminifera as are typical of shallow water high energy deposits.

More sampling may be useful to study the estimation of the break in sedimentation in this area.

The replacement dolomite is present, as a thick bed in Spin Karez, Hanna and Spezand R.S. sections, which was observed as a thin bed in section B1. This characteristic unit in *G. concavata* zone can be found in other areas and used for correlation.

The two sections of Kach area revealed deposition of volcanic rocks simultaneously with carbonates in Quetta region during upper Cretaceous. Some more sections must be studied to determine the extension of the volcanics.

ACKNOWLEDGEMENTS

We are greatly indebted to Dr. Abdul Haque, Acting Director Centre of Excellence in Mineralogy, University of Balochistan, and Dr. Akhtar Mohammad Kassi, Chairman, Department of Geology, University of Balochistan for allowing us to use their laboratories and for their valuable suggestions.

Our thanks are also due to Jean F. Frys who accompanied us to field in his vehicle and permitted us to use C.R.S. computer.

Our special thanks go to Anwar Ali, for his help in preparing thin-sections.

REFERENCES

ALLEMAN, F. (1979) Time of emplacement of the Zhob valley ophiolites, and Bela ophiolites, Balochistan. (preliminary report). *In:* Farah, A & De Jong, K.A. (eds.) GEODYNAMICS OF PAKISTAN. Geol. Surv. Pakistan, Quetta, pp. 215-242.

AUBRY, T., AHMED, Z. & BALOCH, M.K. (1988) Preliminary study of cherts from Balochistan. Acta Mineralogica Pakistanica **4,** pp. 102-112.

BUTT, A.A. (1986) Plate tectonics and the upper Cretaceous biostratigraphy of Pakistan. Acta Mineralogica Pakistanica **2,** pp. 60-64.

——— (1988) Upper Cretaceous foraminiferal biostratigraphy of Pakistan. Acta Mineralogica Pakistanica **4,** pp. 90-95.

DUNHAM, R.J. (1962) Classification of carbonate rocks according to depositional texture. *In:* Ham, W.E. (ed.), Classification of Carbonate Rocks. Am. Assoc. Petrol. Geol. Mem. **1,** pp. 108-121.

DURRANI, K.H., MIRKIANI, H.R. & HAQ, Z. (1985) Geology around the "Gogai village", and its southern part (Quetta-Ziarat road) B.Sc. Report, University of Balochistan, Quetta. (Unpublished).

FATMI, A.N., HYDRI, I.H., ANWER M., & MENGAL, J.M. (1986) Stratigraphy of "Zidi Formation" (Ferozabad group) and "Parh group" (Mona Jhal group), Khuzdar District, Balochistan, Pakistan. Rec. Geol. Surv. Pakistan **75,** 32p.

FOLK, R.L. (1974) PETROLOGY OF SEDIMENTARY ROCKS. Hemphills, Austin, Texas.

HARLAND, W.B., COX, A., LLEWELLYN, P.G., PICKTON, C.A.G., SMITH, A.G. & WALTERS, R. (1982) GEOLOGICAL TIME SCALE. Cambridge University Press. 131p.

HUNTING SURVEY CORPORATION (1960) RECONNAISSANCE GEOLOGY OF PART OF WEST PAKISTAN. Jones, A.G. (ed.), Colombo Plan Cooperative Project Report. Toronto, Govt. of Canada, 550p.

KAZMI, A.H. (1979) The Bibai and Gogai nappes in the Kach-Ziarat area of Northeast Balochistan. *In:* Farah, A & Deong, K.A. (eds.), GEODYNAMICS OF PAKISTAN, pp. 333-339. Geol. Surv. Pakistan, Quetta.

——— (1984) Petrology of the Bibai Volcanics, N.E. Balochistan. Geol. Bull. Univ. Peshawar, **17,** pp. 43-51.

KENT, V., GRADSTEIN, F.M. (1985) A Cretaceous and Jurassic geochronology. Geol. Soc. of America Bull. **96,** pp. 1419-1427.

Mc CORMICK, G.R. (1985) Preliminary study of the volcanic rocks of the south Tethyan suture in Balochistan, Pakistan. Acta Mineralogica Pakistanica **1,** pp. 2-9.

SHAH, S.M.I. (1977) STRATIGRAPHY OF PAKISTAN, Mem. Geol. Surv. Pakistan **12,** 138p.

Manuscript received on April 20, 1991.
Accepted for publication on December 20, 1991.

ACTA MINERALOGICA PAKISTANICA
VOLUME 5 (1991) pp. 129 - 134.

HERCYNIAN AND ALPINE TECTONICS IN THE EASTERN PART OF ARGENTERA-MERCANTOUR MASSIF, FRANCE.

ABDUL HAQUE
Centre of Excellence in Mineralogy, University of Balochistan,
P.O. Box 43, Quetta, Pakistan.

ABSTRACT: Hercynian compression directed NS has simultaneously produced: first order EW folds of detritic Carboniferous rocks; NS joints, and NE-SW and NW-SE conjugated strike-slip faults. Alpine stresses oriented NE-SW have produced NW-SE folds within Triassic carbonate rocks; reorientation of the axes of Carboniferous folds into NW-SE direction, and the development of N120 and N160 strike-slip faults within the area. Thus, a fluctuation of regional compressive forces had taken place from NS to NE-SW during the passage of Hercynian to Alpine tectonics.

INTRODUCTION

The Argentera-Mercantour massif constitutes metamorphic and sedimentary rocks. The metamorphic part belongs to the basement having been defined by foliated and non-foliated rocks (Faure-Muret, 1955; Abdul Haque, 1987). Such Precambrian metamorphic series of the basement are highly folded, faulted, metamorphosed, largely granitized, and mainly composed of gneisses, migmatites, layered and augen-type embrachite, amphibolite, quartzite, aplite and ultrametamorphic granite (Fig.1).

The basement had successively registered Caledonian, Hercynian and Alpine orogenies resulting in different petrological and structural effects.

The tegument which constitutes both Carboniferous and Permo-Triassic continental rocks was deposited unconformably over already-deformed basement. Since Hercynian and Alpine orogenic movements, these tegument rocks have tectonically adhered to the basement inspite of its lithological differences (Abdul Haque, 1989).

The first marine transgression starts from the base (Upper Triassic) of sedimentary cover. One Triassic carbonate lenticule is mapped in the SE of Moliere which is enveloped by the basement series (Fig. 2).

The basement of Argentera-Mercantour massif has been divided into two zones, the western and the eastern zones by the mylonite of Valleta-Moliere (Abdul Haque, 1986; 1987).

The eastern part is geologically composed of three different rock types: the metamorphic series belonging to the basement (Abdul Haque, 1987); the continental Carboniferous rocks which define the lower-most part of tegument, and the marine Triassic carbonate rocks of the sedimentary cover (Fig. 1).

The structural analysis of the eastern part of this massif is the subject of present paper.

STRUCTURE

The eastern part is situated in the west of mylonite of Volleta-Moliere which is defined as a major dextral strike-slip fault (Abdul Haque, 1986). The eastern part has arbitrarily been divided into northern and southern sectors (Abdul Haque, 1984). Both display small and large scale structures which are described in detail in the following paragraphs.

NORTHERN SECTOR

The outcrops of northern sector lie to the NE of Moliere (Fig. 1). Lithologically it constitutes Adus migmatite, Chastillon gneiss, and anatectic granite belonging to the basement series as well as metamorphic carbonate lenticule of Triassic age being part of sedimentary cover.

