Geol. Bull. Univ. Peshawar, Vol.30, pp. 227-249, 1997.

Petrography of the Nagar Parkar Igneous Complex, Tharparkar, Southeast Sindh

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ABSTRACT: *The Nagar Parkar igneous complex in southern Tharparkar desert is a Late Proterozoic fragment of the western Indian shield. Six major magmatic episodes of intrusive and extrusive activity have been identified: 1) amphibolites and related dykes, 2) riebeckite-aegirine grey granite, 3) biotite-hornblende pink granite, 4) acid dykes, 5) rhyolite "Plugs", and 6) basic dykes. In terms of volume, the first three make most of the complex. The amphibolites, apparently forming basement for the subsequent intrusions, show low-grade metamorphism. The riebeckite-aegirine grey granite is mostly undeformed, and essentially composed of perthitic feldspar (microperthite, mesoperthite) and quartz, with a small amount of plagioclase (albite-oligoclase), and characteristic presence of riebeckite and aegirine. The biotite-hornblende pink granite is mostly coarse- to medium-grained, and commonly homogeneous. It is generally leucocratic and essentially made up of perthitic feldspar, local microcline, quartz, and minor plagioclase (oligoclase), with biotite and horrnblende as the varietal minerals along with iron-oxide. Some rocks contain sufficient plagioclase to be termed quartz monzonite or adamellite. The pink colour of the granite is due to hematitic staining resulting from alteration of ferromagnesian minerals. A wide range of minor accessory minerals occurs in the two types of the granite.*

The acid dykes, ranging from aplite to microgranite and rhyolite to quartz trachyte, contain phenocrysts of perthite, plagioclase and quartz in an allotriomorphic matrix of these minerals and accessory iron oxide, blue-green amphibole, biotite, zircon, apatite, fluorite, sphene, allanite and secondary epidote. Feldspar alteration (clouding, sericitization) imparts many of these a brownish colour. These rocks generally occur in small bodies but, locally (as in Dhedhvero), form up to 6 m thick dykes extending for more than 2 km. The rhyolites occur in two small, domal outcrops surrounded by alluvium, and may be an effusive phase genetically related to the granites. They are dark grey to black, glassy-looking rocks with whitish bands and consist of phenocrysts of feldspar and quartz in a very fine-grained matrix. All the major rock units of the complex are intruded by undeformed basic dykes, mostly less than 3 m thick. These show considerable petrographic variation and range from hornblende microdiorite to gabbro and dolerite, some of which contain titanian augite suggestive of alkaline affinity.

INTRODUCTION

The Nagar Parkar igneous complex is exposed in the southern extremity of the Tharparkar desert near the Runn of Kutch (24° 22' 18" N, 70° 43' 14" E). Covering an area of approximately 480 km^2, it is surrounded by Indian territory on three sides, thus forming an enclave of Pakistan within India. The road from Karachi and Hyderabad to Mithi is metalled, whereas 190 km long all-weather desert track connects Mithi with the Nagar Parkar town. The complex was mapped on 1:50,000 scale (simplified and reduced in

Fig. 1). In this paper we present a generalized account of the petrography of the various rock units. Details of geochemistry will be presented subsequently.

Wynne (1867) was the pioneer worker who conducted field work, and noted the occurrence of red syenite with hornblende diorite dykes from Nagar Parkar area. Fermor (1932) reported amphibolites and dolerites, intruded by grey and purplish varieties of granite, and minor veins of quartz porphyry, felsite and aplite. Pascoe (1959) presented a cursory account of the Nagar Parkar rocks, without refering specifically to the source of his information. Kazmi and Khan (1973) suggested a Precambrian age for the complex. They also recognized a sedimentary sequence of gritty sandstone and ocherous clay near Bartalao village and named it as Bartalao Formation. Pathan and Ahmed (1975-76) proposed the probability that the area is the western continuation of the Indian shield region, and suggested the bosses and stocks as connected with a batholithic mass at depth. Kazmi and Khan (1973) and Kella (1983) presented details on the china clay occurrences of the area. From gravity anomaly data, Butt et al. (1989) concluded that much of the Nagar Parkar is underlain by mafic rocks whereas the granitic intrusions form thin, sheet-like masses. Butt et al. (1994) proposed that the Nagar Parkar granitic rocks are the products of crustal anatexis in an intraplate (continental) anorogenic environment. Muslim and Akhtar (1995), like previous workers, differentiated two varieties of granite, assimilative pink granite and grey granite.

To the south of the Kirana Hills in Punjab, Nagar Parkar is the only area in Pakistan from where Late Precambrian basement rocks of the Indian shield are reported (Shah, 1977; Kella, 1983). The igneous rocks in the area crop out abruptly and stand out boldly in otherwise sandy planes. The Nagar Parkar igneous complex contains two major varieties of granite, riebeckite-aegirine grey granite and biotite-hornblende pink granite (Butt et al., 1994). Previously, these were termed as Karunjhar grey granite and Nagar pink granite, respectively (Kazmi and Khan, 1973). There are outcrops of mafic dykes, and amphibolite which form low ground and, at times, are rather inconspicuous. But further northeast of the Karunjhar body, these also crop out as isolated bold hills. The Karunjhar Hill, extending in NW-SE direction, is the highest range (356 m) in the area and forms the largest outcrop. Other outcrps of granitic rocks form rather subdued hills, occurring to the north, northeast and east of the Karunjhar hill. The granitic rocks have petrographic similarities with the Late Proterozoic granitoids of neighbouring Rajasthan. It is likely that they constitute a single petrographic province.

FIELD FEATURES AND PETROGRAPHY

On the basis of field features, composition of xenoliths, and petrographic study, several major magmatic episodes of intrusive and extrusive activity have been identified. The relationship of various litho-units has been elucidated in the geological map of the area (Fig. 1). Multiple intrusive phases of granite can be seen in several outcrops. One of the best examples is that of the pluton north of Ranpur, which shows at least five phases. The southern part of this pluton is occupied by grey granite. The eastern part at Ranpur is pink granite with abundant black to grey fine-grained xenoliths, generally <2 cm in length. The northwestern part consists of coarser, locally porphyritic granite containing light pink and white feldspar. The northwestern margin of this one is made up of pink granite.

