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PETROGRAPHY OF THE AMBELA GRANITIC COMPLEX, NW PAKISTAN

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ABSTRACT

The Ambela granitic complex occupies the southeastern part of the Buner subdivision of Swat. It is a composite batholith consisting of a variety of oversaturated (70%), saturated (20%), and undersaturated rocks (50%). The batholith may have formed over a considerable length of time, spanning from middle to late Paleozoic. Petrographic studies (800 thin section) allow a three fold grouping of the rocks. Group I includes granites, alkali granites and microporphyrites; these appear to represent the early magmatic episode of the complex. Group II includes quartz syenites, alkali quartz syenites, syenites, feldspathoidal syenites, carbonatite, ijolite, lamprophyre, and associated pegmatites and fenites. Considerable metasomatic changes were associated with successive alkali rich intrusive phases of this group of rocks. Basic dykes (Group III), intruding both Group I and II rocks, represent the last magmatic episode and constitute about 5% of the complex. This paper presents petrographic details of the various types of rocks in the complex.

INTRODUCTION

Several episodes of granitic magmatism from northern Pakistan, ranging from Proterozoic to those related to the tectonic evolution of the Karakoram-Hindukush-Himalayan ranges, have been described by Jan et al. (1981) and Shams (1983). Among these, the complexes constituting the alkaline igneous province stretch over a distance of 200 km in the north of Peshawar Plain (Kempe and Jan, 1980). The Ambela granitic complex (AGC), thought to be a member of this igneous province, was first described by Martin et al. (1962). This batholithic mass comprises a varied assemblage of granites, alkali granites, quartz syenites, syenites, feldspathoidal syenites and related rocks, and basic dykes. It covers over 900 km^2 area of the southern part of Buner (Swat district) and northern extremities of Mardan district in the N.W.F.P. (Fig. 1).

Early workers (Siddiqui, 1965, 1967; Siddiqui et al., 1968) restricted their studies to the north and north-central part (Koga area) of the AGC and suggested that these rocks were the products of a peralkaline syenitic magma. Later on, Kempe and Jan (1970, 1980), Ahmad and Ahmed (1974), Kempe (1983), Chaudhry et al., (1981) and Rafiq et al. (1984) grouped these with other rocks of the alkaline igneous province and considered them related to rebound relief tension or rifting during Late Cretaceous or Early Tertiary. Shams (1983) described the rocks of the alkaline igneous province (including the AGC) as reconstituted and remobilized basement belonging to the northern margin of the Indo-Pakistan craton. Le Bas et al. (1986) published Rb/Sr isochron ages for the Ambela complex. The Babaji granites and syenites have an age of

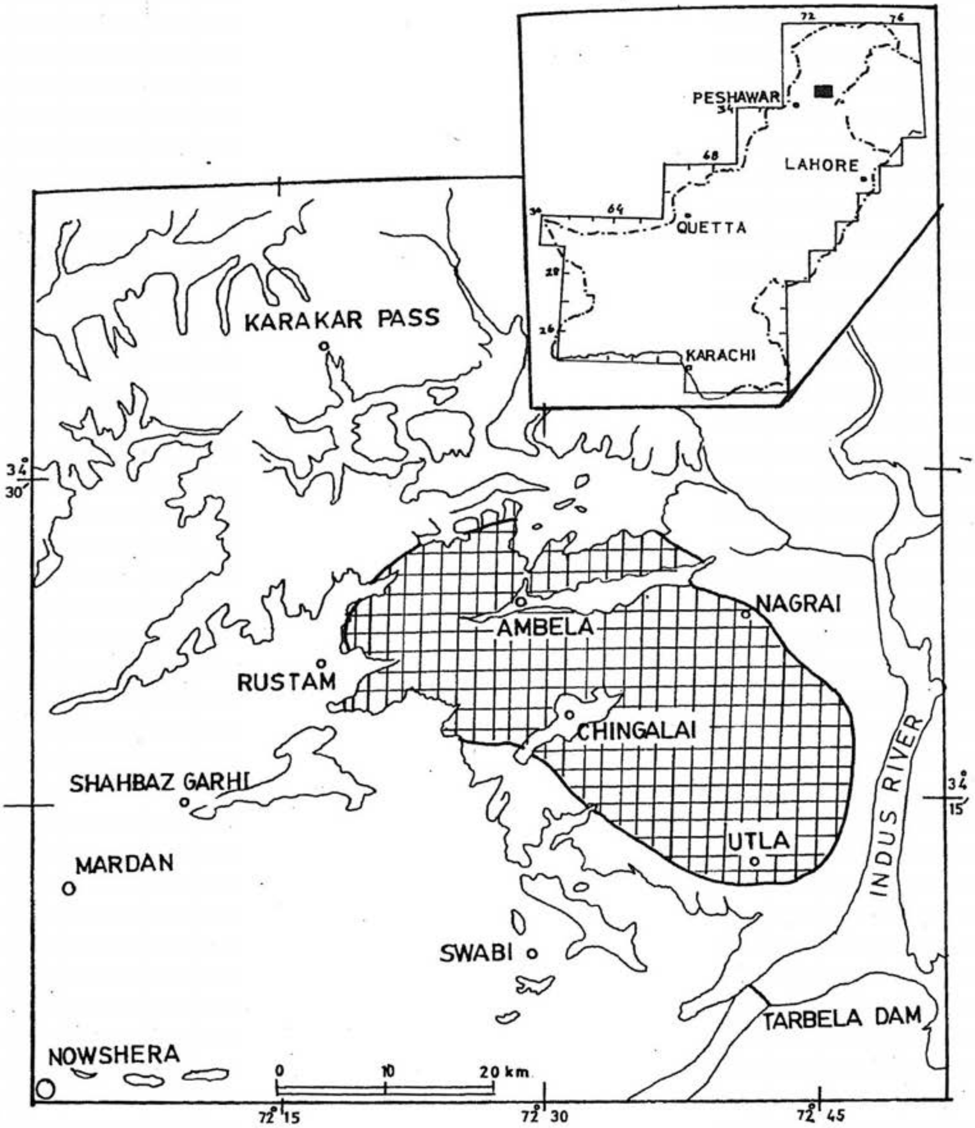

Fig. 1. Index map showing the location of the Ambela granitic complex, N.W.F.P., Pakistan.

315 ± 15 Ma, whilst the Koga nepheline syenites and ijolites intruding them are dated at 297 ± 4 Ma. U–Pb dating of zircon from Koga confirms their Carboniferous age (Zeitler, 1988).

In this paper we present a generalized account of the petrography of the various rock types in the AGC. The complex was mapped on 1:50,000 scale (simplified and reduced in Fig. 2) and more than 1200 samples were collected. Of these, 800 were cut into thin sections and 175 were analysed chemically. Details of geochemistry would be presented in a separate paper. This paper does not describe the Shewa-Shahbaz Garhi "microgranites" occurring to the SW of the complex.

GENERAL GEOLOGY

The area between the Main Mantle and Main Boundary Thrusts in northern Pakistan is characterized by a series of thrusts and nappes (Tahirkheli, 1982; Treloar, 1989). This area represents the northwestern margin of the Indo-Pakistan plate and consists of a Precambrian basement and Paleozoic to Mesozoic cover (Ashraf et al., 1980; Coward et al., 1982, 1986; Baig et al., 1988). The country rocks into which are emplaced the various complexes of the alkaline igneous province include slates, phyllites, pelitic and psammitic schists, quartzites, calcareous schists, limestone, marbles and granitic gneisses of Precambrian and Paleozoic ages.

The host rocks for the Ambela granitic complex belong to the Lower Swat-Buner schistose group on its north and the Swabi-Chamla sedimentary group on its south (Martin et al., 1962). On the southwest of the complex is the alluvium of the Peshawar Plain. The metasedimentary series north and south of the complex show a NE–SW to E–W regional structural trend. The structural elements within and in the immediate vicinity of the complex deviate very little from the regional trend, and fluctuate between N 25°E to N 45°E. Rocks of the complex are at places gently-folded, cut by numerous faults and are intruded by basic dykes.

PETROGRAPHY

Several petrographic varieties constitute the AGC. These were classified according to the nomenclature of Streckeisen (1976) into three groups. Group I consists of oversaturated rocks, i.e. granites and alkali granites. Group II comprises quartz syenites, alkali quartz syenites, syenites, alkali syenites and their close associates forming minor bodies of carbonatites, fenites, lamprophyres and related pegmatites. Group III incorporates the local and small masses of basic dykes. The individual rock units vary from a few square meters to several square kilometers in surface extension. These occur as thin to thick and extensive sheet-like masses, displaying very gentle folding and transverse faulting.

