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Classification and Genesis of Late Paleozoic, Volcanic Rocks from Peshawar Plain, North West Pakistan

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ABSTRACT: *Acidic microporphyries and rhyolites of Late Paleozoic age are intimately associated with acidic plutonic rocks, i.e., the Ambela granitic complex of alkaline igneous province of Peshawar plain. Basic rocks occurring as flows are also associated with these acidic rocks. Field evidences including the association of metasedimentary sequence of Carboniferous age, i.e., Jaffar Kandao and Baroach Formation, provide constraints on the date of their emplacement. The microporphyries and rhyolites have a fine-grained texture with feldspars and quartz as phenocrysts. The rocks are classified as A-type, mildly alkaline and peraluminous on the basis of major and minor element chemistry. Tectono-magmatic discrimination diagrams, Zr and Ta concentration, Hf/Th and Hf/Ta ratios, and low Sr reveals that these rocks are of crustal origin and were emplaced in intra-cratonic rift environment. The Th, Hf and Ta concentrations indicate crustal contamination, and Eu anomaly shows soda metasomatism due to the intrusion of late magmatic fluids in these rocks.*

INTRODUCTION

Volcanic rocks of both acidic and basic compositions are associated with the alkaline to peralkaline rocks of Peshawar plain alkaline igneous province (Kempe & Jan, 1970, 1980, 1983; Le Bas et al., 1987; Rafiq & Jan, 1989). The volcanics are considered to be representing the early magmatic episode along a rift zone, extending 200 km from Tarbella in the east to Warsak in the west of Peshawar plain (Fig. 1A). Several authors have called these acidic volcanics as miroporphyries (Chaudhry and Shams 1983, Ahmad et al., 1990). The occurrence of these microporhpyries is not frequent and extensive, however, their distribution throughout the Peshawar plain at Tarbella, within the host peripheral metasedimentary sequence (Jaffar Kandao formation and Baroach formation) of Ambela Granitic Complex, Gohatai, Turlandai, Tarakai, Rashakai, Mansurai, Naugram, along Totalai Changlai roadside, Dari Dhob, Sorai-Malandrai, Ziarat, Nawa-Kali, Mula-Yusaf, is indicative of a widespread volcanic activity in the region (Fig. 1A). These microporphyries are generally interbedded with meta-sedimentary sequence.

Dyke swarms of tholeiitic basic composition intrude the Pre-Cambrain to Late Paleozoic rocks and certain Late plutonic and volcanic phases (e.g. Koga syenites, Rafiq, 1987) in the area. These dykes are now believed to be the Late Paleozoic or early Mesozoic in age (Rafiq, 1987). Apart from the above mentioned localities where only acidic microporphyries exist, the acidic microporphyries and basic lavas (as green schists)are also exposed near Gajju Ghundai, Shewa-Shahbaz Ghari, Jaffer Kandao, Nawekili, Krappa, Dari Dhob and Warsak. The present study has been carried out to investigate the lithology and stratigraphy of the volcanic rocks of the former localities where only acidic volcanic rocks exist, and to envisage their possible petrogenetic interpretation on the basis of this data and chemical feature.

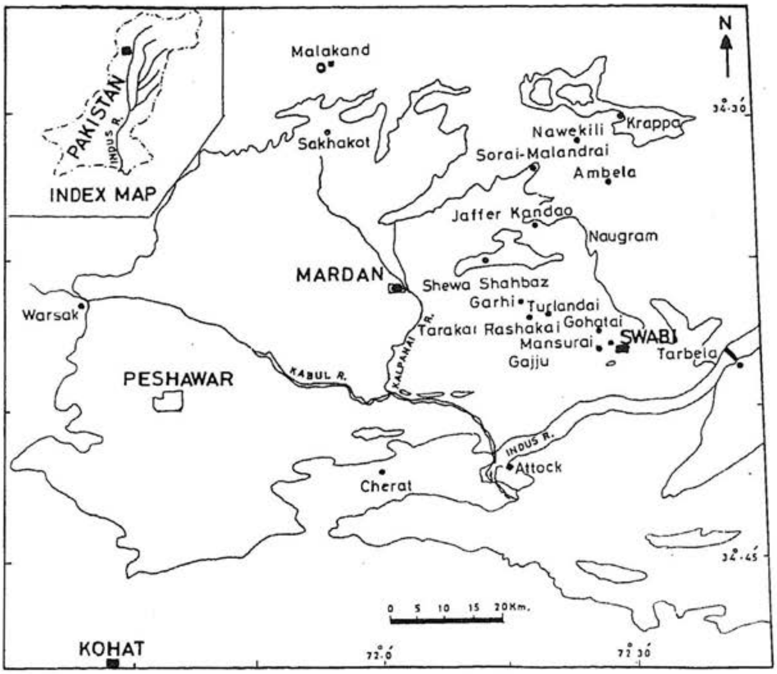

Fig. 1A. Location map of subvolcanic-volcanic rocks and extension of rift zone along Peshawar Plain.

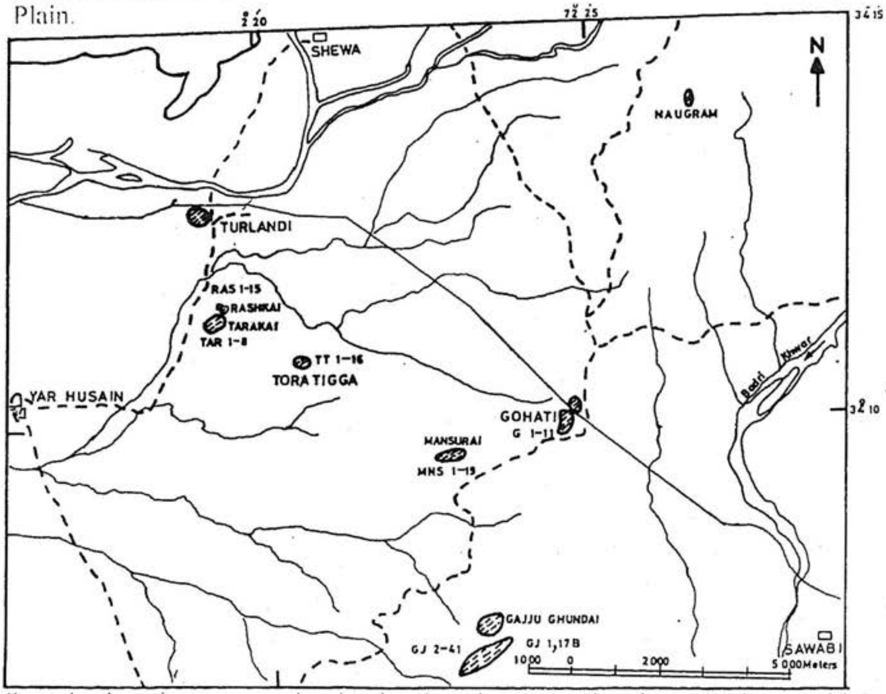

Fig. 1B. Sample location map of subvolcanic-volcanic rocks from Peshawar Plain, NW Pakistan.

Petrographic studies have been carried out for more than 100 rocks and 22 samples were selected for chemical investigation from the various outcrops of the microporphyries in the area (Fig. 1B). Both major and trace element analyses have been carried out using wet chemical methods and neutron activation techniques.

GEOLOGICAL SETTING

The sporadic outcrops of the volcanic rocks of Peshawar Plain roughly an east-west trending belt extending from Tarbella in the east, through isolated outcrops in the north-east of Peshawar Plain and around Ambela Granitic Complex, to Warsak in the west. This belt occupy the internal zone of the NW-Himalaya in northern most part of Indian Plate. Members of these microporphyries exposed at Warsak and Shewa Shahbaz Gharhi are interpreted as a part of the alkaline igneous province (Kempe and Jan 1970, 1980). The microporphyries of acidic composition are present as an interlayered sequence in the middle part of the Jaffar Kandao formation throughout the western and northwesten margin of the Ambela Granitic Complex (at Dhari Dhob, Sorai-Malanderai, Nawekili, Bar China etc.). South of the Ambela Granitic Complex these microporphyries crosscut the Amber formation (Cambrian) Misri Banda formation (Early to Middle Ordovician) and Panjpir formation (Early to Middle Silurian) at Naugram and several other places. Field evidence and previous studies (Kempe and Jan, 1970, 1980; Rafiq, 1987; Rafiq and Jan, 1989) suggest initiation of rifting and magmatism which probably started during Devonian and span over Carboniferous and Permian. It is now believed that before the disintegration of Pangea the alkaline igneous province and its parental rift zone of the Peshawar basin might be a continuation of the East African rift system and the Alkaline igneous Province of Nile (Rafiq, 1987). Both the acidic microporphyries and their basic associates with microporphyries elsewhere (Shewa Shabaz Ghari, Jaffar Kandao, Sorai Malanderi, Nawekili and Krappa), occurs as plugs, lenses and dykes and show alkaline to peralkaline and tholeiitic flood basalt affinities respectively (Ahmed et al., 1990). Field, geochronological and geochemical data suggest the following stratigraphic sequence in the region.

