According to Shah (1985), the Indo-Pakistan subcontinent sequence in the area includes granite gneiss, thin-bedded crystalline limestone, quartz-mica schist, graphitic schist and phyllite. The Indus suture melange is comprised mainly of ultramafic rocks, pillow lavas with associated metachert and limestone, greenschists, and blueschist facies metagraywacke. The amphibolites of the Kohistan island arc have been distinguished into epidote-amphibolite and locally developed garnet epidote-amphibolite. These are of great significance from the standpoint of stratigraphy and tectonics of the Allai Kohistan.

Within the Indus suture melange, the dominant rocks are the basic volcanics characterized by pillow structures. These have a thrust contact with the associated ultramafics which are in places highly fractured and brecciated. In this paper, the general field and thin section's characteristics along with a detailed chemical account of the pillow lavas from the studied area are described.

FIELD ASPECTS

The lavas of the Shergarh Sar area constitute an elongated belt following the general trend of the ultramafic rocks in the studied area (Fig. 1). Good exposures occur in the Natal Khwar section, north-west of Pashtu Village, and along the southern slopes of the Shergarh Sar. In the Natal Khwar section the volcanics have a thrust contact with the serpentinites. Tectonically emplaced huge blocks of the volcanic rocks are also exposed along the south-western flank of Qarghan Sar.

Pillow structures are nicely developed in these lavas south-west of Qarghan Sar and also along the Natal Kharw. Individual pillows are roughly rounded to ellipsoidal in shape, from a few centimeters to more than 1/2 meter across, and are enclosed in a yellowish green glass (palagonite) or a mixture of broken pillows and palagonite.

The lavas are compact and mostly fine grained. These have a dark-green to yellowish green colour on the fresh surface, while the weathered surfaces show thin dark-brown coating. Most of the handspecimens exhibit cooling cracks which are partially filled with carbonate material. Some samples indicate chilling effects at the surface and are glassy in appearance. Angular fragments of limestone and dirty white to reddish chert are commonly enclosed within the lavas especially in the south-western flank of Qarghan Sar and north-west of Pashtu Village.

PETROGRAPHY

The lavas in thin sections exhibit crystallites and tiny laths of plagioclase, amphibole and clinopyroxene in a matrix of dark-green to yellowish green glass. Acicular character and turbid nature of the plagioclase laths is typical. Due to the fine-grained and glassy nature of the flows, modal composition could not be determined.

Amphibole and plagioclase occur as tiny laths which are randomly oriented in a glassy matrix. Rounded amygdules of radial zeolite and smaller, less regular pseudoamygdules filled with chlorite are common. Large, rounded grains of chert,

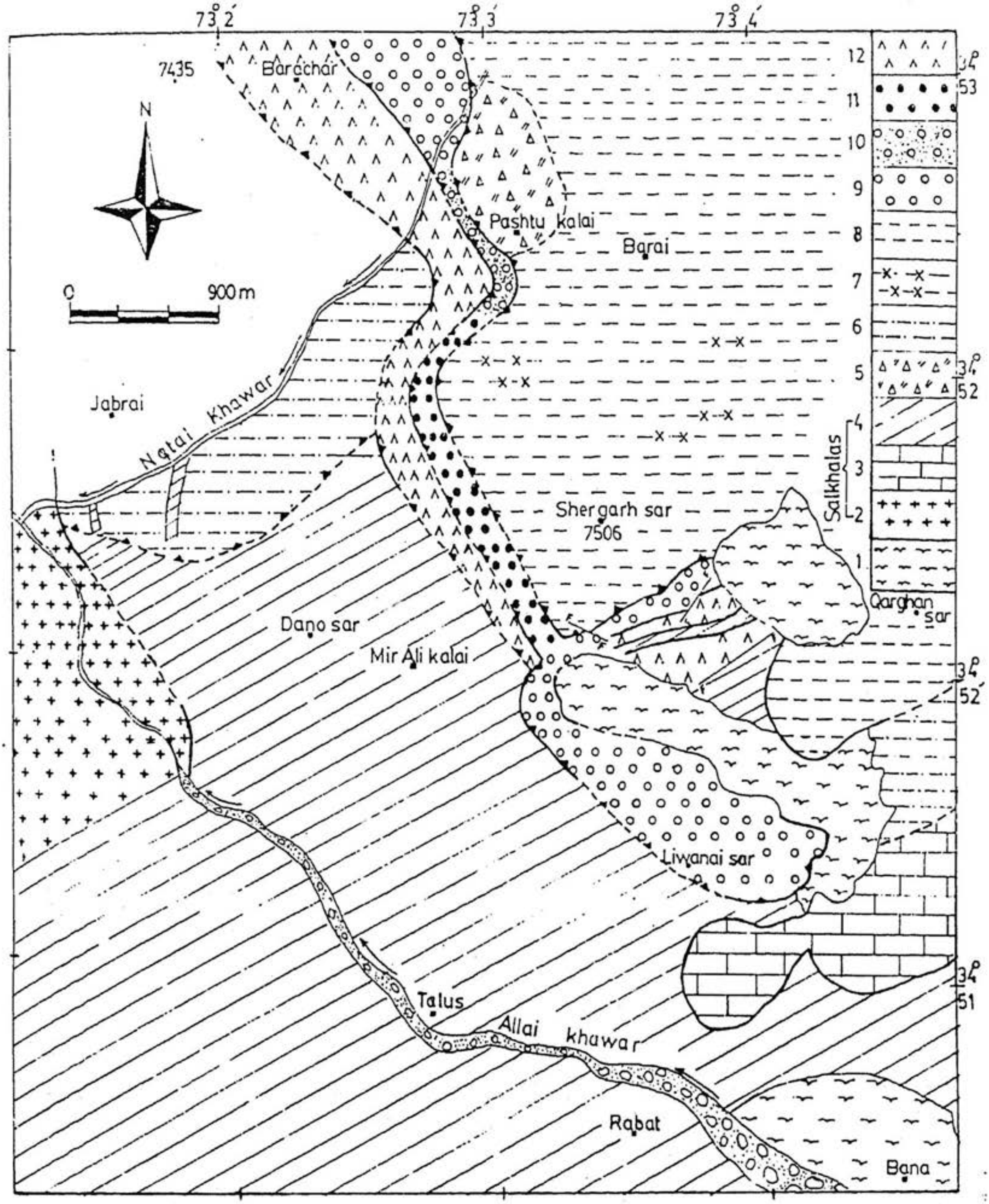

Fig. 1. Geological map of Shergarh Sar Area, Allai Kohistan.

1. Alluvium; 2. Granite gneiss; 3. Limestone; 4. Schists; 5. Brecciated zone; 6. Greenschist rocks; 7. Garnet epidote-amphibolite; 8. Epidote-amphibolite; 9. Serpentinite; 10. Peridotite; 11. Clinopyroxenite; 12. Lavas. .... Thrusted contact, dashed where infered.

partially encircled by carbonate material, have also been noticed. In some thin sections the lavas are composed entirely of dark-green to yellowish green glass with embryos of plagioclase and microcrystalline opaque material. The glassy matrix also contains xenoliths of limestone. The development of siderite is confined to the contact zone of limestone and glass.

A regional low-grade paragenesis is by far the most extensive within the lavas in some sections. It is characterized by a patchy appearance and incomplete gradation of lavas to low temperature mineral assemblage, primarily chlorite, albite, quartz, sphene, calcite, epidote and zeolite. Patchy development and the tendency of the most complete mineralogical transformation to occur in amygdular parts of flows and along fratucres are the major characteristics of the low grade metamorphism of lavas from the studied area. Patches of the low-grade mineral assemblages are usually subrounded to subangular in shape but occasionally are bounded by concave surfaces. In some sections, a thin veneer of vermicular chlorite and opaque material surrounds a fine- to medium-grained crystal aggregate of albite, quartz. sphene, calcite and epidote.

Presence of the pillow structures and incorporation of angular to rounded blocks of carbonate rock confirm the eruptive character of the studied rocks in addition to their amygdaloidal nature and volcanic texture (i.e. the lava flow structure) in thin sections.

CHEMISTRY

Eighteen least altered lava samples were selected for analysis and for treatment in this section. Selection of samples for chemical analysis has been made on the basis of the thin sections study, and samples showing regional low-grade paragenesis were omitted.