In the central part, particularly along the road section from Khanpur to Ambela Kandao, the granites and alkali granites are studded with xenoliths ranging from a few centimeters to two meters in size. These are greyish black to greenish black in colour and contain variable proportions of alkali-feldspars, quartz, biotite (locally abundant), epidote, sphene, in some hornblende and in rare cases chloritoid. The phenomenon of contact metamorphism was not studied during the present investigation.

Group I Rocks

The granites and alkali granites constituting the Group I rocks make nearly 70 per cent of the surface exposure of the Ambela complex. These are the predominant rocks between Rustam in the West, Utla in the southeast and Nagrai in the northeast (Fig. 2). These rocks are subdivided into various textural varieties, ranging from very coarse-grained porphyritic granites to microporphyrites and tuffs on one hand, and very coarse-grained granites to aphyric rhyolite on the other. The various textural types are separately described in the following. Modal compositions are presented in Tables 1, 2, 3 and plotted in Fig. 3.

Porphyritic Coarse-Grained Granites: These appear to constitute the earliest member, forming an elongated, oval-shaped body occupying about 60% of the central part of the area covered by the granites. The northern and north-western contacts of these granites are faulted against

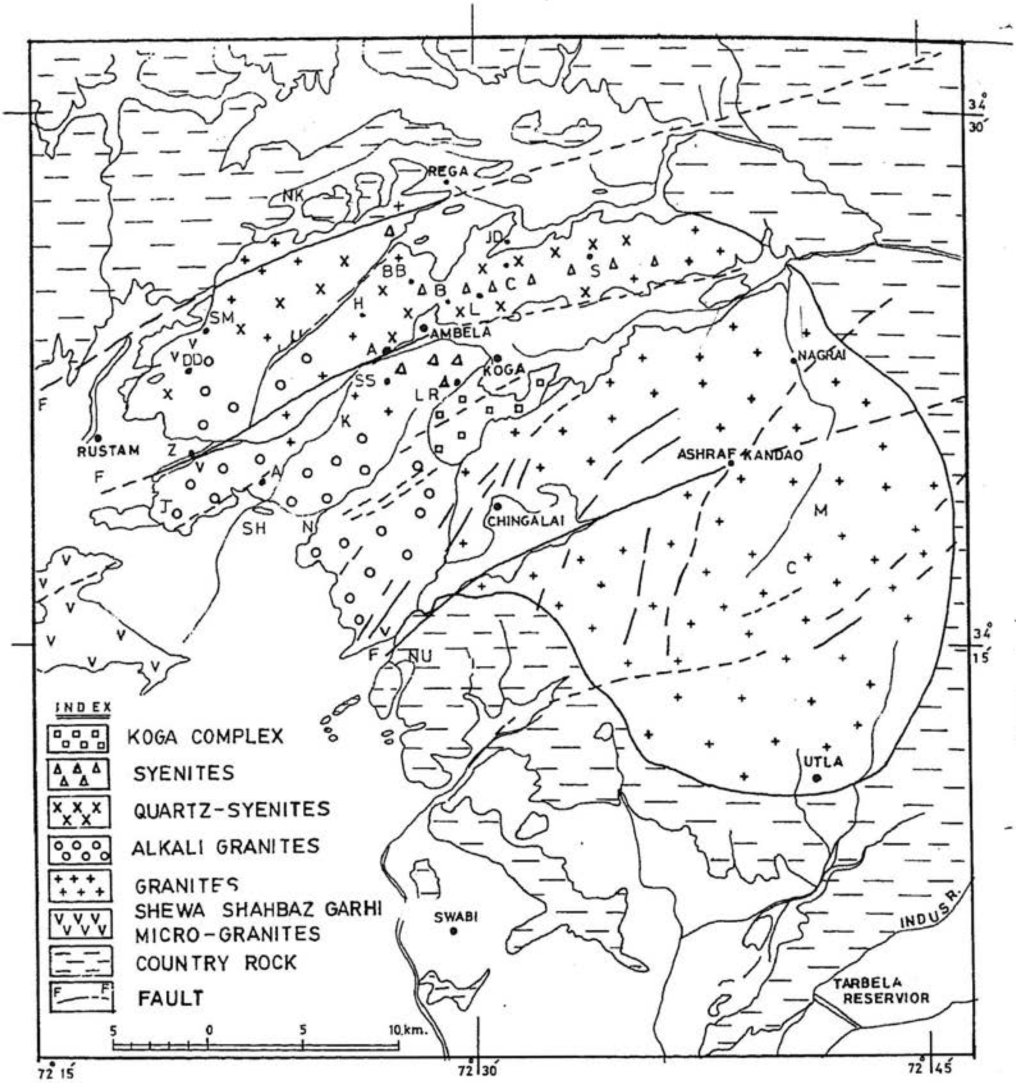

Fig. 2. Simplified geological map of the Ambela granitic complex.

A– Ambela Kandao, An-Anwarai Sar, B– Babaji Kandao, BB– Bagh Banda, C– Chamcharnai Sar, D- Dhari Dhob, H– Hashamai, J– Jaffar Kandao, JD–Jang Dara, K– Khanpur, L– Ladwano Sar, LR– Lalu-Razar, M–Malka, N– Naranji, NK– Nawe-Kili, NU– Naugram, S–Sar Banda, SH– Sher Dara, SM– Sorai Malandrai, SS– Shama Sar, Z– Ziarat.

Group II rocks, while in the southern margins there is interlayering and intertonguing with the coarse-grained granites. Major exposures lie near Nagrai, Ashraf Kandao, Malka and Utla areas and extend laterally over a distance of six kilometers toward Chingalai. These granites are characterized by the presence of megacrysts (5x3x2 mm to 80x50x30 mm) of perthitized K–feldspar (± cross-hatched twinning) and zoned plagioclase (An_{12-22}) in a coarse-grained (2–6 mm grains) matrix. The megacryst are randomly distributed, but along the cataclasized zones