Amongst structures foliation, joints, strain-slip schistosity and folds are systematically described below:

(1) **Foliation**

Foliation being the result of Caledonian

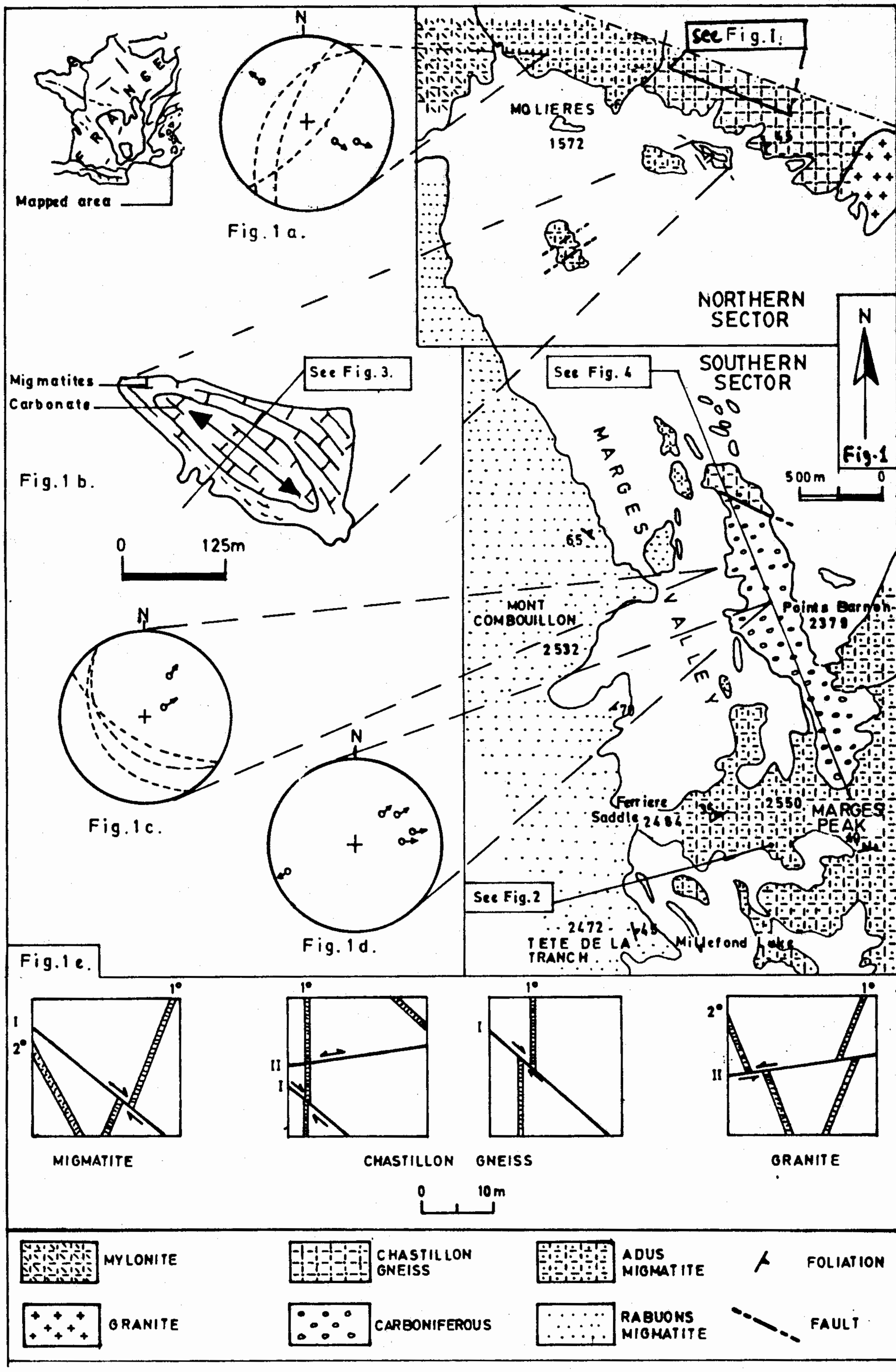
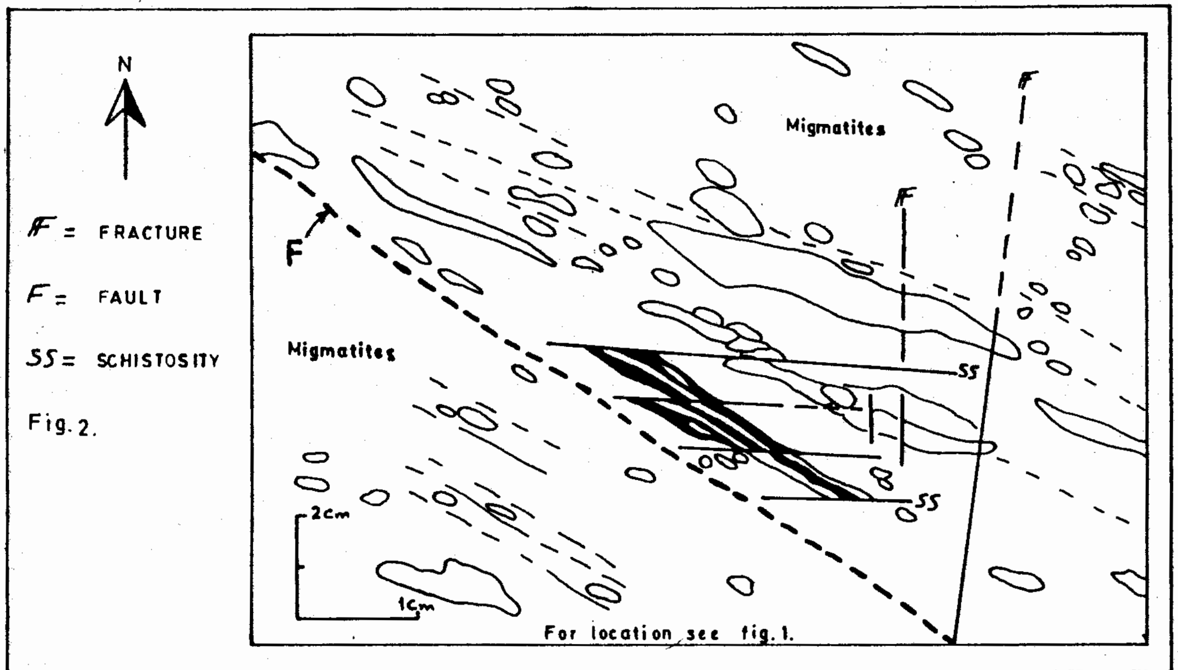
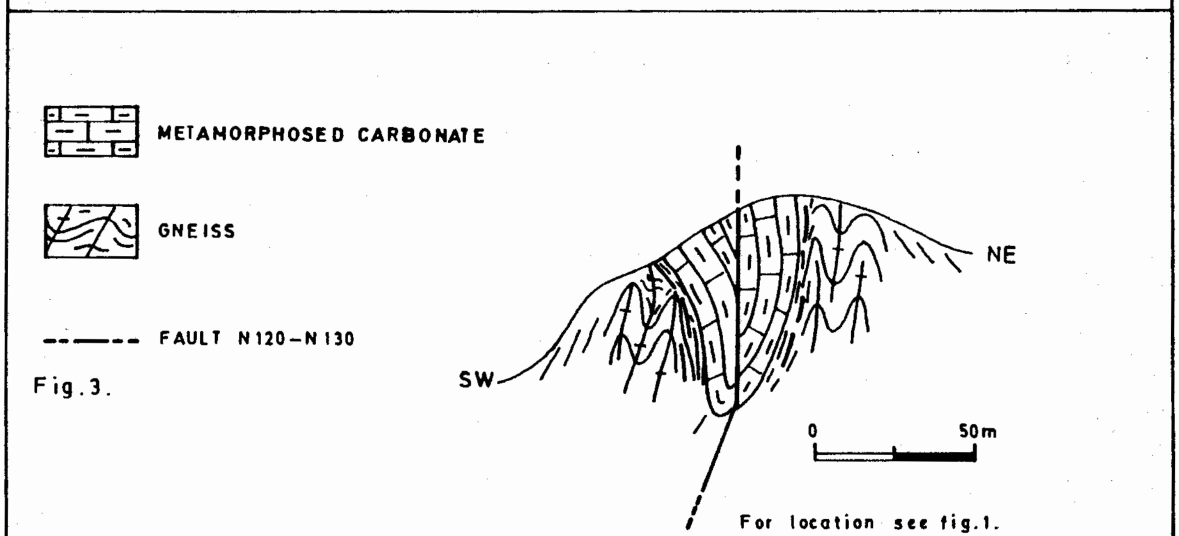


Fig.1. Geolofical map of the eastern part of the studied area. Stereographic projections of the axes of described folds (Fig. 1a, 1c, 1d). Outcrop's enlargment of Triassic Carbonate rocks (Fig. 1b). Sketch of the studied joints within the northern sector (Fig. 1e).





