Geol. Bull. Univ. Peshawar, 1990, Vol. 23, pp. 135-159

PETROLOGY OF THE SHEWA-SHABAZGARHI COMPLEX, MARDAN, NORTH PAKISTAN

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ABSTRACT

The Shewa-Shabazgarhi complex is an isolated triangular outcrop, occurring about 12 km northeast of Mardan. The complex resides 60 km south of Main Mantle Thrust as part of the Indo-Pak plate and consists of basic and acidic rocks including microporphyry, metagabbro, metadolerite and local quartz monzonite, riebeckite gneiss, aegirine riebeckite porphyry and porphyritic microgranite, together with basic and acidic dykes and sills.

The common minerals in basic rocks include hornblende, clinopyroxene, magnetite, biotite, epidote and apatite. The acidic rocks contain orthoclase, perthite and palgioclase together with riebeckite and aegirine, indicating alkaline characters. The mineralogy reflects amphibolite facies metamorphism followed by retrogression down to at least the upper greenschist facies environment in basic as well as in acidic rocks. Following metamorphism a considerable degree of deformation (cataclasis and/or mylonisation) is indicated in the acidic rocks.

Assessment of the chemical data suggests two different parent magmas; a rift-related tholeiitic type for the basic rocks and an alkaline to peralkaline type for the acidic rocks; both being emplaced in continental environments. The chemistry also suggests the control of fractional crystallization on the initial distribution of elements among the minerals of the two groups. A plagioclase-magnetite-clinopyroxene dominant assemblage on the liquidus in basic rocks and a plagioclase-hornblende dominant assemblage on the liquidus in acidic rocks, during fractionation, are suggested. A rift valley origin proposed by previous workers is supported.

INTRODUCTION

The Shewa-Shabazgarhi complex is an isolated triangular outcrop (Fig. 1) consisting of basic and acidic meta-igneous rocks occurring ~60 km south of MMT (Main Mantle Thrust) in the Indo-Pak plate and emplaced into a metasedimentary sequence known as the Sawabi-Chamla group of possible Precambrian age. The complex is located about 12 km northeast of Mardan (longitude 72° 10'- 72° 20' E, latitude 37° 10' to 34° 30' N) and has been frequently investigated by workers since Coulson (1936) who described the petrography and chemistry of some of the rocks for the first time. He described these rocks as porphyries of Mesozoic age and correlated these with the soda granite at Warsak. Martin et al. (1962) called these rocks as albite porphyries and pointed out cataclasization in certain types. Several other workers (Siddiqui, 1965; Chaudhry & Shakoor, 1968; Kempe & Jan, 1970; 1980; Kempe, 1973; 1983; Ahmed & Ahmed, 1974; Chaudhry et al., 1976; Bakhtiar & Waleed, 1980) have investigated these rocks and correlated with various complexes of the Peshawar alkaline igneous province, in particular with Koga alkaline complex (cf. Fig. 1). These workers have assigned a probable Early Tertiary to Late Cretaceous age to the rocks of the Shewa-Shabazgarhi complex.

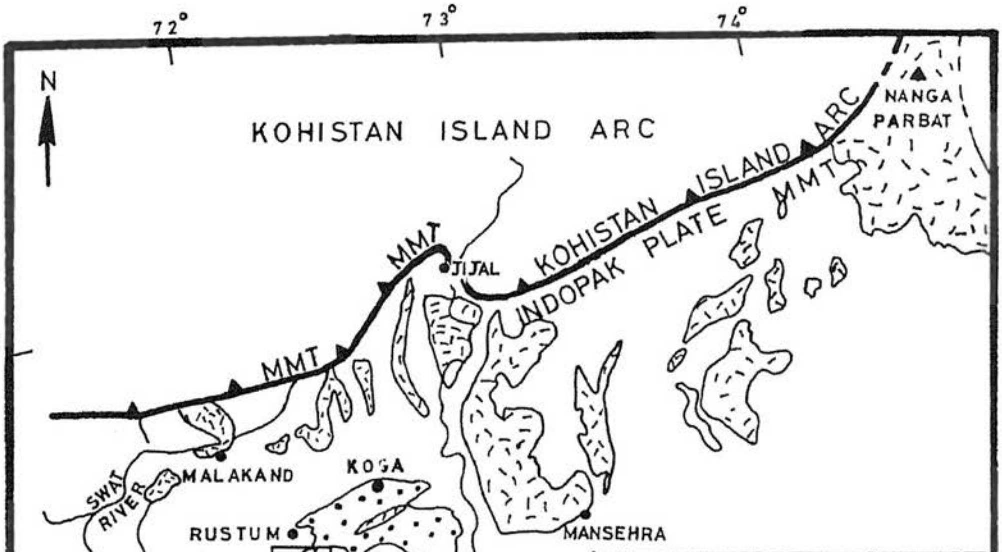


Fig.1. Generalized geological map, showing the major granitic rocks in North Pakistan. The Shewa-Shabazgarhi complex together with the other alkaline complexes around Peshawar plain are also shown (after Butt, 1983).

The different rock types described by previous workers and also under present investigation are: (a) metagabbro, metadolerite [associated with local quartz monzonite] and basic dykes comprising the basic suite, and (b) microporphyry, riebeckite gneiss, aegirine-riebeckite porphyry and the acidic dykes comprising the acidic suite. A small outcrop of basaltic breccia reported by Ahmad (1986) north-west of Asota (Fig. 2) may also be included in the basic group. The country rocks hosting the igneous lithology are the metasediments of the Sawabi-Chamla group comprising mainly of phyllitic shale, quartzite and schist (Fig. 2; see also Noor Jehan, 1985; Ahmad, 1986).

The present study was carried out to map and perform further petrographic and geochemical study of the complex in order to determine magmatic affinities and tectonic environment and elucidate the metamorphic and igneous crystallization histories of the various rock types in the Shewa-Shabazgarhi complex. Samples were prepared and analyzed for major and trace elements by wet chemical and X-Ray Fluorescence techniques, using U.S.G.S. standards, in the National Centre of Excellence in Geology, University of Peshawar. For details see Ahmad (1986).

FIELD FEATURES AND LOCAL GEOLOGICAL SETTING

The field relationship of the Shewa-Shabazgarhi complex has been described by several workers (Martin et al., 1962; Bakhtiar & Waleed, 1980; Chaudhry & Shams, 1983; Noor Jehan, 1985; Ahmad, 1986). The various rock types mentioned above (Fig. 2) have generally sharp contacts with each other.

The microporphyry is an extremely fine-grained rock varying in colour from earthy white through greyish green to slaty black. It is splintery and well jointed, with slaty appearance on the surface. Near Shewa (Shewa is just north-east of Asota; not shown in Fig. 2) it is highly sheared whereas at Machi it shows layering. At Budsari it contains both of these features.

The metagabbro is the dominant basic igneous rock (Fig. 2). It is medium-to coarse-grained in texture and yellowish green to reddish brown in colour. It is hard, compact and fresh except locally where substantial weathering and iron leaching can be observed.

The riebeckite gneiss is prominently exposed north of Shera Ghund and at Gariala Kandao-Taja sections (Fig. 2). In hand specimen it is a fine-grained rock highly sheared and foliated showing large crystals of quartz and feldspar. The aegirine-riebeckite porphyry is mainly exposed at Machi. It is a bluish rock with "porphyroclasts" of quartz and feldspar, lying parallel to the general fabric (N-S) of the rock. Aplitic veins crosscutting aegirine-riebeckite porphyry have also been noticed.