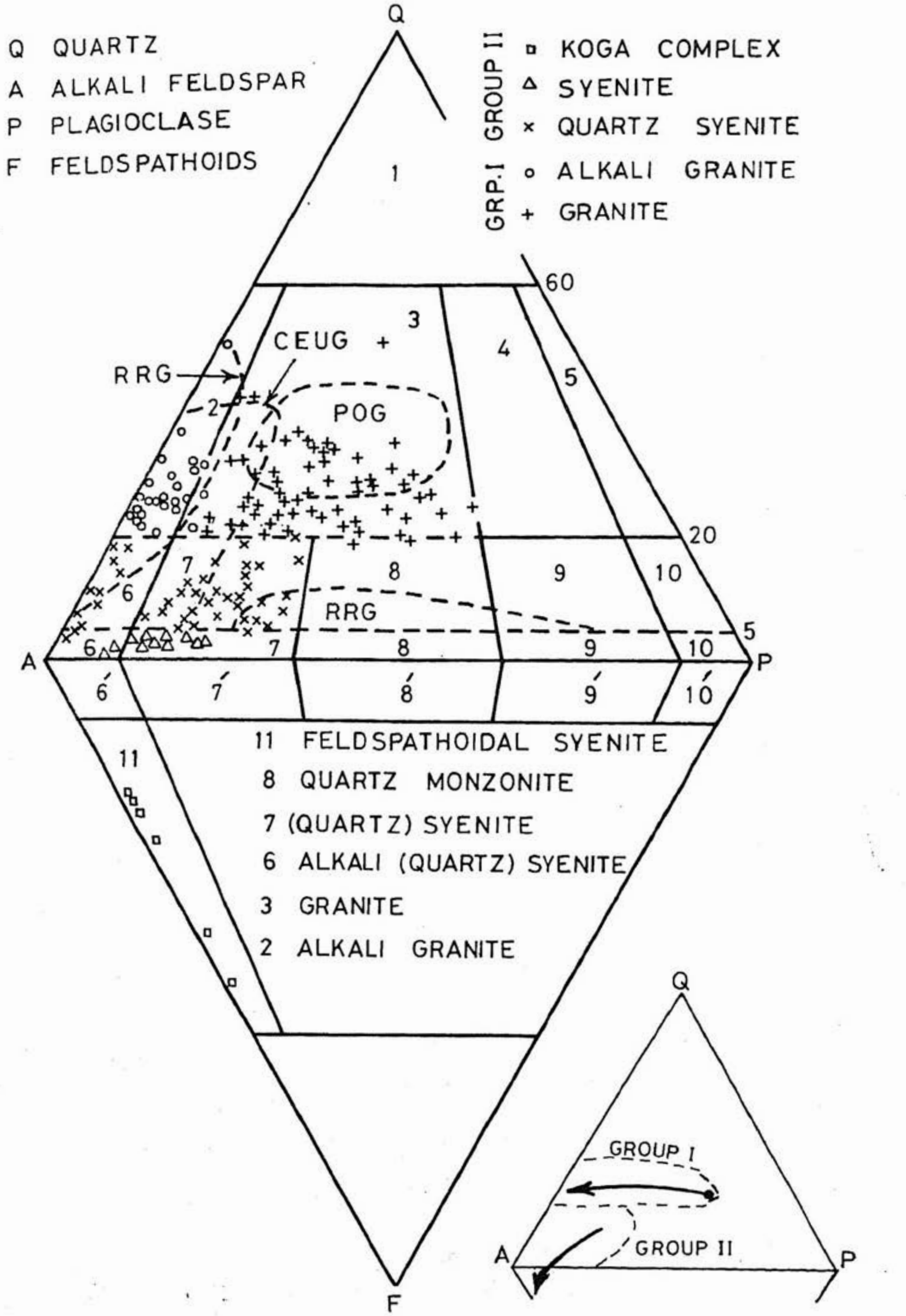

Fig. 3. Plots of the modal composition of the rocks of Ambela granitic complex on Streckeisen diagram (1976). QAP triangle on the bottom right shows the fields and evolutionary trends (arrowed) of the Group I and II rocks.

TABLE 1. MODAL COMPOSITION OF PORPHYRITIC GRANITES

	CH-16	610	CH-2	644	650	331	91	107	159	185-B	212
					MEGACRYST/PHENOCRYST						
K-f	—	10	—	12	—	—	Tr	—	5	5	—
K-fp	50	50	65	42	60	55	55	60	35	25	65
Plg	25	15	35	16	30	45	20	40	45	25	5
Qtz	25	25	—	30	10	—	25	—	15	45	30
					GROUNDMASS						
K-f	Tr	10	—	2	3	—	Tr	30	Tr	5	8
K-fp	25	30	48	42	45	55	52	31	44	27	40
Plg	32	14	10	14	15	—	20	15	28	35	24
Qtz	22	25	25	30	25	20	22	20	23	30	22
Bio	7	4	7	6	3	15	1	2	2	1	1
Mus	8	7	4	5	6	3	3	Tr	Tr	Tr	Tr
Scr	2	5	2	1	1	3	Tr	Tr	Tr	Tr	Tr
Chl	—	—	Tr	—	—	—	—	—	—	—	—
Hbl	—	—	—	—	—	—	—	—	Tr	—	2
Bl-am	—	—	—	—	—	—	—	—	—	—	3
Sph	—	—	—	—	—	—	—	Tr	—	—	—
Leu	Tr	Tr	1	Tr	—	Tr	—	—	—	Tr	—
Ore	1	3	2	Tr	Tr	2	1	1	2	2	Tr
Apt	Tr	1	—	Tr	2	Tr	—	Tr	Tr	Tr	Tr
Zir	Tr	Tr	Tr	—	—	—	Tr	Tr	Tr	Tr	Tr
Epi	Tr	1	1	Tr	Tr	Tr	Tr	Tr	1	Tr	Tr
Tour	3	—	—	—	—	2	1	—	—	—	—
Gar	—	—	—	—	—	—	—	1	—	—	—
Rt	Tr	—	—	—	—	—	—	—	—	Tr	Tr
Clay	Tr	Tr	—	Tr	—	—	—	—	—	—	Tr
Ala	—	—	—	—	—	—	—	—	Tr	—	Tr
P/G	20/80	20/80	15/85	30/70	30/70	35/65	25/75	25/75	30/70	30/70	25/75

CH 16–331: coarse-grained with mega/phenocrysts 91–212: medium and fine-grained.

SYMBOLS USED IN TABLES

K-f = K-feldspar
Qtz = Qartz
Scr = Sericite
Bl-am = Blue amphibole
Apt = Apatite
Tour = Tourmaline
Ala = Alanite

K-fp = K-feldspar (perthitized)
Bio = Biotite
Chl = Chlorite
Sph = Sphene
Zir = Zircon
Gar = Garnet
Aeg = Aegirine/augite

Plg = Plagioclase
Mus = Muscovite
Hbl = Hornblende
Leu = Lucoxene
Epi = Epidote
Rt = Rutile
P/G = Megaeryst/Phenocryst / Groundmass.

TABLE 2. MODAL COMPOSITION OF NON-PORPHYRITIC GRANITES

	D–10	88	221	312	177B	175	185	319	C–10	12	47	50	78	87	230B	31
K–f	Tr	—	5	10	Tr	2	—	Tr	—	12	Tr	Tr	35	Tr	—	—
K–fp	51	48	30	30	50	43	41	45	60	15	45	32	8	55	46	65
Plg	20	16	25	30	20	22	30	15	11	40	27	38	35	20	17	20
Qtz	22	20	27	20	23	24	20	25	22	20	20	24	20	22	30	15
Bio	1	5	Tr	3	1	3	6	9	Tr	5	Tr	Tr	Tr	2	2	Tr
Mus	—	—	4	2	3	1	Tr	1	Tr	4	5	1	1	—	—	Tr
Ser	Tr	1	4	1	Tr	1	Tr	1	2	3	2	Tr	Tr	Tr	Tr	Tr
Chl	—	—	—	—	—	—	Tr	—	—	—	—	—	—	—	—	—
Bl. am	—	—	—	—	—	Tr	—	—	—	—	—	—	1	—	—	—
Sph	2	—	—	Tr	Tr	2	Tr	—	—	Tr	—	—	—	—	—	—
Leu	—	3	—	Tr	1	Tr	Tr	2	—	Tr	—	Tr	Tr	—	—	—
Ore	1	2	4	2	1	1	Tr	1	2	1	Tr	Tr	Tr	Tr	1	Tr
Apt	1	2	Tr	Tr	Tr	1	—	Tr	Tr	—	Tr	Tr	Tr	Tr	2	—
Zir	Tr	Tr	—	Tr	—	Tr	—	—	Tr	—	Tr	Tr	Tr	Tr	—	Tr
Epi	1	2	Tr	1	1	Tr	2	1	2	Tr	Tr	1	Tr	Tr	1	—
Tour	—	—	Tr	—	Tr	—	Tr	—	—	—	1	4	Tr	—	—	—
Gar	—	—	—	—	—	—	—	—	Tr	—	—	—	Tr	—	1	—
Carb	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rt	1	—	—	—	—	Tr	—	—	—	—	—	—	—	—	—	—
Clay	Tr	Tr	—	—	Tr	Tr	1	Tr	Tr	Tr	Tr	—	Tr	Tr	—	—
Ala	—	—	Tr	—	—	—	—	—	Tr	—	—	—	—	—	—	—

D 10–319 coarse-grained, C 10–230 B Medium- and fine-grained varieties, 31 graphic granite.

TABLE 3. MODAL COMPOSITION OF ALKALI GRANITES

	355	J-5	99	208	306	534	402	111	170	196	669	368	502	C-15	110	223	373	646
K–f	Tr	Tr	—	—	—	—	—	—	—	—	Tr	5	—	—	—	—	—	—
K–fp	70	68	69	70	70	70	74	70	66	65	65	61	70	61	73	70	69	65
Plg	3	5	7	4	—	3	3	4	4	Tr	3	2	3	4	3	3	4	6
Qtz	25	25	16	17	25	23	18	24	25	26	22	27	25	30	21	20	25	20
Bio	Tr	Tr	2	1	—	2	2	Tr	2	Tr	Tr	3	2	3	Tr	2	Tr	Tr
Mus	—	—	—	—	2	—	Tr	Tr	Tr	1	2	Tr	Tr	—	Tr	—	Tr	3
Ser	—	—	—	—	1	—	Tr	—	—	—	Tr	—	—	—	—	—	—	4
Chl	—	—	—	—	—	—	—	—	—	—	—	—	Tr	—	—	—	—	—
Hbl	—	—	—	3	—	—	Tr	—	—	—	—	Tr	—	—	—	2	—	—
Bl. am	—	1	3	2	—	—	Tr	—	—	—	—	—	—	—	—	Tr	—	—
Sph	—	Tr	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Leu	—	—	Tr	—	—	—	—	—	—	—	1	—	—	—	—	Tr	—	1
Ore	1	Tr	1	2	2	2	1	1	3	—	1	2	Tr	2	3	1	1	1
Apa	—	Tr	2	—	—	—	—	—	—	—	Tr	—	—	—	—	Tr	—	Tr
Zir	—	—	—	—	—	Tr	—	Tr	—	—	Tr	—	—	—	Tr	Tr	—	—
Epi	—	Tr	—	1	—	Tr	2	1	Tr	8	Tr	Tr	—	Tr	Tr	2	Tr	—
Tour	—	—	—	—	—	—	—	—	—	—	5	—	—	—	—	—	—	Tr
Gar	—	Tr	—	—	—	Tr	—	—	—	—	—	—	—	—	—	—	1	—
Rt	—	—	—	—	—	—	—	—	—	Tr	—	—	—	—	—	—	—	—
Clay	—	—	—	—	—	—	—	—	—	—	1	—	Tr	_	Tr	—	—	—

355–402 Coarse-grained

111–502 Medium and fine-grained

C–15–646 Porphyritic variety.