Whole rock samples were analysed by atomic absorption and uv/visible spectrophotometer. A measured amount of each sample, usually about 0.5 gram, was digested with hydrofluoric acid (HF) and taken into solution. Eight of these samples analysed by wet chemical methods were duplicated by X-ray fluorescence spectrophotometry using G–2, DNC–1, and BCR–1 as internal standards.

Total iron was determined as Fe_2O_3. The weight percent of FeO was determined in each sample by the ammonium metavanadate method (Wilson, 1955, 1960). C.I.P.W. norms were calculated using a computer programme. Analyses in Table 1 show that even after a careful selection of samples for chemical study, some effects of the metamorphic alteration remained unavoidable. As a result, volatile contents and oxidation states of the analysed samples listed in Table 1 do not represent original compositions.

For a satisfactory comparison (particularly on normative plots) the analyses in Table 1 are, therefore, recalculated on anhydrous basis and Fe_2O_3 contents are standardized through the calculation procedure suggested by Irvine and Baragar (1971), in which Fe_2O_3 is assumed to equal the TiO_2 content of the rock plus

1.5 per cent. The C.I.P.W. norms calculated after the oxidation state correction are presented along with analyses in Table 2. The oxidation state, after standardizing Fe_2O_3 contents, varies in the range 0.22 to 0.51 with an average value of 0.33 which is very close to oxidation state value suggested for most of the tholeiitic lavas (0.15, Brooks, 1976). This procedure causes changes of several per cent in the normative content of ferromagnesian minerals but has a very little effect on other parameters (e.g. Fe/Mg ratios).

Major elements

The lavas from the studied area are mostly glassy and modal contents cannot be determined, therefore, the chemical parameters are considered in their nomenclature. The average SiO_2 content of approx. 52% (calculated on anhydrous basis, see Table 3 column 1) and the average normative colour index of about 40 per cent by weight are the combined criteria which, according to the volcanic rocks classification scheme of Streckeisen (1979), are indicative of their basaltic nature. Normative plagioclase composition (at a limit of An 50 per cent) is less suitable for the distinction of these rocks as basalt because some samples have An contents below 50: ~ 30.56 to 49.75% (see Table 2). Out of 18 analysed samples, twelve are quartz normative (with average normative quartz = 11.74%) and six are olivine normative (average normative olivine = 11.5%). Both types contain normative hypersthene (average 13.26%). Following Yoder and Tilley (1962) and Carmichael *et al.* (1974) the first six samples in Table 2 classify as olivine tholeiite and the remaining as quartz tholeiite. The tholeiitic nature of these lavas is also evident from SiO_2 vs FeOt/MgO ratio diagram (Fig. 2, after Miyashiro, 1974) and on the AFM ternary plot (Fig. 3).

Analysis of the average tholeiite from the studied area is compared with average tholeiitic basalt (Halberg and William, 1972), tholeiitic lava, Thingmuli, Iseland (Carmichael, 1964b), average island arc tholeiitic and calc-alkaline basalt (Halberg and William, 1972), average oceanic tholeiite (Engel *et al.,* 1965) and with average pillow lavas of ophiolite from north-eastern Iran (Lensch, 1980), in Table 3. Beside having general similarities in the major element abundances, the lavas from the studied suite show chemical affinities (i.e. FeOt/MgO ratio) with the island arc tholeiitic basalt rather than with oceanic tholeiites or calc-alkaline types.

MgO, Fe_2O_3 + FeO, TiO_2, P_2O_5, CaO, Al_2O_3 and SiO_2 vs solidification index (S.I. = 100 MgO / MgO + Fe_2O_3 + FeO + Na_2O + K_2O), Kuno, 1959) are coherent in their distribution (Fig. 4). Each constitute a smooth variation trend. Characteristic of this trend is a progressive MgO and CaO depletion and subdued Fe-enrichment together with more or less constant Al_2O_3 values during fractionation. Total alkalies vs S.I. show a complete scatter. Most of this effect can be attributed to localized changes in Na_2O contents because of an exchange with sea water in ways similar to those proposed by Cann (1966), Melson *et al.* (1968) and Fyfe (1976). As a consequence of the anomalous Na_2O

TABLE I. MAJOR AND TRACE ELEMENT DATA FOR THE LAVAS FROM SHERGARH SAR AREA

	Alk 33A	Alk 110A	Alk 116A	Alk 109A	Alk 54	Alk 139A	Alk 27A	Alk 64A	Alk 112A	Alk 113A
SiO_2	46.22	48.51	46.94	43.54	45.17	46.77	49.96	52.31	50.55	51.48
TiO_2	0.61	1.21	1.02	0.85	3.20	1.34	1.77	1.21	1.28	1.12
Al_2O_3	14.91	14.71	12.19	12.65	14.32	13.61	12.96	13.78	11.34	13.72
Fe_2O_3	8.35	13.26	9.49	6.98	7.68	8.92	11.98	9.89	9.20	8.32
FeO	3.89	0.00	3.51	3.68	7.50	5.05	2.97	3.58	4.12	4.12
MnO	0.18	0.18	0.17	0.13	0.17	0.29	0.29	0.14	0.19	0.17
MgO	10.54	7.17	7.97	8.42	5.06	7.77	4.68	4.19	5.05	4.32
CaO	10.00	8.07	10.62	11.22	6.58	7.21	7.07	5.34	9.68	7.89
Na_2O	1.20	3.59	2.67	1.48	3.69	2.94	2.90	3.99	1.56	2.12
K_2O	0.05	1.76	0.59	2.52	1.23	1.57	0.90	1.66	0.66	0.73
P_2O_5	0.01	0.16	0.12	0.13	0.31	0.14	0.21	0.19	0.15	0.13
H_2O^-	0.21	0.12	0.18	0.13	0.00	0.12	0.12	0.09	0.21	0.21
Ig. loss	1.89	2.97	4.69	8.12	3.78	4.59	4.19	3.93	4.05	4.89
Total	98.02	101.71	100.16	99.85	98.69	100.37	100.00	100.30	98.04	99.22

Continued

Table 1. Continued

	Alk 57	Alk 57A	Alk 49B	Alk 49A	Alk 49	Alk 68A	Alk 106A	Alk 60
SiO_2	49.32	49.92	48.20	50.21	48.20	49.64	54.32	48.31
TiO_2	1.75	0.85	1.47	0.90	1.80	1.03	1.12	1.22
Al_2O_3	14.85	14.02	14.89	15.21	13.92	14.78	14.26	15.45
Fe_2O_3	2.64	5.04	3.38	3.83	3.99	8.42	2.16	1.60
FeO	7.60	5.49	8.50	7.44	8.42	4.89	5.18	6.18
MnO	0.22	0.21	0.19	0.19	0.19	0.20	0.19	0.20
MgO	2.86	2.88	5.20	4.41	5.57	4.52	5.17	3.19
CaO	11.47	14.70	9.44	8.59	9.90	9.78	12.74	11.99
Na_2O	1.19	0.89	0.68	0.24	0.25	2.10	1.48	2.78
K_2O	0.03	0.00	0.05	0.22	0.00	0.32	0.30	0.31
P_2O_5	0.31	0.00	0.12	0.29	0.37	0.00	0.17	0.00
H_2O^-	0.31	0.00	0.12	0.29	0.37	0.00	0.17	0.00
Ig. loss	6.31	7.57	6.38	6.39	5.83	4.32	2.68	6.97
Total	98.98	101.87	98.75	98.17	99.23	100.21	100.11	98.23

TABLE 2. THE ANHYDROUS MAJOR ELEMENTS DATA AND C.I.P.W. NORMS OF THE LAVAS FROM SHERGARH SAR AREA, AFTER CORRECTION FOR OXIDATION.