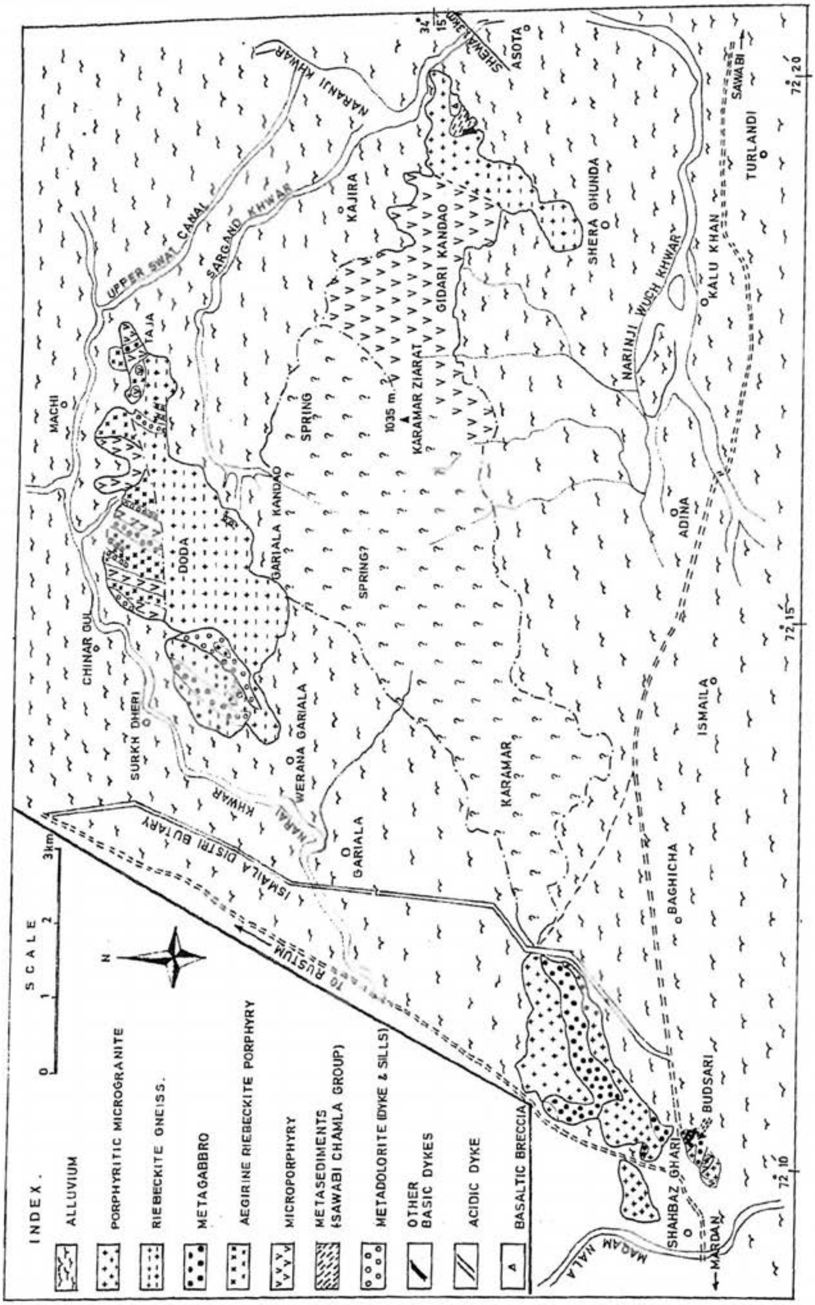


Fig.2. Geological map of the Shewa-Shabazgarhi complex, Mardan, North Pakistan.

The porphyritic microgranite occurs as the major rock unit at Shabazgarhi and Shewa and is locally present at Machi (Fig. 2). On the basis of grain size, coarse, medium and fine grained varieties, and on the basis of colour, light grey, grey and greyish green varieties, have been noticed in porphyritic microgranite. The coarse grained variety is hard, compact and light grey in colour. It contains large porphyroblasts/porphyroclasts of felsic minerals upto 3 mm in diameter. Foliation and augen structure with alternating feldspar and biotite are the characteristic features of this variety. At Gidara Kandao mural joints have caused the development of pillar type structure (Fig. 3a). This feature together with porphyritic texture and volcanic layering noticed at Budsari (Figs. 3b,c) indicates the porphyritic microgranite to be of volcanic origin. The medium and fine grained varieties generally do not show foliation and other deformation structures in hand specimen, probably due to the scarcity of large crystals.

The metadolerite dykes and sills are associated with the riebeckite gneiss and aegirine-riebeckite porphyry throughout the Machi section (Fig. 2). The metadolerite is generally a massive and soft rock having spheroidal weathering in the central parts of the large bodies. These bodies are coarser grained towards their centres and finer towards margins. Near Werana Gariala, in the vicinity of the contact with granite a large metadolerite body shows an abrupt change in lithology, probably due to differentiation or hybridization and is classified as quartz monzonite. A small fine-grained body of whitish colour and a brecciated basaltic rock of dark green colour have been found intruding the porphyritic microgranite, northwest of Asota (Fig. 2). Basic dykes intruding metagabbro and acidic dykes intruding porphyritic microgranite at Budsari have also been noticed. The basic dyke at Budsari may be corresponding to the metadolerite at Machi section (Fig. 2).

The metasediments of the Sawabi-Chamla group are represented by biotite schist at Asota and Budsari. These are fine grained, light green rocks having sharp contacts with porphyritic microgranite at both the localities.

Xenoliths of microporphyry have been noticed in porphyritic microgranite near Budsari, in aegirine-riebeckite porphyry near Machi. Metagabbro has developed chilled margins against microporphyry and the former type contains xenoliths of, and is intruded by, the porphyritic microgranite at Budsari. On the other hand at Taja, Gariala Kandao and Shera Ghund xenoliths of microporphyry and porphyritic microgranite have been noticed in aegirine-riebeckite porphyry whereas riebeckite gneiss has developed chilled margins against porphyritic microgranite (for detail see Noor Jehan, 1985; Ahmad, 1986).

On the basis of field features noticed during the present investigation and also described by the previous workers, at Shewa-Shabazgarhi complex, rock types in the descending order of age are: (1) microporphyry [Budsari], (2) metagabbro/metadolerite [& the basic dykes ?], (3) porphyritic microgranite, (4) riebeckite gneiss, (5) aegirine-riebeckite porphyry [& microporphyry at Machi] and (6) the acidic dykes.

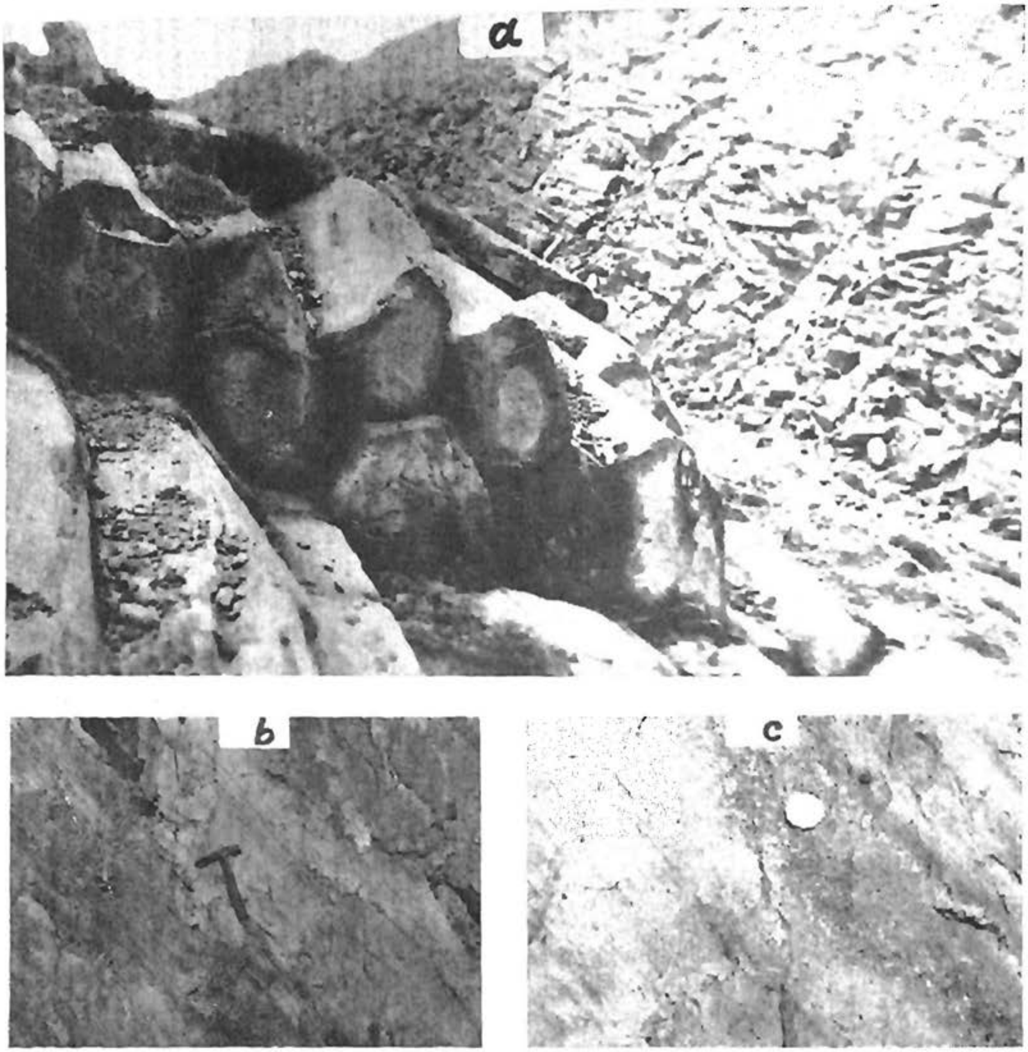


Fig. 3(a). "Pillar type" structure or mural joints in the porphyritic microgranite at Gidari Kandao.

(b-c). Cataclasized and mylonized zone in the porphyritic microgranite at Budsari.

PETROGRAPHY

The petrography of various rocks of the Shewa-Shabazgarhi complex has been described by Bakhtiar & Waleed (1980) and Chaudhry & Shams, (1983). More petrographic studies performed during the present investigation are briefly described here.

Microporphyry

The microporphyry is a very fine-grained rock with orthocalse, plagioclase, perthite, quartz, biotite, magnetite and epidote as the major constituents while amphibole, sphene and muscovite occur as accessories.