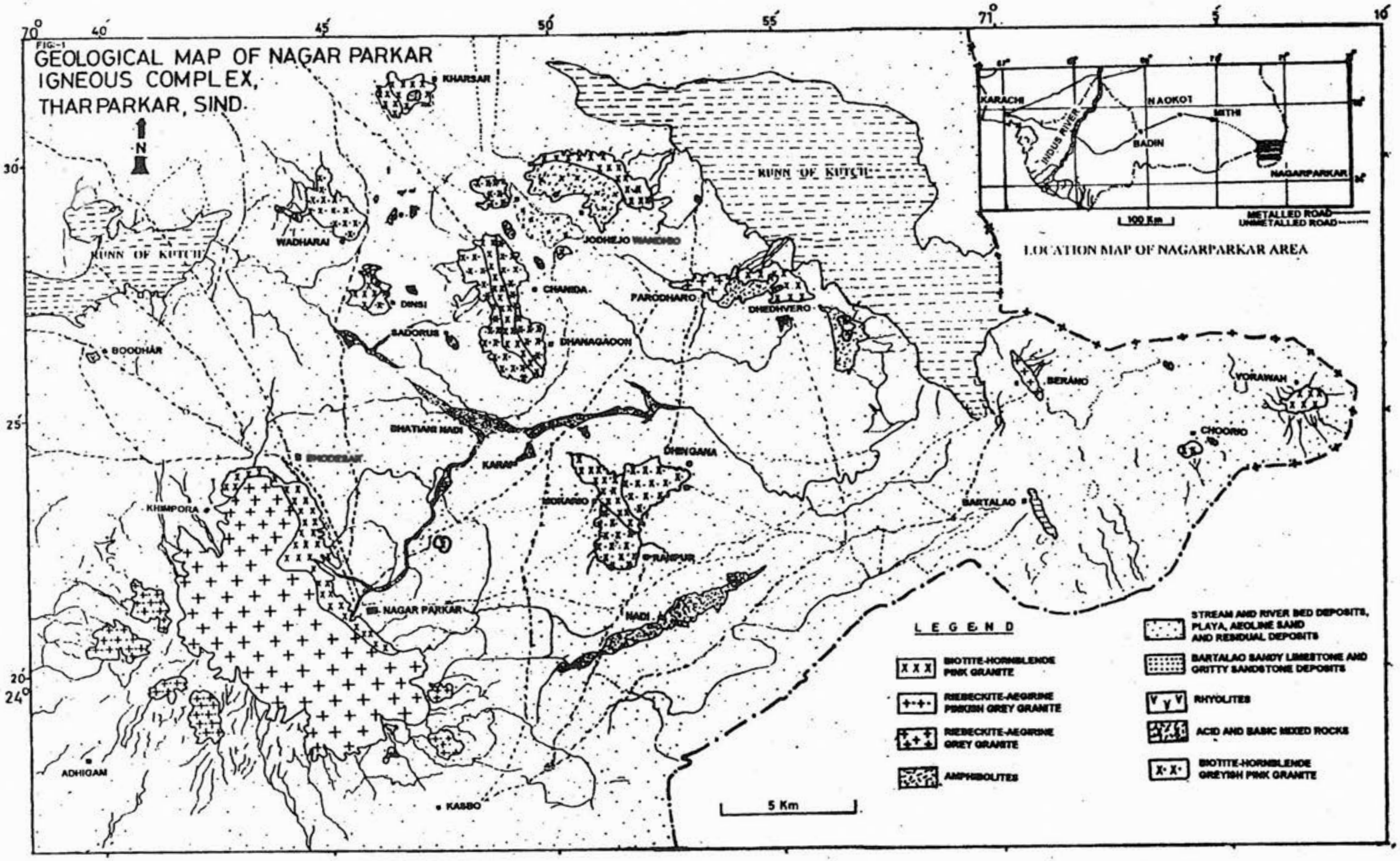


Fig. 1. Geological map of the Nagar Parkar Igneous Complex, Tharparkar, Sind.

There are aplitic dykes, possibly of more than one generation. The magmatism in the complex can be grouped broadly into six phases; Phase-1: Amphibolites and related dykes, Phase-2: Riebekite-Aegirine Grey Granite, Phase-3: Biotite-Hornblende Pink Granite, Phase-4: Acid Dykes, Phase-5: Rhyolite "Plugs", and Phase-6: Basic Dykes. Some field features of the rocks are displayed in Fig. 2A to 2F.

Phase-1 Amphibolites

Amphibolites, representing the earliest magmatic activity in the area, occur in small exposures near Dedhvero, Jodhe-jo-Wandhio, and Nadi-jo-Wandhio. Interpretation of the gravity anomaly data of Farah and Jafree (1965), according to Butt et al. (1989), suggests that much of the Nagar Parkar area is underlain by basic rocks, whereas the granitic intrusions form thin, sheet-like masses.

The amphibolites, forming the basement for the subsequent acid and basic magmatism, are medium- to fine-grained rocks commonly metamorphosed in epidote amphibolite facies or greenschist facies, but Wynne (1867) also reported the occurrence of mafic volcanics. They display two distinct cleavages contained within the gneissosity which itself is folded. Butt et al. (1989) reported graphic patches in the metabasites and took them as indicative of tholeiitic affinity. In the following, we describe the exposures near Dedhvero as an example.

The Dedhvero amphibolites are located at 24° 27′ 04″ N , 70° 53′ 33″ E. Covering about 10 km^2, these consist of foliated metagabbroic amphibolites with isolated patches of granite. These are cut by long dykes of brown-red rhyolite extendig in N 12° W direction. The dykes are mostly small but one of these is 5 to 6 m thick and extends more than 2 km. There are several younger mafic dykes, at least some of which are possibly related to the amphibolites. All show low grade metamorphic overprint; some also have planar fabric. These range from hornblende gabbro, through diorite and quartz diorite, to hornblende/biotite granodiorite. The amphibolites can be seen as narrow strips in the centrally located flat zones or as xenoliths in the granitic masses. However, a broader strip of the amphibolites trending in the northwest-southeast direction occurs in the plains to the north of the Dedhvero village and disappears at the depression of the Runn of Kutch (Muslim and Akhtar, 1995). To the south, the strip has intrusion of the granitic rocks showing chilling and alteration effects at the contacts. Apophyses of these granites have also been noticed traversing the metagabbroic amphibolites.

The Dedhvero amphibolites vary in colour from greenish grey to greenish black. They are generally medium-grained, at places foliated, highly sheared, a little banded in NE-SW direction, and contain quartz veins up to 1 cm thick. These veins are associated with granite also. The rocks are mainly composed of plgioclase and hornblende, with small amounts of quartz, augite, epidote, chlorite, sphene, and iron oxide. Biotite, zircon, apatite, allanite and carbonate occur as minor accessories (Table 1). Plagioclase is generally cloudy (altered), but fresh plagioclase with weakly developed zoning is also present.