C–15 Includes 18% K–fp and 12% Qtz phenocrysts.

110 Includes 28% K–fp and 3% Qtz phenocrysts.

223 Includes 40% K–fp and 10% Qtz phenocrysts.

373 Includes 24% K–fp, 8% Plg and Qtz phenocrysts.

646 Includes 22% K–fp and 5% Qtz phenocrysts.

these are rotated and aligned parallel to foliation, imparting a gneissose texture to the rocks. The megacrysts are euhedral to subhedral in shape, tabular to oblate or discade in form, fresh and least fractured in the undeformed granites.

Representative modal compositions of the porphyritic coarse-grained granites are given in Table 1. The megacrysts constitute 10 to 40% of these rocks. Apart from these, there are phenocrysts of feldspars (similar in composition to their megacrystic counterparts) and quartz, the latter forming polygonal aggregates in rare cases. The groundmass consists mostly of perthitized orthoclase, microcline, plagioclase (An_{10-20}), quartz, muscovite, biotite, ore, sphene, sericite and minor chlorite. Garnet occurs locally and fibrolitic sillimanite in a few rocks.

Coarse-Grained Granites: These form the most extensively developed rock unit, and are exposed around Sherdara, Narangi and Utla areas in the south. These decrease gradually towards the central and northwestern part of the area occupied by granites. On the basis of field relationship, these rocks constitute the second oldest unit of the complex. These are generally equi- to subequigranular and hypidiomorphic to locally allotriomorphic in texture. The proportions of perthitized K–feldspar, plagioclase (An_{8-15}) and quartz display considerable variation, and cover a wide area of the field of granites in QAP triangular diagram (Fig. 3) of Streckeisen (1976). Other mineral constituents are biotite, muscovite, sericite, ore, sphene, apatite, zircon, epidote, locally tourmaline, garnet, rutile, allanite and, in sheared samples, clay. Tourmaline granites, seemingly a younger phase, intrude the coarse-grained variety 3 km NE of Koga village.

Medium- and Fine-Grained Varieties: The medium- to fine-grained granitic rocks, porphyritic as well as aphyric, are very similar in modal composition to their porphyritic and coarse-grained equivalents (Table 1 and 2). These occur as thin to thick sheet-like masses (three to tens of meters) within the coarse-grained granites near Ambela Kandao, Khanpur, Baghbanda, Shamshatai and in the central part of the complex. The continuation of these masses is characteristically disrupted by step faulting.

Alkali Granites: Restricted in distribution to the southwestern part of the complex, these also display textural variations as found in the granites. In porphyritic alkali granite with mega/phenocrysts, the perthitized K–feldspar is subhedral (common) to euhedral (rare) in shape, and has two grain-size population (1x1 to 3x6 mm and 10x15 mm). These mega/phenocrysts lie in a medium-grained groundmass of K-feldspar, quartz, plagioclase ($An_{5-12,}$ trace to 8%), biotite, muscovite, and minor zircon, rutile and sphene (Table 3). The volume ratio between the mega/phenocrysts and the groundmass ranges from 3:7 to 3:1. The coarse-grained non-porphyritic variety of alkali granites is intimately associated with the coarse-grained granites, and the two are very similar in texture. Perthitized K–feldspar constitutes about 70% of the rocks and quartz 20 to 28%. Medium to fine-grained alkali granites of similar modal composition are interlayerd with these and well-exposed near Anwarai Sar and Khanpur.

Microporphyrites and Rhyolites: Isolated outcrops of microporphyrites are exposed in the west (Sorai Malandrai, Dhari Dhob and Nawe Kili), southwest (Jaffar Kandao, Ziarat) and south (Naugram) of the complex. Many isolated outcrops of more or less similar petrography are also exposed in the northeastern part of the Peshawar Plain near Gajju Ghundai, Tora Tigga, Turlandai, Tarakai-Rashakai, Mansurai, Gohatai, etc. (Rafiq et al., in prep.). In hand specimens these rocks resemble those of Shewa-Shahbaz Garhi.

On the basis of phenocryst content, texture and occurrence, these are distinguished into two subgroups: (1) microporphyrites with alkali feldspar as dominant phenocryst, and (2) microporphyrites with quartz as dominant phenocryst. The first subgroup locally contains granite and alkali granite fragments. Phenocrysts of perthitized orthoclase and microcline, with minor quartz and plagioclase lie in a microcrystalline groundmass dominated by felsic minerals (Table 4). The phenocrysts commonly show a random orientation, are subhedral to anhedral in shape, and vary in size from 1x1 to 2x3 mm in most rocks. The plagioclase (An_{12-20}) constitutes 5 to 10% of the total phenocrysts, and is frequently fresh, but locally cloudy or dusty due to kaolinization and/or saussuritization. Texturally these rocks vary from felsophyric to spherulitic. In the second subgroup, phenocrysts of quartz make 60 to 95% of the total phenocrysts, and the rest include perthitized K–feldspar, plagioclase, and lithic fragments (Table 4). The groundmass is similar to the other group. The quartz phenocrysts are generally medium-grained with corroded margins. They are mostly strained, fractured, and are penetrated by groundmass material along fractures (Fig. 4A). Flow structure with aligned phenocrysts impart some rocks a microgneissose texture (Fig. 4B).

TABLE 4. MODAL COMPOSITION OF MICROPORPHYRIES AND RHYOLITES

	SMI, SM9	SMII	522	DII	332	337A	379	136	224
				PHENOCRYST					
K–fp	70	80	75	80	30	15	15	80	100
Plg	5	—	5	20	10	10	10	20	—
Qtz	25	20	20	—	60	75	75	—	—
				GROUNDMASS					
Felsic	70	90	72	77	65	50	54	80	80
Bio	20	7	20	10	—	Tr	—	—	Tr
Mus	—	—	—	—	Tr	19	4	—	—
Scr	—	—	Tr	1	Tr	10	Tr	—	—
Chl	—	—	Tr	—	Tr	Tr	Tr	—	—
Hbl	—	—	—	—	1	1	2	—	—
Bl. am	—	—	6	Tr	—	—	—	—	—
Sph	—	1	—	—	Tr	—	Tr	Tr	Tr
Leu	—	—	—	Tr	Tr	Tr	Tr	—	—
Ore	5	1	2	2	Tr	—	Tr	—	10
Apa	—	—	Tr	Tr	Tr	Tr	Tr	—	—
Zir	Tr	—	—	Tr	Tr	—	—	—	—
Epi	5	1	Tr	10	34	20	40	—	10
Gar	—	Tr	Tr	—	—	—	—	20	—
P/G	35/65	30/70	30/70	35/65	45/55	30/70	40/60	20/80	10/90

Microphyries SMI–DII the phenocrysts population is dominanted by alkali feldspar and in 332–379 by quartz. 136 and 224 are rhyolites. Present in trace amounts: Clay in 522 and 332, Ala in DII.