	Alk 33A	Alk 110A	Alk 116A	Alk 109A	Alk 54	Alk 139A	Alk 27A	Alk 64A	Alk 112A	Alk 113A
SiO_2	48.48	49.27	49.63	47.78	47.74	49.21	52.69	54.31	54.28	55.04
TiO_2	0.64	1.23	1.08	0.93	3.38	1.41	1.87	1.21	1.37	1.20
Al_2O_3	15.64	14.94	12.89	13.88	15.14	14.32	13.67	13.78	12.18	14.67
Fe_2O_3	2.21	13.47	2.66	2.58	4.97	2.99	3.45	2.71	2.99	2.80
FeO	9.97	0.00	10.33	8.60	10.76	11.06	11.39	10.03	10.62	9.88
MnO	0.19	0.02	0.18	0.14	0.18	0.31	0.31	0.14	0.20	0.18
MgO	11.06	7.28	8.43	9.24	5.35	8.18	4.94	4.19	5.42	4.62
CaO	10.49	8.20	11.23	12.31	6.95	7.64	7.46	7.78	10.39	8.43
Na_2O	1.26	3.65	2.83	1.02	3.90	3.09	3.06	3.99	1.68	2.27
K_2O	0.05	1.79	0.62	2.77	1.30	1.65	0.95	1.66	0.71	0.78
P_2O_5	0.01	0.16	0.13	0.14	0.33	0.15	0.22	0.19	0.16	0.14
Total	100.00	100.00	100.00	100.00	99.99	100.00	99.99	99.99	100.00	100.00

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MAJOR AND TRACE ELEMENT VARIATIONS IN THE LAVAS OF SHERGARH SAR AREA AND THEIR SIGNIFICANCE WITH RESPECT TO THE KOHISTAN TECTONIC ANOMALY

M. TAHIR SHAH[1] & M. MAJID[2]
[1]National Centre of Excellence in Geology, University of Peshawar
[2]Department of Geology, University of Peshawar

ABSTRACT

A belt of dark-green volcanics along with serpentinite, peridotite, pyroxenite and greenschist marks the spatial disposition of the Indus suture zone in Allai Kohistan of Hazara division. Major and trace element analyses of selected lava samples are used to investigate geochemical variations in the Shergarh Sar Pashtu village section of the volcanic belt.

The lavas are mostly glassy but occasionally show phenocrysts of plagioclase, clinopyroxene and, very rarely, brown hornblende. On the basis of normative mineralogy, two compositional groups, e.g. olivine tholeiite and quartz tholeiite, are identified. Fractionation control of the observed phenocrysts over the major and trace element distribution in the lavas is established through the solutions of chemical data in the C.M.A.S. model and conventional two-dimensional plots.

The major and trace element constraints of the studied lavas are corresponding more closely to tholeiites developed in the island arc type environments and substantiate, through a chemical comparison, the assumed prevalence of such structure(s) in the Tethys ocean before the the complete closure as proposed in the tectonic models of the Himalayan development.

INTRODUCTION

Rocks of the Shergarh Sar area (34°50′ 15″N – 34°54′ 15″N and 73°1′E – 73°5′E, Sheet No. 43F/1), in Allai Kohistan of Hazara division have been distinguished into three tectono-stratigraphic groups. From south to north in the type Bana-Baracher section of the studied area occur (1) rocks of the Indo-Pakistan subcontinent sequence, (2) rocks of the Indus suture melange, and (3) amphibolites of the Kohistan island arc (Fig. 1).

C.I.P.W. NORMS

Q	—	—	—	—	—	—	4.66	1.35	10.82	10.72
Or	0.31	10.56	3.69	16.34	7.68	9.76	5.61	10.27	4.19	4.61
Ab	10.65	30.85	23.89	13.76	33.00	26.17	25.88	35.34	14.17	19.18
An	36.95	19.20	20.72	22.49	20.03	20.39	20.84	15.56	23.68	27.62
Di	12.20	12.60	27.97	30.55	10.12	13.58	12.27	9.01	22.29	11.10
Hy	30.41	4.50	3.87	—	4.04	3.66	21.72	21.53	17.56	20.15
Ol	5.05	5.46	13.69	14.93	10.77	19.12	—	—	—	—
Mt	3.21	—	3.86	3.74	7.20	4.33	5.00	4.11	4.33	4.06
Hm	—	13.43	—	—	—	—	—	—	—	—
Il	1.22	0.04	2.05	1.77	6.42	2.68	3.55	2.41	2.61	2.27
Ap	0.02	0.36	0.28	0.31	0.72	0.32	0.48	0.43	0.35	0.30
100 MgO/MgO+FeO	66.50	51.72	59.21	65.80	46.90	56.90	43.57	42.56	47.68	45.41
FeO_T/MgO	1.08	1.66	1.50	1.18	2.84	1.68	2.93	2.97	2.46	2.68
An content of Plag. (normative)	77.62	38.36	46.44	62.04	37.77	43.80	44.61	30.56	62.56	49.75
Oxidation state.	0.22	—	0.25	0.30	0.46	0.27	0.30	0.27	0.28	0.28
Col. Index	52.07	36.03	51.44	50.99	38.55	43.37	42.54	37.06	46.79	37.58

Table 2. Continued

	Alk 57	Alk 57A	Alk 49B	Alk 49A	Alk 49	Alk 60	Alk 68A	Alk 106A	Average
SiO_2	53.40	53.10	52.24	54.88	52.20	52.94	52.01	55.85	52.06
TiO_2	1.89	0.90	1.59	0.98	1.93	1.34	1.08	1.35	1.41
Al_2O_3	16.08	14.91	16.19	16.62	14.92	16.93	15.51	14.76	14.83
Fe_2O_3	2.86	2.50	3.66	4.19	4.28	1.75	2.66	2.22	3.61
FeO	8.21	8.40	9.23	8.13	9.02	0.77	10.68	5.33	8.80
MnO	0.24	0.22	0.21	0.21	0.20	6.22	0.21	0.20	0.20
MgO	3.10	3.06	5.64	4.82	5.89	0.22	4.74	5.32	5.86
CaO	12.43	15.63	10.23	9.39	10.61	3.50	10.26	13.10	10.17
Na_2O	1.29	0.95	0.74	0.26	0.27	13.14	2.20	1.50	2.09
K_2O	0.03	0.00	0.05	0.24	0.00	3.05	0.34	0.31	0.74
P_2O_5	0.47	0.32	0.27	0.27	0.25	0.03	0.22	0.35	0.23
Total	99.99	100.00	100.00	100.00	100.00	100.00	100.00	99.99	99.99

C.I.P.W. NORMS

Q	15.71	13.24	14.67	21.51	18.18	5.08	6.13	11.45	7.41
Or	0.19	0.00	0.32	1.42	—	0.19	1.98	1.82	4.38
Ab	10.90	8.01	6.24	2.22	2.27	25.77	18.65	12.88	17.77
An	38.08	36.50	40.65	43.56	39.59	32.51	31.52	32.34	29.01
Di	17.11	32.76	6.85	1.01	7.76	25.24	15.01	24.56	16.22
Ol	—	—	—	—	—	—	—	—	13.26
Hy	9.22	3.42	22.34	21.74	21.12	5.37	20.33	7.76	3.80
Mt	4.14	3.62	5.31	6.07	6.20	2.54	3.85	3.22	4.16
Hm	—	—	—	—	—	—	—	—	0.74
Il	3.6	1.72	3.03	1.87	3.66	2.54	2.05	2.19	2.54
Ap	1.02	0.70	0.59	0.60	1.19	0.74	0.48	0.76	0.54
100 Mgo/Mgo+FeO	40.42	39.39	52.05	51.29	53.87	48.22	44.15	63.90	51.08
FeO_T/MgO	3.47	3.48	2.22	2.46	2.18	2.38	2.76	1.37	2.06
An content of plag. (normative)	77.74	82.01	86.69	95.28	94.59	55.78	62.83	71.5	62.21
Oxidation state.	0.34	0.29	0.40	0.51	0.47	0.26	0.25	0.42	0.33
Col. Index	34.07	41.52	37.53	30.69	38.74	35.69	41.24	37.73	40.75

TABLE 3. COMPARISON OF MAJOR ELEMENT DATA OF LAVAS FROM SHERGARH SAR AREA WITH SIMILAR ROCK COMPOSITIONS FROM ELSEWHERE IN THE WORLD.

Column	1	2	3	4	5	6	7
SiO_2	52.06	51.30	50.83	51.57	50.59	49.90	51.42
TiO_2	1.41	0.96	3.44	0.80	1.05	1.51	1.62
Al_2O_3	14.83	14.80	12.67	15.91	16.29	17.20	15.82
Fe_2O_3	3.61	—	3.10	2.74	3.66	2.00	—
FeO	8.80	10.5*	11.39	7.04	5.08	6.90	9.59*
MnO	0.20	—	0.25	0.17	0.17	0.17	0.16
MgO	5.86	6.70	4.19	6.73	8.96	7.20	5.43
CaO	10.17	10.80	8.18	11.74	9.50	11.80	10.53
Na_2O	2.09	2.70	3.24	2.41	2.89	2.70	4.49
K_2O	0.74	0.18	0.87	0.44	1.07	0.16	0.92
P_2O_5	0.23	0.12	0.75	0.11	0.21	0.01	0.00
FeO_T/MgO	2.06	1.56	3.38	1.41	0.93	1.20	1.76

* Total iron expressed as FeO.