1. An early bimodal (basic and acidic volcanic) sequence erupted at the early stage of rifting and interrupted by deposition of conglomerates, argillites, and thin bands of limestones. At Jaffar Kandao this mixed volcanic-metasedimentary sequence unconformably overlies the Nowshera formation of Early Devonian age. There on the basis of this observation a Late Devonian age can be assigned to this sequence. This interpretation coincide with the dates (Early Carboniferous) assigned to the microporphyries of Shewa Shahbaz Garhi Complex.

2. The main plutonic phase of alkaline igneous province including granites and alkali granites (Ambela) represents the early plutonic episode in the rift zone. This is succeeded by the desilicified alkaline sequence of quartz-syenites, syenites, foidal syenites, carbonatites, ijolites etc. of second phase (Rafiq, 1987; Rafiq and Jan, 1989). Incorporation of roof sediments including Sawawai and Bagh Marbles of Nowshera formation of Devonian age and microporphyries as enclave in the Ambela granite as xenoliths (Rafiq et al., 1988) suggest a post Devonian age for the granite. Reliable Rb-Sr isochron ages of 297-315 Ma (Le Bas et al., 1987) for Ambela Granitic Complex, U- Pb systematic of Zircon in the Malakand Granite (Zeitler, 1988) support such interpretation.

3. Late magmatic episode of basic dykes intrude most part of the internal zone (area between Main Mantle Thrust and Main Boundary Thrust) of Indian plate in

Peshawar plain, Swat and Hazara areas. These quartz-hypersthene normative continental tholeiitic basic dykes are considered to be most probably of Permain or Early Triassic age (Rafiq, 1987, Jan and Karim, 1990). These dykes cross cut the whole stratigraphic sequence of Paleozoic age in Peshawar, Swat and Hazara (Rafiq and Jan, 1989). No genetic age correlation of these dykes has been noticed with the microporphyries under discussion.

PETROGRAPHY

The newly investigated volcanic rocks exhibit porphyritic texture with feldspar-quartz phenocrysts in either fine gained or aphinitic groundmass. The rocks are bimodal in composition at places based on mineral contents, phenocryst/groundmass ratio and type of phenocryst. Volcanic glass is also common at various places.

Gajju Ghundai and Naugram Microporphyries

The microporphyies of Gajju Ghundai and Naugram are composed of phenocrysts of perthetised alkali feldspar (up to 5mm in diameter). Amphibole (richterite), epidote and minor plagioclase (An_{12-20}), ore, quartz and aegirine augite in the order of decreasing abundance (Table 1). Epidote amygdules with chlorite ± quartz and xenocrysts of basic rocks are also present. Overgrowths/reaction rims along the margins of amphibole (grains with brownish green core and green to greenish blue rim) are seen in most of the rocks. Fused margins of feldspar phenocrysts and concentration of fine blue amphibole and aegirine around them indicate metasomatic effect of late stage fluids and/or devetrification/reaction of phenocrysts with groundmass. The groundmass is either very fine grained aphinitic or glassy and its constituents are dominantly felsic with secondary epidote, bleby to tiny crystals of riebeckite, aegirine augite, ilmenite and rare sphene. The phenocrysts/groundmass ratio varies from 10/90 to 30/70. Blow vesicles are stretched indicating the direction of lava flow. These vesicles are mostly filled by the secondary limonite. Perlitic and variolitic structures are common in the groundmass. Linear orientation of primary mineral constituents is also observed which indicate flow phenomenon. Lenses, interrupted bands, patches of ash and fracture fills supporting a volcanic origin are also present.

Mansurai Ghundai microporphyries

In Mansurai Ghundai microporphyries, the phenocryst/groundmass ratio is higher than Gajju Ghundai. Also in the former location the phenocrysts are larger and a higher proportion of subhedral phenocrsysts surrounded by reaction rims of soda amphibole occur as compared to the latter, indicating a high degree of metasomatism and closer occurrence to the source of metasomatic fluids. The groundmass contains fine needles of epidote and arfvedsonite/richterite which follow the boundaries of phenocryst indicating flow phenomenon, in addition to indistinguishable felsic constituents.

The bands of felsic and occasionally of mafic volcanic ashes and lenses are noticed in these rocks.

Gohati Rhyolites

The Gohati rhyolites are exposed near Gohati village, Sherdarra, south-east of Jaffar Kandao, Sorai-Malanderai, Nawekilli along Totalai Chingalai roadside and at several other localities. The rhyolites are composed of thin and thick lava sheets well jointed and fractured with dimension blocks locally used as building stones. These rocks are grey to light grey in colour with well marked manganese dendrites along fractures. The rocks show flow structures, blow holes (1mm-10cm) partially filled with secondary epidote, quartz and ore. Plagioclase and alkali feldspar occur as phenocrysts (<5%) where as polygonal quartz (<1%), epidote, opaque ore and chlorite (amygdaloidal) occur as secondary phases.

Nawekili rhyolites are very similar in character to those exposed at Gohati village. Also the Nawekili rhyolite have vesicles following regular outlines and filled with alteration products.

The ground mass is generally glassy, but locally devitrified to very fine grained material composed dominantly (>90%) of felsic constituents. Secondary epidote, sericite, ore dust and chlorite occur as secondary product which cluster around elongated vesicles.

Tarakai-Rashakai and Tora-Tiga microporphyries

The microporphyries contain comparatively larger phenocrysts of cloudy perthetized alkali-faldspar (2 to 10mm), strained quartz, plagioclase (An_{12-18}), granitic rocks fragments and basic rock xenoliths (see modal composition table-1) as compared to Mansurai, all unevenly distributed. Also relatively smaller phenocrysts of primary hornblends are also present. Here the flow structure and foliation texture are more common than the early mentioned localities. Phenocrysts of alkali-feldspar are commonly corroded and show reaction with the groundmass along margins and cracks. Metasomatic acicular needles and fine irregular patches of richterite have developed along the fractures in alkali-feldspar phenocryst. Sodic amphibole has grown along the cleavages in primary hornblende.

TABLE 1. MODAL COMPOSITION OF SUBVOLCANIC-VOLCANIC ROCKS OF THE PESHAWAR PLAIN

S.NO	GJI	GJIA	GJ2	GJ2A	GJ3A	GJ4A GJ5A	GJ5	GJ7	GJ8 GJ11	GJ9A GJ10A
					Phenocrysts					
PAF	80	45	10	65	60	60	85	70	80	85
Pg	10	5		5	3		7	10	10	5
Qtz	7	5	90	10	7	10	8	5	5	5
RF	3	45		20	30	20		15		
Epi	Tr					5			5	Tr
Amp	Tr					5				5
Ore	-	Tr	Tr	Tr	Tr	Tr				
					Ground Mass					
FGM	80	80	85	70	68	65	88	90	85	95
Bio		1	Tr		Tr	Tr			Tr	
Epi	Tr	3	2		1	7	3		8	
Ore	5	6	4	5	15	12	5	3	5	2
Hbl		1				5		Tr	1	2
Bam	13	2				Tr	1	Tr	Tr	Tr
Aeg	Tr	Tr			Tr		Tr			
OreD		5	8	25	15	10	2	5	1	1
Sph	1	1								
P/G Ratio	20/80	20/80	10/90	25/75	30/70	25/75	10/90	10/90	12/88	10/90

S.NO	GJ12A	GJ13	JG13A	GJ14	GJ32	GJ41 GJ15	TAR1 TAR2		TARS
					Phenocrysts				
PAF	82	20	75	85	90	50	80	68	85
Qtz	10	70	5	5	5	10	10	12	10
RF	5	5	15	2	3	8	8	15	5
Epi			Tr			1	1		
Amp	2		2	5				1	
Ore		5	1	2	1	30		3	
					Ground Mass				
FGM	96	92	85	88	95	95	95	92	88
Bio			Tr					1	2
Epi		3	7	1		Tr	Tr	Tr	2
Ore	3	4	5	5	3	3	2	3	2
Hbl	Tr		2	2	1		1		
Bam	Tr		Tr			Tr	1	2	5
Aeg							Tr		Tr
OreD	1	1	1	5	1	1		1	Tr
Sph					1		Tr		
ALT									1
P/G	20	20	10	25	30	25	10	10	18
Ratio	80	80	90	75	70	75	90	90	82