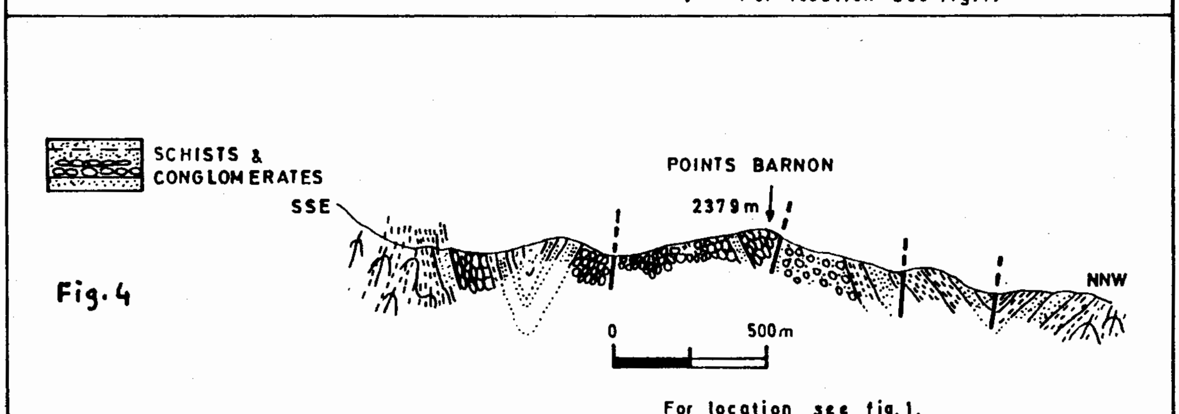


Fig. 2. Structural relationship between fractures, schistosity and faults, mapped near the south of Marges peak (Southern sector).

Fig. 3. Sketch of Alpine fold (NW-SE axis) within Triassic Carbonate rocks, mapped in the SE of Moliere (northern sector).

Fig. 4. Sketch of Hercynian fold (EW axis) within Carboniferous rocks, situated in the southern sector.

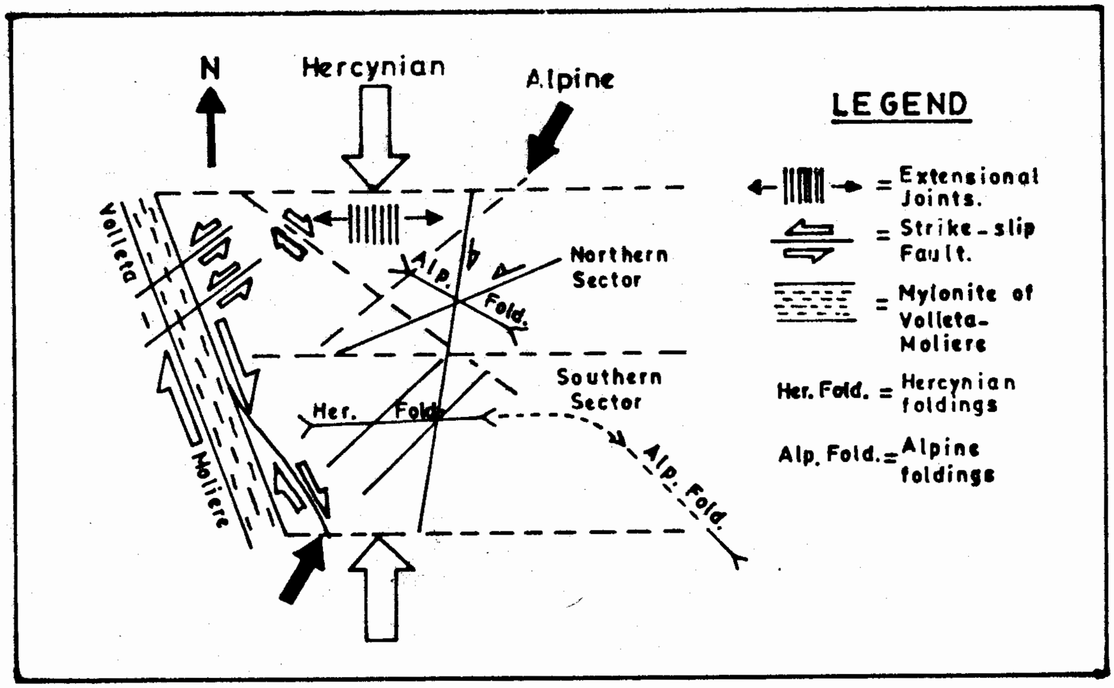


Fig. 5. Interpretation of Hercynian and Alpine tectonics with respect to the different studied structures within the mapped area

orogenesis and is anterior to all sort of deformations of the basement of Argentera-Mercantour. It is only measureable in the Adus migmatite, here its orientation is N112, 70S to N168, 30E. Towards east its orientation becomes progressively rough and finally absent in the anatecic-granite. This variation of direction as well as its progressive disappearance in the east are due to cataclasis and retromorphism of Alpine age.

The constructed axes of folds from the field data vary in direction from N130 to N140 plunging 30SE and 45NW (Fig.1a).

(2) **Strain-Slip Schistosity**

Within this sector near the eastern contact of mylonite of Valleta-Moliere strain-slip schistosity has been measured and which is oriented N75, 20S. Such schistosity cuts the preexisting foliation being oriented N112, 70S to N168, 30E.

(3) **Joints**

Two sets of joints were studied in the leucocratic bands each with one-metre thickness. (1) One set is oriented NS to N120 dipping 75E or W, sometimes vertical. (2) The other set is directed N160, dipping 65W, sometimes vertical. These two sets of joints are refilled by recrystallized chlorite and have been afterward displaced both by (II) sinistral, N80, 80N & (I) dextral (N135, 56N) strike-slip faults (Fig. 1e). Both schistosity of crenulation and disclases are probably associated with the movement of the major strike-slip fault of Valleta-Moliere (Abdul Haque, 1986).

(4) **Folds**

In the SE of the studied area (Figs. 1 & 3) a small lenticular outcrop of folded Triassic carbonate rock is enveloped by the basement rocks of Argentera-Mercantour. The axis of this fold is N140-N150, plunging 20N, while the directions of foliation as well as the axes of microfolds within the enclosing migmatite are respectively N166, 70E and N160, 70S.

SOUTHERN SECTOR

This sector is juxtaposed to the south of northern sector (Fig. 1). Lithologically it is composed of Abdus migmatite (enclosing rocks) and Carboniferous continental rocks (enclosed rocks), (Abdul Haque, 1989).

Structures within the basement

(1) **Foliation**

Scree deposits and thick vegetation mask foliation within Adus migmatite. However, it is more or less visible, fluctuating from N35, 15NW; N90, 50N; N130, 65N; N165, 60NE, which show a great difference of orientations from that measured in the northern sector. Consequently, the constructed axes of folds give variable values ranging from N32 to N59 and plunging 30 to 60 NE (Fig. 1c).

(2) **Strain-slip schistosity**

In the southern part of this sector between Forriere saddle and Marges Peak (Fig. 1), the foliation within the basement is N135, 30NE which is displaced posteriorly by strain-slip schistosity being oriented N110, 10NE. Foliation together with schistosity are likely to be transcepted by fractures which are directed N40 dipping 55 to 70 NW or even vertical (Fig. 2).