TABLE 1. MODAL ANALYSES OF REPRESENTATIVE SAMPES OF BASEMENT AMPHIBOLITES AND BASIC DYKES

S.No	Pl	Seri	Qtz	Am	Pyx	Ol	Bt	Ms	Chl	Ep	Spn	Opq	Zrn	Ap	Idg	Car	Rt
E 7	44	5	4	25	3	T	7	T	6	3	2	4	-	T	-	-	-
E18b	40	4	3	30	4	-	5	T	5	3	2	4	T	-	-	-	-
E 35	44	3	5	10	-	-	18	T	5	5	3	7	-	T	-	-	9
E 39	40	7	4	20	2	-	4	T	6	6	3	8	-	T	-	-	T
E 43	44	8	3	25	2	-	T	-	5	5	2	4	-	T	-	-	T
E 44	41	5	20	15	3	-	1	-	5	4	2	4	T	T	-	T	-
E 50	42	5	6	22	T	-	6	T	6	5	3	5	-	-	-	-	-
189	48	6	5	22	3	T	T	T	4	6	3	3	T	T	-	-	T
256	47	4	20	15	2	T	-	-	5	3	T	4	T	T	-	-	-
258b	40	6	T	35	4	-	-	-	5	6	1	3	-	T	-	T	T
E 52	41	8	4	25	-	-	T	T	8	6	4	4	-	T	-	-	-
E 55	50	8	4	22	T	-	T	T	5	4	2	4	-	T	-	T	-
E 78	48	6	3	25	T	-	T	2	6	4	2	3	-	T	-	-	T
204	43	12	5	20	2	-	T	T	6	4	2	6	-	-	-	-	T
249	44	12	2	22	2	-	-	T	4	5	3	5	-	T	-	-	-
P 52	58	T	-	T	18	12	2	T	2	1	1	4	-	T	T	1	-
W 57	47	8	-	2	12	15	4	T	3	2	2	4	-	-	-	-	-
161	45	7	T	18	12	-	1	T	5	4	3	5	-	-	-	T	T
194	48	-	-	30	4	T	2	T	5	-	6	4	-	-	-	-	-
219	53	-	T	-	22	20	1	-	-	-	-	5	-	-	T	-	-
220	53	T	1	-	15	25	1	-	1	-	T	4	-	-	T	-	T
223	52	T	T	-	15	25	2	-	2	-	T	3	-	-	T	-	-
224	42	5	3	8	25	1	2	-	3	2	2	6	-	T	-	-	-
226	57	-	T	-	15	22	2	-	-	-	T	3	-	-	T	-	-

E7 - 258b Basement amphibolites; E52 - 249 Hornblende diorite/lamprophyric dykes and P52 - 226 Alkaline gabbro/dolerite dykes.

Symbols used in Tables (after Kretz 1983)

Prt :	Perthite	Am :	Amphibole	Fl :	Fluorite	Pl :	Plagioclase	Cpx :	Clinopyroxene	Tur :	Tourmaline
Seri:	Sericite	Opq :	Opaque	Car :	Carbonate	Mic :	Microcline	Spn :	Sphene	Ast :	Astrophylite
Qz :	Quartz	Leu :	Leucoxene	Cst :	Cassiterite	Bt :	Biotite	Ep :	Epidote	Aln :	Alanite
Mu :	Muscovite	Zrn :	Zircon	Ol :	Olivine	Chl :	Chlorite	Ap :	Apatite	Idg :	Iddingsite

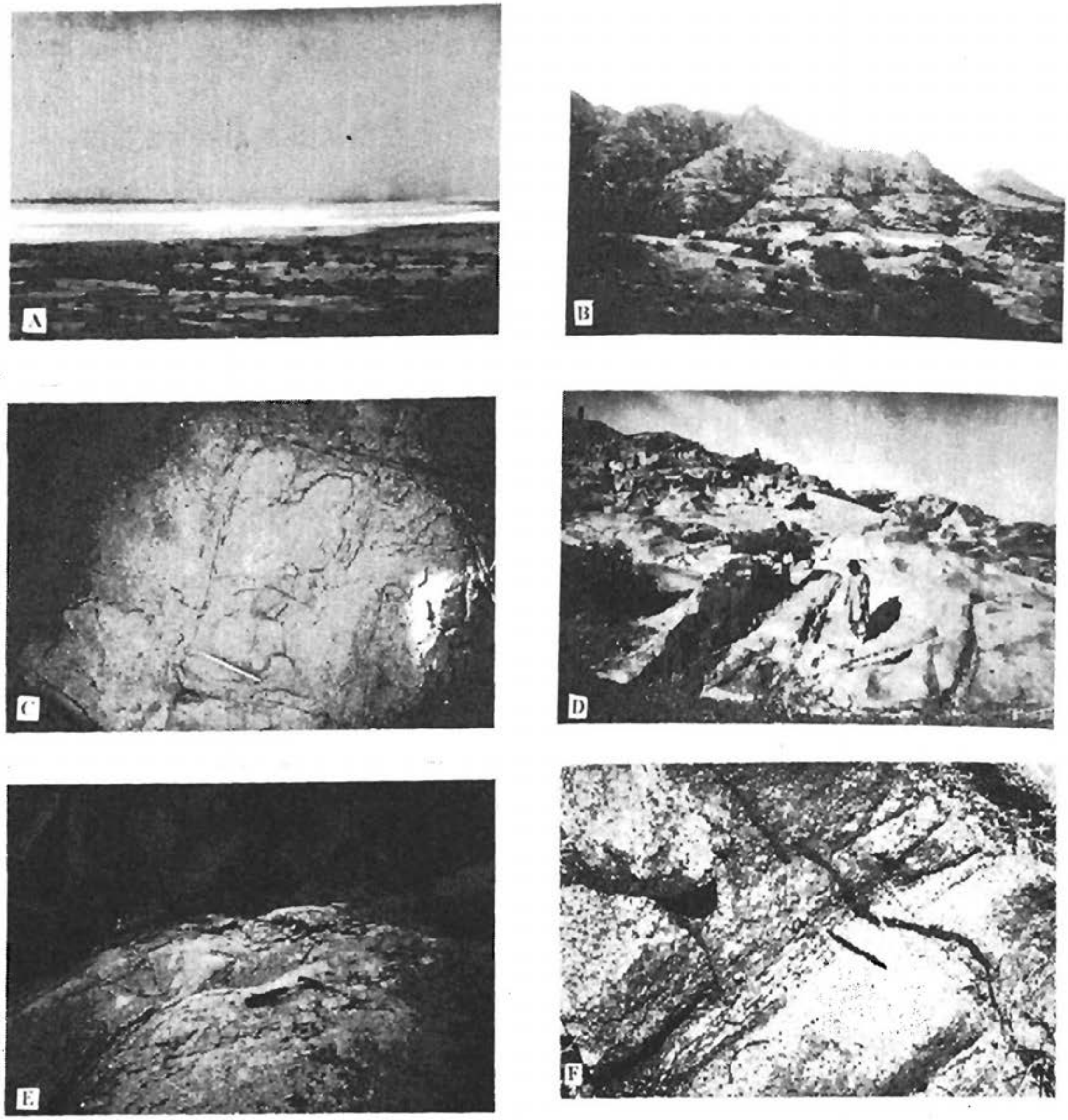


Fig. 2A. A general view of the great Runn of Kutch at the border of Pakistan and India.

2B. General view of Karunjhar Hill. Grey granite intruded by pink granite (foreground) to the west of the Nagar Parkar town.

2C. Pink granite, showing jointing, exfoliation and a mafic xenolith, near Jodhejo Wandhio.

2D. Pink granite, showing spheroidal weathering. Note mafic dyke in the lower left being observed by two of the authers, near Bhanbhan-ji-dungri.

2E. Grey granite with aplite dykes of pinkish colour, near Rarkoa.