Alkaline feldspar (perthite and orthoclase) make up to 84% of the rock. These minerals occur as microporphyroclasts, stretched and elongated along the foliation planes, generally parallel to the primary layering (cf. Fig. 4a). The microporphyroclasts are generally corroded at margins and their sizes vary from layer to layer. Biotite (2-8%) occurs as small grains and thin flakes in the interstices between the quartz and feldspar grains. It has partially altered to epidote. Magnetite altered to limonite has also been noticed. Fine needles of riebeckite apparently developed at the expense of greenish brown amphibole have also been found. The other characteristic features of the microporphyry are the myrmekitic texture of feldspar incorporating quartz and muscovite, abrupt variation in grain size (Fig. 4a), and the development of fluxion structure around the microporphyroclasts of feldspar (Fig. 4b) indicating cataclasis. At Budsari in certain sections, the microporphyry incorporates metasediments containing <5-90% graphite, occurring as spindle shape material, deformed thin layers and as fine grains and dust.

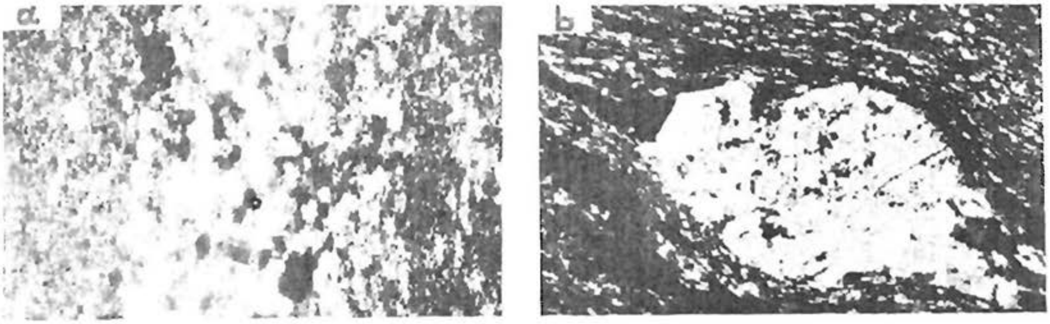


Fig.4(a-b). Photomicrograph showing (a) abrupt change in grain size of the groundmass and (b) fluxion structure superimposed on volcanic flow texture, in microporphyry, at Budsari and Gariala Kandao, respectively. Mag. x 22; cross nicols.

Metagabbro

The dominant constituents of metagabbro are amphibole, plagioclase, magnetite, biotite, epidote, orthoclase, whereas quartz, sphene apatite and chlorite occur as minor constituents. Nearly all the major constituents are subhedral to anhedral and their average grain size varies between 1 and 2 mm. The texture is generally inequigranular to subophitic.

Amphibole occurs as large and small irregular, corroded and fractured crystals of ferro-hornblende composition (Hamidullah & Ahmad in prep.), having inclusions of biotite and magnetite. It is associated with plagioclase and magnetite and seems to have been developed at the expense of these minerals and probably a pre-existing magnesium-rich mineral (olivine or pyroxene). Plagioclase (20-45%) is of oligoclase composition and where fresh, it occurs as twinned prismatic and subhedral to euhedral crystals. Most of plagioclase is however, cloudy and epidotized. Some grains are fractured and biotite, amphibole and apatite have developed along these fractures. Magnetite occurs as small rounded and large irregular grains generally surrounded by amphibole, biotite, epidote and in some cases by coronas of sphene and leucoxene. Biotite and epidote occur together normally along the margins and cleavages of amphibole, indicating the development of the former two minerals at the expense of the latter one. Biotite is pleochroic from pale green to dark brown and is occasionally replaced by chlorite. Orthoclase and quartz (10-15%) occur in the interstices of, and as inclusions in, the hornblende crystals. Apatite (~2-3%) is associated with hornblende and magnetite and in certain cases the former occurs as inclusions in the latter ones.

Riebeckite gneiss

The major constituents of the riebeckite gneiss are perthitized orthoclase, plagioclase, quartz, riebeckite, biotite, epidote and opaque ore. Sphene, zircon, apatite and sericite are found as accessories. Sillimanite needles have been noticed in a few sections.

Evidence of intensive cataclasization have been noticed in feldspars occurring as porphyroclasts, and in their surrounding groundmass. The porphyroclasts are deformed and rotated and in certain cases show a high degree of alteration. The groundmass shows abrupt changes in grain size and in certain cases it becomes very fine, glassy, highly laminated and foliated, particularly around the porphyroclasts indicating fluxion structure (see Figs. 5a,b).

Riebeckite, biotite and epidote occur in close association with each other. The former two minerals are found as thin elongated tabular grains while epidote occurs as aggregates of small rounded grains. Riebeckite is pleochroic from light green to deep blue. The textural relation of riebeckite with biotite, K-feldspar and magnetite is such that riebeckite appears to have developed at the expense of the other three minerals. Magnetite itself occurs as irregular grains associated with biotite. Sillimanite occurs as thin prismatic needles and appears to be a development after feldspars.

Aegirine-riebeckite porphyry

The aegirine-riebeckite porphyry is mineralogically similar to riebeckite gneiss except for the finer grain size and the presence of aegirine in the former type. Feldspars, riebeckite, quartz, opaque ore and aegirine occur as porphyroclasts (10-70%) as well as in the fine grained groundmass. The grain size of the porphyroclasts ranges from 1 to 3 mm (in diameter). Riebeckite occurs as light brown to deep blue fine needles, crystallites and globules along the planes of weaknesses and its development can be attributed to Na-metasomatism along these planes. Biotite is light brown to reddish brown and indicates its growth after magnetite and feldspar. Aegirine is pleochroic from light to dark green. It occurs as subhedral to anhedral broken grains and shows alteration to epidote.

Metadolerite and other basic dykes

Except for the presence of some clinopyroxene, the metadolerite and other basic dykes (i.e. at Budsari etc.) closely correspond to metagabbro on the basis of petrographic features. In the quartz monzonitic portions of metadolerite near Werana Gariala (Fig. 2), the dominant mineral constituents are perthite, quartz, biotite, epidote and opaque ores. Sphene and apatite occur as accessories. The texture of such rocks is inequigranular hypidiomorphic. In one of the quartz monzonite sections an aggregate of probable relic dark minerals showing reaction relation with felsic material is noticed, indicating hybridization of the basic rock (metadolorite) by the acidic magma.

Porphyritic microgranite

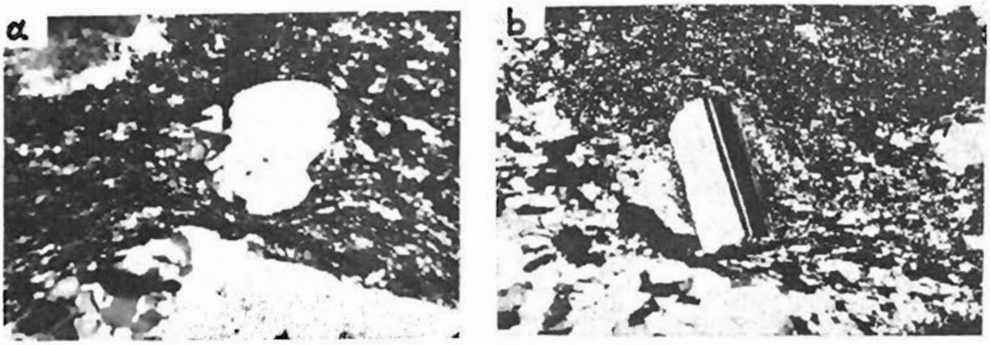
The important mineral constituents of the porphyritic microgranite (Fig. 6a-b) are orthocalse, perthite, plagioclase, microcline, biotite, epidote, opaque ores and amphibole. Apatite, sphene and muscovite occur as minor constituents. In thin section, the porphyritic microgranite shows a well developed fabric and augen structure.

Feldspars (including orthoclase, microcline and their perthitized equivalents together with plagioclase) and quartz occur as porphyroclasts and phenocrysts. The phenocrysts are euhedral to subhedral while the porphyroclasts are corroded up to roundedness and failed by stress, showing wavy extinction. Stretching elongation, sericitization and kaolinization are all variably present in alkali feldspar porphyroclasts. Certain plagioclase porphyroclast show good albite twinning while quartz porphyroclasts are highly fractured containing biotite and epidote along these fractures. Quartz also occurs in groundmass and in myrmeketic intergrowth with alkali feldspars. Certain quartz grains show overgrowth of a second generation. The proportion of porphyroclasts with respect to the groundmass varies between 20 and 70% and their length varies between 1 and 4 mm.

Opaque minerals (mostly magnetite; 5-10%) occur as rounded grains scattered throughout the groundmass. Sphene is generally associated with magnetite.

Biotite, epidote, amphibole (light grey) and apatite occur in close association and constitute up to 20% of the total rock. Biotite is pleochroic from pale brown to greenish brown. It seems to be developed at the expense of magnetite and K-feldspar. Garnet and chlorite have been reported in porphyritic microgranite by Kempe (1973).

The most peculiar feature of the porphyritic microgranite is the development of fluxion structure and mortar texture, apparently superimposed upon a volcanic flow texture. In certain sections, the comparatively coarse-grained matrix of angular fragments also shows similar features (Fig. 6a-b).