Structures within Carboniferous rocks

Within the Carboniferous part of tegument the pebbles and grains derived from the preexisting basement series and have been oriented all along a schistosity being oriented N80 to N90 dipping 55 NW. Faure-Muret (1955) mentions that at extreme stage, these pebbles are flattened due to pressure and temperatures, and crushed because of tectonics, therefore producing only alternating leucocratic and melanocratic bands and lenticules. Romain (1978) mentions in these Carboniferous rocks a schistosity oriented N120 - N140 in the region "Balaour inferiour" near "Anduebic cowhide" outside from the mapped area (Fig. 1).

Folds axes within Carboniferous rocks are not measurable because they are intensely deformed during Hercynian and Alpine orogenies. Alpine tectonics is manifested by strike-slip faults which displace not only the stratification, but also the preexisting schistosity. However, these Carboniferous rocks have been folded in E-W direction, because their constructed axes are N42 to N86, most of them plunging 10 to 40 NE (Fig. 1d & 4). Moreover, joints N35 to N55 dipping 45S pass both through the Carboniferous and the enclosing basement rocks and they are not refilled by chloritic materials. Faults N80, 90 and N120, 90 which intercept at the same time these joints and probably the axes of the folds.

The southern contact of these Carboniferous rocks with the basement rocks is more or less normal where greenish grey flakes of migmatite passing callousnessly from fine black to grey schists of Carboniferous age (Fig. 4). Further north, these schisto-arenaceous as well as very fine micaceous terms are underlain by fine conglomerate with some passage of grey-black schists (Abdul Haque, 1987). This N60, 40N oriented transitional portion (Fig. 4) defines either the contact between the two rocks or the schistosity which affects both the underlying migmatite and the overlying schists of Carboniferous age.

The constructed axes of the folds both for the Adus migmatite and for the Carboniferous rocks, practically show the same orientation (Fig. 1c & 1d).

CONCLUSION

Hercynian compression directed NS had produced (1) EW foldings (Asturian or Saalian phase) of Carboniferous rocks (southern sector), (2) NS extensional joints (northern sector) which are materialized by green chlorite fillings and (3) NE-SW and NW-SE conjugated strike-slip faults which are replayed during Alpine tectonics (Fig. 5).

Alpine compression oriented NE-SW (Fig. 5) has from its part created (1) NW-SE foldings of Triassic rocks (northern sector) (2) reorientation of the axes of Carboniferous rocks into NW-SE (southern sector) and (3) extensional joints without filling of chloritic materials.

The studied structures of the area invite us to think that probably in the early tectonic history of Argentera-Mercantour massif a fluctuation of regional stresses from N-S to NE-SW had taken place during the passage of Hercynian to Alpine tectonics.

REFERENCES

ABDUL HAQUE (1984) Analyse des structures Alpine du socle-tegument de la converture sur la transversale de la Tinée (Alpes-Maritimes. France) These 3 cycle, Univ. Caen, 153p. (Unpublished).

——(1986) Microstructures of Valleta-Moliere, Fault of France & Italy. Acta Mineralogica Pakistanica **2**, pp. 153-157.

——(1987) Petrological study of part of the basement of the Argentera-Mercantour massif, France. Acta Mineralogica Pakistanica **3**, pp. 42-50.

——(1989) Lithostratigraphy of the part of tegument of the massif of Argentera-Mercantour, France. Kashmir Jour. Geol. **6&7**, inpress.

FAURE-MURET, A. (1955) Etudes geologiqussur le massif de 1'Argentera-Mercantour et ses enveloppes sédimentaires, Mem. Expl. Carte Geol. France. 336p.

ROMIAN, J. (1978) Etude petrographique et structurale, de la bordure sudoccidentale du massif de 1 'Argentera, Saint-Martin vesubie a la cime du Diable (A.M.) These 3 cycle Univ. Nice. 365p. (Unpublished).

Manuscript received on April 20, 1991.
Accepted for publication on October 3, 1991.

ACTA MINERALOGICA PAKISTANICA
VOLUME 5 (1991) pp. 135 - 136.

SHORT COMMUNICATIONS

PETROLOGY AND PROVENANCE OF THE SIWALIKS OF KACH AND ZARGHUN AREAS, NORTHEAST BALOCHISTAN: COMMENTS AND CLAPIFICATIONS:

AKHTAR M. KASSI
Department of Geology, University of Balochistan, Quetta.

The final published version of the above mentioned paper in the Acta Mineralogica Pakistanica Vol. 3 (1987) contains some very serious mistakes. The paper was revised and amended by the co-author (Abdul Haque) in response to the referee's comments. The other authors, Abdul Salam and Akhtar Mohammad Kassi were unaware of the referee's comments and also of the amendments proposed by Abdul Haque untill it was published. Therefore, as one of the authors of the published paper, I wish to correct the published mistakes and make clarifications and comments as follows:

1) **Page 134, Abstract, 1st sentence:**
Published : Sandstones **and conglomerates** of the Nagri and Dhok Pathan Formations of Kach area and the Soan Formation of Zarghun were classified microscopically, as lithic arenites and calclithites.
Correct Statement: Sandstones of the Nagri and Dhok Formations of the Kach area and the Soan Formation of the Zarghun area were classified as lithic arenites and calclithites on the basis of microscopic study.

2) **Page 134, Introduction, 2nd paragraph, 1st sentence:**
Published: This Siwalik consists of fine to coarse grained or even pebbly sandstone, conglomerate **and rarely clay.**
Correct statement: The Siwalik Group consists of fine to coarse grained sandstone, conglomerate and claystone.

3) **Page 134, Introduction, paragraph 2, line 16:**
Published: With Dhok Pathan Formation, Nagri formation makes a conformable and transitional contact while with that of Soan Formation is also transitional in the area near Sor Range.
Correct Statement:
The Dhok Pathan Formation conformably overlies the Nagri Formation with a transitional contact and underlies the Soan Formation with a conformable and transitional contact.

4) **Page 134, Introduction, paragraph 2, last sentence:**
Published: Moreover, an unpublished work of OGDC (1965) assigned Middle to Late Miocene age **to these formations.**
Comment: This sentence, referred to the unpublished work of the OGDC (1965), implies that all the Siwaliks are of Middle to Late Miocene age. In the original manuscript the OGDC's (1965) reference was given within the description of the Nagri Formation and was ment for the age of the Nagri Formation. Furthermore, in our original manuscript it was mentioned that the Dhok Pathan Formation is of Middle Pliocene and the Soan Formation of Early Pliestocene age. This valuable information has been eliminated in the published version.

5) **Page 134, Nagri Formation, 1st sentence:**
Published: Sandstone of the Nagri Formation is very rick in various rock fragments rather than mineral constituents, quartz and feldspar including plagioclase, orthoclase, microcline and perthite.
Correct statement: Sandstone of the Nagri Formation is very rich in various types of rock fragments which are dominant over mineral constituents. Quartz and feldspars are the most commonly occuring minerals. Feldspars in-

clude orthoclase, microcline and perthite.

6) **Page 134, Nagri Formation, 2nd paragraph, line 3:**
Published: These include limestones (biomicrite and biosparite of Folk, 1959), calcarinite, marl and calcareous foraminifera, sandstone of quartz arenite and calclithite and lithic arenite, shales and siltstones which are sometimes deformed by compaction, and red to grey radiolarian cherts are recognised.
Correct statement: Among the sedimentary rock fragments limestones of biomicrite and biosperite varieties (Folk 1959), calcarenite, marl, calcareous foraminifera, sandstones of quartz arenite and lithic arenite varieties, shales, siltstones and red and radiolarian cherts are recognisable.

7) **Page 136, Nagri Formation, 3rd paragraph, 1st sentence:**
Published: The grains are cemented by calcite being proportionally so high (50%) and mica grains are . . . .
Correct statement: The grains are cemented by calcite which is sometimes as high as 50% and usually mineral grains, specially those of mica, being laterally displaced . . . .

8) **Page 136, subheading:**
Published: DHOK FORMATION
Correct heading: DHOK PATHAN FORMATION

9) **Page 136, Soan Formation, 1st paragraph, last sentence:**
Published: The mudstone is light grey to brownish grey, medium to coarse grained, subangular to subrounded and poor to moderatly sorted.

Clarification: This statement was not a part of the original manuscript. The properties mentioned may only be attributed to sandstones and not to mudstones.