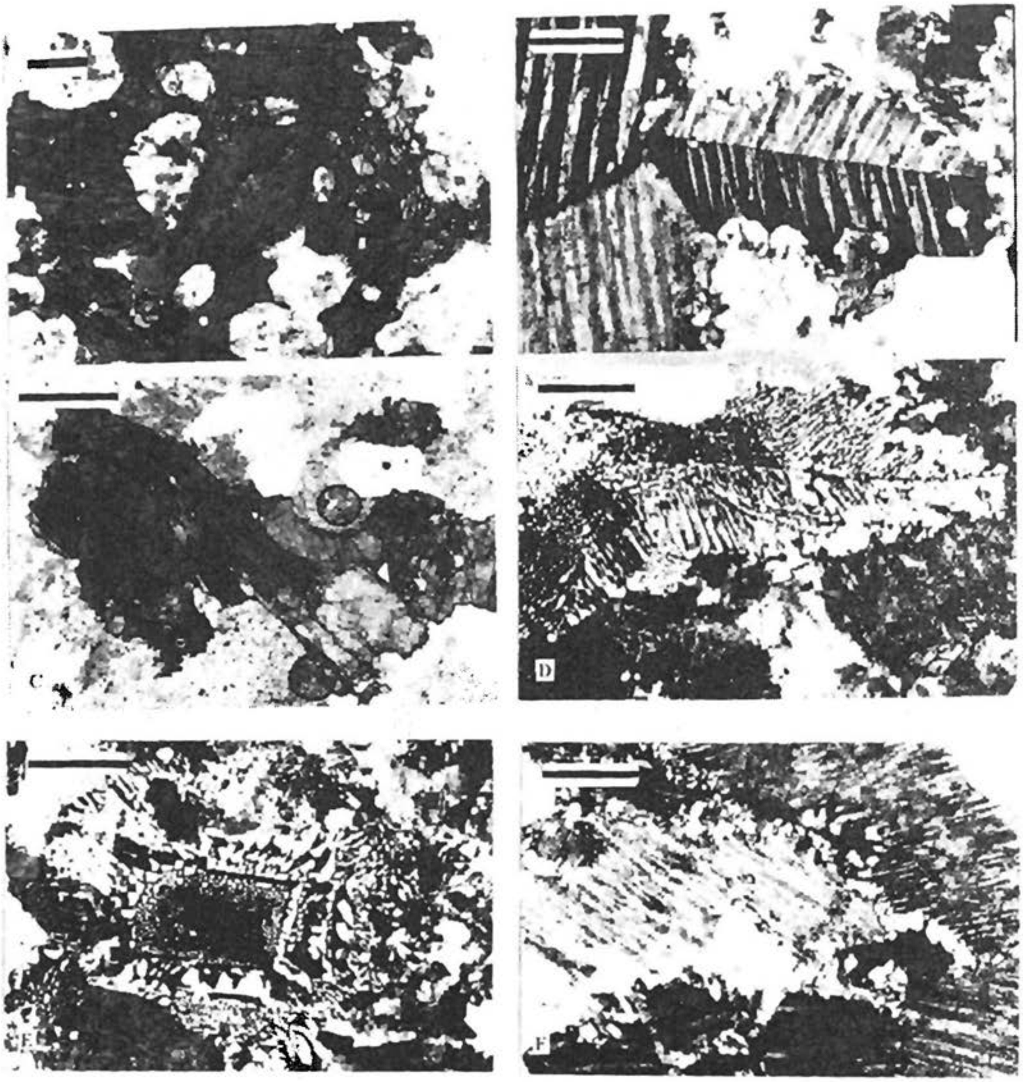
2F. Pink granite showing exfoliation and mafic dykes. Note that displacements in the longer dyke are filled by the matrix granite, suggesting emplacement of the dyke before the solidification of the matrix, near Bhanbhan-ji-dungri.

Hornblende is homogeneously pleochroic from pale green to brownish green and contains inclusions and blebs of cloudy plagioclase (Fig. 3A). Epidote occurs as subhedral crystals in granular and columnar aggregates. It contains small inclusions of plagioclase, sphene and hornblende, and may be accompanied by sericite. Chlorite, occuring as anhedral flakes, is generally associated with hornblende and occassionally with epidote. Quartz occurs as small inclusions in hornblende and plagioclase, or in the form of micro-veins cross-cutting the rocks. Rutile, magnetite and ilmenite occur in variable amounts as small grains in hornblende along fractures, cleavages and grain boundaries, but independent grains of these accessory phases are not uncommon. The composition of plagioclase (probably magmatic relics) ranges from andesine to labradorite.

Similar exposure of amphibolites occur at the back of the Dedhvero village which run northwest-southeast along the edge of the adjacent depression of the Runn of Kutch (Muslim and Akhtar,1995). This variety of amphibolites is highly weathered, fractured and jointed. These rocks are generally greenish black, medium- to fine-grained, hypidioblastic to xenoblastic and subequigranular in texture. They contain hornblende, plagioclase, quartz (minor), epidote and iron oxide. Sphene and apatite occur as accessories. Hornblende occurs as subhedral to anhedral grains of various sizes. The small grains are generally fresh but the large ones are at places altered to chlorite. Hornblende shows evidence of growth prior to as well as along with epidote. It is generally pleochroic from light green to brownish green. Locally it also displays bluish green cores and greenish-blue margins. In some rocks, hornblende surrounds or is surrounded by epidote. Blebs and small inclusion of hornblende within large hornblende grains are also observed. Plagioclase is generally cloudy, but in a few rocks fresh and twined. Whereas much of the plagioclase is andesine-labradorite. some is albitic. The former may be relictual (igneous) or produced during amphibolite facies whilst the sodic variety is a product of a lower grade metamorphic overprint. The quartz (traces to 15%) occurs as small to moderately large, subhedral to anhedral grains, locally exhibiting wavy or undulose extinction. Sphene is a common accessory, generally developed along the fractures, cleavages and grain boundaries of hornblende. Bluish green chlorite occurs along the margins and within the fractures of the hornblende crystals. Opaque minerals generally occur in the cores and at grain boundaries of the hornblende crystals. Rutile is commonly associated with magnetite, suggesting that the two may have developed at the expense of ilmenomagnetite during metamorphism. In some rocks clinopyroxene relics are associated with hornblende.

The basement contains dykes, ranging from gabbro through diorite and quartz diorite to hornblende-biotite granodiorite. Like the basement, these also display low-grade metamorphism and some planar fabric. The dykes are medium-grained, and intergranular to subpoikilitic in texture. The gabbro is mainly composed of plagioclase and hornblende, with minor amounts of quartz, biotite, clinopyroxene, iron oxide, rutile, apatite, and secondary chlorite, epidote and sericite. Plagioclase of andesine-labradorite composition is partially altered to sericite and epidote. Hornblende is pleochroic from light brown to dark brown, contains opaque grains and, in one studied rock, clinopyroxene relics. Biotite and hornblende are closely associated in several places.