Keys: Gj= Gjuu Ghundai, PAF=Perthitized Alkali Feldspar, Pg=Plagioclase, Qtz=Quartz, RF=Rock fragments, Epi=Epidote, Amp=Amphibole, FGM=Fine grained groundmass, Bio=Biotite, Hbl=Hornblende, Bam=Blue Amphibole, Aeg=Aegirine, OreD=Ore dust, Sph=Sphene, P/G=Phenocrysts/groundmass

S.NO	TAR Ash	TAR Tuff	RAS4	RAS9	RAS15	RAS14	MNS2	MNS4	MNS10	MNS11 MNS13
					Phenocrysts					
PAF		60	65	62	65	50	70	75	60	70
Pg		30	10	12	2	15	5	5	5	8
Qtz		10	7	12	30	30	15	15	20	12
RF			15	14	2	5	10	5	15	7
Epi										
Amp										
Ore	2		2							2
					Ground Mass					
FGM	96	88	89	91	78	95	77	80	88	85
Bio		8	3	2	2	1	Tr	Tr		
Epi		1	1	1	12	1	2	1	1	1
Ore	1	1	3	3	5	3	2	2	1	1
Hbl							2	3	1	2
Bam		Tr	1	1	1	Tr	15	12	7	8
Aeg		Tr	Tr		Tr	Tr	Tr	1	Tr	1
OreD	Tr	Tr	Tr				1	1	1	1
Sph						Tr	1	1	Tr	1
ALT	3		1			Tr	1		Tr	1
P/G	2	5	20	20	35	35	12	15	10	18
Ratio	98	95	80	80	65	65	88	85	90	82

Keys: TAR = Tarakai Ghundai, RAS= Rashkai Ghundai, MNS = Mansurai Ghundai, ALT=Alteration

The groundmass is fine-grained and composed of felsic constituents with streaks of aegirine, richterite, biotite, ore, sphene, and epidote. At Tarakai the high proportion of richterite (>5%) (Table 1), indicate higher metasomatic signature as compared to other localities.

In Tarakai Ghundai, ash and volcanic tuffs are interlayered with the acidic microporphyries.

Ambela microporphyries

Outcrops of acid and basic microporphyries intercalated with the metasedimentary sequence of Jaffer Kandao formation around Ambela granitic complex are exposed at Naugram, Ajmir Ghundai, Sherderra, Ziarat, Dheri-dhob, Sorai-Malandarai, Malandarai Kandao, Nawekili, Beshpur-Cheena and Karapa. On the basis of type and concentration of phenocrysts the acidic microporphyries can be classified as follows:

A) Microporphyries with dominant alkali-feldspar phenocrysts.
B) Microporphyries with dominant quartz phenocrysts.

Microporphyries of type "A" are light grey to dark grey in colour. Randomly oriented phenocrysts of alkali-feldspar with minor quartz and plagioclase occur embedded in a very fine grained groundmass of felsic minerals indicating a felsitic to spherulitic texture. The phenocryst groundmass ratio varies from 1:6 to 9:1 (Table 1). Perthetized alkali-feldspar phenocrysts are subhedral to anhedral in shape and vary in diameter from 1×1 to 2 ×3 mm. Plagioclase (An_{15-20}) is fresh, however, sausseritized and kaolinized grains are also present. The groundmass consists of 70 to 90 % of felsic and 30 to 10 % mafic (some identified as biotite, epidote) constituents.

The type "B" microporphyries consist of dominant quartz phenocrysts in addition to those of alkali-feldspar and plagioclase, together with some lithic fragments. Phenocrysts of quartz are medium to fine-grained subhedral with corroded margins. Most of these are fresh, strained and contain cavities filled with microlitic felsic groundmass. The phenocrysts/groundmass ratio varies from 1:5 to 1:1 (Table 1). The groundmass is similar to that of the type "A" microporphries with exception exhibiting flow structure.

Basic volcanic of Gajju Ghundai, Jaffar Kandao, Malanderai, Nawe-kili and Karrapa

Basic volcanic rocks (mostly green schists) are exposed east of acid microporphyries at Gajju Ghundai, in the metasedimentary sequence of Jaffar Kandao formation at Jaffar Kandao, Sorai Malanderai, Malanderai Kandao, Nawe-Kili and Karrapa. Although metamorphism has obliterated primary textures in these rocks, the porphyritic texture and cavity fills suggest their extrusive origin. Gajju Ghundai rocks are porphyritic in texture and contain mostly altered phenocrysts of plagioclase (An_{35-40} & 2 × 3 mm in diameter) and cavity fills of epidote and quartz. Epidote, chlorite, and white mica in association with quartz are found as the alteration products of phenocrysts. Some cavities indicate epidote core successively rimmed by chlorite, epidote, quartz and finally again by epidote.

Chlorite schists containing large crystals of epidote (formed after plagioclase phenocryst) exposed at Nawe-kili, Malanderai Kandao and Cheena are generally similar to Gajju Ghundai volcanics on the basis of mineralogy and texture. Here the groundmass is fine-grained, showing schistose texture, and amphibole, epidote, chorite and orange red ore can be recognised in these rocks.

GEOCHEMISTRY

Twenty two representative samples marked in Figure 1B were selected for chemical analyses. Major element analyses were carried out in duplicate using atomic absorption and flame spectro photometer. Minor, trace and rare-earth elements, together with Na_2O, K_2O and FeO were analysed using Neutron activation techniques. The data is present in Table 2.

TABLE 2: MAJOR AND TRACE ELEMENT ANALYSES OF SUBBOLCANIC, VOLCANIC ROCKS OF PESHAWAR PLAIN

S.NO	GJ2	GJ3A	GJ3	GJ4	GJ5	GJ6	GJ8	GJ11	GJ12A	GJ35	GJ41
Wt%	68.92	71.52	66.92	70.14	69.34	71.08	70.62	71.4	69.5	76.12	74.28
SiO_2	0.12	0.13	0.13	0.13	0.14	0.12	0.13	0.7	0.13	0.13	0.12
TiO_2	13.76	12.8	12.76	13.22	13.31	14.32	13.1	14.01	13.86	13.8	13.89
Al_2O_3	3.14	2.9	3.03	3.26	3.78	3	3.3	3.1	3.06	2.06	3.24
MnO	0.16	0.13	0.13	0.17	0.16	0.17	0.11	0.11	0.13	0.13	0.22
MgO	2.22	1.94	2.72	2.41	3.03	2.02	1.06	2.07	2.67	0.35	0.64
CaO	1.55	3.66	3.88	2.1	2.3	2.03	2.03	2.01	5.21	0.2	0.21
Na_2O	3.89	1.08	1.38	5.76	5.59	3.41	4.53	4.24	1.81	0.84	2.32
K_2O	2.71	4.91	3.94	2.52	2.27	4.11	6	3.23	3	4.73	5.43
P_2O_5	0.18	0.15	0.12	0.31	0.18	0.2	0.17	0.32	0.32	0.06	0.03
Ig.l	0.51	1.26	1.59	0.54	0.7	0.42	0.34	0.3	0.41	1.86	0.26
Total	98.53	100.48	99.65	100.56	100.8	100.88	101.39	100.49	100.1	99.28	100.64
Ppm											
Sc	7.2	6.9	7.2	8	8.4	6.9	7.7	7.3	7.6	4.8	7.7
Cr	0.5	6	2	5	1	3	3	1	1	2	4
Co	0.4	0.6	8.3	0.4	1.7	0.5	0.2	0.2	0.8	0.2	0.3
Ni	29	6.6	7.5	37	38	37	51	22	26	16	40
Zn	124	70	8.4	89	98	88	95	110	87	85	142
As	108	4.9	4.2	9.9	7.6	5.4	101	3.6	3.5	7.5	5.4
Sb	0.3	1.3	1	0.4	0.5	0.2	0.4	0.3	1.2	1.1	0.4
Se	13.3	13.4	12.9	15.1	9.9	12.4	13.3	13.5	13.6	9.4	12.5
Rb	121	1.4	113	33	68	139	156	120	91	140	174
Cs	0.88	3.2	5	0.25	3.5	0.4	0.8	0.6	2	4.3	1.6
Sr	1	419	358	2	211	99	1.4	1.3	479	1.1	1.2
Ba	767	534	695	560	119	545	475	535	707	807	617
La	111	111	1413	126	113	74.2	116	107	114	77.2	115
Ce	232	256	140	297	350	155.9	238	226	245	186.3	270
Nd	110	123	113	143	121	75.8	113	107	116	90.8	129
Sm	24.49	21.93	23.82	26.05	22.2	17.64	21.84	22.55	23.47	17.17	26.12
Eu	5.57	5.04	5.45	6.31	5.73	4.28	5.17	5.29	5.52	3.88	5.96
Tb	3.38	2.91	3.26	3.16	2.69	2.55	3.06	3.23	3.33	2.23	3.4
Yb	8.77	7.78	8.5	8.75	6.02	7.25	8.62	8.42	8.91	5.85	8.68
Lu	1.12	1.05	1.14	1.14	0.73	0.92	1.18	1.06	1.14	0.82	1.16
Zr	749	753	741	800	522	607	817	738	741	535	885
Hf	27.8	36.4	25.9	35	61.5	3434	30.9	27.4	26.2	19.7	31.2
Ta	8.5	8.6	8.3	10.3	6	7.5	9.4	8.5	8.6	6.9	9.3
W	11	3	5.1	8.4	5.4	4.5	9.6	1	6.6	1	4.2
Th	20	19.1	19.7	21.9	14.6	18.2	21.9	20	20.2	17.2	23
U	2	4.8	4.7	5	4.1	3.2	3.4	3.5	5.1	2.8	4.9