REFERENCE

FOLK, R.L. (1959) Practical petrographic classification of limestone. Bull. Amer. Assoc. Petrol. Geol., **43**, pp. 1-38.

Received on July 31, 1991.
Accepted for Publication July 31, 1991.

ACTA MINERALOGICA PAKISTANICA
VOLUME 5 (1991) pp. 137 -140.

ANNUAL REPORT OF THE CENTRE OF EXCELLENCE IN MINERALOGY, QUETTA (1991)

ACADEMIC STAFF

Date of joining C.E.M.

Director
1. ZULFIQAR AHMED
Ph.D. (London), PG. DIP.
(Mining Univ., Austria)
M.Sc. & B.Sc. Honours (Punjab) — August 25, 1984

Associate Professors
2. ABDUL HAQUE
Dr. Troisieme Cycle (Caen, France)
M.Sc. (Balochistan) — November 21, 1989

AKHTAR M. KASSI
3. Ph.D. (St. Andrews, UK)
M.Sc. (Balochistan) — August 11, 1991

Assistant Professor
4. JAWED AHMED
M.Sc.(Karachi), M.Phil.
(Balochistan) — April 1, 1980

Lecturer-Cum-Research Associates
5. KHALID MAHMOOD
M.Phil., M.Sc. (Balochistan)
(On doctoral study leave to
University of Montpellier II, France) — November 5, 1989
6. MOHAMMAD AHMED FAROOQUI
M.Sc. (Balochistan)
(On doctoral study leave to
Montana University, USA) — November 5, 1989
7. MEHRAB KHAN
M.Phil., M.Sc. (Balochistan) — November 5, 1989
8. AMJAD RASHID
M.Sc. (Balochistan) — August 11, 1991

GENERAL STAFF

Date of joining C.E.M.

Administrative Officer
1. S. SHAHABUDDIN
M.Sc. (Balochistan) — May 21, 1977

Accounts Officer
2. MIRZA MANZOOR AHMED
B.Com. (Karachi) — May 7, 1980

Senior Technician
3. KHUSHNOOD AHMED SIDDIQUI
Dip. Assoc. Engr. (Hyderabad) — March 1, 1976

Assistant Librarian
4. ABDUL GHAFOOR
M.L.S. (Balochistan) — May 2, 1985

Superintendent (Office)
5. LAL MOHAMMAD DURRANI — May 12, 1973

Photographer
6. HUSSAINUDDIN — June 16, 1981

Stenotypists
7. M. GHALIB SHAHEEN KHAN — July 17, 1985
8. SAID RASOOL MAHJOOR — June 6, 1990

Draftsman
9. AHMED KHAN MANGI — July 1, 1981

Assistant
10. MOHAMMAD ANWAR — September 18, 1973

Laboratory Assistant
11. SHER HASSAN — August 22, 1977

Store Keeper
12. MUSA KHAN — August 20, 1977

Senior Clerk
13. JUMA KHAN — June 12, 1985

Junior Clerk
14. ABDUL MALIK — April 28, 1987

Drivers
15. ALI MOHAMMAD — July 17, 1984
16. SALEH MOHAMMAD — August 18, 1990

Junior Mechanic
17. ABDUL QADIR — August 21, 1977

Laboratory Attendants
18. GHULAM RASOOL — August 20, 1977
19. MEHRAB KHAN — August 21, 1977

	Date of joining C.E.M.
Naib Qasids	
SIKANDAR KHAN	April 30, 1976
MOHAMMAD RAFIQUE	October 10, 1978
ATTA MOHAMMAD	March 25, 1986
Loader	
RAWAT KHAN	July 2, 1977
Sweeper	
NAZIR MASIH	April 1, 1977
Chowkidar	
ABDUL WADOOD	January 26, 1992

M. PHIL. STUDENTS

1. Din Mohammad Kakar
   Supervisor: Akhtar M. Kassi
   Dissertation Title: Structural and sedimentological studies of the coal-bearing Ghazij Formation of Sor Range area, Quetta District.

2. Mian Hassan Ahmed (Session 1989-1991)
   Supervisor: Jawed Ahmed
   Dissertation Title: Petrography and stratigraphy of Chiltan Formation, South of Quetta, Balochistan.

3. Masood Iqbal (Session 1989-1991)
   Supervisor: Abdul Haque
   Dissertation Title: The ophiolitic rocks of Sra-Salwat, south of Muslim Bagh, Balochistan.

4. Mohammad Ibrahim Baloch (Session 1991-1993)
   Supervisor: Abdul Haque/Mehrab Khan
   Dissertation Title: Structural, stratigraphic and petrographic studies of ophiolitic rocks of a part of Lukh Abdul Rehman, Khuzdar District, Balochistan.

5. Mr. Qaiser Mahmud has completed all the course work and was asked to revise his dissertation entitled "Geology of Wadh-Goth Haji Shakar area, Khuzdar District, Balochistan".

Following three students registered on April 24, 1991 (1991-1993 session), with Dr. Abdul Haque as Supervisor, discontinued their studies:

Mr. Hassan Shaheed, Mr. Syed Zainuddin, Mr. Sajid Mehmood.

For admission to new M.Phil. Class for session 1991-1993, aptitude and proficiency test was held on May 12, 1991 and the Admission Committee of C.E.M. decided to admit 14 fresh M.Phil. students. The cases were sent for registration to the University of Balochistan, through the Dean, Faculty of Science, on July 29, 1991. The Academic Committee of CEM also approved these admissions on August 10, 1991. The names of the students are as follows:

1. Mr. Mohammad Sadiq
2. Mr. Amjad Rashid
3. Mr. Mohammad Ayub Baloch
4. Mr. Mohammad Abdullah
5. Mr. Khalid Rehman
6. Mr. Masud Tariq
7. Mr. Mohammad Omer
8. Mr. Mohammad Rahim Jan
9. Mr. Zulfiqar Ahmed
10. Mr. Khan Bakhsh Bugti
11. Mr. Mohammad Saeed
12. Mr. Abdul Razzak Khilji
13. Mr. Munir Ahmed Baloch
    S/o Dr. Habibullah
14. Mr. Munir Ahmed Baloch
    S/o Mr. Mohd Gul

CEM Research Publications (1991) in Journals Other than Acta Mineralogica Pakistanica

AHMED, ZULFIQAR & McCORMICK, G.R. (1990): A newly discovered kimberlitic rock from Pakistan. Mineralogical Magazine (Mineralogical Society, U.K.). Vol. **54**, pp. 537-546.

AHMED, ZULFIQAR (1990) Geochemical characterization of Proterozoic upper crustal metamorphic terrain of southern Malakand Agency, Pakistan. **Precambrian Research** (Elsevier, Netherlands), Vol. **46**, pp. 181-194.

AHMED, ZULFIQAR (1991) Comparison of the geochemistry of ophiolitic pyroxenites with a strongly fractionated dyke of pyroxenite from the Sakhakot-Qila ophiolite, Pakistan. **Chemical Geology** (Elsevier, Netherlands), Vol. **91**, pp. 335-355.

ABSTRACTS (1991)

Abstracts are condensed but informative summaries of presentations made at meetings of scientific and professional organizations.

AHMED, ZULFIQAR (1991) Plate tectonic settings of ophiolites and geochemical study of rocks from the Bela and Khuzdar regions of Pakistan. First Postgraduate Training Course in Plate Tectonics. April 25 to May 8, 1991; Lahore, Pakistan, p. 9.

AHMED, ZULFIQAR (1991): Tectonic setting of associated alkali basalts and ultramafic lamprophyres from Pishin District, Pakistan. UNESCO Regional Postgraduate Course in Plate Tectonics, Peshawar University; October 12-27, 1991.

OTHER ACADEMIC ACTIVITIES

The research work conducted during the year 1991 is also reflected in the articles included in Volume 5 of Acta Mineralogica Pakistanica.