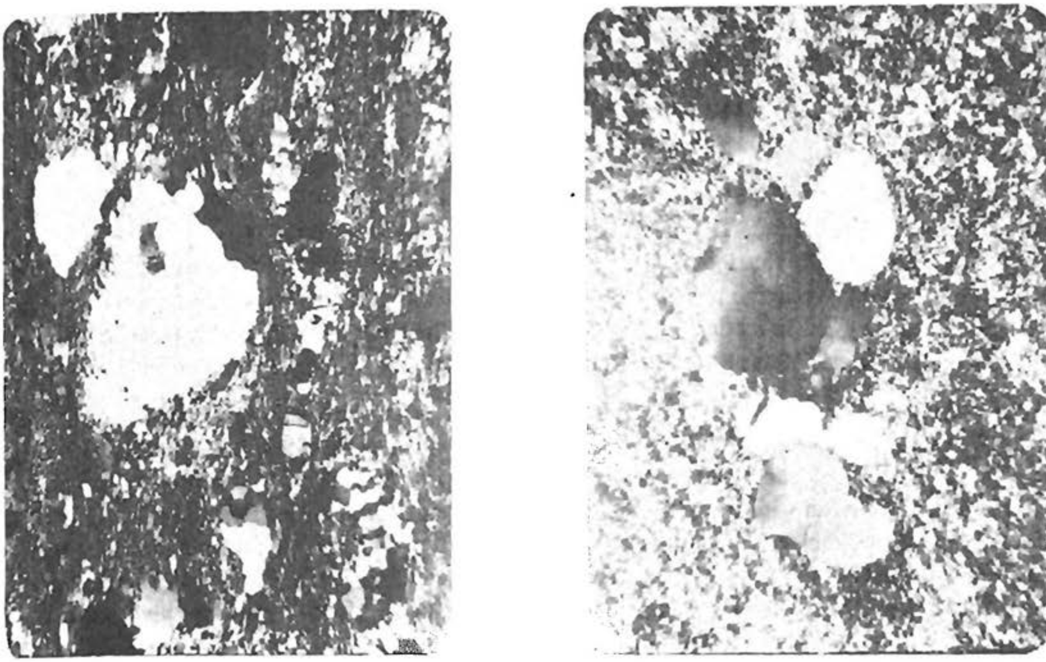

Fig. 4A. Photomicrograph showing phenocrysts of feldspar and quartz in microcystalline groundmass of microporphyrite.

4B. Photomicrograph showing flow structure with aligned phenocrysts in microporphyrite.

A small sheet of thin-bedded (platy) rhyolite is exposed 200 m SE of Lalu-Razar village. The rocks contain fine-grained phenocrysts of feldspars in a glassy to cryptocrystalline or microcrystalline, dominantly felsic (75–85%) groundmass. Very fine crystals of biotite, epidote, sericite, and ore are identified as neomineralized product, probably formed during devitrification and alteration of groundmass.

Graphic Grantites: Several occurrences of graphic granites have been found in the complex. Some of these appear to be the product of eutectic crystallization and some of replacement origin. The former constitute an east-west trending body within the syenites at the top of Ladwano Sar, about 3 km north-east of Ambela village. It consists primarily of perthitized K–feldspar and graphic quartz in the 76:24 ratio with secondary albite, sericite and opaqe dust (Table 2). The graphic quartz grains are euhedral, show parallel arrangement to one another and a definite orientation relationship with orthoclase. The graphic granites of replacement origin occur as sporadic outcrops in the northern part of the complex. These contain inconsistent proportions of feldspar and quartz; The latter is irregularly distributed, varies in form, size, and infiltrates alkali-feldspar (Rafiq and Jan, in prep.).

Group II Rocks

Quartz-Syenites and Alkali-Quartz Syenites: These occur in three separate localities, and the major outcrops comprise gently folded, thick, sheet-like bodies extending from Sar Banda in the north through Jhangdarra to Mamorain village on the southwestern slopes of the complex. These rocks grade into syenites but have sharp contacts with granites and alkali granites. Textural variations are common and, among these, the coarse-grained hypidiomorphic types are widely exposed in the northern parts (particularly near Ambela-Babaji Kandao, Shama Sar and Sar Banda) of the complex. Medium- to fine-grained and porphyritic varieties are interlayered and associated with these. The quartz content (6 to 15%) is lower in these rocks than in the granites. But they are characterised by a higher proportions of mafic constituents (especially hornblende, biotite) and the appearance of bluish green amphibole (arfvedsonite) and aegirine augite. Increased perthitization of K–feldspar, and albite overgrowth of plagioclase are the distinctive features of these syenites. Representative modes are given in Tables 5 and 6.

Syenites and Alkali Syenites: These are restricted in occurrence and exposed near Charncharnai Sar, Ladwano Sar and 800 m SW of Koga between Lalu-Razar and Shama Sar. These rocks are found as irregular pockets and lenses intertongued with quartz syenites. Porphyritic and medium- to fine-grained varieties were distinguished only in thin-sections. Perthitization of orthoclase and microcline, significant decrease of quartz content (3–5%), and increase in aegirine-augite and bluish green amphibole (arfvedsonite) are the major distinguishing characteristics of syenites and alkali syenites from quartz syenites and granites. Modal compositions of the representative thin sections of the rocks are given in Tables 5 and 6.

TABLE 5. MODAL COMPOSITION OF PORPHYRITIC SYENITES

	26	72	35	42	44,46	63,64
K-fp	100	100	100	100	90	100
Plg	—	—	—	—	10	—
			PHENOCRYST			
K-fp	55	65	53	70	70	60
Plg	15	12	22	12	13	18
Qtz	12	8	3	3	3	5
Bio	3	4	5	4	4	10
Aeg	—	3	3	6	6	Tr
Bl. am	5	2	8	4	2	Tr
Sph	5	2	4	Tr	1	3
Ore	2	2	2	Tr	1	1
			GROUNDMASS			
Apa	Tr	1	Tr	1	Tr	1
Zir	Tr	Tr	Tr	Tr	Tr	Tr
Epi	3	2	Tr	1	Tr	2
P/G	20/80	25/75	30/70	40/60	40/60	40/60

26 & 72 are quartz syenites, others are syenites.
Present in trace amounts: Leu in 26, Gar in 63, 64, Ala in 72.

TABLE 6. MODAL COMPOSITION OF NON-PORPHYRITIC SYENITES

	11	13	52	108	71	217	231	351	45	185	100	57	71
K–fp	65	75	60	60	35	50	55	60	85	87	78	51	40
Plg	12	13	22	20	35	25	20	20	2	2	3	20	20
Qtz	13	6	5	11	7	8	10	15	5	8	15	4	5
Bio	3	Tr	4	4	8	5	4	—	6	2	1	15	10
Mus	1	1	—	1	—	Tr	Tr	—	—	—	—	—	—
Seri	Tr	Tr	—	Tr	—	Tr	Tr	—	—	—	—	—	—
Chl	Tr	—	—	—	—	Tr	—	Tr	—	—	—	—	—
Aeg	—	—	—	—	—	3	2	Tr	—	—	—	—	—
Bl. am	—	—	3	—	8	2	2	3	—	—	—	Tr	17
Sph	Tr	—	3	Tr	2	2	3	—	1	—	—	5	4
Leu	2	—	—	1	—	Tr	2	—	—	—	—	—	—
Ore	2	1	—	1	1	2	2	2	Tr	1	2	—	Tr
Apa	1	1	1	Tr	1	—	Tr	—	—	Tr	1	Tr	1
Zir	—	Tr	Tr	Tr	Tr	Tr	Tr	—	Tr	—	—	Tr	Tr
Epi	1	2	2	2	3	3	Tr	Tr	Tr	—	—	5	3

11–108 coarse-grained and 71–351 medium- and fine-grained quartz syenites; 13 contains traces of clay and 217 traces of Ala.

45 & 185 coarse-grained and 100 medium-grained alkali-quartz syenites.

57 & 71 medium- to fine-grained syenites; 71 contains traces of rutile.

Feldspathoidal Syenites and Associated Rocks: An oval-shaped body of these rocks, named as the Koga Complex (Siddiqui, 1965), occupies the west-central part of the Ambela granitic complex. These rocks have irregular intrusive/faulted contacts with the rest of the Group II rocks in the west and those of Group I in the south and southeast. These rocks were not studied in detail during the present investigation and the reader is referred to Siddiqui et al. (1967), Chaudhry et al. (1981), and Mian (1988) for further details.

This group of rocks is characterized by the presence of feldspathoids: nepheline, cancrinite and sodalite. On the basis of modal composition (see also Chaudhry *et al.,* 1981), these can be divided into nepheline syenites, nepheline- cancrinite syenite, sodalite syenite and syenitic pegmatites. The nepheline syenite is the most common rock type, and further classified on the basis of modal nepheline/microcline ratio into (1) foyaite, (2) litchfieldite, and (3) nepheline syenite proper. These are mostly medium- to fine-grained rocks, with prominent flow structures at places. Nepheline-cancrinite syenite, sodatite syenite ad syenitic pegmatites are restricted in their distribution and found as irregular small bodied to large outcrops (i.e. sodalite syenite near Miane and Nawe Kili).