S.NO	TAR2	TAR8	RAS2	RAS15	MNS4	MNS19	TT5	TT16	G17B	G11	GJ1B
Wt%											
SiO2	71.5	70.42	73.96	73.4	69.54	71.36	73.04	72.55	55.08	73.16	48.14
TiO_2	0.13	0.12	0.13	0.12	0.13	0.11	0.12	0.13		0.61	
Al_2O_3	15.84	15.94	14.25	14.05	15.88	16.02	15.19	14.98	22.08	13.85	19.36
Fe_2O_3	3.05	3.25	3.27	3.19	3.78	3.46	2.3	2.69	10.92	0.33	7.14
MnO	0.15	0.13	0.13	0.11	0.12	0.14	0.11	0.12	0.12	0.15	0.13
MgO	0.13	0.13	0.11	0.13	0.14	0.13	0.08	0.09	2.27	0.26	4.71
CaO	0.49	0.45	0.13	0.2	0.5	0.31	0.32	0.11	9.52	1.2	14.37
Na_2O	5	4.8	4.42	4.65	3.02	3.96	4.79	3.95	1.51	4.8	1.32
K_2O	3.45	4.52	3.62	5.01	4.71	4.01	3.98	3.71	1.53	4.5	3.62
P_2O_5	1.13	0.11	0.12	0.05	0.17	0.04	0.05	0.07		0.26	
Ig.l	0.77	0.58	0.13	0.35	1.95	1.2	0.4	1.23	1.85	0.65	2.25
Total	100.64	100.45	100.27	100.27	99.94	100.74	100.38	99.63	100.61	99.77	101.04
Ppm											
Sc	4.9	6.5	6.5	5.7	8.3	8	4.5	4.4	39.8		38.8
Cr	1	0.4	4	2	5	5	2	8	150		147
Co	0.7	0.7	0.8	0.3	1.1	1.1	0.2	0.8	39.5		42.4
Ni	7.8	29	35	26	7.5	33	28	27	84		71
Zn	113	60	123	92	169	148	133	111	171		156
As	6.6	9	3.6	7.2	4.8	6	6.3	5.7	8.1		5.5
Sb	0.4	0.2	0.2	0.3	0.3	0.6	0.5	0.6	7.2		0.3
Se	12.8	11.9	9.8	11	13.3	12.9	11.4	12.3	4.8		4.5
Rb	91	124	106	129	121	148	111	144	42		24
Cs	7	0.72	0.74	0.79	0.51	1	0.5	1.5	0.86		0.43
Sr	170	90	1.3	9.6	1.3	1.6	8.7	1.9	282		263
Ba	965	547	466	500	587	648	666	678	266		227
La	114	112	111	110	30.8	110	105	134	11.5		11.2
Ce	251	256	242	260	130	282	252	227	23.7		24.8
Nd	121	116	115	123	61	129	119	125	13.8		14.9
Sm	24.99	20.42	21.27	22.29	14.46	25.58	22.77	26.87	3.91		3.97
Eu	6.24	4.69	4.8	4.81	3.54	5.94	4.66	6.06	1.42		1.44
Tb	3.18	2.71	2.89	2.91	2.28	3:34	2.93	3.31	0.73		0.71
Yb	7.56	6.7	6.14	7.01	8.18	8.29	7.03	7.41	2.56		2.36
Lu	97	1387	0.83	1.03	177	1.17	1	1	0.33		0.33
Zr	823	580	638	680	900	894	697	766	188		77
Hf	27	21.2	20.6	24.2	32.2	29.4	24.3	27.1	2.9		2.7
Ta	8.2	6.8	7	8	9.5	9.5	8.5	9	0.58		0.6
W	2	3	2	6	3.9	6	4.8	2	3		4.5
Th	17.8	15.9	17.4	18.5	24.9	21.7	18.9	22.2	1.9		1.6
U	3.6	3.3	3.7	4	6.4	5.3	44	3.6	1.1		2.1

Majority of the felsic modal data of microphorhyries displayed on Bowden (1985), QAP diagram show A-type affinity (alkaline) Fig. 2a. On the Heitenen's (1963) and O'Conner's (1965) classification diagrams majority of these microporphyries fall in the granitic (rhyolite) field (Fig. 2b, 2c). Also majority of the data plot in the field shown for rhyolite on the R_1 Vs R_2 diagram (Fig. 3) of De La Roche (1978, 1980).

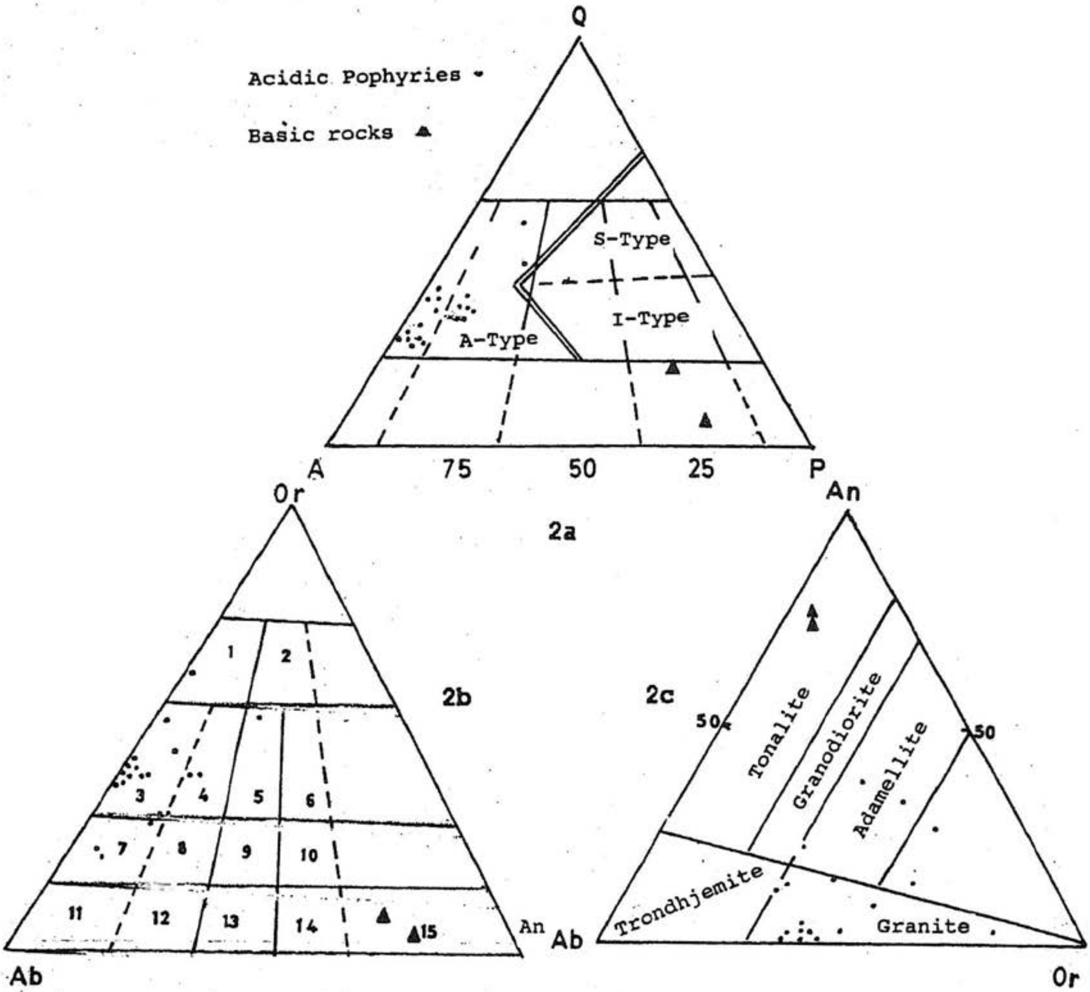

Fig. 2a. QAP plots of subvolcanic-volcanic rocks from Peshawar plain on triangular diagram. Boundaries between A, S and I-type granites are from Bowden (1985).