The diorites contain plagioclase and hornblende as the dominant constituents. Quartz, biotite, iron oxide and sphene occur as accssories. Plagioclase is partially cloudy, contains small inclusion of quartz and hornblende, and shows alteration to sericite and secondary epidote. But fresh plagioclase



Bar scale = 0.5 mm

Fig. 3A. Amphibolite with hornblende, plagioclase, and iron oxide with locally associated sphene.

3B. Grey granite showing Carlsbad twinning in perthitic alkali feldspar (fish bone).

3C. Grey granite containing cloudy plagioclase, quartz (clear), riebeckite (left), and aegirine (right). Note a thin rim of aegirine on the upper left margin of the riebeckite.

3D. Porphyritic micrograpite showing intergrowth of quartz and feldspar arranged in cuniform shape, and enclosing hornblende (lower left) grains.

3E. Graphic intergrowth with variable grain size. That in the center is very fine-grained and contained in a rectangular area with euhedral outline.

3F. Pink granite showing myrmekite at the interface of two perthitic feldspar grains. The feldspar is dusted with pink iron oxide.

(andesine) with weakly developed zoning is also present. Hornblende occurs as long, prismatic crystals, strongly pleochroic from yellowish green to bluish green and contains quartz, iron oxide, sphene, epidote, muscovite along fractures, cleavages and grain boundaries. Chlorite is produced due to the alteration of hornblende and biotite. Epidote is generally colourless and grown from plagioclase. Sphene occurs as pale-yellow to brownish anhedral grains, mostly within hornblende crystals.

The quartz diorites are similar in mineralogy and texture but contain more quartz and small amount of pyroxene. Their hornblende is pleochroic from pale green to brown and plagioclase is An 28-32. There also are rare occurrences of hornblende-biotite granodiorite containing some K-feldspar.

The amphibolites contain mafic dykes, the characteristics of which are similar to the dykes in the granites. These are thus young dykes of Phase 6 and are described later in the paper. The body near Karai, however, is worth mentioning. The unmetamorphosed nature of this body together with the presence of olivine and titanian-augite groups it with the phase 6 alkaline dykes. However, these rocks show shearing and are intruded by small granitic and doleritic dykes themselves.

Phase-2 Riebeckite-Aegirine Grey Granite (RAGG)

The RAGG is widely exposed, especially in the southern part of the mapped area (Fig. 1), and covers much of the Karunjhar Hill. Striking in the NW-SE direction, the body contains xenoliths of metabasites (particularly in the northern margin) and is itself intruded by the biotite-hornblende pink granite (BHPG) which has a chilled contact against it, especially in the outcrops to the south of the Nagar Parkar town. The RAGG and BHPG are intruded by aplite, porphyritic microgranite and rhyolite dykes. Mafic dykes cut across all the units and are therefore the youngest phase.

The RAGG is mostly undeformed, but in some places shows weak deformational features. There is variation from medium- to coarse-grained, but no pegmatitic facies was observed within this granite. The granite is generally grey to greyish white, but at places turns pinkish due to weathering, especially along joints and fractures. It ranges from equigranular to subporphyritic or, locally, porphyritic and contains hypidiomorphic grains. It is essentially composed of perthitic feldspar (microperthite, mesoperthite), quartz, and small amounts of plagioclase and sodic minerals such as riebeckite and aegirine which are characteristic constituents of this granite (see Kazmi and Khan, 1973, and Butt et al., 1989, 1994). Fe-oxide and zircon occur in almost all of the studied samples. Tourmaline, fluorite and rutile occur in only some samples, and astrophyllite is rare. Allanite, sphene and leucoxene occur as minor accessories along with local epidote (Table 2). The mineral composition of the RAGG, especially the presence of sodic pyroxene and amphibole, is similar to Warsak and Sheva-Shahbaz Garhi granites in northern Pakistan (Kempe, 1973 ; Kempe and Jan, 1980; and Tahirkheli et al., 1990) and indicative of their sodic alkaline nature. A few of the thin sections lack aegirine.

Perthitic feldspar is the most abundant constituent of the RAGG. It is mostly fresh; but occassionally altered to sericite and muscovite. The perthite is either of string type or of bead or vein type (Barth, 1969; Augustithis, 1973). Cloudy veins and veinlets of perthite on both sides of the Carlsbad twin plane characteristically ornament these grains and form fish-bone type of structure (Fig. 3B). The concentration and textural behaviour of perthitic intergrowth are probably controlled by the presence of intracrystalline structures (cleavage, twin plane, and fracture), availability of perthite-forming liquid, and mode of origin (whether exsolved or metasomatic). In some rocks graphic intergrowth of quartz occurs as globules, blebs, fine irregular masses to large allotriomorphic grains, and stubby rods within and near the edge of perthitic feldspar (compare Augustithis, 1973).

Myrmekite is observed in some sections. This intergrowth of quartz and albite occurs as fine vermicules, pods, fans and dendritic masses in the perthitic alkali-feldspar. Several theories have been put forward to explain the origin of myrmekite (Raguin, 1965; Phillips and Carr, 1973; Phillips, 1980). In the investigated rocks, it appears that microshears channelized the metasomatizing fluids and led to alteration and the development of myrmeketic structure in the perthitic alkali-feldspar.

A small amount of plagioclase (An 8 - 24) occurs mostly as inclusions in the perthitic feldspar. It shows albite twinning, however, pericline twinning has also been noticed. The plagioclase appears to be of two generations. The primary plagioclase occurs as subhedral to euhedral grains showing albite twinning and containing small inclusions of muscovite. Secondary pagioclase occurs as rims around the grains of K-feldspar, and as graphic intergrowths within them. Quartz occurs as small to large, subhedral to anhedral, interstitial grains. At places the quartz grains form aggregates enclosed within feldspar. In some rocks, graphic intergrowth of quartz and feldspar is also seen.

TABLE 2. MODAL ANALYSES OF REPRESENTATIVE SAMPLES OF GREY GRANITE

S.N.	NP 7	NP 38	NP 39	NP 62	NP 85	NP 86	NP 87	W 6	W 20	W 43b	W 47	W 48	E 63
Prt	60	45	50	57	56	50	52	50	56	52	51	54	47
Pl	3	12	8	6	3	6	5	5	T	3	8	3	7
Mic		-	-	-	-	-	-	-	-	-	-	-	-
Qz	30	28	30	28	32	33	32	35	32	33	28	28	36
Bt	-	-	-	-	-	-	-	1	-	-	-	-	-
Mu	T	T	-	T	T	T	T	-	T	T	-	T	T
Chl	-	-	-	-	-	-	-	-	-	T	-	-	-
Am	4	7	6	2	6	5	2	5	5	5	4	5	4
Cpx	T	4	3	5	T	3	7	2	2	3	3	4	3
Spn	T	-	T	T	T	1	T	T	1	T	1	-	1
Leu	-	-	T	T	-	-	T	-	T	-	-	-	-
Opq	2	3	2	2	2	1	1	2	2	3	3	3	2
Ep	T	T	T	-	T	1	T	-	T	1	-	T	T
Zrn	-	-	T	-	T	T	T	T	T	T	-	T	T
Ap	T	-	-	-	T	T	-	T	T	-	T	-	-
Fl	-	-	-	-	T	T	T	-	-	-	-	-	-
Tur	T	-	T	T	T	-	-	-	-	-	-	-	-
Car	-	-	-	-	-	T	T	-	-	-	-	T	-
Ast	-	T	T	-	-	-	-	-	-	-	T	-	-
Rt	-	-	-	-	-	-	-	-	-	-	-	1	-
Aln	T	T	T	T	T	T	T	T	1	T	1	1	-