Zulfiqar Ahmed worked as a faculty member with the designation of Visiting Associate, at the Division of Geological and Planetary Sciences, California Institute of Technology (abbreviated 'Caltech'), Pasadena, California, U.S.A., from January 8, 1990 to March 10, 1991. During this period, Zulfiqar Ahmed continued his research work on the Bela ophiolite, Pakistan. He used a wide spectrum of instrumental and laboratory techniques for studying the rock samples from Bela ophiolite. These techniques included quantitative mineral chemical analyses on the electron microprobe and scanning electron microscope, quantitative bulk-rock chemical analyses by the direct current plasma spectrometry (DCP) and X-ray fluorescence (XRF), microchemical extraction of selected radiogenic and related parent elements by clean room laboratory techniques, isotopic high-precision quantitative abundance analyses by thermal ionization mass spectrometry, petrographic microscopy and infra-red spectromety. Some of the results are presented already within and outside Pakistan. More articles are under preparation.

Jawed Ahmed attended the UNESCO Regional Training Course on Plate Tectonics held from October 12 to 27, 1991, at the University of Peshawar, including a guided field excursion to Northern Areas of Pakistan.

Prof. Francoise Boudier from the Laboratory of Tectonophysics, University of Montpellier II, France, visited CEM and conducted field studies on Muslim Bagh Ophiolite from April 21, to May 28, 1991. The purpose was the modelling of ocean-floor spreading using kinematic interpretation of asthenospheric and obduction-related flow structures in Muslim Bagh ophiolite, which exposes complete sequence from the metamorphic sole to the sheeted dyke complex. Mr. Khalid Mahmood of CEM will present doctoral thesis on this work after conducting microstructural studies at Montpellier, France. Mr. Khalid Mahmood conducted the field studies in the same area from April 11, 1991 to June 12, 1991. Zulfiqar Ahmed also joined this field study from May 5 to 9, 1991.

Mehrab Khan accompanied the first field trip of Prof. F. Boudier from April 24, 1991, to May 28, 1991. His focus was on the structure, flow direction, emplacement age and direction of the ophiolitic rocks. He collected 80 rock samples for persuing laboratory studies during his intended visit to the University of Montpellier, France.

Mr. Khadim Hussain Durrani, availed CEM scholarship for Ph.D. study in France. He is enrolled at University of Oreleans, France.

Zulfiqar Ahmed participated in the International Petroleum Seminar held from November 22 to 24, 1991, at the Hotel Holiday Inn, Islamabad, and organized by the Oil & Gas Development Corporation.

Under the British Council's linkage programme, David H. Alderton and R.J.L. Colvine of the U.K. institution (Geology Deptt., RHB New College, University of London) carried out geological field studies from August 8 to 23, 1991, accompanied by Zulfiqar Ahmed and Mehrab Khan from C.E.M. The visits were made to the fluorite mining area of Phade Maran, Kalat District; barite deposits of Gunga valley, Khuzdar District; lead-zinc mineralized, gossan-bearing areas of Shekran, Khuzdar

District; chromitiferous areas of Khuzdar and Bela Districts. Special lectures were delivered on August 21 and 22, 1991, by the UK scientists on fluid inclusions and sedimentary lead-zinc deposits.

Zulfiqar Ahmed has continued further work on the following projects:

1. The kimberlitic and associated alkali basaltic rocks from Balochistan. (The project proposal is submitted to the University Grants Commission for funding).
2. Mineralogy, petrology and geochemistry of the Bela ophiolite.
3. Economic mineral deposits associated with the Bela ophiolite including managenese and chromite.

1989 - 1991 PAPERS OF REGIONAL INTEREST FROM OTHER JOURNALS

(A) WITH PUBLICATION DATES OF 1988

BAIG, M.S., LAWRENCE, R.D. & SNEE, L.W. Evidence for late Precambrian to Early Cambrian orogeny in northwest Himalaya, Pakistan. Geological Magazine, Vol. **125**, pp. 83-86.

BARNICOAT, A.C. & TRELOAR, P.J. Himalayan metamorphism —— an introduction. Journal of Metamorphic Geology, Vol. **7**, no. 1, pp. 3-8.

BERTRAND, J.M., KIENAST, J.-R. & PINARDON. J.-L. Structure and metamorphism of the Karakorum gneisses in the Braldu-Baltoro Valley (North Pakistan). Geodinamica Acta (Paris) Vol. **2-3**, pp. 135-150.

CHAMBERLAIN, C.P., ZEITLER, P.K. & JAN, M.Q. The dynamics of the suture between the Kohistan island arc and the Indian plate in the Himalaya of Pakistan. Journal of Metamorphic Geology, Vol. **7**, no. 1, pp. 135- .

FRANCE-LANORD, C. & LE FORT, P. Crustal melting and granite genesis during the Himalayan collision orogenesis. Transactions of the Royal Society of Edinburgh: Earth Sciences, Vol. **79**, pp. 183-195.

FRANCE-LANORD, C., SHEPPARD, S.M.F. & LE FORT, P. Hydrogen and oxygen isotope variations in the High Himalaya peraluminous Manaslu leucogranite: Evidence for heterogeneous sedimentary source. Geochimica et Cosmochimica Acta, Vol. **52**, pp. 513-526.

HONEGGER, K., LE FORT, P. MASCLE, G. & ZIMMERMAN, J.-L. The blueschists along the Indus suture zone in Ladakh, NW Himalaya. Journal of Metamorphic Geology, Vol. **7**, no. 1, pp. 57-72.

SBORSHCHIKOV, I.M. Closure of Tethys and the tectonics of the eastern part of the Alpine Belt. Geotectonics (English Edition) Vol. **22**, no. 3, pp. 195-203.

SENGÖR, A.M.C., ALTINER, D., CIN,A., USTAOMER,T. & HUS, K.J. Origin and assembly of the Tethyside orogenic collage at the expense of Gondwana Land. *In*: Audley-Charles, M.G. & Hallam, A. (Eds.) GONDWANA AND TETHYS. Geological Society of London Special Publication no. **37**, pp. 119-181.

TRELOAR, P.J., BROUGHTON, R.D., WILLIAMS, M.P., COWARD, M.P. & WINDLEY, B.F. Deformation, metamorphism and imbrication of the Indian plate, south of the Main Mantle Thrust, north Pakistan. Journal of Metamorphic Geology, Vol. **7**, no. 1, pp. 111-126.

(B) WITH PUBLICATION DATES OF 1989

BURBANK, D.W. & BECK, R.A. Development of the Himalayan frontal thrust zone: Salt Range, Pakistan: Comment. Geology, Vol. **17**, no. 4, p. 378.

BURBANK, D.W. & BECK, R.A. Early Pliocene uplift of the Salt Range; Temporal constraints on thrust wedge development, northwest Himalaya, Pakistan. Geological Society of America Special Paper **232**, pp. 113-128.

BUTT, K.A. Release of uranium through cataclastic deformation of Mansehra granitic gneiss and its precipitation in the overlying intramontane basin in northern Pakistan. *In*: URANIUM DEPOSITS IN MAGMATIC AND METAMORPHIC ROCKS. I.A.E.A. Publ. no. STI/PUB/767, pp. 155-166, IAEA, Vienna.

BUTT, K.A. Uranium Occurrences in magmatic and metamorphic rocks of northern Pakistan. *In:* URANIUM DEPOSITS IN MAGMATIC AND METAMORPHIC ROCKS, I.A.E.A. Publ. no. ST/PUB/767, pp. 131-154, IAEA, Vienna.

CERVENY, P.F., JOHNSON, N.M., TAHIRKHELI, R.A.K. & BONIS. N.R. Tectonic and geomorphic implications of Siwalik Group heavy minerals, Potwar Plateau Pakistan. Geological Society of America Special Paper **232**, pp. 129-136.

CERVENY, P.F., NAESER, C.W., KELEMEN, P.B., LIEBERMAN, J.E. & ZEITLER, P.K. Zircon fission -track ages for the Gasherbrum Diorite, Karakoram Range, northern Pakistan. Geology Vol. **17**, no. 11, pp. 1044-1048.