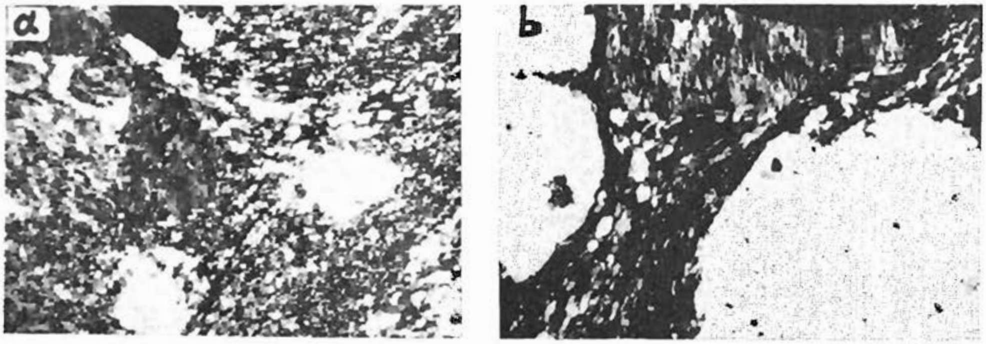


Fig. 5 (a-b: Top). Photomicrographs showing (a) fluxion structure around corroded feldspar grains, and (b) mortar texture around rotated plagioclase crystals, in riebeckite gneiss from Gariala Kandao- Taja section. (Mag. x 18; cross nicols).

Fig. 6 (a-b: Bottom). Photomicrograph showing fluxion structure around feldspar grains in porphyritic microgranite. Fine flakes are muscovite associated with epidote (dark) lying parallel to the fluxion structure. (Mag. x 22; cross nicols).

Chemical analyses of 59 rock samples from the Shewa Shabazgarhi complex were carried out and 18 representative analyses are presented in Table 1. The overall variation in SiO_2 from mafic to felsic rocks is between 42 and 78%. On the basis of SiO_2 two major groups of rocks can be distinguished, (a) basic rocks with $SiO_2 < 55$ wt% comprising metagabbro, metadolerite and other basic dykes, and (b) acidic rocks with $SiO_2 > 66$ wt% comprising of microporphyry, riebeckite gneiss, aegirine-riebeckite porphyry and porphyritic microgranite. Two of the compositions with SiO_2 contents between 55 and 65 wt% (Table 1. 7,8) represent quartz monzonite, and are considered hybrids on the basis of field features and petrography. Two other rock samples containing SiO_2 in the same range (Table 1. 9, 10) are associated with metagabbro and the basic dykes in the field and may be representing their differentiates or hybrids, respectively. Majority of the samples are quartz normative. Among the acidic rocks $Na_2O > K_2O$ in aegirine-riebeckite porphyry and riebeckite gneiss. In the other varieties K_2O exceeds Na_2O. P_2O_5 is higher in those acidic rocks which lie at close contacts with basic rocks in the field. The acidic rocks range from per-aluminous to alkaline which is indicated by the presence of corundum and acmite in their norms.

Major element Chemistry

Variation in major element chemistry is represented on oxide vs. S.I. ($MgO \times 100/MgO+FeO+Fe_2O_3+Na_2O+K_2O$) plots for both basic and acidic rocks whereas oxides are plotted against D.I. (normative Qtz+Or+Ab+Ne+Ks) for acidic rocks. On the oxide vs. S.I. plots MgO shows a linear positive correlation both in basic and acidic rocks (Fig. 7a), indicating crystallization differentiation and the control of ferromagnesium minerals including olivine, pyroxene and/or hornblende on the liuidus. By careful examination, however, the general trend of the basic rocks has a slope which does not correspond to that of the acidic rocks. This sort of discrepancy is meaningful not only in terms of the genetic difference between the two groups but also reveals that the type, or proportion, or both, of the fractionating phases were not similar in the two magmatic domains. On a CaO vs. S.I. plot (Fig. 7b) majority of the basic rocks show a linear positive correlation indicating clinopyroxene and/or plagioclase as the dominant mineral(s) having been fractionated. Plots of the acidic rocks which show some scatter, however, indicate a considerably different pattern than the basic rocks. The general trends of both the groups also show difference on Al_2O_3 vs S.I. plot (Fig. 7c). The basic rocks reflect a negative correlation with S.I. and a scatter at S.I. ~20; indicating the dominant fractionation of clinopyroxene and the association of plagioclase with clinopyroxene on the liquids, respectively. On the other hand the trend of the acidic rocks is positive and reflect a major contribution of plagioclase fractionation on the liquidus.

TABLE 1. MAJOR AND TRACE ELEMENT DATA OF THE REPRESENTATIVE ROCK SAMPLES FROM THE SHEWA-SHABAZGARHI COMPLEX.

Sample	SN49	SN44	SHM60	SHM40	SN30	SN4	SHM110	SHM113	SN5	SN27	SHM45	SHM44	SHM88	SHM64	SHM109	SHM65	SH20	SHM12
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
SiO2	43.46	49.21	42.64	50.99	46.50	48.17	63.95	65.35	59.41	60.00	70.25	71.00	70.72	75.79	71.22	74.04	74.45	69.52
TiO2	3.77	3.91	6.05	3.34	3.96	4.11	1.05	1.08	1.39	3.05	0.69	1.02	1.50	0.89	1.03	0.45	0.00	0.47
Al2O3	10.60	11.34	11.86	12.80	12.80	10.55	15.00	14.00	12.34	10.26	13.50	13.27	12.08	11.06	11.65	11.79	12.00	13.73
Fe2O3	8.42	8.93	16.82	6.35	10.60	7.98	7.51	5.93	10.41	9.11	2.61	2.23	3.37	1.31	3.25	1.76	2.37	2.59
FeO	5.98	6.79	0.51	9.20	3.34	6.54	0.00	0.43	2.48	1.60	0.65	0.65	0.00	1.02	0.00	1.05	0.51	1.13
MnO	0.18	0.18	0.13	0.18	0.17	0.18	0.61	0.14	0.17	0.20	0.17	0.16	0.12	0.11	0.13	0.13	0.14	0.17
Mgo	10.29	4.67	8.22	3.49	6.37	4.54	1.06	0.90	1.57	0.49	0.57	0.44	1.32	0.27	0.99	0.55	0.05	1.21
CaO	10.27	8.51	1.49	8.10	7.54	9.21	1.91	0.86	4.52	8.34	0.62	0.54	0.24	0.12	0.44	0.40	0.17	0.24
Na2O	2.37	2.83	1.61	3.25	2.74	2.85	5.61	5.91	3.84	3.58	6.00	6.35	3.40	2.86	0.84	0.73	4.82	2.58
P2O5	1.20	1.48	0.65	0.95	0.61	0.66	0.21	0.15	0.65	0.72	0.09	0.08	0.06	0.04	0.07	0.05	0.00	0.01
H2O+	2.40	0.80	3.60	0.00	3.00	2.80	0.30	0.80	1.40	0.00	1.30	0.90	0.20	0.30	2.30	0.80	0.01	0.00
K2O	0.86	1.28	6.22	1.25	1.90	1.71	2.99	3.98	2.14	2.18	4.02	3.63	6.50	6.20	8.00	8.20	5.46	3.77
Total	99.8	99.93	99.8	99.9	99.53	99.3	100.2	99.53	100.32	99.53	100.47	100.27	99.51	99.97	99.92	99.95	99.98	95.42
Ni	60	43	81	41	72	48	45	52	40	0	62	57	63	55	68	64	65	40
Cr	220	27	55	27	102	31	37	15	16	0	31	26	27	73	39	26	20	3
Co	60	58	75	60	57	145	29	6	43	0	71	45	49	40	27	42	247	83
V	421	493	814	344	507	510	0	0	37	0	790	0	0	0	0	0	0	0
Zr	290	26	145	155	148	126	688	612	397	0	123	124	1024	895	1012	858	924	1641
Rb	263	226	217	18	70	35	62	111	48	0	55	57	111	142	208	200	162	159
Sr	491	568	63	217	170	145	633	488	311	0	1306	121	128	11	48	38	12	37
Ba	263	32	522	374	285	382	871	841	582	0	86	78	706	342	701	415	74	849
Y	27	52	49	30	29	26	62	72	51	0	0	0	89	81	106	94	107	144
Zn	0	0	75	72	225	168	126	148	114	0	157	0	202	139	180	164	191	0
Cu	0	0	0	0	139	0	0	0	0	0	3	0	0	0	0	0	0	0
NB	17	25	7	15	13	4	95	102	82	0	0	139	163	150	182	148	172	221
Ta	0	0	7	6	6	6	4	0	5	0	0	2	3	3	3	3	2	0
CE	0	0	61	61	2	64	105	104	77	0	0	0	137	120	101	94	128	486
La	0	0	73	0	0	0	43	84	19	0	0	0	115	48	57	50	46	0

Group numbers 1,2 metagabbro; 3,4,9 metadolerite; 5,6 basic dykes; 7,8,10 quartz monzonite; 11,12 riebeckite gneiss; 13,14 aegirine-riebeckite porphyry; 15,16 microporphyry; 17,18 porphyritic microgranite. Unanalyzed trace elements are presented as zeros. Group Nos. 9 & 10 (hybrids) are represented along with metagabbros and basic dykes, respectively, due to their field association. Only representative analyses are given. Detailed data available on request.