Riebeckite shows brown to dark blue pleochroism. It is commonly stumpy, prismatic, and subhedral to euhedral in shape. At places, it is typically needle-like to prismatic in habit and disseminated in the rock with a weak alignment. Aegirine, showing yellowish green to green pleochroism, is usually subordinate to riebeckite and occurs either in stocky, prismatic to stubby crystals, or in aggregates of lenticular, and subhedral to euhedral grains. In some rocks, there are inclusions of aegirine in quartz and of riebeckite in turbid feldspar. The aegirine and riebeckite are closely associated in many cases and show complex relationships (Fig. 3C). Some pyroxene grains have lilac brown (titanium-augite) cores and green (augite) margins (Butt et al., 1994). Both riebeckite and aegirine appear to have crystallized later than quartz and feldspar. The RAGG has close petrographic similarity with the Siwana Granite of Rajasthan. The nearest outcrops of the latter at Chandan are only 110 km from the Berano RAGG exposures of Nagar Parkar (Mukherji and Roy, 1981; Bhushan and Yagi, 1981; Kochhar, 1984; Bhushan and Mohanty, 1988; Bhushan, 1989, 1991).

Phase-3 Plutons

a. Biotite-hornblende pink granite (BHPG)

A typical outcrop of the BHPG is exposed along the northeasten margin of the Karunjhar Hill. It may be a sub-horizontal sheet-like intrusion in the RAGG. In the central portion, this granite is not exposed due to the thick cover of RAGG except where the latter is deeply dissected. The BHPG has chilled contact against RAGG, especially in the outcrops to the south of the Nagar Parkar town where the (chilled) margin is some 45 cm thick. Immediatly at the contact, quartz is associated with the BHPG. It occurs in the form of veins and lumps up to 15 cm thick. Locally the granite is light pink due to leaching. The BHPG contains xenoliths of mafic rocks, up to a couple of meters in size and displaying some linear arrangment. Aplite, porphyritic rhyolite and basic dykes are commonly observed in this granite (Kazmi and Khan, 1973; Butt et al., 1989, 1994; Muslim and Akhtar, 1995). The largest body of this granite covers about 9 km^2 and is characterized by a typical pink colour. On the basis of colour and modal mineralogy, the BHPG may be equated with the pink Jalore and Erinpura Granites of southwest Rajasthan (Bhushan, 1989, 1991; Pandit and Deep, 1994; Banjeri and Pandit, 1995).

The BHPG is mostly leucocratic but locally rich in biotite (up to 7 %) and having a greyish tone. It is commonly homogeneous and frequently shows spheroidal forms (Wynne, 1867; Butt et al., 1994). The granite is generally coarse- and medium- but locally fine-grained, hypidiomorphic, equigranular to subequigranular. It is essentially made up of perthitic feldspar and quartz, with local microcline, and minor plagioclase (oligoclase); but some cotains sufficient plagioclase to be termed as quartz monzonite or adamellite (Butt et al., 1994). Biotite and hornblende are the main accessory minerals along with iron oxide. In a few thin sections, hornblende is lacking. Fayalitic olivine, zircon, sphene, apatite, tourmaline, fluorite, allanite and cassitterite occur as sporadic accessory minerals (Table 3). Epidote, carbonate, sericite and muscovite are produced due to the alteration of feldspar. Butt et al. (1994) reported dumortierite grains in one of the granite samples of the area. Locally, the rocks contain riebeckite and aegirine-augite, thus grading modally into RAGG, paricullarly near the contact with Karunjhar grey granite. The pink colour of the granite is due to hematitic staining resulting from alteration of ferromagnessian minerals. In several places, the grey granite has turned pink upon alteration, making its distinction from the pink granite quite difficult.

An intresting variety of pink granite occurs to the NE of Kharsar. This medium-grained rock contains some feldspar grains of white colour and higher proportion feromagnesian minerals. Under the microscope, it consists of abundant perthite and quartz-feldspar intergrowth and some plagioclase, independent quartz grains, dark green hornblende, biotite, opaque, sphene, epidote, leucoxene, allanite and apatite. Some plagioclase grains are surrounded by perthite. The rock shows a fairly strong alteration.

The guest phase in the perthite of the BHPG, as in the Paleozoic Ambela complex (Rafiq and Jan, 1987, 1988) and many other granites, varies in form and shape from stringlets to coarse beads, patches and ganglia-like masses developed along cleavage traces, and other intracrystalline structures of the host. Granophyric texture showing intergrowth of quartz and K-feldspar is of several kinds, such as blebs, globules, cuniform (Fig. 3D) and laths of quartz in K-feldspar arranged radially or parallel. The lamellar intergrowth in the studied samples resembles lamellar twinning in plagioclase (cf. Augustithis, 1973).

Myrmekitic intergrowths are common. They usually occur at the border of plagioclase and K-feldspar, and may be a consequence of siliceous metasomatism involving the addition of silica and removal of alumina and lime (Raguin, 1965).But they are also formed by exsolution, deriving both the components, quartz and plagioclase, originally held in solid solution in the alkali feldspar. They consist of small buds, fine vermicules, crusts, pods, fans and dendritic masses (Fig. 3E). Details of the early works on myrmekite have been summarised by many workers (Raguin, 1965; Sarma and Raja, 1959; Shelly, 1964; Bhattacharyya, 1971; Phillips and Carr, 1973; Phillips, 1980; Tullis, 1983; Hibbard, 1987; and Rafiq and Jan, 1988).