Occurrences of carbonatite plugs, fenites within and around the feldspathoidal syenites, and lamprophyre dykes have been described by Siddiqui (1967) and Siddiqui et al. (1968). Details of fenitization have been given by Mian (1988) who also reported ijolites. Sporadic veins and lenticular masses of carbonatite were found during the present investigation near Hashmai, NW of Ambela Kandao, and Khanpur village. Fenitization associated with the carbonatite bodies is extensive. It can be easily identified by the presence of irregular to angular pits and cavities after dissolved calcite. Intersticial calcite in perthitized orthoclase and microcline, and cavity fills along the fractures, cracks or tensional gashes are the prominent features in thin sections of fenites.

Ijolite intrusions in the feldspathiodal syenites occur near Bagoch Sar, Naranji Kandao and east of Lalu-Razar village (see also Le Bas et al., 1987). These are meso- to melanocratic, medium to coarse-grained and consist of idiomorphic nepheline (15–35%) and prismatic aegirine-augite (10–50%). Zircon (traces), apatite (traces to 4%) and sphene (2–6%) occur as ubiquitous accessories, while analcite and calcite are present in rare cases. Albite and microcline are also seen in these rocks.

The lamprophyre dykes occurring near Lalu-Razar intrude into syenites whilst those northeast of Sahbaga village intrude feldspathiodal syenites. These are dense, dark grey-green, medium- to coarse-grained rocks with panidiomorphic texture, and consist chiefly of amphibole (65–70%), sphene (8–10%), and small amounts of biotite (4–6%), apatite (6%), ore (4–6%), and alkali feldspar, including albite (6–8%).

Group III Rocks

The basic dykes mostly have N 25–45°E trend and intrude all the rock types of Groups I and II. These have chilled margins, and at places contain inclusions of host rocks. The dykes constitute about 5% of the entire complex and form 1 to 7 m thick bodies that may extend for hundreds of meters. These rocks are mostly weathered and friable, however, at places these are dense, massive and fresh. The fresh rocks generally display ophitic to subophitic texture which is frequently modified by the growth of secondary minerals, especially hornblende.

Many dykes have fairly uniform modal composition and consist of plagioclase (An_{35-55}), hornblende, pyroxene, epidote, biotite, sphene, apatite, ore and rarely quartz. However, hornblende content varies from dyke to dyke and ranges from 5% in pyroxene dolerite to 85% in the "hornblendite". Epidote (traces to 3%) and accessory biotite/chlorite occur as the alteration product of plagioclase and hornblende, respectively. Ilmanite and possibly titaniferous magnatite are the common opaque accessories. Modal composition of 16 samples is given in Table 7.

MINERAL CHARACTERISTICS

The various minerals (e.g. feldspars) display broadly similar features in different rock types of the complex. For this reason, an integrated account of these is given in the following.

K–feldspar: Perthitized K–feldspars are the most dominant constituents of the complex. These range from 40 to 60% on average in all the rock types of Group I, and quartz syenites, syenites and feldspathoidal syenites of Group II. Symmetrical and asymmetrical Carlsbad twins are their common features whereas tartan or cross-hatched twin is the characteristic of microcline (Fig. 5A). Irregular, repeated twins and ploy-junction of Carlsbad twin plains radiating from a common centre (Fig. 5B) are the characteristics of orthoclase/microcline in alkali granites. Intimate intergrowths of sodic plagioclase (mostly albite) and quartz comprise perthite, graphic intergrowth and myrmekite in perthitized K–feldspar.

The perthite within the mega/phenocrysts and coarse grains of K–feldspar varies in form and shape from very tiny strings or stringlets to coarse beads, patches and ganglia-like masses developed mostly along cleavage traces, twin planes and other intracrystalline struc-

TABLE 7. MODAL COMPOSITION OF DYKES FROM THE AMBELA GRANITIC COMPLEX

S. No.	Plg	Qtz	Bio	Mus	Hbl	Sph	Leu	Ore	Apt	Epi	Chl	Cpx
2	10	—	—	—	60	—	—	25	Tr	5	—	—
4	15	5	—	—	65	—	—	Tr	—	15	—	—
92 A	10	Tr	—	—	13	—	12	—	—	60	5	—
167	8	—	—	—	65	—	—	2	—	25	—	—
210	30	Tr	5	—	55	—	5	5	Tr	—	—	—
218	Tr	—	25	Tr	65	—	5	—	—	5	—	—
336	5	Tr	—	—	85	—	4	5	Tr	Tr	—	—
344	40	Tr	—	—	28	—	—	18	4	10	—	—
390	27	—	—	—	50	—	—	15	—	8	—	—
390 B	15	—	—	—	70	5	—	—	—	10	—	—
391	5	—	20	Tr	35	—	—	15	—	10	—	15
389	30	—	—	—	45	—	—	15	Tr	7	1	2
C–5	15	—	—	—	50	Tr	Tr	Tr	—	30	—	5
92	30	2	30	—	10	5	—	—	1	20	3	—
388	55	—	—	—	40	—	—	3	—	2	Tr	Tr
405	54	—	—	—	5	—	—	10	—	—	1	30

tures (Fig. 5C). The perthite in some granites and alkali-granites of Group II forms beads, waves and clusters of en-echelon veins producing anastomozing type texture. Cloudy veins and veinlets of perthite on both sides of the Carlsbad twin plane characteristically ornament these grains and form fish-bone texture (Fig. 5D). The concentration and textural behaviour of perthitic intergrowth depend upon the presence of intracrystalline structures (cleavage, twin plane, fracture, etc.), availability of the perthite-forming liquid, and mode of origin (whether exsolved, anatectic or metasomatic). In most thin sections, more than 60% area of the K–feldspar grains is occupied by perthitic albite (Fig. 5E). In extreme cases, in the quartz syenites and syenites occurring close to the feldspathoidal syenites, the non-perthitized part of these grains appear as small windows (Fig. 5F). The intensity of perthitization is higher in the rocks of Group II where at least three phases of perthitization of probable metasomatic origin were noted in quartz syenites and syenites (Fig. 6A). Albite twinning is seen in early phases of perthite intergrowth.

Graphic quartz occurs as globules, blebs, irregular masses and stubby rods within and near the edges of the perthitized orthoclase and microcline grains (Fig. 6B and 6C). Microveins protrude into these grains, following the interlaptonic spaces provided by the cleavage planes, twin lamellae and fractures. Other topocrystalline ornamentation in the K–feldspar are the presence of euhedral to subhedral graphic plagioclase, producing flaky to patchy intergrowths that may exhibit a chess-board mossaic. Compositionally it is sodic (An_{0-7}) with typical albite twining. The development of albite along two sets of cleavages in orthoclase grains gives the impression of albite-pericline twin combination (Fig. 6D). Non-oriented graphic albite grains in perthitized K–feldspar are mostly subhedral in shape, and contain a reaction rim or overgrowth