Except for the presence of a considerable compositional gap between the two groups the overall variations of the basic and acidic rocks are similar on SiO_2 and K_2O vs S.I. plots (Figs. 7d,e), indicating negative correlations and the concentration of SiO_2 and K_2O in the residual liquid during fractionation. On a Na_2O vs S.I. plot (Fig. 7f), the two groups, however, reflect different behaviours. Na_2O is more or less constant as S.I. varies in basic rocks, whereas, the former shows a considerable variation within a

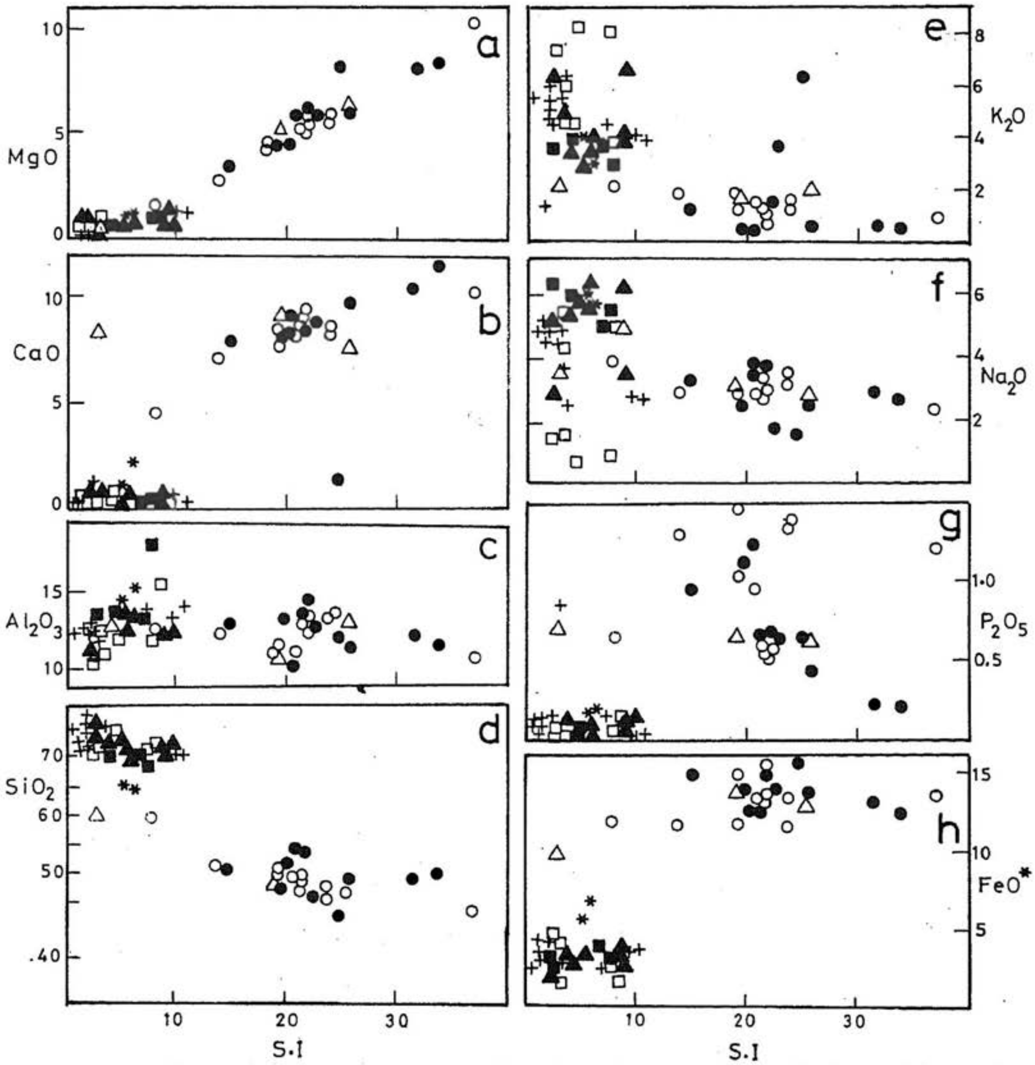


Fig.7 (a-h). Oxide vs S.I. plots of the basic and acidic rocks from Shewa-Shabazgarhi complex. Symbols: solid circle = metagabbro, open circle = metadolerite, open triangle = other basic dykes, * = quartz monzonite, solid square = reibeckite gneiss, solid triangle = aegirine-reibeckite porphyry, open square = microporphyry, + = porphyritic microgranite.

limited range of the latter (0-10) in the acidic rocks. Such plots support contrasting genetic and fractionation histories for the two groups.

The P_2O_5 vs. S.I. plots of the basic rocks (Fig. 7g) indicate a general negative correlation, suggesting the buildup of P_2O_5 in the residual liquid. Similarly P_2O_5 is generally low in the acidic rocks (Fig. 7g). Apatite, however, occurs in association with hornblende and magnetite in the marginal sections of certain metagabbros. In addition, one porphyritic microgranite sample shows substantially higher P_2O_5 (0.85%) than the other acidic rocks. Such abnormalities can be related to metasomatic concentration of P_2O_5 and other volatiles along the contacts between basic and acidic rocks where high proportions of apatite have been noticed in both of the rock groups.

In basic rocks individual plots of FeO and Fe_2O_3 vs S.I. reflect high scatter (not represented) but the total iron (FeO*) when plotted against S.I. (Fig. 7h) shows a flat pattern with a limited range of variation which is considerably distinct from that of the acidic rocks. This shows that the overall partitioning of iron between liquid and solids (i.e. ferromagnesium minerals) was in a 1:1 ratio. MnO (plot not represented) generally behaves like FeO*.

Fractional crystallisation having been also responsible for producing the chemical variation in acidic rocks is well displayed on oxide vs D.I. plots. SiO_2 and K_2O indicate an overall positive correlation whereas MgO, FeO*, CaO, Na_2O, Al_2O_3 and P_2O_5 indicate overall negative correlations (Figs 8a-h) suggesting fractional crystallization and the prominent role of plagioclase subordinated by ferromagnesian minerals and some apatite on the liquidus.

The two quartz monzonite analyses show relatively higher FeO* (and MnO in one sample; Table 1.7-8) than the other acidic rocks (Fig. 8d). On certain oxide vs. S.I. plots (i.e. CaO, SiO_2 and FeO*; Figs. 7b,d,h) and several trace element plots (i.e. Zr ,Nb and Y vs S.I.; Figs. 9c-e), these analyses reflect themselves as bridging samples between two major groups of basic and acidic rocks. All these features support the hybrid nature of quartz monzonite, as suggested earlier based on petrographic and field relationship.

Despite their association with basic rocks in field, the two samples containing higher SiO_2 than other basic rocks (Table 1. 9,10) also show low S.I. values and corresponds to the acidic rocks on many of oxide vs S.I. plots (Figs. 7,9). As suggested earlier, like the quartz monzonites, these rocks may also be representing hybrids.

Trace element chemistry

The trace element variation of both the basic and acidic suites are also indicative of variation produced under igneous crystallization or partial melting processes. On Cr and Ni vs S.I. plots (Figs. 9a,b), the acidic rocks are scattered but the basic ones show linear positive trends indicating the role of ferromagnesium minerals (pyroxene, olivine and hornblende) on the liquidus in the latter group. The latter type rocks also show similar trend on Ti vs V plot (not presented). General negative correlations are also shown by the majority of analyses of the basic rocks on Zr, Nb and Y vs S.I. plots (Fig. 9 c-e), indicating that hornblende did not play any major role in the fractional evolution of these rocks (see Pearce & Norry, 1979).