TABLE 3. MODAL ANALYSES OF REPRESENTATIVE SAMPLES OF PINK GRANITES

S.N.	NP 13	NP 16	NP 84	W 9	W 53	NP 192	NP 196	NP 209	NP 231	NP 259	NP 268	E 16	E 17	E 25
Prt	50	58	50	52	58	57	47	45	32	30	20	42	45	58
Pl	12	8	7	8	7	6	10	10	15	17	40	18	10	3
Seri	2	T	2	2	2	2	5	4	3	2	4	T	2	T
Mic	T	-	-	-	1	-	-	T	3	6	3	3	2	T
Qz	32	30	32	30	32	28	28	30	20	22	20	30	30	30
Bt	2	1	2	3	T	2	1	3	5	6	5	2	3	2
Mu	T	1	T	T	T	T	1	T	-	-	1	T	1	1
Chl	-	T	1	2	-	2	1	2	3	2	2	1	2	1
Am	-	T	2	-	-	1	2	1	10	10	1	2	T	1
Cpx	-	-	T	-	-	-	-	-	T	1	T	-	-	-
Opq	1	1	2	2	T	2	2	2	2	2	2	1	2	2
Ol	T	T	T	-	-	T	T	-	-	-	-	-	-	-
Spn	-	-	-	T	-	T	1	T	2	1	1	T	T	T
Leu	-	-	-	-	-	-	T	-	-	-	-	-	T	-
Ep	-	T	1	T	-	T	1	2	2	T	1	-	1	1
Zrn	T	T	T	T	T	T	-	T	T	T	T	T	-	-
Ap	-	-	T	T	-	T	T	T	1	-	T	-	T	-
Fl	-	T	-	-	T	T	T	T	-	T	T	-	-	-
Tur	-	-	T	-	-	-	-	-	-	-	-	-	-	T
Car	-	-	T	-	-	T	T	T	-	-	-	-	2	1
Ast	-	-	-	-	-	-	-	-	-	-	-	-	T	T
Cst	-	T	T	-	-	-	-	-	-	-	-	-	-	-
Aln	-	T	1	-	T	-	T	T	-	-	-	-	T	-

NP 268 - Adamellite

The general aspects of the myrmekitic growth in the area are summarized in the following:

1) An extensive myrmekite development is noted at the interface of the perthite and plagioclase with convexity of myrmekite mass towards the perthite.

2) The quartz 'stems' forming the myrmekite fabric extend their branches towards perthite without touching each other. In the begining the stems are often thicker and the distance between them is larger.

3) Myrmekite growth at the interface of two perthite grains (Fig. 3F).

4) Myrmeckite totally enclosed in perthite without any connection with the adjoining plagioclase and quartz. The enclosed myrmekite is rounded in some cases and highly irregular with corrugated borders in others.

5) Myrmekite developed as a thin films at the interface of perthite and quartz.

6) Myrmekite occurrence at the interface of plagioclase and quartz.

Plagioclase (An 26-30) is mostly enclosed in perthitic feldspar. It is generally altered to sericite, muscovite and kaoline. The central parts of the grains are more altered than the margins, either due to a difference in composition or overgrowth during the later processes such as metasomatism and exsolution. As compared with RAGG, plagioclase in the BHPG is more calcic and shows a higher degree of alteration. Microcline appears to be of two textural types: perthitic and non-perthitic. Quartz occurs as coarse grains displaying wavy extinction as well as in fine-grained interstitial aggregates. Sericitization commonly renders the feldspar grains turbid and "dirty".

Biotite is of two types: i) iron-rich, showing pleochroism from yellowish brown to dark brown, and ii) coloured. It occurs as elongated flakes interstitial to plagioclase and quartz (Fig. 4A). A few grains show pleochroic halos around tiny zircon. The green biotite often shows incipient alteraion to chlorite and contains inclusions of apatite, zircon, fluorite, ilmenite and magnetite. The ilmenite inclusions in biotite are generally rimmed by sphene. This features has been attributed to deformation by Vernon et al. (1983), however, no evidence of deformation exists in the rocks under study. Biotite is closely associated with hornblende which shows pleochrism from pale green to dark green. Muscovite grains are mostly interlaminated with biotite flakes, but small flakes of white mica also occur within the grains of K-feldspar and plagioclase as alteration product.

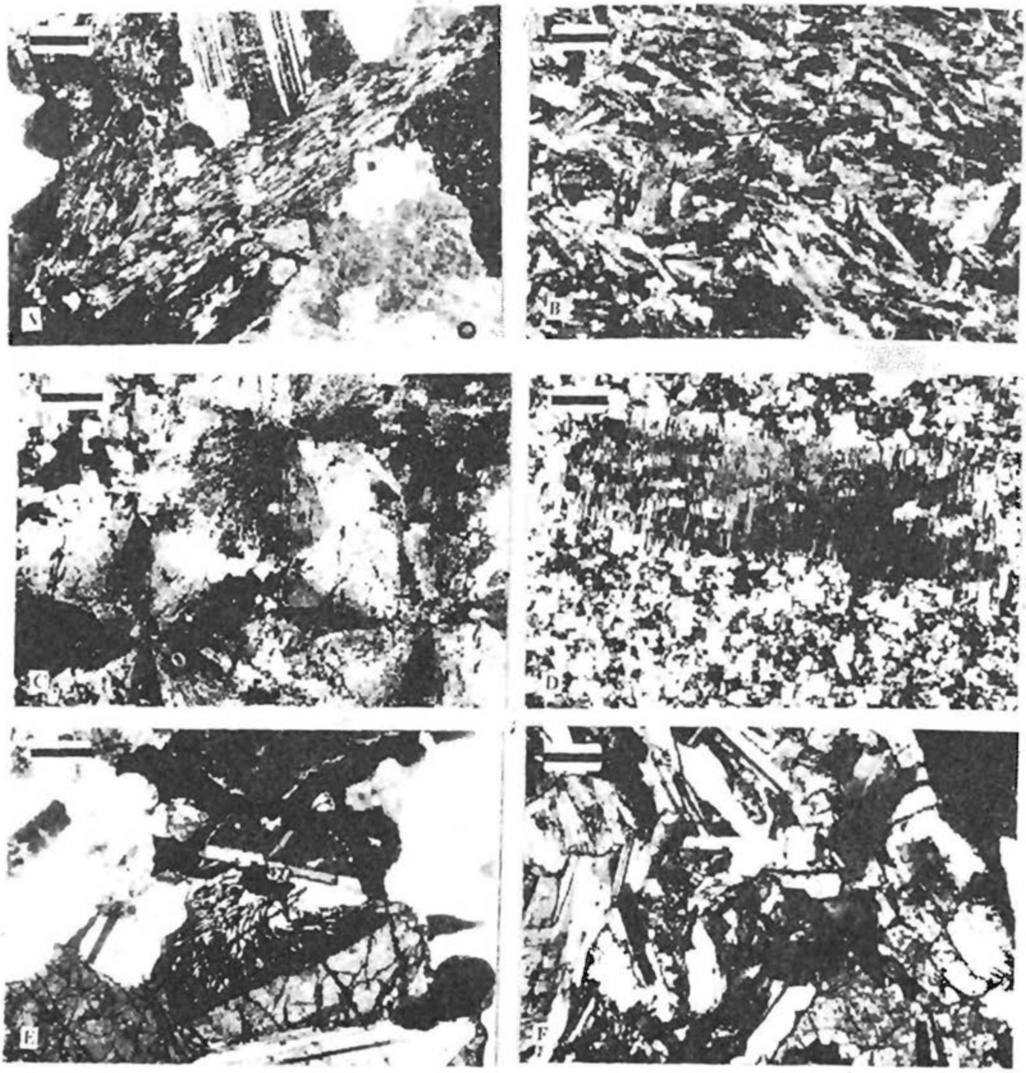
Opaque minerlas include Fe-Ti oxide, magnetite, hematite and illmenite. They occur as specks, tiny inclusions, interstitial grains and irregular aggregates. At places, the oxides, especially magnetite and hematite, occur as alteration products, the latter staining the rocks.

b. "Mottled" pink granite

In NE of Mokario village, there is an unusual medium-coarse variety of this granite containing light pink and white feldspar. This adamellitic rock consists of perthitic K-feldspar, zoned plagioclase and quartz. Biotite and hornblende are the main accessory minerals along with iron oxide. Other, less abundant minerals, are augite, sphene, allanite, zircon and apatite. Alteration, though not intense, has produced white mica, epidote and chlorite. This rock is locally porphyritic with over a centimeter large plagioclase enclosed in pink perthitic jackets.

c. Quartz monzonite

The quartz monzonites are exposed in the



Bar scale = 0.5 mm.