CHAMBERLAIN, C.P., JAN, M.Q. & ZEITLER, P.K. A petrological record of the collision between the Kohistan Island Arc and Indian plate, northwest Himalaya. Geological Society of America Special Paper **232**, pp. 23-32.

CRONIN, V.S. Structural setting of the Skardu intermontane basin, Karakoram Himalaya, Pakistan. Geological Society of America Special Paper **232**, pp. 183-202.

CRONIN, V.S., JOHNSON, W.P., JOHNSON, N.M. AND JOHNSON, G.D. Chronostratigraphy of the upper Cenozoic Bunthang sequence and possible mechanisms controlling base level in Skardu intermontane basin, Karakoram Himalaya, Pakistan. Geological Society of America Special Paper **232**, pp. 295-310.

DUROY, Y., FARAH, A. & LILLIE, R.J. Subsurface densities and lithospheric flexure of the Himalayan foreland in Pakistan. Geological Society of America Special Paper **232**, pp. 217-227.

GEE, E.R. Overview of the geology and structure of the Salt Range, with observations on related areas of northern Pakistan. Geological Society of America Special Paper **232**, pp. 95-112.

GORDON, R.G. & DE METS, C. Present- day motion along the Oman Fracture Zone and Dalrymple Trough in the arabian Sea. Journal of Geophysical Research, Vol. **94**, pp. 5560-5570.

GRECO, A., MARTINOTTI, G., PAPRITZ, K. & RAMSAY, J.G. The crystalline rocks of the Kaghan Valley (NE-Pakistan). Eclogae Geologicae Helvetiae, Vol. **82**, pp. 629-653.

HANSON, C.R. The northern suture in the Shigar valley, Baltistan, northern Pakistan. Geological Society of America Special Paper **232**, pp. 203-216.

KHAN, M.A., JAN, M.Q., WINDLEY, B.F., TARNEY, J. & THIRLWALL, M.F. The Chilas mafic-ultramafic complex: The root of the Kohistan Island Arc in the Himalaya of northern Pakistan. Geological Society of America Special Paper **232**, pp. 75-94.

LILLIE, R.J., BAKER, D.M., YEATS, R.S., JOHNSON, G.D., YOUSUF, M. & ZAMAN, A.S.H. Development of the Himalayan frontal thrust zone; Salt Range, Pakistan: Reply. Geology, Vol. **7**, no. 4, pp. 378-380.

MADIN, I.P., LAWRENCE, R.D. & UR-REHMAN, S. The northern Nanga Parbat-Haramosh Massif; Evidence for crustal uplift at the northwestern corner of the Indian Craton. Geological Society of America Special Paper **232**, pp. 169-182.

MALINCONICO, L.L. JR., Crustal thickness estimates for the western Himalaya. Geological Society of America Special Paper **232**, pp. 237-242.

MOGHAL, M.Y. Field test for in situ leach mining of uranium in Pakistan. I.A.E.A. Technical Document TECDOC-500, pp. 214-224. IAEA, Vienna.

NAKATA, T. Active faults of the Himalaya of India and Nepal. Geological Society of America Special Paper **232,** pp. 243-264.

PARRISH, R.R. & TIRRUL, R. U-Pb age of the Baltoro granite, northwest Himalaya, and implications for monazite U-Pb systematics. Geology, Vol, **17,** no. 12, pp. 1076-1079.

SEARLE, M.P., REX, A.J., TIRRUL, R., REX, D.C., BARNICOAT, A & WINDLEY, B.F. Metamorphic, magmatic and tectonic evolution of the central Karakorum in the Biafo- Baltoro- Hushe regions of northern Pakistan. Geological Society of America Special Paper **232,** pp. 47-74.

SHRODER, J.F., JR., KHAN, M.S., LAWRENCE, R.D., MADIN, I.P. & HIGGINS, S.M. Quaternary glacial chronology and neotectonics in the Himalaya of northern Pakistan. Geological Society of America Special Paper **232,** pp. 275-294.

TRELOAR, P.J., COWARD, M.P., WILLIAMS, M.P. & KHAN, M.A. Basement-cover imbrication south of the Main Mantle Thrust, north Pakistan. Geological Society of America Special Paper **232,** pp. 137-152.

TRELOAR, P.J., REX, D.C., GUISE, P.G., COWARD, M.P., SEARLE, M.P., WINDLEY, B.F., PETTERSON, M.G., JAN, M.Q. & LUFF, I.W. K-Ar and Ar- Ar geochronology of the Himalayan collision in NW Pakistan: constraints on the timing of suturing, deformation, metamorphism and uplift. Tectonics, Vol. **8,** no. 4, pp. 881-909.

TRELOAR, P.J., WILLIAMS, M.P. & COWARD, M.P. Metamorphism, and crustal stacking in the North Indian plate, north Pakistan. Tectonophysics, Vol. **165,** pp. 167-184.

YEATS, R.S. & HUSSAIN, A. Zone of Late Quaternary deformation in the southern Peshawar Basin, Pakistan. Geological Society of America Special Paper **232,** pp. 265-274.

ZEITLER, P.K., SUTTER, J.F., WILLIAMS, I.S., ZARTMAN, R. & TAHIRKHELI, R.A.K. Geochronology and temperature history of the Nanga Parbat - Haramosh Massif, Pakistan. Geological Society of America, Special Paper **232,** pp. 1-22.

ABSTRACTS:

FIFTH MEETING OF THE EUROPEAN UNION OF GEOSCIENCES, MARCH 20-23, 1989, STRASBOUG, TERRA ABSTRACTS, Vol. **1,** No. 1:

Copeland, P. & Harrison, T.M. Chronology of the Manaslu granite: implications for magma segregation. Sy. 21-04, p. 174.

CRAWFORD, M.B. Leucogranites of the northwest Himalaya: melting triggers and the magmatic evolution of continental belts. Sy 21-08, p. 175.

Le Fort, P., Franc-Lanord, C. & Pecher, A. Granites of the Himalayan collision: 1. Petrological constraints. Sy. 21-1, p. 173.

PECHER, A., SCAILLET, B. & LE FORT, P. Granites of the Himalayan collision: 2. Tectonic constraints. Sy. 21-02, p. 173.

(C) WITH PUBLICATION DATES OF 1990

AHMED, Z. A newly discovered kimberlitic rock from Pakistan. Mineralogical Magazine, Vol. **54,** pp. 537-546.

AHMED, Z. Geochemical characterization of Proterozoic upper crustal metamorphic terrain of southern Malakand Agency, Pakistan. Precambrian Research, Vol. **46,** pp. 181-194.

BOSSART, P., OTTIGER, R. & HELLER, F. (1990) Rock magnetic properties and structural development in the core of the Hazara- Kashmir Syntaxis, NE Pakistan. Tectonics, Vol. **9,** no. 1, pp. 103-121.

BOULIN, J. Neocimmerian events in Central and Western Afghanistan. Tectonophysics, Vol. **175,** pp. 285-315.

BROOKFIELD, M.E. & REYNOLDS, P.H. Miocene $^{40}Ar/^{39}Ar$ ages from the Karakorum Batholith and Shyok Melange, northern Pakistan, indicate late Tertiary uplift and southward displacement. Tectonophysics Vol, **172,** no. 1/2, pp. 155-167.

CHAUDHRY, M.N. & GHAZANFAR, M. Position of the Main Central Thrust in the tectonic framework of Western Himalaya. Tectonophysics, Vol. **174,** pp. 321-329.

COLLIER, J.S. & WHITE, R.S. Mud diapirism within Indus fan sediments: Murray Ridge, Gulf of Oman. Geophysical Journal International. Vol. **101,** no. 2, pp. 345-353.

COPELAND, P., HARRISON, T.M. & LE FORT, P. Age and cooling history of the Manaslu granite: implications for Himalayan tectonics. Journal of Volcanology & Geothermal Research, Vol. **44,** pp. 33-50.

CRAWFORD, M.B. & WINDLEY, B.F. Leucogranites of the Himalaya/Karakoram: implications for magmatic evolution within collisional belts and the study of collision -related leucogranite petrogenesis. Journal of Volcanology & Geothermal Research, Vol. **44,** pp. 1-20.