Fig. 2b. Normative classification of subvolcanic-volcanic rocks from Peshawar plain according to Heitanen (1963). Symbols as in Fig. 2a.

1. Kaligranite.	2. Calcigranite.	3. Granite.	4. Quartzmanzonite.
5. Manzonite.	6. Calcimanzonite.	7. Trondhjemite.	8. Manzotonalite.
9. Granodiorite.	10. Granogabbro.	11. Trondhjemite.	12. Tonalite.
13. Quartzdiorite.	14. Gabbro.	15. Mafic Gabbro.	

Fig. 2c. Ternary plots of normative An-Ab-Or for subvolcanic-volcanic rocks from Peshawar plain according to O'conner (1965). Symbols as in fig. 2a.

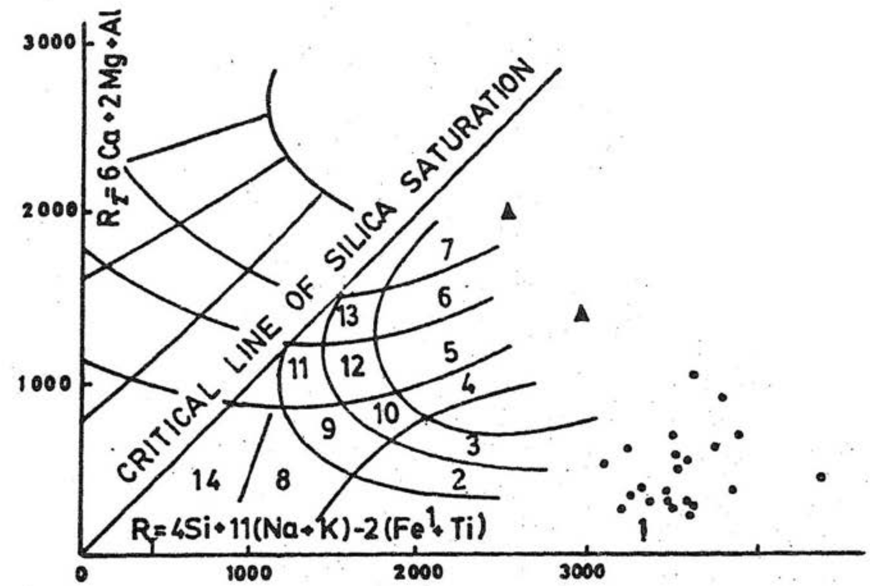

Fig. 3. R_1 vs R_2 Diagram (after De la Roche, 1976) for Late Paleozoic subvolcanic-volcanic rocks from Peshawar plain.

The distribution of selected minor and trace elements (Ti, Zr, Y, Nb, Ce, Ga and Se) which are generally considered to remain inert during secondary processes can be used to classify rocks of alkaline and subalkaline series. On the SiO_2 Vs Zr/TiO_2 and Ce Vs Zr/TiO_2 diagram of Winchester and Floyed (1977) majority of the data plot in the commendite indicating alkaline affinities (Fig. 4a, 4b).

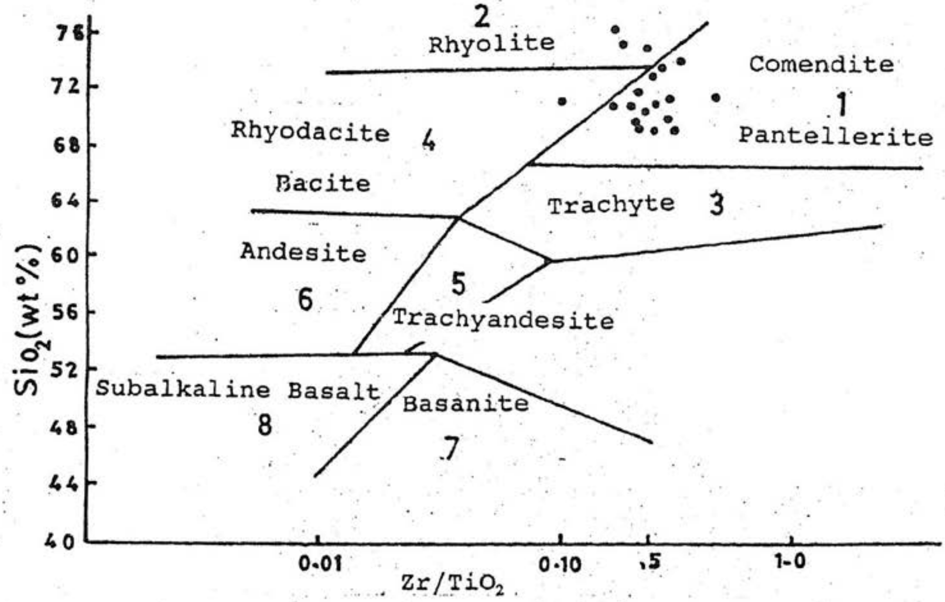

Fig. 4a. Zr/TiO_2-SiO_2 diagram showing the limited fields for the subvolcanic-volcanic rocks from Peshawar plain.

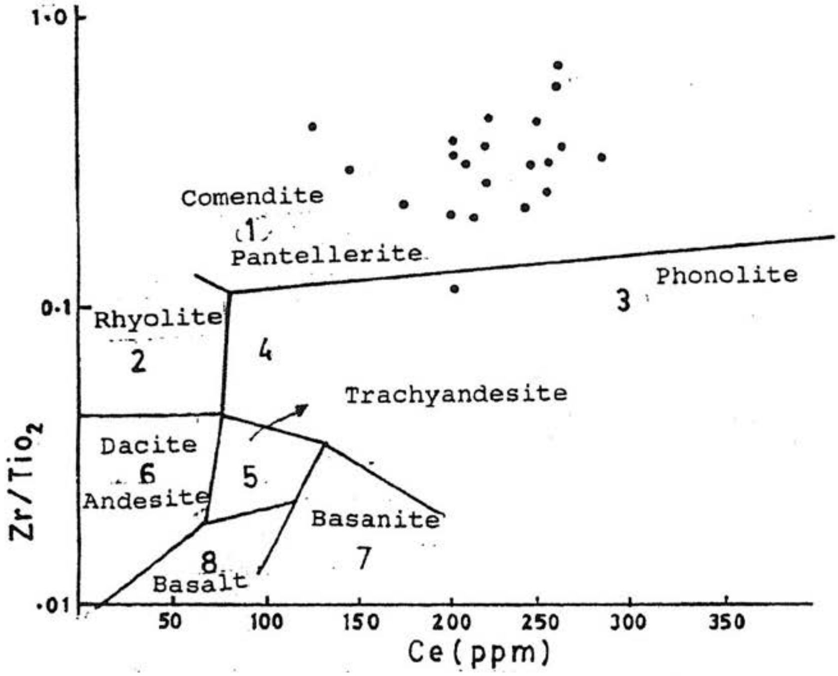

Fig. 4b. Zr/TiO_2-Ce diagram showing distribution of subvolcanic-volcanic rocks from Peshawar Plain.

On the A/CNK Vs A/NK plot (Fig. 5a) of Maniar and Piccoli (1989) these microporphyries indicate peraluminous to metaluminous character with majority of the data showing $Al_2O_3/Na_2O + K_2O$ ratio between 1:00 and 1:4. On the alkalis Vs silica diagram of Miyashiro (1978) (Fig. 5b) the data is scattered in the fields shown for both alkaline and sub alkaline rocks with majority of the plots in the field of alkaline rock. On the alkali-silica diagram of Le Bas et al., 1986; however, these rock occupy the alkali-rhyolitic field (Fig. 5c).