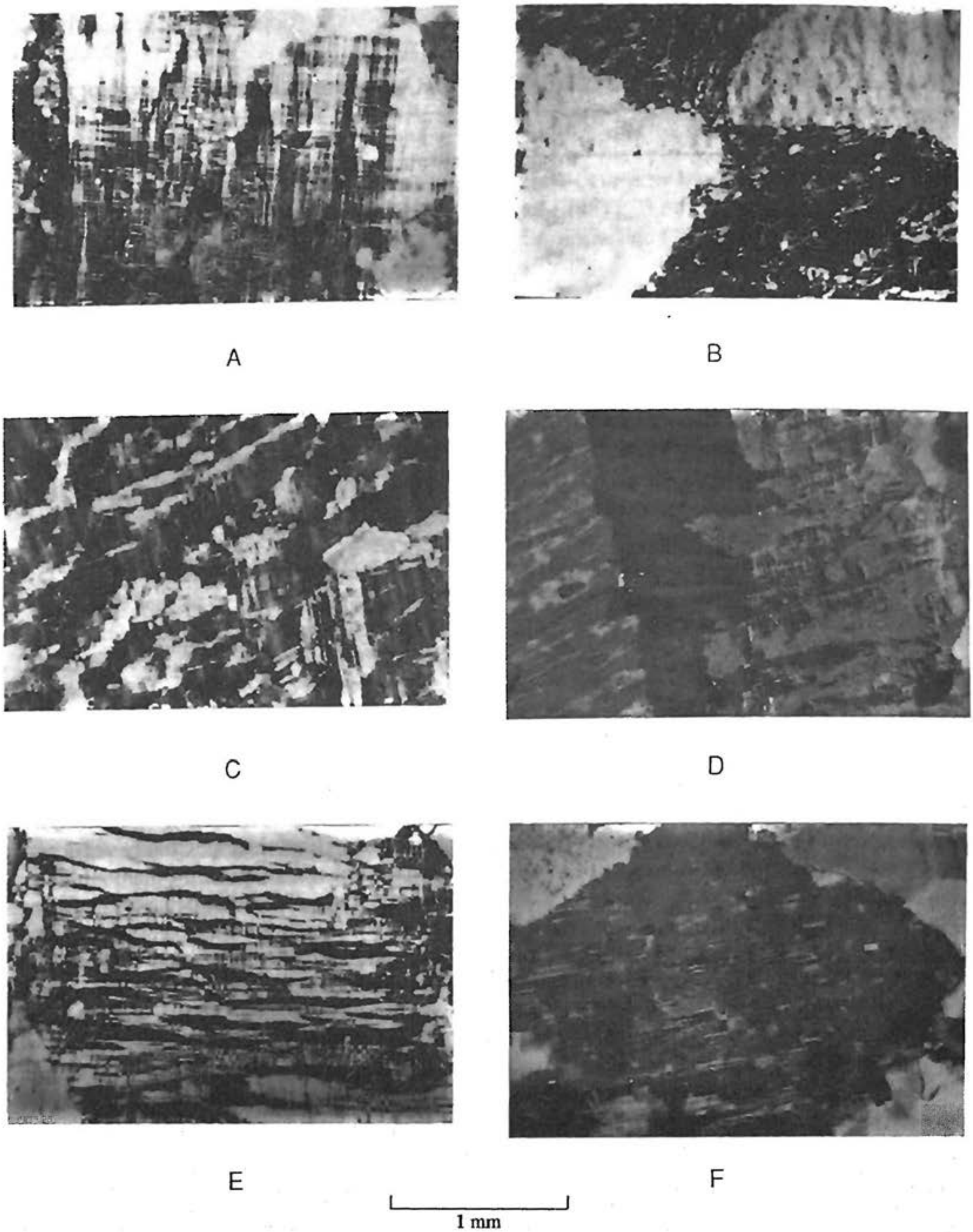

Fig. 5A. Photomicrograph of the tartan or cross-hatched twin in microline.
5B. Photomicrograph of poly-junction of Carlsbad twin planes radiating from a centre.
5C. Different forms of perthite texture along cleavage traces and twin planes.
5D. Perthite form of fish-bone texture in K-feldspar along Carlsbad twin plane.
5E. Nearly 60% concentration of perthite in microcline.
5F. Appearance of host K–feldspar as windows in the invaded perthite.

around their margins (Fig. 6E). These margins are soda rich (albite with An $_{0-5}$), devoid of inclusions and probably produced by late stage soda metasomatism (albitization). The overgrowth fronts are not sharp with their host grains of K-feldspar. Though volumetrically minor in most cases, the graphic intergrowth of albite and quartz in some rocks reaches up to 20% of the total mineral content. Myrmekitic intergrowth of quartz and albite (An_{0-7}) in the perthitized alkali-feldspar occurs as fine vermicules, crusts, pods and fans. These are mostly developed at the margins but penetrate particularly into the strained mega/phenocryst of alkali-feldspar (Fig. 6F). Primary textures have been modified due to cataclasis in shear zones that traverse almost all rock-types of the complex (Fig. 2). The microshears developed in these rocks (particularly granites and quartz syenites), helped in the alteration and development of myrmeketic intergrowth in the perthitized alkali-feldspars (Rafiq and Jan, in prep.).

The perthitized K–feldspar grains are generally fresh, however, some are dusty due to alteration to clay, sericite and muscovite. Intense alteration is restricted to fractures, tensional gashes, cracks and cleavages which are lined with micaceous microlites (sericite and muscovite). Some mega/phenocrysts contain fibry to acicular sillimanite (especially along microshears), which can be attributed to fibrolitization (cf. Vernon, 1979; Ahmad and Wilson, 1982; Rafiq and Jan, 1987) or exsolution (Sturt, 1970).

Plagioclase: It ranges from megacrystic and coarse-grained in the porphyritic and coarse-grained granites to finer grained in other granites. It constitutes 14 to 70% of the mega/phenocryst and 5 to 42% of the groundmass populations in porphyritic coarse-grained granites, 8 to 38% of the rest of the textural varieties of granites, quartz syenite, syenite, and traces to 7% of alkali granite, alkali-quartz syenite and alkali syenite. The mega/phenocrysts are zoned (normal to oscillatory) and range in composition from An_{35-25} (core) to An_{22-5} (margins). The composition in other varieties of granites is in the range of oligoclase to albite (An_{20-5}) and matches the outer zones of the mega/phenocrysts. However, it is more sodic (An_{12-5}) in the alkali granites, quartz syenites and syenites, and albitic (An_{0-5}) in the feldspathoidal syenites.

Polysynthetic twins usually traverse the zonation in mega/phenocryst and in medium- to fine-grained plagioclase the albite twin is the most common. Combination such as albite-Carlsbad or albite-pericline are also present. The degree of alteration varies from grains with dusty appearance to those highly kaolinized and epidotized. Usually the central part is more altered than the margin, either due to difference in composition (zoning), or overgrowth during later processes such as metasomatism and exsolution (Fig. 7A).

Quartz: It is subhedral to anhedral in shape and medium- to fine-grained. It ranges in amount from 20 to 40 per cent in all the varieties of granite and alkali granite, but decreases steadily from quartz syenites to syenites of Group II. In less deformed rocks, the quartz grains exhibit wavy or undulose extinction, but in sheared rocks they are shattered to fine granular aggregate, sometime in crushed powder form.

Biotite: Ranging from traces to 15%, it is the most abundant mafic mineral of the feldspathic rocks of the complex. In thin section it exhibits strong reddish brown to greenish brown colour, with occasional deep to light shades of yellow colour. It occurs in the form of medium-grained, well-developed crystals with tabular habit, but flakes and irregular masses are also present. It is commonly found in isolated clusters, schlieren, and patches in association with other mafic minerals, especially opaque oxide. In addition to a perfect basal cleavage, biotite in deformed rocks sometimes exhibits at least two sets of cleavage-like pattern (Fig. 7B), probably resulting from numerous crystallographically oriented acicular rutile. Of the several interpretations, the