1. Average Pillow lavas from the studied area.
2. Average tholeiitic basalt (Hallberg and William, 1972).
3. Tholeiitic lavas, Thingmuli, Iceland (Carmichael, 1964b, P. 439, No. 10).
4. Average Island arc tholeiitic basalt (Hallberg and William, 1972).
5. Average Island arc Calc-alkaline basalt (Hallberg and William, 1972).
6. Average oceanic tholeiite (Engel *et al.*, 1965).
7. Average pillow lavas of ophiolite from northeastern Iran (Lensch, 1980).

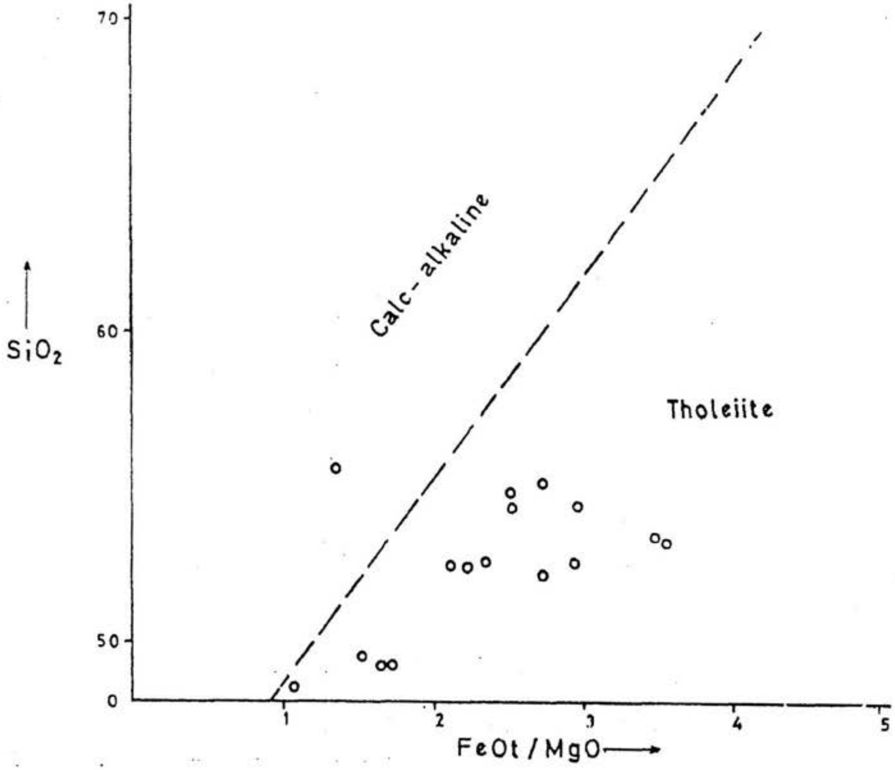

Fig. 2. SiO_2 vs FeOt/MgO plot for the lavas of Shergarh Sar area. The straight line separates tholeiitic rocks from calc-alkaline rocks (after Miyashiro, 1974).

content in some samples, the data points in Fig. 5 exhibit a gradual spread from tholeiite towards high-Al basalt field. Four analyses even plot in the field of mildly alkaline series.

MgO has been plotted against Fe_2O_3 + FeO for these lavas in Fig. 6. Lines of equal Fe/Mg ratios radiating from the origin are also shown. It can be seen that the glassy lavas closely conform to the linear trend, which is identical to similar trends formed on this diagram by many other volcanic series (Brown and Schairer, 1967; Yoder, 1969; Carmichael, 1964). The Fe/Mg ratio varies but there is a restricted range of values of total iron and magnesium at a given Fe/Mg ratio. Samples which plot off the linear trend exhibit the effect of mineral(s) accumulation on the whole rock chemistry as suggested by Wood (1978). The consideration of the whole rock analysis in such cases is, in fact, crystalliquid + liquid composition rather than assuming that they represent liquid compositions.

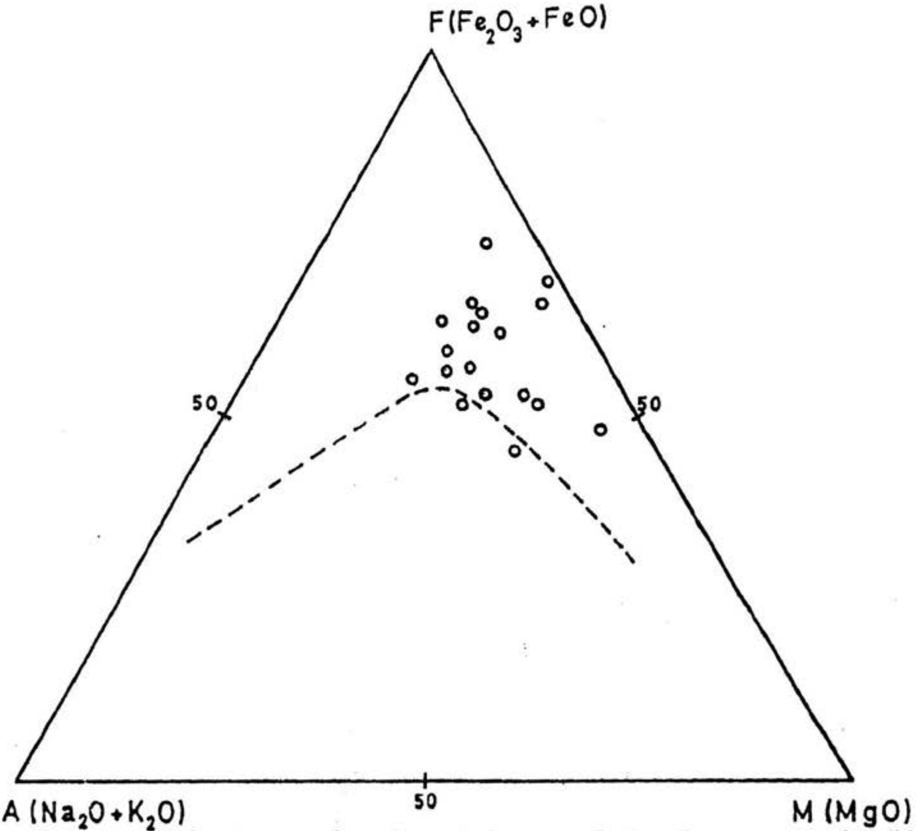

Fig. 3. AFM plot for the lavas from Shergarh Sar area. Dashed line separates tholeiitic rocks (above) from calc-alkaline rocks (below). (After Irvine and Baragar, 1974).

Trace Elements and fractionation scheme

Trace elements data of the selected samples is presented in Table 4. The behaviour of these trace elements is discussed individually or in groups possessing similar chemical properties and showing similar variation.

Chromium and Nickel. The strong partitioning of these elements into olivine and clinopyroxene enables their joint/individual behaviour in qualitatively examining the relative significance of these phases in a fractionating system. The higher Cr/Ni ratio of clinopyroxene (augite) relative to olivine is well established (Wood, 1978). Cr decreases more rapidly (345 to 56 PPM) than Ni (100 to 30 PPM) within the observed range of S.I .(see Fig. 7) indicating the predominance of clinopyroxene over olivine in the fractionating assemblages as suggested by the solutions in the C.M.A.S. model.

Strontium. Sr substitutes for Ca in plagioclase. Smooth variation of Sr (ignoring sample No. Alk 49A and 109A) with some positive correlation in Fig. 7 signifies the control of the anorthite content of the fractionating plagioclase over the Sr distribution throughout the crystallization interval.