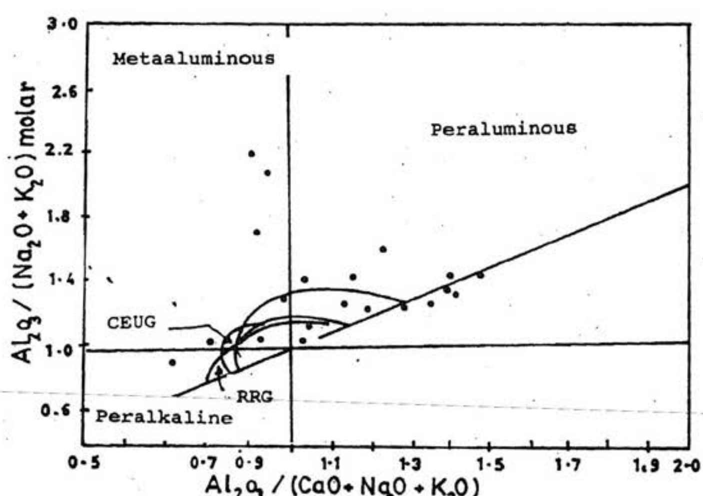

Fig. 5a. Chemical character and tectonic discrimination based on Shand's index for the subvolcanic-volcanic rocks from the Peshawar Plain.

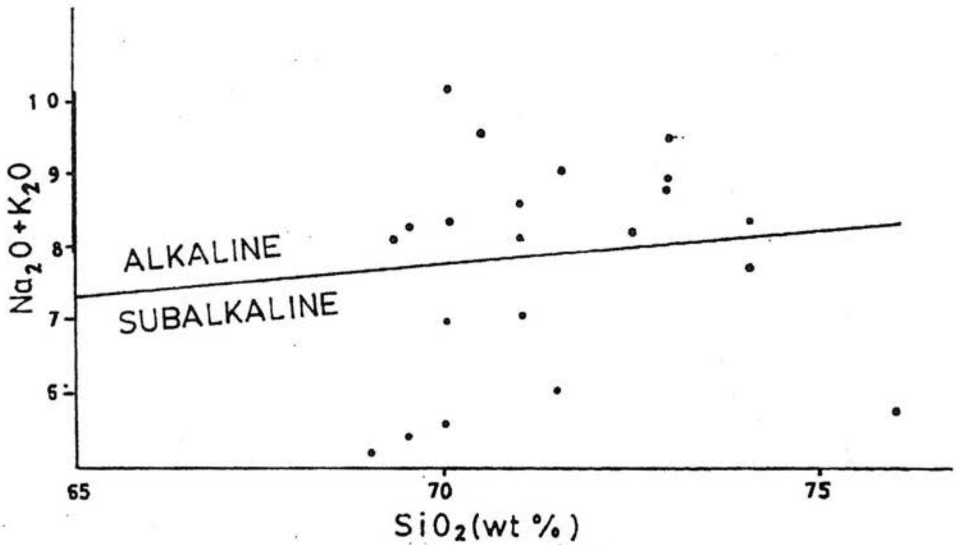

Fig. 5b. Silica-alkali diagram for subvolcanic-volcanic rocks from Peshawar Plain. Line represents boundary of alkaline and subalkaline fields, after Miyashiro Symbols as in Fig. 2a.

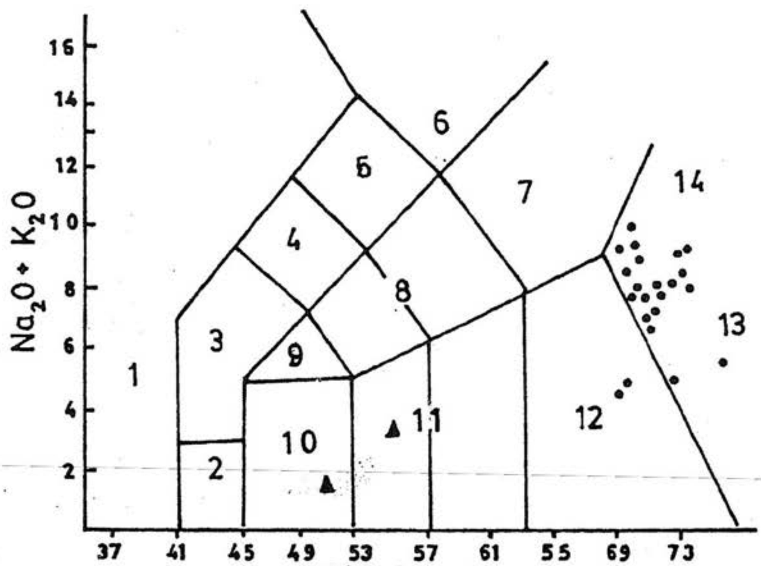

Fig. 5c. Classification based on total alkalies-silica for the subvolcanic-volcanic rocks from Peshawar Plain (after Le Bas et al., 1986).

To distinguish and characterise different rock type, Wright (1969) used alkalinity ratio (Al_2O_3 + CaO + total alkalies / Al_2O_3 + CaO - total alkalies) verses SiO_2 especially for more acid varieties. Eighty percent of the data falls in the alkaline field with the rest falling in the calc-alkaline field (Fig. 6). On the basis of average alkalinity ratio (3:%), these rocks correlate with younger granitic rocks of Northern Nigeria of Jacobson et al., 1958.

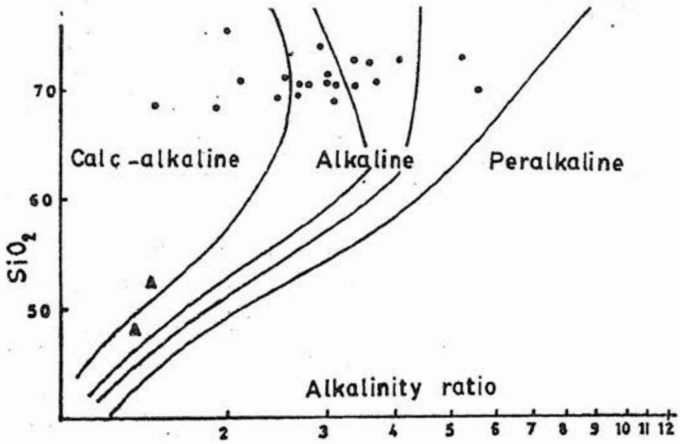

Fig. 6. Alkalinity ratios vs silica diagram showing plots of subvolcanic-volcanic rocks from Peshawar Plain (after Wright - 1969).

Paleotectonic setting of subvolcanic-volcanic rocks

To relate the chemical composition of the rocks to tectonic setting Christiansen and Tipman (1972) used CaO/ (Na_2O + K_2O) ratio to distinguish rocks from orogenic and nonorogenic environments. Majority of the plots indicate extensional environments on the CaO/Na_2O + K_2O Vs SiO_2 plot of Petro et. al, 1979 (Fig. 7).

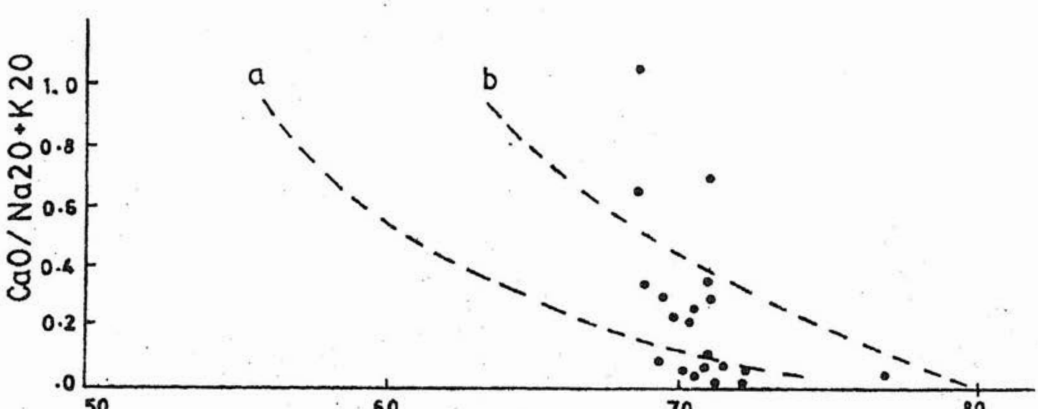

Fig. 7. Variation diagram using Ca/Na_2O+K_2O vs SiO_2 for the subvolcanic-volcanic rocks from Peshawar Plain (after Petro et al., 1979). a) Extensional b) Compressional Environment.