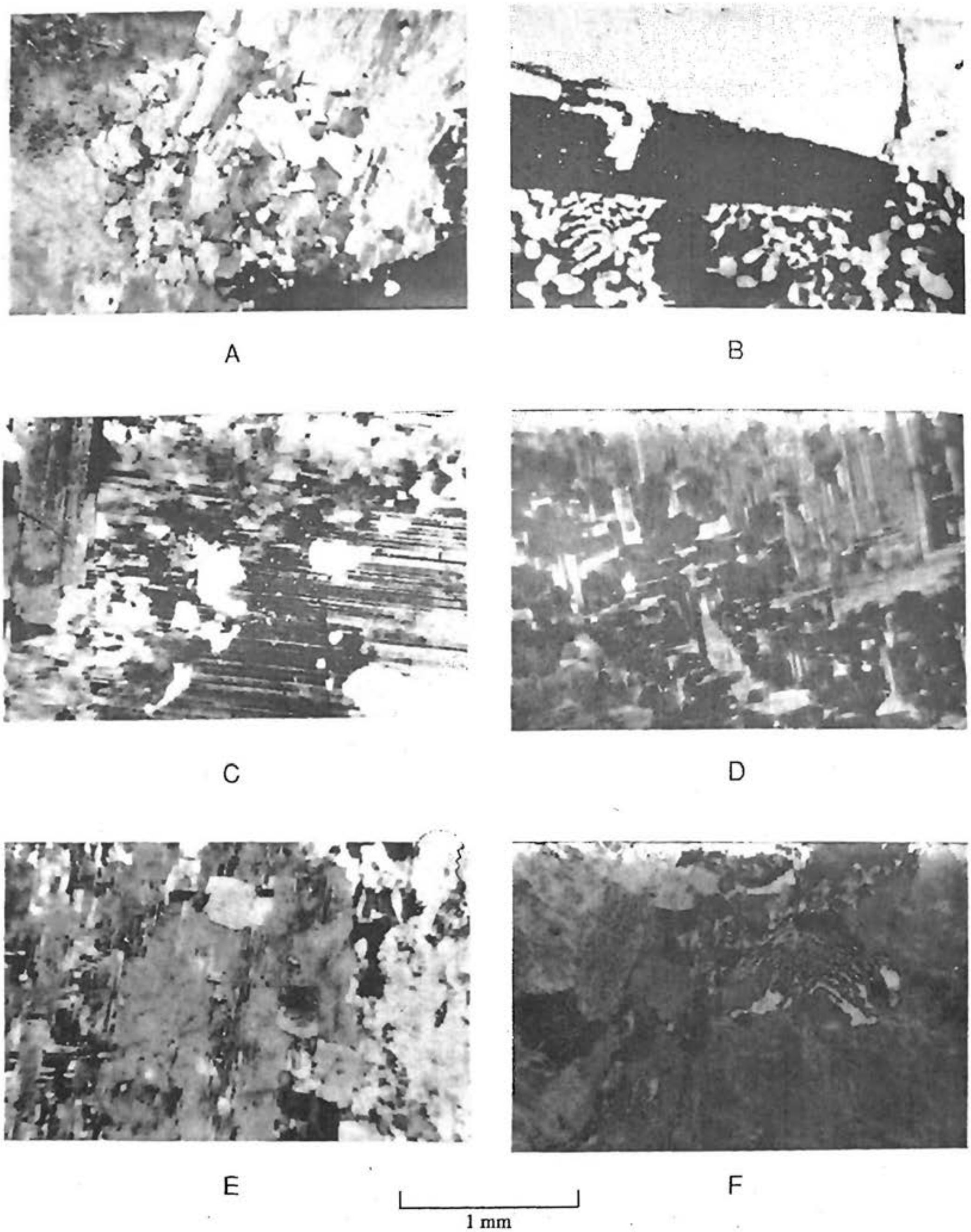

Fig. 6A. Photomicrograph of three sets of perthite in K–feldspar.

6B. Fine globules of graphic quartz in K–feldspar.

6C. Irregular masses of graphic quartz in perthitized K–feldspar.

6D. Development of two sets of perthitic albite along two sets of K–feldspar cleavage.

6E. Reaction rim overgrowth of graphic albite in K–feldspar.

6F. Myrmekitic intergrowth in perthitized K–feldspar.

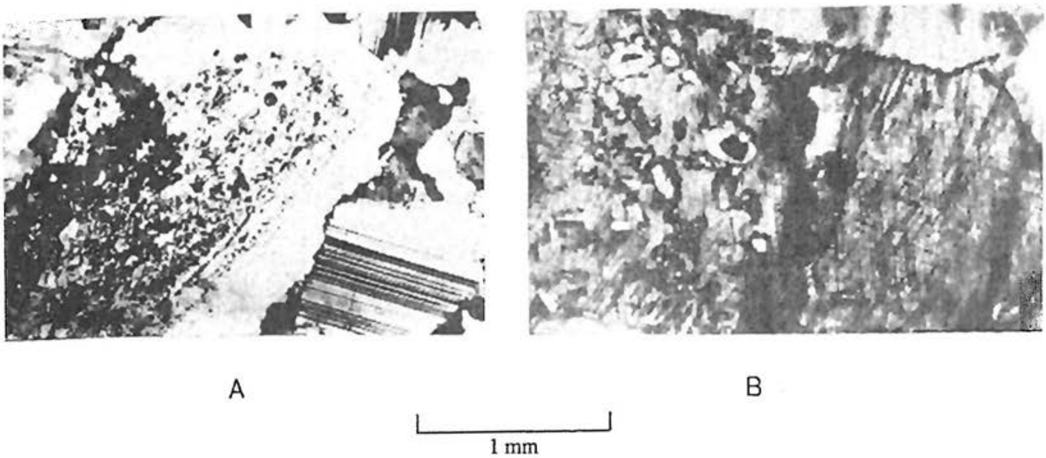

Fig. 7A. Altered plagioclase with albite overgrowth.
7B. Acicular rutile needles arranged as two site of cleavages.

possibility of a sub-solidus exsolution of rutile from titaniferous biotite as a result of stress, which destabilized titanium oxide in the biotite structure, is more favourable (cf. Vernon et al., 1983).

Corrosion and alteration in biotite are usually concentrated along the margins and cleavage planes, and marked by the presence of aggregates of fine microlites of rutile, sphene, leucoxone and sometime epidote. Alteration to chlorite and ore (iron-oxide or ilmenite) is seen in some rocks. Ilmenite inclusions in biotite are generally rimmed by sphene, and can be attributed to deformation in these rocks (c.f. Vernon et al., 1983). In addition, apatite and rarely zircon occur as inclusions in biotite. Yellowish brown structureless droplets or blebs of secondary biotite occur in some varieties of granites and microporphyrites.

Amphibole: Hornblende is a common mineral in the rocks of Group III and in some porphyritic coarse-grained granites, quartz syenites and syenite. The associated textural and topocrystalline features of hornblende and biotite, i.e. the corroded hornblende, the presence of fine to dusty ore within the hornblende grains and appearance of fine globules and flakes of brown colour, suggest its alteration to biotite.

Bluish Green Amphibole: It is the characteristic mineral constituent of the rocks of Group II, particularly syenites and feldspathoidal syenites, and some microporphyrites. Mutual textural relationship of hornblende, biotite and bluish-green amphibole suggests that the latter mineral was formed at the expense of hornblende. Protruding textural behaviour and alignment of neomineralized grains of bluish green amphibole parallel to the cleavage traces of perthitized orthoclase indicate the effect of metasomatism in the phenocrysts of microporphyrites. In detail the intensity of soda-metasomatism in hornblende can be noted from the change in colour. All variations exist from light green hornblende to rarely deep blue amphibole (riebeckite). The neomineralized bluish green amphibole varies from structureless droplets or globules within hornblende to well-crystallized, euhedral grains. In addition the presence of dusty to skeletal ore in and near the disintegrated hornblende suggest the formation of neomineralized phase due to soda-metasomatism and probable release of iron, titanium and/or manganese oxide.

Muscovite and Sericite: Muscovite is closely associated with biotite, and the two are similar in habit, form and occurrence. It is less abundant than biotite and ranges in amount from traces to 7% in the granites. Primary muscovite occurs as fine-grained aggregate. The secondary muscovite, found in feldspars and along micro-shears, occurs as microlites.

Sericite is found in almost all the thin-sections, and ranges in amount from traces to 4%. It occurs as very fine flakes usually in association with opaque dust in the feldspar grains. The growing sericite grains are muscovitized at places.

Other Accessory Minerals: Small quantities of ore, lucoxene, sphene, apatite, and zircon occur in most of the rocks of Group I and II. Garnet, allanite, rutile, carbonate, tourmaline and sillimanite are found locally in some granites, quartz syenites, syenites and even in nepheline syenite of Group II. Aegirine-augite is found mostly in the Group II rocks.

Feldspathoids: Nepheline constitutes 10 to 25% of the nepheline syenites. It forms mosaics of subhedral to anhedral grains frequently altered to sericite and opaque dust. Sodalite occurs as minor constituent in nepheline syenites and is interstitial to other minerals. In sodalite syenite, it contains inclusions of nepheline.

CONCLUDING REMARKS

Like other batholiths, the Ambela granitic complex is also composite in nature. It has a range of lithologies from oversaturated to undersaturated and even carbonatites. The earlier phases of magmatism in the complex produced a variety of granitic rocks and microporphyrites, some of which are alkaline. This group of rocks was followed shortly by saturated to undersaturated rocks (quartz syenites, syenites, feldspathoidal syenites, ijolite, carbonatite, lamprophyre and associated fenites dated at 315 ± 4 Ma by Le Bas et al. (1987). The final phase of magmatism was marked by the intrusion of basic dykes in the complex. Considerable metasomatism appears to have affected the complex, especially the Group II rocks in which albitic perthitization appears to have increased progressively in successive phases. Metasomatism is evidenced not only by the association of fenites with the feldspathoidal rocks but also by the successive development of various sets of perthite in K–feldspar, overgrowths of albite around plagioclase, and secondary formation of a bluish green amphibole in different rocks of Group I and II.

Baking effect, sharp intrusive contacts with Siluro-Devonian rocks and interlayering of some microporphyrites and tuffs with Devonian limestone and phyllites (Jaffar Kandao: K. Pouge, per. comm.) indicate that the igneous activity may have started in early or middle Devonian time. These evidences, along with extensive dimension and varied textural units, suggest that the Ambela granitic complex may have evolved over a long period, possibility between 400 and 300 Ma during one or less likely more episodes of major crustal swelling and extension (rifting). This age span, interestingly, incorporates the reported radiometric ages for Tarbela (350 ±15 m.y.: Kempe, 1986) and Malakand (Carboniferous: Zeitler, 1988) rocks which constitute a part of the Peshawar Plain alkaline igneous province of Kempe and Jan (1980). Several younger ages (Tertiary) have also been reported from the alkaline province (Le Bas et al., 1987; Kempe, 1973, 1986; Maluski and Matte, 1984). It is likely that many if not all of these younger ages represent tectonometamorphic events.

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