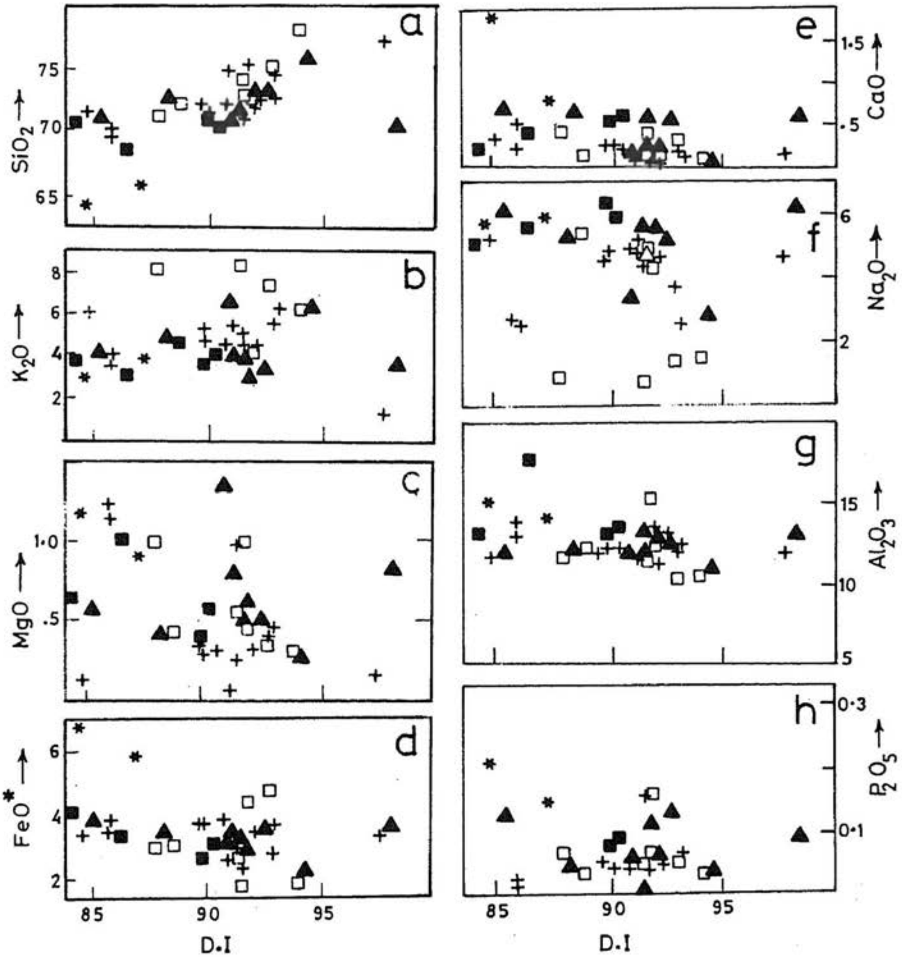


Fig. 8(a-h). Oxide vs D.I. plots of the acidic rocks of the Shewa- Shabazgarhi complex; symbols as in Figure.7.

Linear positive trends reflecting igneous parentage for acidic rocks are well displayed on Y and Nb vs Zr plots (Figs. 10a,b). These elements, however, indicate negative correlation with D.I. (Figs. 10c-d), reflecting concentration in solids, a feature exclusively related to hornblende fractionation (Pearce & Norry, 1979). In Figures 10c,d the quartz monzonite analyses reflect different behavior than the other acidic rocks, supporting the hybrid nature of the former types.

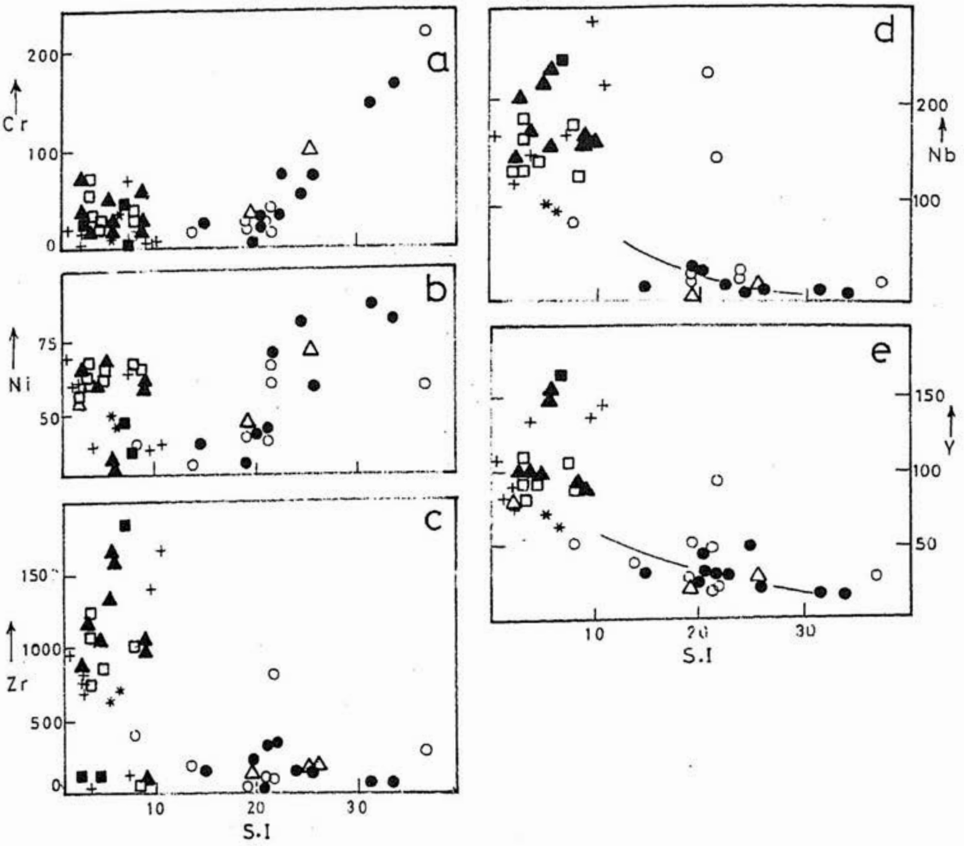


Fig. 9 (a-e). Cr, Ni, Zr, Nb and Y vs. S.I. plots of the basic and acidic rocks from Shewa-Shabazgarhi complex; symbols as in Figure 7.

Magmatic and tectonic characters

On several discrimination diagrams including Zr/Y vs Zr, Ti vs Zr, Ti/Y vs Ti and Zr/Y vs Ti/Y plots of Pearce & Norry (1979), Pearce & Gale (1977), Pearce et al. (1981) and Pearce (1982), majority of the basic rocks from the Shewa-Shabazgarhi complex plot within or very close to the fields described for within plate basalts (Figs. 11a,b,d,h).

On the TiO_2-K_2O-P_2O_5 discrimination diagram of Pearce (1975), 75% of the basic rocks plot in the field shown for continental tholeiites (Fig. 11e). Closer correspondence with continental rift tholeiites than with any other suite on the basis of minor and trace element spidogram is also shown by the mean metagabbro and mean metadolerite compositions from the Shewa-Shabazgarhi complex (Fig. 11i). Tholeiitic characters are also reflected by the basic rocks on FeO/MgO vs SiO_2 plot of Miyashiro (1973) and the Al_2O_3 vs An% and AFM plots of Irvine and Baragar (1971) (Figs. 11g,c,f).

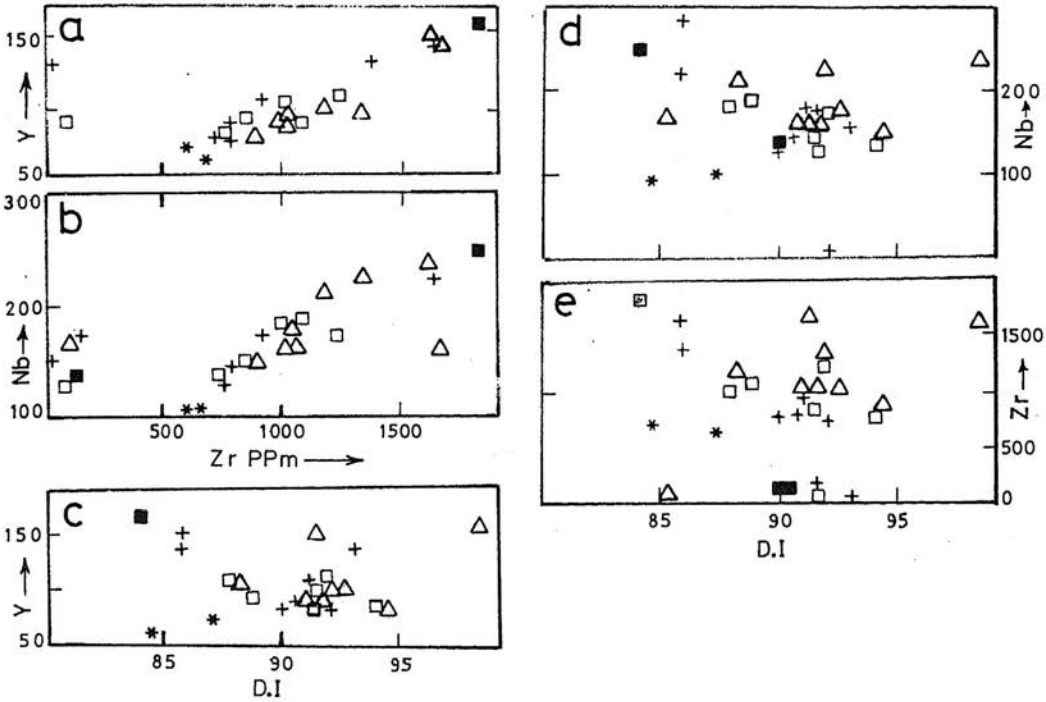


Fig.10 (a-e). Y and Nb vs Zr and Y, Nb and Zr vs. D.I. plots of the Shewa-Shabazgarhi complex; symbols as in Figure 7.