Minor Elements

On the Ta-SiO_2 diagram, (Fig. 8a) 92 percent of the plots occur in the WPG (within plate granite) + ORG (Orogenic granite) field, whereas, on Rb-SiO2 majority of the data show greater affinity towards anorogenic environment (Fig. 8b). On the Yb-Ta diagram of Pearce et al., 1984 (Fig. 9a) all the data is exclusively confined to the field of WPG. The Zr Vs SiO_2 diagram of Pearce and Gale (1977) also classify these microporphyries as within plate granite (Fig. 9b).

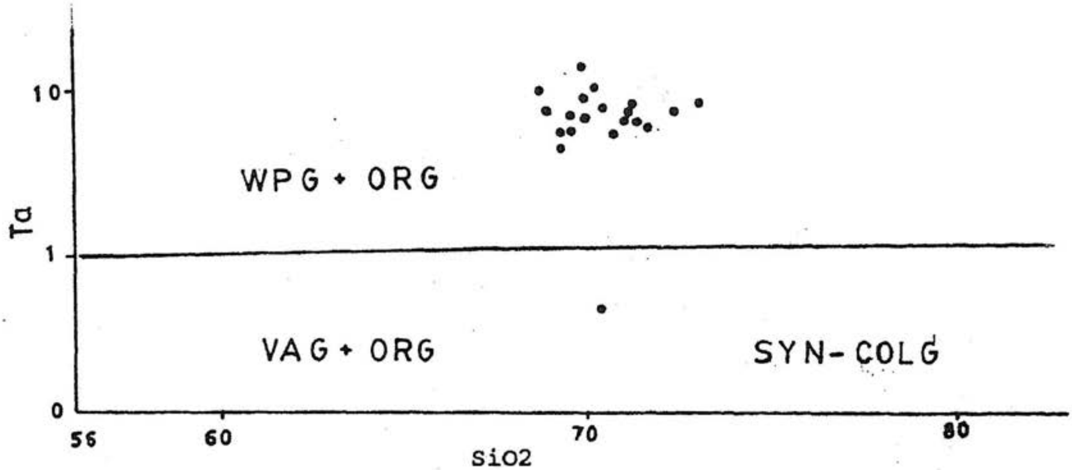

Fig. 8a. SiO_2-Ta diagram based on analysis of subvolcanic-rocks from Peshawar Plain. (after Pearce et al., 1984).

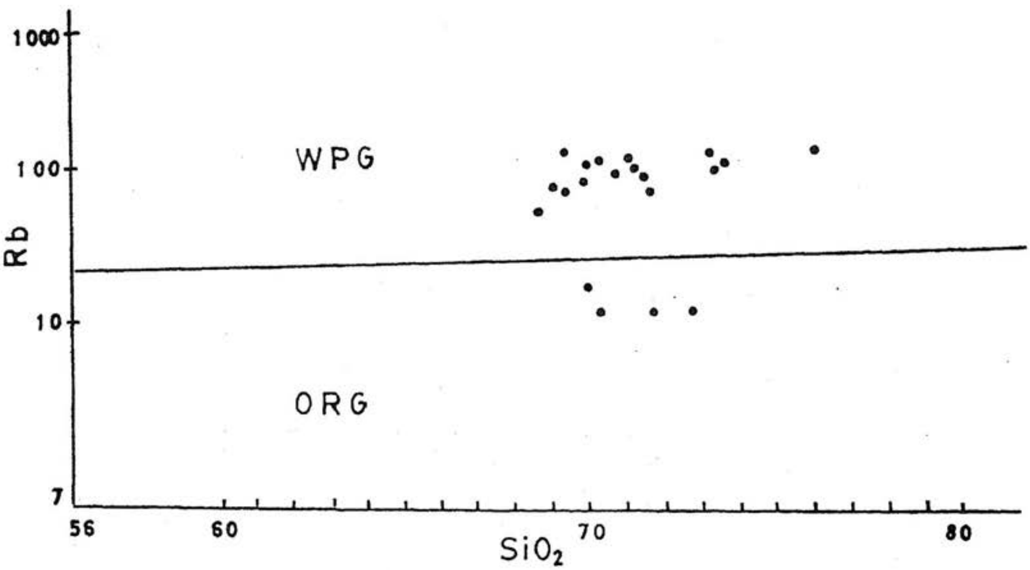

Fig. 8b. SiO2-Rb diagram based on analysis of subvolcanic from Peshawar Plain (after Pearce et al., 1984).

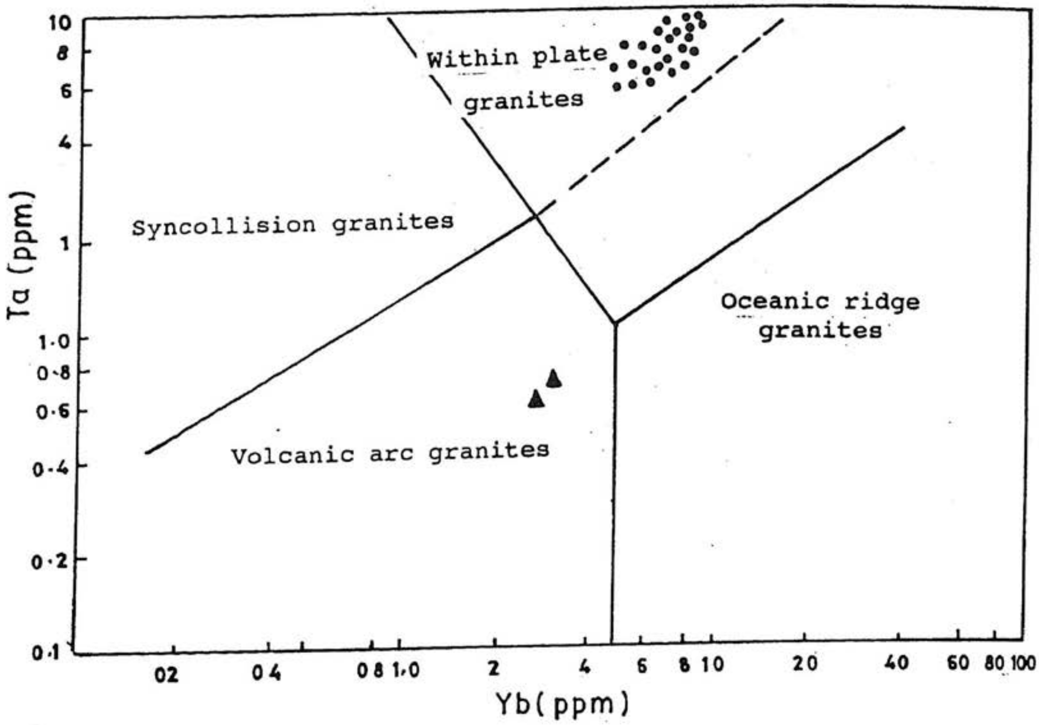

Fig. 9a. Ta vs Yb plots for the subvolcanic-volcanic rock from Peshawar Plain (after Pearce et al., 1984).

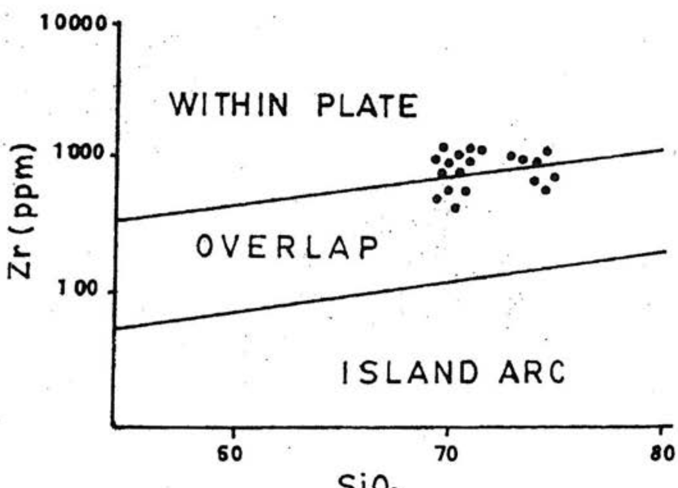

Fig. 9b. Zr vs Silica plots for subvolcanic-volcanic rock from Peshawar Plain (after Pearce and Gale, 1977).