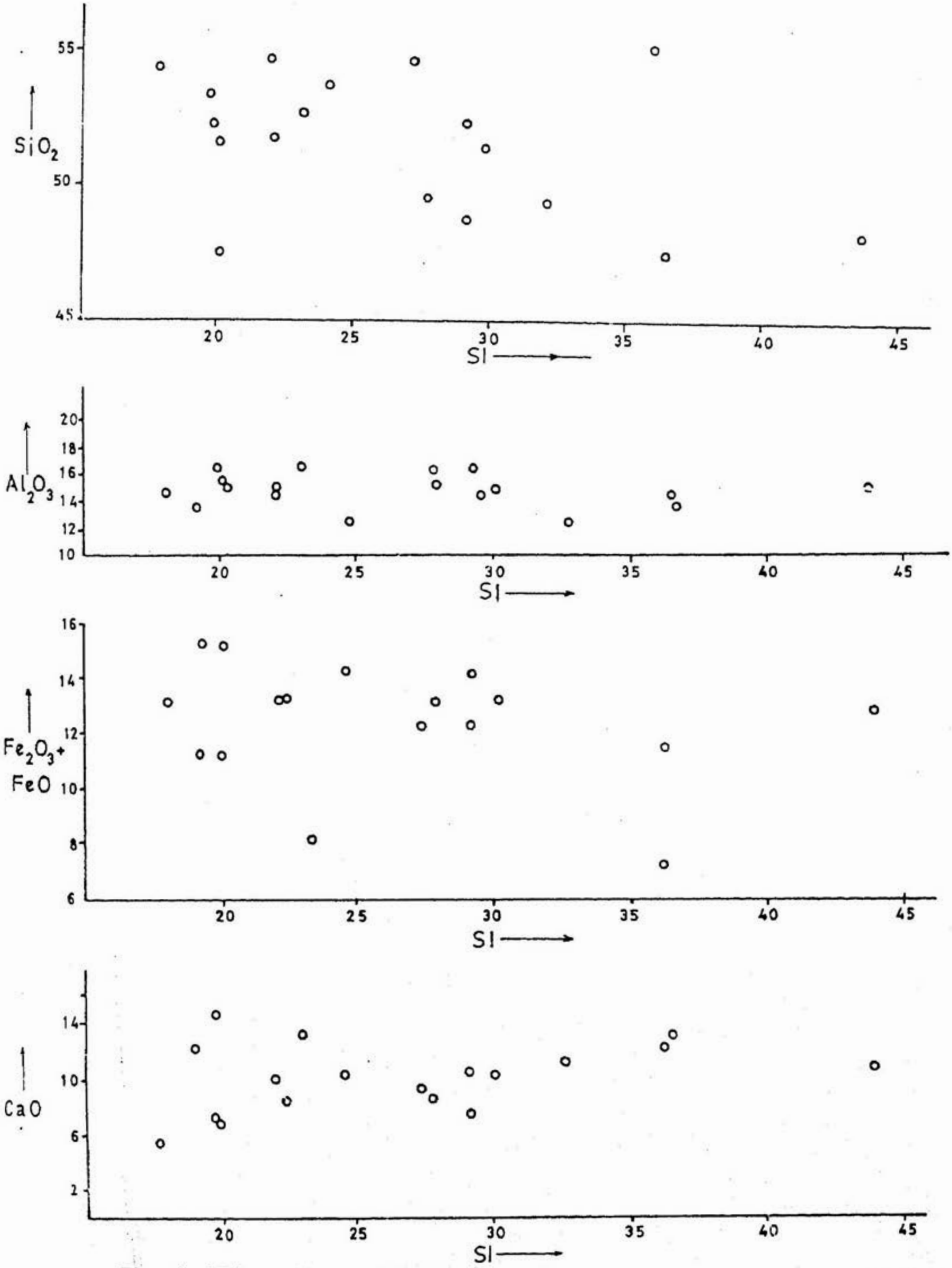

Fig. 4. Major oxides vs. S.I. plot for the lavas from Shergarh Sar area.

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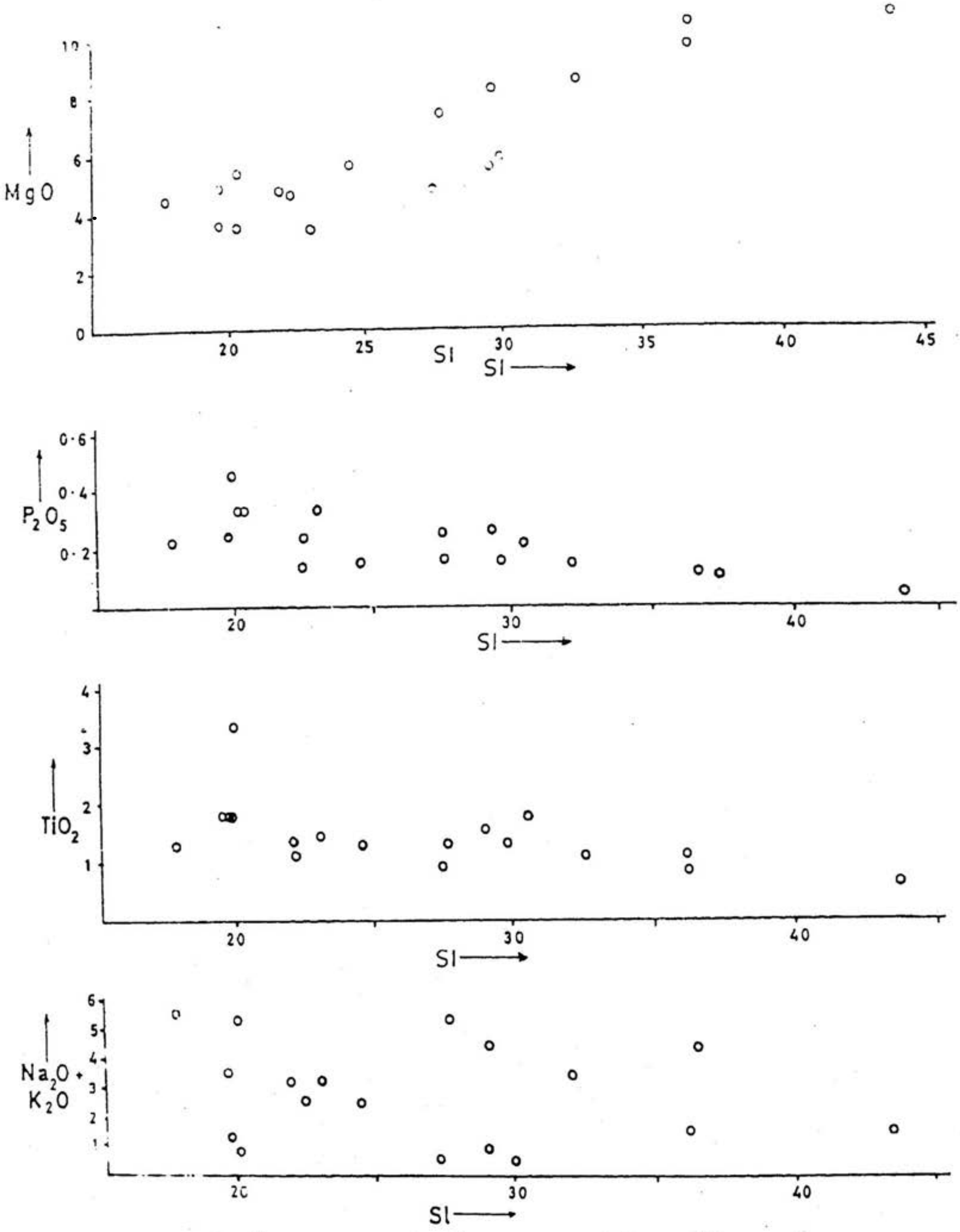
(............Fig. 4. continued)



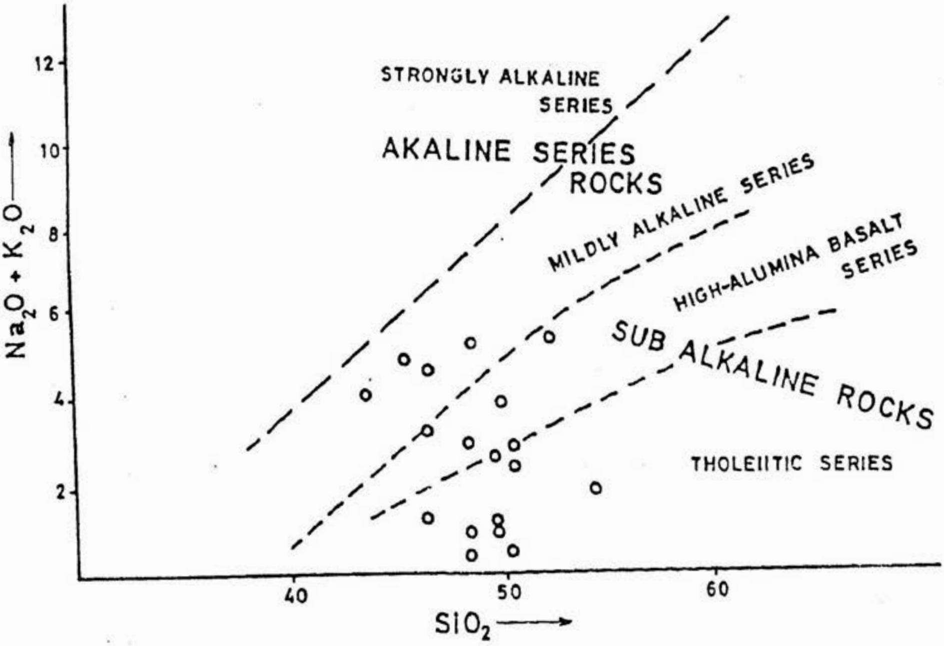


Fig. 5. Alkali vs SiO_2 diagram for the lavas from Shergarh Sar area. Boundary lines for various series are after Schwarzer and Rogers (1974).