GAETANI, M., GARZANTI, E., JADOUL, F., NICORA, A., TINTORI, A., PASINI, M. & KHAN, K.S.A. The north Karakorum side of the central Asia geopuzzle. Geological Society of America Bulletin, Vol. **102,** no. 1, pp. 54-62.

GAETANI, M., GARZANTI, E. & TINTORI, A. Permo-Carboniferous stratigraphy in SE Zanskar and NW Lahul (NW Himalaya, India). Eclogae Geologicae Helvetiae, Vol. **83,** pp. 143-161.

GLENNIE, K.W., CLARKE, M.W.H., BOEUF, M.G.A., PILLAR, W.F.H. & REINHARDT, B.M. Inter-relationship of Makran-Oman Mountains belts of convergence. *In:* Robertson, A.H.F., Searle, M.P. & Ries, A.C. (Eds.) THE GEOLOGY AND TECTONICS OF THE OMAN REGION. Geological Society of London Special Publication no. **49,** pp. 773-786.

JAN, M.Q. & WINDLEY, B.F. Chromian spinel - silicate chemistry in ultramafic rocks of the Jijal complex, northwest Pakistan. Journal of Petrology, Vol. **31,** part 3, pp. 667-715.

McDOUGALL, J.W. & KHAN, S.H. Strike-slip faulting in a foreland fold-thrust belt: the Kalabagh fault and western Salt Range, Pakistan. Tectonics, Vol. **9,** no. 5, pp. 1061-1075.

MOUNTAIN, G.S. & PRELL, W.L. A multiphase tectonic history of the southeast continental margin of Oman. *In:* Robertson, A.H.F., Searle, M.P. & Ries, A.C. (Eds.) THE GEOLOGY AND TECTONICS OF THE OMAN REGION. Geological Society of London Special Publication no. **49,** pp. 725-743.

SCHARER, U., COPELAND, P., HARRISON, T.M. & SEARLE, M.P. Age, cooling history and origin of post-collisional leucogranites in the Karakoram batholith: a multi-system isotope study. Journal of Geology, Vol. **98,** no. 2, pp. 233-251.

SEARLE, M.P., PARRISH, R.R., TIRRUL, R. & REX, D.C. Age of crystallization and cooling of the K2 gneiss in the Baltoro Karakoram. Journal of the Geological Society, London, Vol. **147,** pp. 603-606.

SEARLE, M.P., PICKERING, K.T. & COOPER, D.J.W. Restoration and evolution of the intermontane Indus molasse basin, Ladakh Himalaya, India. Tectonophysics, Vol. **174,** pp. 301-314.

STEWART, A.G. For debate: Drifting continents and endemic goitre in northern Pakistan. British Medical Journal, Vol. **300,** pp. 1507-1512.

VOLPE, A.M. & MACDOUGALL, J.D. Geochemistry and isotopic characteristics of mafic (Phulad ophiolite) and related rocks in the Delhi Supergroup, Rajasthan, India: implications for rifting in the Proterozoic. Precambrian Research Vol. **48,** pp. 167-191.

TAUXE, L., CONSTABLE, C. & STOKKING, L. Use of anisotropy to determine the origin of characteristic remanence in the Siwalik red beds of northern Pakistan. Journal of Geophysical Research, Vol. **95,** no. B4, pp. 4391-4404.

TRELOAR, P.J. & REX, D.C. Cooling and uplift histories of the crystalline thrust stack of the Indian Plate internal zones west of Nanga Parbat, Pakistan Himalaya. Tectonophysics, Vol. **180,** pp. 323-349.

TRELOAR, P.J. & REX, D.C. Post-magmatic cooling history of the Indian Plate crystalline thrust stack, Pakistan Himalaya. Journal of the Geological Society, London, Vol. **147,** pp. 735-738.

(D) WITH PUBLICATION DATES OF 1991

AHMAD, M. & IBRAHIM, M. A study of mineralogy and physico-chemical properties of Swat clay reject (fine slip). Pakistan Journal of Scientific & Industrial Research, PCSIR, Karachi, Vol. **34,** no. 12, pp. 500-505.

AHMED, Z. Comparison of the geochemistry of ophiolitic pyroxenites with a strongly fractionated dyke of pyroxenite from the Sakhakot-Qila ophiolite, Pakistan. Chemical Geology, Vol. **91,** pp. 335-355.

CHAMBERLAIN, C.P., ZEITLER, P.K. & ERICKSON, E. Constraints on the tectonic evolution of the northwestern Himalaya from geochronologic and petrological studies of Babusar Pass, Pakistan.. Journal of Geology, Vol. **99,** no. 6, pp. 829-849.

MILLER, D.J., LOUCKS, R.R. & ASHRAF, M. Platinum-group element mineralization in the Jijal layered ultramafic-mafic complex, Pakistani Himalayas. Economic Geology, Vol. **86,** pp. 1093-1102.

PECHER, A., BOUCHEZ, J.-L. & LE FORT, P. Miocene dextral shearing between Himalaya and Tibet. Geology, Vol. **19,** pp. 683-685.

QURESHI, A.A., BUTT, K.A. & KHAN, H.A. Eplacement time of Salai Patai carbonatite, Malakand, Pakistan, from fission track dating of zircon and apatite. Nucl. Tracks Radiat. Meas., Int. J. Radiat. Appl. Instrum., Part D. Pergamon, Great Britain.

SEARLE, M.P. & TIRRUL, R. Structural and thermal evolution of the Karakoram crust. Journal of the Geological Society, London, Vol. **148,** pp. 65-82.

INFORMATION FOR AUTHORS

ACTA MINERALOGICA PAKISTANICA publishes in English annually the results of original scientific research in the multifaceted field of mineral sciences, covering mineralogy, petrology, crystallography, geochemistry, economic geology, isotope geoscience, petrography, petrogenesis, mineral chemistry and related disciplines. Review articles and short notes are also considered for publication. Priority is given to geoscientific papers with impact on Pakistan region.

In general, the manuscripts be organized in the following order: title; name(s) and institutional address(es) of the author(s); abstract; introduction; methods, techniques, material studied and area descriptions; results; conclusions; acknowledgements; references; tables; figure captions. The abstract should not exceed 300 words. All tables and figures should be referred in the text and numbered according to their sequence in the text. All references to publications are given in the text by author's name and year of publication; and are listed at the end of text alphabetically by author's names and chronologically per author.

Authors of the articles submitted for publication in ACTA MINERALOGICA PAKISTANICA should send two complete copies of the manuscript, typed double-spaced on one side of the paper only. Copies of tables should be in final format. As far as possible, tables and figures should be prepared for reduction to the single column size or to the page size (204mm x 278mm). Use of mineral symbols by Kretz (The American Mineralogist, 1983, Volume 68, pp. 277-279) is recommended for superscripts, subscripts, equations, figures and tables. The Concise Oxford Dictionary is adopted for spelling. Underlining of text by a single line will mean printing in italics; that by a double line will mean printing in bold letters. The use of metric system and S.I. units is recommended. Bar scales should be used in all figures rather than numerical scales.

Only articles not previously published and not about to be published, wholly or in part, in either Pakistani or foreign journals, are considered for publication. Submission of an article is understood to imply that the article is original and unpublished and is not being considered for publication elsewhere. Publication is subject to the discretion of the Editor. All manuscripts are refereed before being accepted. Accepted papers become copyright of the Centre of Excellence in Mineralogy, Quetta. Authors alone are responsible for the accuracy of the contents and views expressed in their respective papers. Fifty off-prints of each published paper will be sent to authors free of charge. Additional copies may be ordered just after receiving the acceptance letter from the Editor. Manuscripts should be sent to: Acta Mineralogica Pakistanica C/O Centre of Excellence in Mineralogy, University of Balochistan, G.P.O. Box 43, Quetta, Pakistan. Phone Nos. are (081) 41974 & 40500.

ACTA MINERALOGICA PAKISTANICA VOLUME 5, 1991

CONTENTS