Like the basic rocks, the acidic rocks of the Shewa-Shabazgarhi complex also show continental characters when plotted on tectonic discrimination diagrams. On Ta, Nb and Y vs SiO_2 plots (Ta vs SiO_2 plot not represented) of Pearce et al. (1984), the acidic rocks occupy the combined field defined for "within plate" and other types of granites but on Nb vs Y and Rb vs (Y+Nb) plots of Pearce et al. (1984), these compositions occupy the field defined separately for "within plate granites" (Figs. 12 a-e). This chemical feature of the acidic rocks is not only in line with their spatial association with basic rocks which also show continental character on the basis of chemistry, but also corresponds with their emplacement into the continental crustal rocks of the Indo-Pak plate. On the affinity diagrams, the granitic rocks are, however, different from their basic counterparts. On a SiO_2 vs Al_2O_3+CaO+Alk/Al_2O_3+CaO-

Alk diagram majority of the acidic compositions plot in the fields of alkaline and peralkaline rocks, indicating similarities to other alkaline complexes around the Peshawar basin, i.e. Warsak complex (Khan, 1990; Kempe, 1973). The Zr content of 500 ppm in all the acidic rocks of the Shewa-Shabazgarhi complex also supports their peralkaline affinities (see Bowden & Turner, 1974).

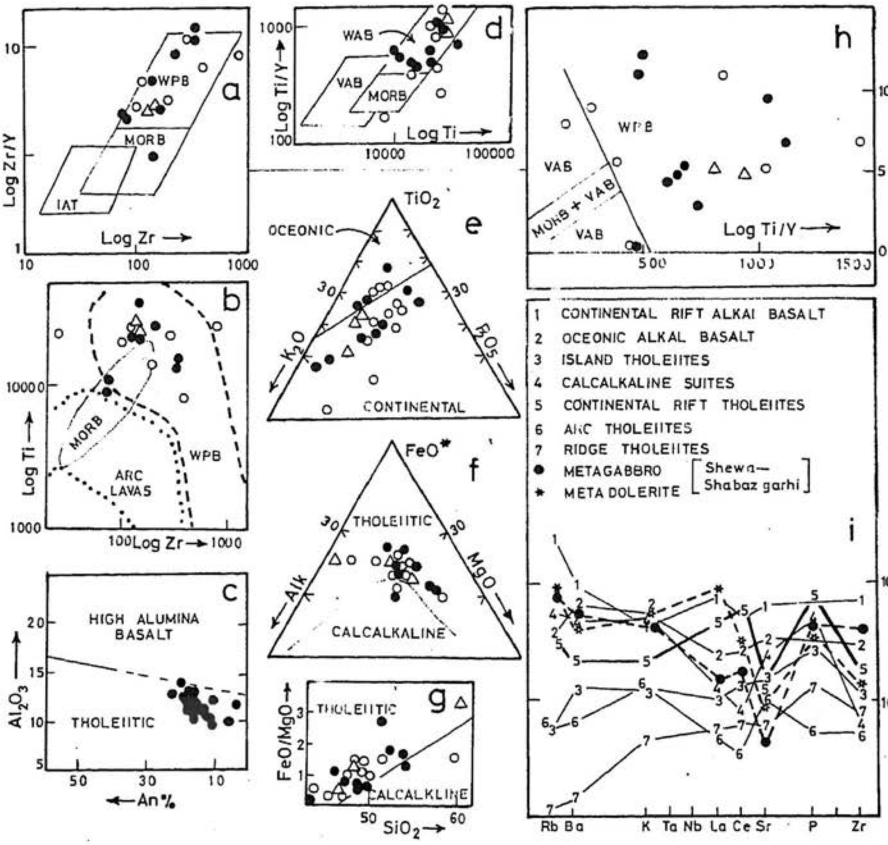


Fig. 11 (a-h). Discrimination diagrams for the Shewa-Shabazgarhi complex based on: (a) Zr/Y vs Zr plot (fields after Pearce and Norry, 1979), (b) Ti vs Zr plot (fields after Pearce et al., 1981), (c) Al_2O_3 vs normative An% plot (fields after Irvine & Baragar, 1971), (d) Ti/Y vs Ti plot (fields after Pearce, 1982), (e) TiO_2-K_2O-P_2O_5 plot (fields after Pearce et al., 1975), (f) AFM plot (fields after Irvine & Baragar, 1971), (g) FeO/MgO vs SiO_2 plot (fields after Miyashiro, 1973), (h) Zr/Y vs Ti/Y plot (fields after Pearce & Gale, 1977) and (i) minor and trace cleof the ment spidergram [1-7: data from Hart et al., 1970; Jakes & White, 1972]; symbols as in Figure 7 except in Figure 11c where all solid circles represent basic rocks from the Shewa-Shabazgarhi complex; WPB = within plate basalt, MORB = mid ocean ridge basalt, IAT = island arc tholeiites, VAB = volcanic arc basalt.

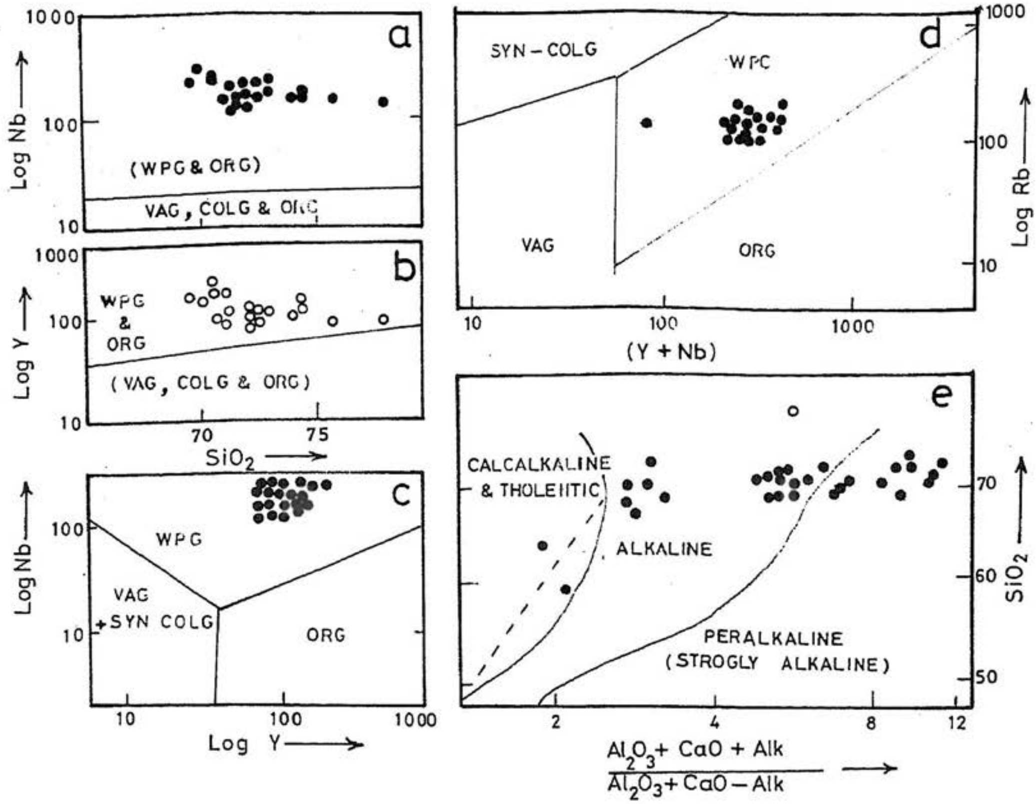


Fig. 12 (a-e). Discrimination diagrams for the acidic rocks of the Shewa-Shabazgarhi complex, based on Nb and Y vs SiO_2, Nb vs Y, Rb vs Y + Nb (fields after Pearce et al., 1984) and SiO_2 vs $Al_2O_3 + CaO + Alk/Al_2O_3 + CaO$-Alk (field after Wright, 1969); all solid circles represent acidic rocks exclusively; WPG = with plate granite, VAG = volcanic arc granites, ORTG = Occon ridge granite, COLG = collision granite, SYN-COLG = syn-collision granite.

DISCUSSION

It is obvious from the field relationship, petrography and chemistry of the Shewa-Shahbazgarhi complex that the basic and acidic rocks existing more than one independent suites in the sense that their genetics belong to different ages, source regions and crystallization histories. The basic rocks including metagabbro, metadolerite and the basic dykes intruding the metagabbro at Budsari represent one major suite of rocks. Whereas, the acidic rocks including microporphyry, aegirine-riebeckite porphyry, riebeckite gneiss and porphyritic microgranite together with the acidic dykes (i.e. at Budsari) represent the other major cognate suite. On many of the discrimination diagrams the basic suite indicates characters of tholeiitic flood basalts and the acidic ones show characters of alkaline to peralkaline rocks; both the groups however, unanimously reflect emplacement in continental environment.

The major element chemistry indicates crystal fractionation (and possibly partial melting of the same source for various rock types) and the control of clinopyroxene, plagioclase and magnetite on the liquidus being responsible for producing the evolutionary trend of the basic rocks. Presently, the basic rocks contain amphibole, plagioclase and magnetite as their important constituents. As stated earlier the trace element chemistry oppose the role of amphibole as one of the fractionating phases. The texture of the metagabbro and metadolerite clearly reflects the formation of the bluish-green to brown amphibole of ferro-hornblende composition (Hamidullah and Ahmad in prep.) at the expense of plagioclase and magnetite. Clinopyroxene is missing from majority of the sections of metagabbro and metadolerite and whereever it is present, it occurs as relics in a minor proportion but indicates transformation to amphibole. All such features indicate the prevalence of lower amphibolite facies environment for a considerable time in basic rocks (see Miyashiro, 1973). Also in basic rocks, brown biotite and epidote both occur in close association indicating development after hornblende and plagioclase. This feature can be attributed to retrogression and the possible prevalence of epidote-amphibolite facies environment subsequent to the pre-existing lower amphibolite facies conditioons. The occasional replacement of biotite with chlorite in metagabbro signify further retrogression to greenschist facies.