On the Th-Hf-Ta triangular diagram (Fig. 10) Wood et al., (1979) and Wood, 1980), the rock straddle along the boundaries of E-type MORB (Mid Oceanic Ridge Basalt), tholeiitic within plate basalts and within plate Alkaline basalts indicating transitional characters. However, two rocks plot near the calc-alkaline boundary of Th and Hf most probably reacted to crustal contamination (see Wood 1980).

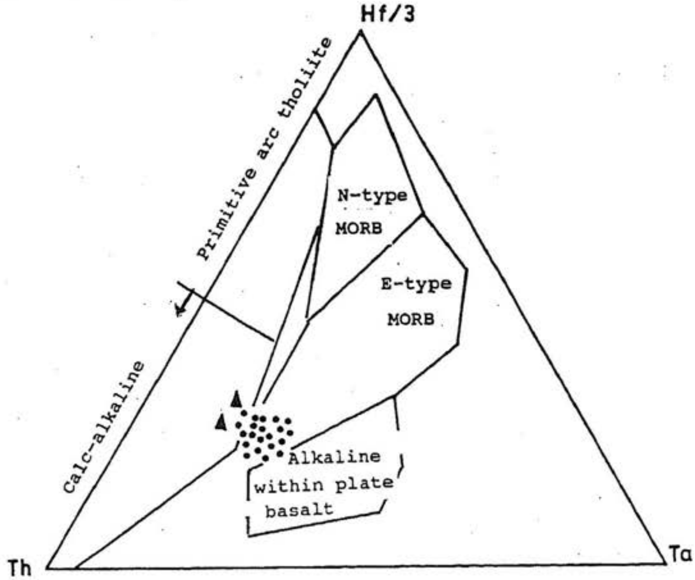

Fig. 10. Th-Ta-Hf/3 plot for subvolcanic-volcanic rock from Peshawar Plain (after Wood, 1980).

MAGMA SOURCE

As stated earlier, the subvolcanic-volcanic rocks of Peshawar plain are characterised by a dominance of acidic magma. Basic rocks are present locally in a small proportion (Gujju Ghundai, Shewa-Shahbaz Ghari, Nawi-Kili, Krappa etc.). The preponderance of felsic magma has been described in Ambela Granitic Complex which is considered to be specially related to these microporphyries and rhyolites (Rafiq, 1987; Rafiq and Jan, 1989).

By computing the well documented data, Bouseily et al., 1985 based on rocks with a mantle source noted that there is an increase of Ba from 55 ppm and Rb from 190 in the normal granites to Ba 100 ppm and Rb 260 in the strongly differentiated granites. In the case of rocks under present investigation both Ba and Rb contents are extremely high with the former varying 466 to 1190 ppm and the latter from 66-174 ppm similar values have also been obtain from the Ambela Granitic Complex (AGC) and associated acidic microporphyries (Rafiq, 1987). Such value may, therefore, point either to high degree of crustal contamination or lower crustal melting as a source for these rocks. Working on trace element data, Gerasimovsky (1974), stated that rock having low content of Sr may be considered as the product of palingenesis, and those with high Sr, the product of crystallization from residual melt. Our results of 60 % rocks show very low values of Sr (1.7-9 ppm) and the rest from 90-419 ppm. This data very much favour their palingenetic origin. Rocks with a little high Sr contents may have produced through hybridization of silicic melt by deeper source component (upper mantle).

The Sm/Nd ratio of the rocks under present investigation is about 0.2, and simple batch-melting calculations of a garnet/ herzolite

(Hawkesworth et al., 1979) indicate that mantle of such a composition only provide melts with trace-element characteristic similar to that of granite (Hawkersworth et al., 1979). Such type of limited melting from mantle would result undersaturated melt (Green, 1973). All the rock types (except basic members) under study are oversaturated and require a quartz normative parent, with enriched LREE (Light Rare Earth Elements). This suggest a source in the crust (just separated from LREE depleted mantle) or a source in the mantle which has undergone enrichment shortly before melting. The mantle derived basic magma produce several time more basic fractions than the acidic ones. Looking into voluminous silicic rocks exposed in the region with very minor basic fractions (at Gajju Ghundai, Nawi Kili, Krappa, this study), it is therefore, proposed that these acidic subvolcanic-volcanic rocks are of crustal origin.

The main features of the chondrite-normalised complete rare earth abundance pattern (Fig. 11) are enrichment in the light REE (La to Sm) relative to heavy REE (GD to Yb), development of a negative Eu anomaly and a small but distinct decrease of the heavy REE from Gd to Yb; all indicating transitional characters between alkaline to mildly alkaline of crustal origin. (see also Rafiq, 1987).

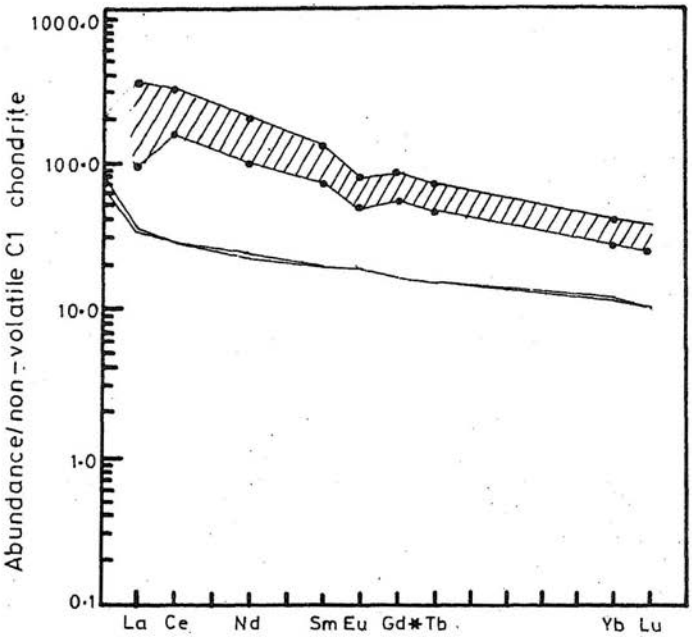

Fig. 11. Chondrile-normalized REE Pattern of Late Paleozoic volcanic rocks from Peshawar Plain, NW Pakistan.

Marked negative Eu-anamolies are distinctive of all the rocks and, together with the slightly less steep HREE profile, and similar to many other acidic rock elsewhere (i.e. from the British Tertiary volcanic province; Walsh and Hinderson, 1977; Meighan, 1979; Meighan et al., 1964). The interpretation of Eu depletion is to ascribe its effect to fractionating plagioclase and alkali feldspar preferentially removing Eu from the residual liquid. However, the experimental work by Flynn and Burnham (1978) have demonstrated that Eu is preferentially incorporated into the fluid phase. Based on this and other evidence Muecke and Clarke (1981) have suggested that Eu leaching by fluoride or the metasomatic fluids were the main mechanism of Eu-depletion. In addition, the high Cs/Rb ratio of some of the samples is a good indication of hydrothermal alteration. Microporphyries and rhyolites from Peshawar plain may be related to effect of metasomatic phenomenon induced by successive periods of rock-fluid interaction (Rafiq, 1987). Evidence of albitization and sodium metasomatism in these rocks (see petrography) support such interpretation.

CONCLUSION

Based on the evidence presented in this paper it is concluded that the microporphyries and rhyolite rocks of the Peshawar plain belong to the A-type spectrum.

Petrographic and chemical characters classify these rocks as rhyolites of peraluminous character. Major elements and their various ratios suggest a mildly alkaline character, while HFS elements, Hf/Th and Hf/Ta ratio support such an interpretation.

The concentration of discrimination elements in the subvolcanic-volcanic rocks indicate an anorogenic environment of eruption, which took place in a rift setting representing the initial phases of fracture. Th-Hf-Ta diagram favours the generation of magma from a deep crustal reservoirs accumulation at higher limits in the crust and subsequently contaminated by more silicic rocks. This is also reflected in concentration of Hf and increase in Hf/Ta and Hf/Th ratios.

All samples display Eu anomalies more or less similar to aluminous and peralkaline anorogenic granitic rocks of Nigeria (Bowden et al., 1979; Bowden, 1985) and demonstrate fluid solid rock interaction, confirming soda metasomatism due to late magmatic phases.

Intercalation of these rocks with the Jaffar Kandao formation (of Carboniferous age) suggest an early Carboniferous acidic magmatism in the Region.

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