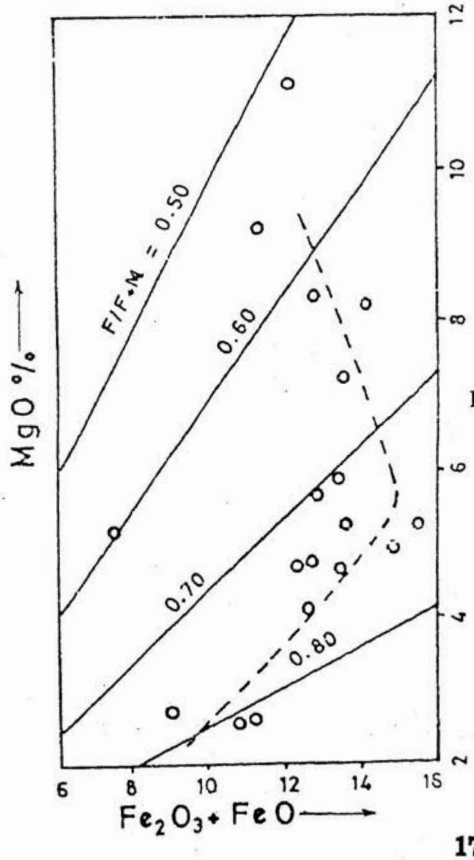


Fig. 6. Plot of MgO vs $Fe_2O_3 + FeO$ for lavas from Shergarh Sar area. Lines of equal iron magnesium ratios are also drawn.

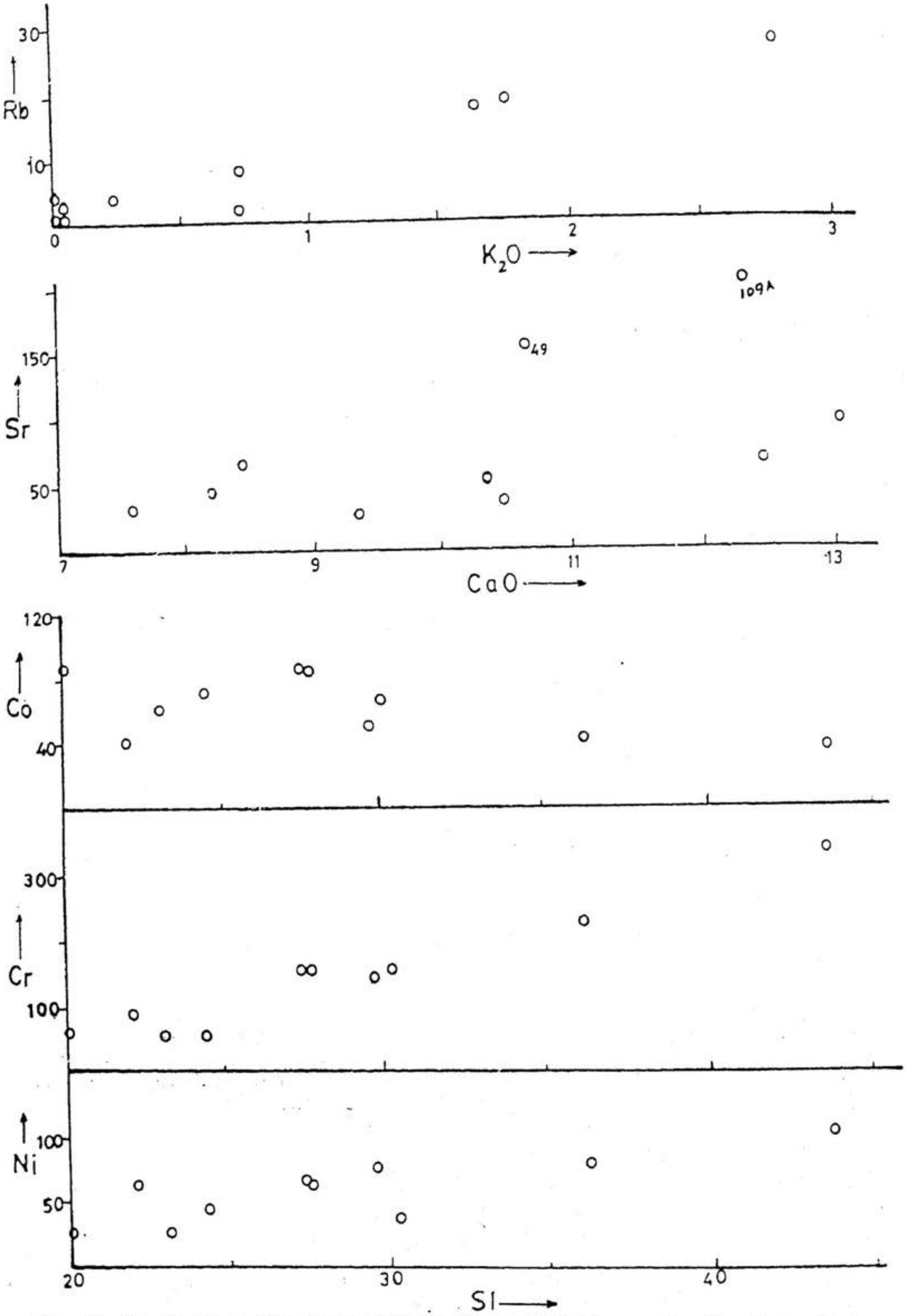


Fig. 7. Co, Cr, Ni vs. S.I., Sr vs. CaO and Rb vs. K_2O diagram for the lavas from Shergarh Sar area.

Rubidium. The extremely large ionic radius of this element results in its exclusion from almost all the fractionating phases in the early stages of crystallization. It incorporates in the K-bearing minerals and an ordered distribution behaviour to K_2O during crystallization (Fig. 7) indicates the control of K-bearing mineral(s) in the fractionating assemblage.

Nature of minerals identified within the fractionating assemblages on the basis of the study of trace element behaviour is further confirmed through assessment of the compositional plots of the lavas in the projections from Quartz into En-Ky-Wol and from Quartz into Ky-Diop-Ol plane of the C.M.A.S. model (Cox *et al.,* 1979).

Two fractionation trends are observed in the projection from Quartz into the En-Ky-Wol plane (Fig. 8). One trend is parallel to the Cpx-Ky join with an affinity towards plagioclase while the other is parllel to Hb–Ky join with an affinity towards biotite. This suggests that the former is controlled by the clinopyroxene and plagioclase fractionation while the latter trend corresponds to the fractional control of hornblende and biotite or of clinopyroxene, biotite and/or hornblende and plagioclase.

Distribution of the data points in the projection from Quartz into the Ky-Diop-Ol plane (Fig. 9), however, signifies the predominance of plagioclase over the clinopyroxene and/or hornblende in the fractionating assemblages. Samples showing affinity towards biotite in the previous projection (Fig. 8) also plot closer to the biotite position in the Fig. 9 and further stress the role of biotite in the fractionating scheme.