The basic dykes generally correspond with metagabbro and metadolerite on the basis of mineralogy and chemistry. These dykes can be therefore considered differentiates of the same magma which has given rise to metagabbro and metadolerite.

A completely different evolutionary trend is reflected by the major element chemistry of the acidic rocks. A dominant feldspar (plagioclase, K-feldspar) fractionation is shown by these data and hornblende fractionation by the Zr vs D.I. plots (cf. Pearce & Norry, 1979). Plagioclase, orthoclase and perthite phenocrysts/porphyroblasts/porphyroclasts occur in all the acidic rocks and a plagioclase megacryst of 1 cm diameter, retaining igneous signatures has been noticed in aegirine-riebeckite porphyry (Ahmad, 1986), confirming plagioclase fractionation. No igneous hornblende has been however, identified in the acidic rocks but a considerable amount of post-emplacement greenish- brown hornblende replaced by blue-green riebeckite and biotite occurs in riebeckite gneiss and aegirine-riebeckite porphyry. Biotite of greenish brown colour, also replaced by riebeckite and epidote, is noticed in these rocks. Therefore, any igneous hornblende if present seems to have been consumed during the formation of ferromagnesium minerals in the latter events. The textural relationship of the minerals present thus indicates an evolutionary sequence of metamorphic events encompassing amphibolite facies conditions (greenish-brown hornblende) , followed by retrogression (development of biotite after greenish-brown hornblende and epidote after biotite) into epidote-amphibolite or upper greenschist facies. The development of riebeckite after greenish-brown hornblende and biotite, as well as after aegirine, in riebeckite gneiss and aegirine riebeckite porphyry (see Ahmad, 1986), can be attributed to a second phase of relatively high grade metamorphism (blue-green hornblende is rare in greenschist facies; Miyashiro 1973, p.254) or Na-metasomatism during the emplacement of the latter phases, i.e. porphyritic microgranite and acidic dykes.

On the basis of chemical data the microporphyry closely corresponds with other acidic rocks (Figs. 7-10). This observation is in accord with the gradational contact of the microporphyry with aegirine-riebeckite porphyry at Machi and Taja (Fig. 2; Ahmad, 1986). At Budsari, however, the microporphyry has been reported to be older than the metagabbro (Noor Jehan, 1985). The term microporphyry has been in fact invariably used for the fine-grained splintery and well jointed rocks with variable colour from earthy-white through greysh-green to slaty-black (see Ahmad, 1986, p.18). A careful examination unravel that in certain sections the Budsari microporphyry shows volcanic flow phenomenon but in other sections a considerable amount of graphite is present; feature indicating it to be a combination of volcanic and sedimentary material and a possible member of the Sawabi-Chamla group. Unfortunately, all the chemical data presented on the variation diagrams belong to the microporphyries of the Machi section. This microporphyry thus seems to be a differentiate of the aegirine-riebeckite porphyry. In such a case the origin of the microporphyry at Budsari needs to be re-considered for detailed investigation.

The most significant feature of the rocks of Shewa-Shabazgarhi complex is the severe impact of cataclasis in acidic rocks, particularly in microporphyry and porphyritic microgranite. Fluxion structure and mortar texture superimposed on "volcanic flow" type of texture, broken and elongated grains of quartz and feldspar, broken aggregates of these large crystals, the laminated groundmass indicating abrupt variation in grain size and in some cases indications of recrystallization and neo-mineralization, all provide ample evidence of this phenomenon. On the basis of grain size, presence and absence of fluxion structure and the comparison of cataclasis with neo-mineralization and recrystallization the cataclasized portions of the affected rocks were classified following the scheme of Higgins (1971) and Bell & Etheridge (1973). The various varieties identified are structureless cataclasite, pseudo-tachylite, protomylonite, mylonite, ultra-mylonite and cataclasite. Ahmad (1986) has attributed the formation of certain new minerals, including biotite, epidote, aegirine, riebeckite and sillimanite in the aegirine-riebeckite porphyry and riebeckite gneiss to the mobility of elements (release of alkalies and concentration of Al_2O_3) during cataclasis. Cataclasis is however, generally referred to brittle deformation at shallow levels of low temperature with a minimum degree of recrystallization. Therefore, as mentioned earlier, the growth of new minerals in these rocks may be considered solely a metamorphic or metamorphic-cum-metasomatic phenomenon. In this context Na-metasomatism can be considered a factor in the development of alkali minerals, like aegirine and riebeckite.

One of the confusing aspects of the Shewa-Shabazgarhi complex is the nomenclature of various rocks suggested by various workers (i.e. Martin et al., 1962; Chaudhry &

Shams, 1983, Waleed & Bakhtiar, 1980; Noor Jehan, 1985; Ahmad, 1986). These authors have classified the rocks considering only a particular aspect among mineralogy, grain size, metamorphism and cataclasis etc. In fact the intensities of various phenomenon, which have played roles in the evolution of the Shewa-Shabazgarhi complex, vary from place to place and thus granting different appearance to one and the same rock at different places in a single outcrop, or vice-versa. For example, the cataclasized porphyritic microgranite and microporphyry appear similar, whereas, the cataclasized porphyritic microgranite looks very different from its uncataclasized counterpart, at the western edge of Budsari outcrop. Also as mentioned earlier, the porphyritic microgranite has characters which are more representative of volcanic rather than plutonic origin, e.g. layering, "pillar type" structure due to the development of mural joints, phenocryst-groundmass relation, groundmass grain size and volcanic flow texture (Figs. 3,6). In fact, the superimposition of metamorphism and cataclasis has overshadowed its volcanic appearance. Therefore, considering all the genetic and mineralogical aspects a careful examination is needed to re-classify all rocks of the Shewa Shabazgarhi complex.

Several theories have been proposed about the generation of magma(s) for the Shewa-Shabazgarhi complex and in general for the alkaline igneous complexes around the Peshawar basin (cf. Fig.1), among which are the differentiation theory of Kempe (1973), the intra-continental subduction theory of Powell & Conaghan (1973), the vale-rift zone theory of Kempe & Jan (1980), the Indo-Pak subduction-related theory of Chaudhry & Shams (1983) and the theory of a Pre-Himalayan subduction of Noor Jehan (1985). The present study has confirmed that both the basic and acidic rocks are of continental rift type. Comparable complexes have been dated as old as 315 Ma (Malakand granite; Zeitler, 1988) and 250 Ma (Koga corbonatite; LeBas et. al., 1987) and thus the Shewa-Shabazgarhi complex also seems to be much older than the collision date along MMT (i.e 55 ma; Coward et al., 1987; Hamidullah & Onstot in prep.) and therefore, a product of some Pre-Himalayan tectonism. It is not very clear, wheather the individual rock types are solely the products of differentiation in separate basic and acidic large magmatic chambers or batch partial melting of the source rock has also played a role in the production of the evolutionary trends at Shewa-Shabazgarhi. Rare earth and isotopic studies are needed to resolve these issues. It is appealing however to consider, that the generation of the basic magma(s) at deep crustal or upper mantle level due to rifting has provoked the melting of the upper crust to produce acidic magma(s) for rocks younger than the metagabbro and matadolerite. The acidic magma which has given rise to the igneous portion of the microporphyry at Budsari (i.e. older than the basic rocks) may be considered then, the product of an earliest rift-related anataxis probably at higher levels than that responsible for the later acidic types.

CONCLUSIONS

1. Rocks of the Shewa-Shabazgarhi complex are the product of basic and acidic magmatism/volcanism initiated as a result of rifting of the Indo-Pak continental crust.

2. The basic rocks, including metagabbro, metadolerite and other basic dykes are derived from a tholeiitic flood basalt type of magma, whereas the acidic rocks including microporphyry, riebeckite gneiss, aegirine-riebeckite porphyry and porphyritic microgranite are derived from a magma of alkaline to peralkaline characters.

3. During igneous crystallization clinopyroxene, plagioclase and magnetite were the dominant fractionating phases on the liquidus in the basic rocks, whereas, feldspar and amphibole were the dominant fractionating phases on the liquidus in the acidic rocks.

4. The existing mineral assemblages both in the basic and acidic rocks indicate the prevalence of amphibolite facies metamorphism followed by retrogression.

5. Cataclasis followed metamorphism in the acidic rocks.

Acknowledgments: Professors M. Qasim Jan, M. Majid, Dr. M. Rafique, Mr. M. Humayun and Mr. M. Tahir Shah are highly acknowledged for fruitful discussion and critically reading the manuscript. Mr. M. Tahir Shah also helped in wet analyses. Mr. Jamil Ahmed and Mr. Abid Ahmed as well as their field staff provided appreciable accommodation and help in the field. Mr. M. Riaz and Ms. Fatima Gul are acknowledged for drafting and Mrs. Seemi Javed and Ms. Farhidoon Sahar for typing the manuscript.

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