DISCUSSION

The major and trace element constraints of the studied lavas are employed in the problem of identifying their primary/derivative character and more usefully elucidated as tectonic fingerprints in revealing the type of environment at the time of their generation. Green (1976) and Frey *et al.* (1978) suggested a few general criteria to check whether basalts occurring in an area represent primary melts from the upper mantle or liquids modified by fractionation (derivative liquids). These are (a) the presence of the spinel lherzolite xenoliths (b) Mg-values, and (c) compatible trace element concentrations. Occurrnce of spinel lherzolite xenoliths in basalts suggests that magma has ascended from depths $\geqslant$ 30 km without crystal fractionation. The absence of such xenoliths in lavas from the studied suite make their primary status doubtful at first instance.

Mg-value (100 $Mg/(Mg+Fe^{+2})$) within the range of 88–89 are suggested for the least refractory upper mantle peridotite parent for the generation of basaltic liquids (Frey *et al.,* 1978). Magma of basaltic composition derived from such a source peridotite must have Mg-values of 68–75 for upto about 30 per cent melting (using $K_{D(Ol/Liq)}^{Fe/Mg} = 0.3$, Roeder and Emslie, 1970). Applying this criterion to the compositions in Table 2, it is clear that Mg-values are varying between 39–67 and all the analyses are regarded as fractionated liquids, as also suggested by the absence of spinel lherzolite.

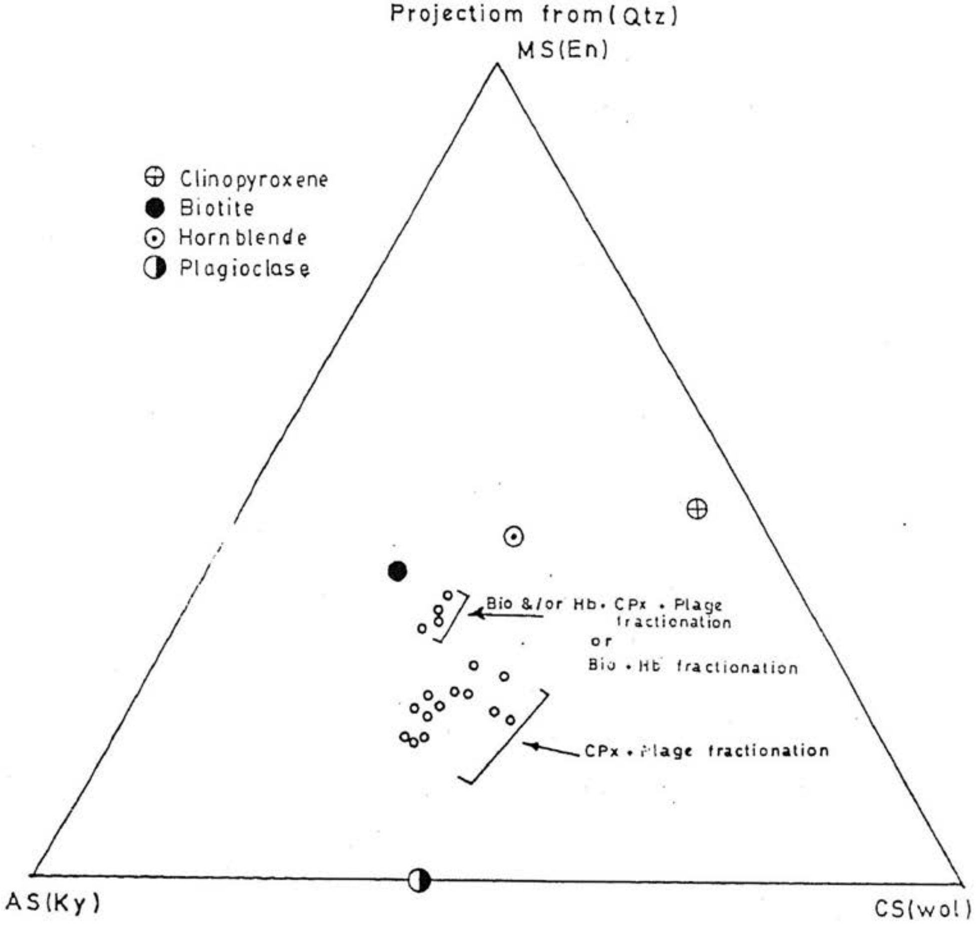


Fig. 8. Plot of analyses of lavas from the Shergarh Sar area in a projection from Quartz into En-Ky-Wol plane of the C.M.A.S. model.

The concentrations of Ni and Cr within the analysed samples are well below the reported range of these elements in basalts derivative from mantle peridotite (Ni 250–300 PPM and Cr 500–600 PPM, Green, 1976). Frey *et al.* (1978) in their partial melting model of lherzolite reported a Co range of 27–80 PPM in the primary basalts. The Co abundances in Table 4 lie within this range. However, it is not appropriate to assume on the basis of only Co abundances that these lavas are primary partial melts from the upper mantle peridotite while the remaining petrochemical indices strongly oppose such a relationship.

Close correspondence between the average analysis of tholeiite from the studied area and tholeiite from the island arc type environments is further dis-

TABLE 4. TRACE ELEMENT DATA FOR THE LAVAS FROM SHERGARH SAR AREA (IN PPM).

	Alk33A	Alk110A	Alk109A	Alk139A	Alk112A	Alk113A	Alk57	Alk49	Alk49A	Alk60
Ni	101	63	76	79	46	67	27	37	65	27
Cr	345	155	230	145	67	93	62	158	110	58
Sr	36	46	207	30	54	63	65	157	28	96
Rb	—	19	27	18	2	8	—	4	4	3
Y	15	20	21	20	19	17	16	15	17	14
Ba	88	130	108	213	160	45	189	88	72	72
V	212	250	168	398	310	327	168	142	357	100
Cu	281	—	5	154	—	—	—	24	—	169
Co	39	85	41	54	72	45	86	69	86	65
Zn	41	114	121	58	118	43	194	151	—	31
Zr	39	1	1	43	31	38	35	29	48	13

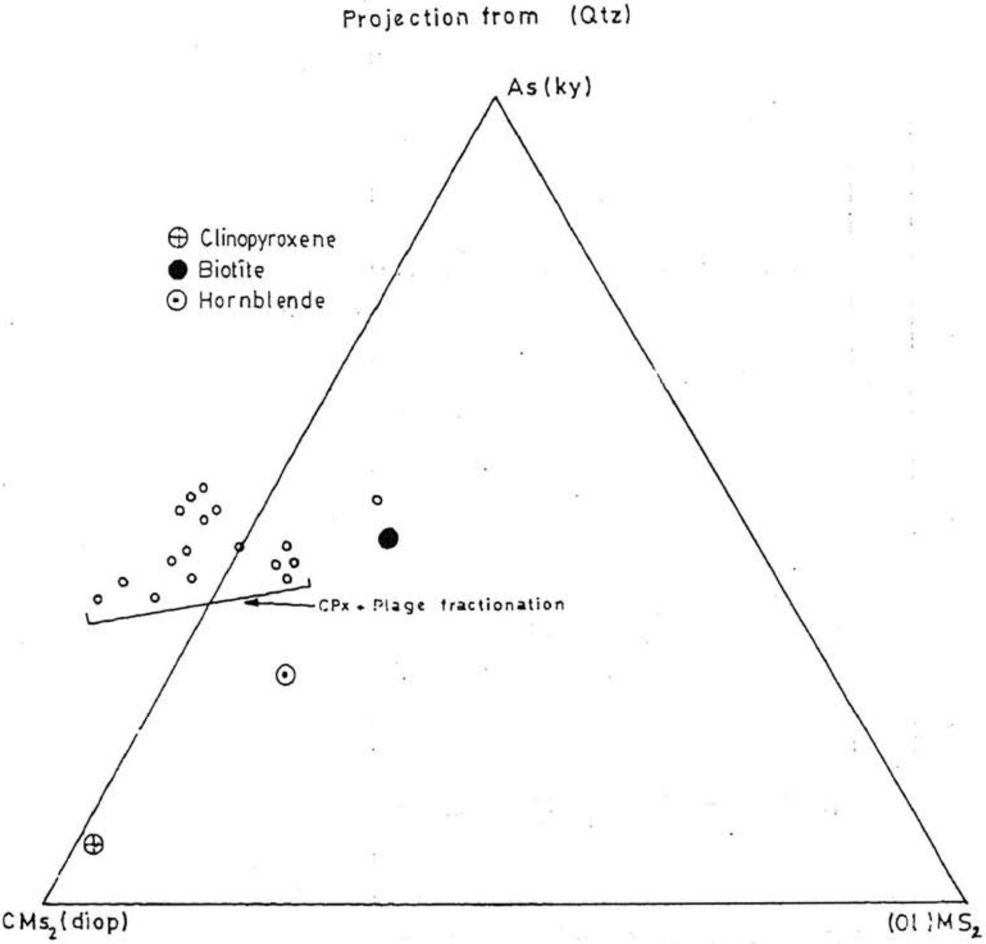


Fig. 9. Plot of analyses of lavas from the Shergarh Sar area in a projection from Quartz into Ky-Diop-Ol plane of the C.M.A.S. model.

played graphically with the help of selected discriminative type two-dimensional and triangular plots in Fig. 10 to 12 (after Pearce, 1975; and Mullen, 1983). Concentration of the composition points of lavas from the Shergarh Sar area within the areas outlined for island arc tholeiites favours their production in an island arc type environment.

Prevalence of the island arc structure(s) in the Tethys ocean before the collision between the Indo-Pakistan and Asian Plates (Cretaceous) is already interpreted fully in accordance with the proposed plate tectonic models of NW Himalaya (Tahirkheli, *et al.,* 1979; Klootwijk *et al.,* 1979; Majid and Paracha, 1980; Jan, 1980; Majid, *et al.,* 1981; Jan and Asif, 1983; Virdi, 1981; Andrews-

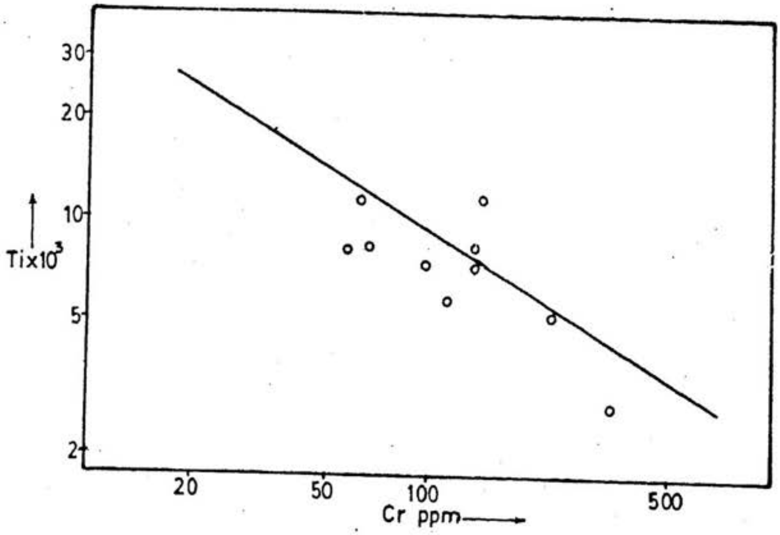


Fig. 10. Ti vs Cr plot for the lavas from Shergarh Sar area, the line discriminating between the island arc tholeiite (below) and ocean-floor basalt (above) is after Pearce (1975).

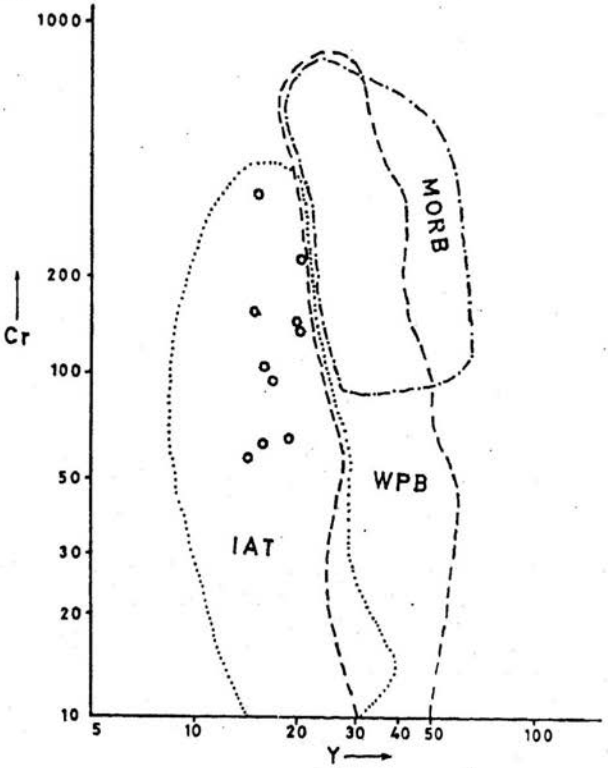


Fig. 11. Cr vs Y plot for the lavas from Shergarh Sar area. Fields of mid-ocean ridge basalt (MORB), island arc tholeiite (IAT) and within plate basalt (WPB) are after Pearce (1979).

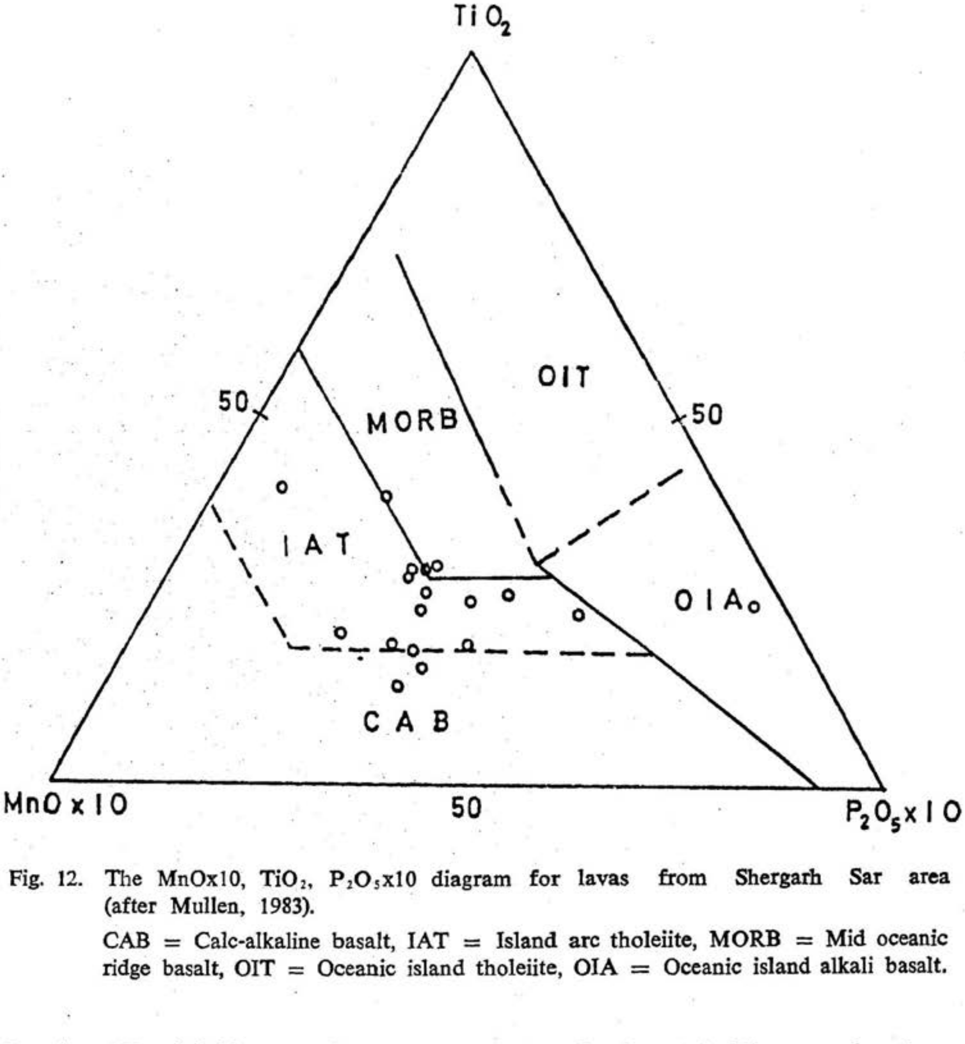


Fig. 12. The MnOx10, TiO_2, P_2O_5x10 diagram for lavas from Shergarh Sar area (after Mullen, 1983).
CAB = Calc-alkaline basalt, IAT = Island arc tholeiite, MORB = Mid oceanic ridge basalt, OIT = Oceanic island tholeiite, OIA = Oceanic island alkali basalt.

Speed and Brookfield, 1982, Coward *et al.,* 1982; Bard, 1983). The petrochemistry of lavas from the studied suit provides a chemical support for such a supposition.

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