Fig. 4A. Pink granite, showing perthite (lower right), plagioclase, quartz, and biotite. The latter contains magnetite inclusions and is slightly altered to chlorite.

4B. Trachytoid rhyolite showing aligned plagioclase microlites. The plagioclase looks cloudy due to inclusion of iron ore dust.

4C. Rhyolite showing spherulitic texture.

4D. Resorbed, perthitic feldspar phenocrysts in a fine-grained quartzo-feldspathic matrix with minor biotite.

4E. Olivine gabbro showing vermicular intergrowth of iron oxide and titanian-augite. Thin rims of epidote around iron oxide have grown due to reaction with plagioclase.

4F. Dolerite dyke containing zoned plagioclase, olivine (centre) and locally ophitic titanian-augite (lower right).

Ranpur dungri: 24° 21′ 44″ N, 70° 51′ 46″ E. They contain xenoliths of mafic rocks (particularly to the north of Ranpur), and up to 5 cm thick quartz veins. The rocks are mostly homogeneous, medium- to coarse-grained, and porphyritic to subporphyritic. These are essetially made up of perthite (microperthite, microcline), plagioclase, quartz and hornblende. Accessories include biotie, chlorite, opaque oxide, sphene, apatite, zircon, fluorite, ± augite. Epidote, sericite and muscovite are local alteration products. The perthitic feldspar grains are generally fresh, however, some are dusty due to alteration to clay, sericite and muscovite. Plagioclase (An 10-28) is partially altered to secondary epidote and sericite, but fresh plagioclase with weakly developed zoning is also present. Quartz is interstitial to plagioclase and hornblende. The latter is pleochroic from light green to brownish green and contains inclusions and blebs of cloudy plagioclase, quartz and opaque minerals. Like biotite, it is partly altered to chlorite.

Phase-4 Acid dykes

Extending mostly in NW-SE to almost N-S direction, many small dykes of acidic composition cut the older lithologies. They range from aplite to porphyritic microgranite, and rhyolite to quartz trachyte in composition. The rhyolite to quartz trachyte of Butt et al. (1989,1994) were named by Muslim and Akhtar (1995) as orthphyres in the Nagar Parkar and Dedhvero areas. These dykes were thought to be older than granites (Butt et al., 1994), however, the present study reveals that at least some are definitely younger in age as they intrude the Dedhvero and Nagar Parkar pink and grey granites. It is probable that the minor dykes represent more than one phase of magmatic activity. A good example of this is noted in Banbhan-ji-dungri. Here the pink granite is intruded by a 10 × 300 m aplite dyke (N 40° E) which is cut and terminated by a strongly porphyritic, fine-grained, dark grey quartz monzonite dyke trending N 30° W. The latter contains xenoliths of pink and white granite and is cut by dolerite dykes. Other exposures are seen in Dedhvero and to the southwest of Ghantiari village. Here the rhyolitic dykes seem to emanate from the Nagar Parkar pink granite. The Karunjhar grey granite contains rhyolite porphyry dykes. Other rhyolitic dykes are exposed in Kharsar, Bhanbhan-ji-dungri and Boodhar village. Here we describe the more common varieties.

a. Porphyritic microgranite dykes

The porphyritic microgranite dykes are exposed to the southwest of the Ghantiary and Nagar Parkar town. Two of the dykes at Ghantiary are about 3 m thick and extend more than 500 m in N30°W direction. These are brown-red in colour, and mostly fine- to medium-grained. They contain phenocrysts of K-feldspar (mainly perthite), quartz and plagioclase embedded in a groundmass of micrographic intergrowth of quartz and feldspar. Accessory minerals include iron oxide, greenish blue amphibole (riebeckite), biotite, aegirine, muscovite, zircon, fluorite, apatite, sphene, allanite, tourmaline, and secondary epidote, chlorite, carbonate and leucoxene (Table 4). Feldspar alteraion (clouding, sericitization) and staining imparts the rocks a brownish colour. Graphic intergrowth of quatz and plagioclase occurs as fine vermicules, pods, fans, globules, sieves, and sheaf-like masses near the grains of perthitic feldspar. Biotite and iron oxide are partly altered to chlorite, and secondary carbonate is seen along fractures in the rocks.

b. Rhyolitic dykes

Acidic dykes of rhyolitic to quartz trachytic composition are exposed in Dedhvero (Fig. 1). This area is occupied by metagabbroic amphibolites with isolated patches of granites. These are cut by dykes of brown-red rhyolite extenting in the N 12° W direction. The dykes are mostly small but one of them is 5 to 6 m thick and extends for >2 km. They might represent feeders to Malani-type volcanics now eroded away or covered by the Quaternary deposits (Chandrasekaran and

Srivastava, 1992; Butt et al., 1994; Pandit and Deep, 1994).

The rocks are generally fine-grained, porphyritic, and slightly deformed. Trachytic textuture is prominent in them and grains of plagioclase are aligned in subparallel directions (Fig.4B). They contain phenocrysts of perthite and plagioclase, with small amount of quartz. The feldspar phenocrysts contain inclusions of iron oxide, some of which shows chery red colour. Plagioclase laths are fractured, and some grains show alteration at the margin. Other minerals include Fe-Ti oxide, bluish-green amphibole, biotite, apatite and zircon as accessories, and secondary epidote.

c. Rhyolite porphyry and aplite dykes

Rhyolite porphyry dykes are exposed in the Kharsar, Dinsi and Boodhar village. The dykes are mostly small, but one at Kharsar is 5 m thick and extends for more than 300 m in N 60° W direction. These dykes are dark red to purple in colour, fine-granied and porphyritic. Some of them also display spherulitic texture (Fig. 4C). They contain phenocrysts of pink alkali feldspar (mainly perthite), quartz and plagioclase, embedded in a fine-grained grounmass of micrographic intergrowth of K-feldspar and quartz. Accessory minerals include bluish-green amphibole, Fe-Ti oxide, aegirine, sphene, biotite, zircon, apatite and secondary epidote (Table 4). Feldspar alteration (clouding, sericitization) imparts the rocks a brownish colour. The quartz phenocrysts are often embayed and broken, as in the Malani dyke swarm of Rajasthan (Pandit and Deep, 1994; Rathore et al. 1996; Rathore and Venkatesan, 1996). A characteristic feature of these dykes is the presence of mafic xenoliths, derived from the subsurface fine-grained rocks.

The aplite dykes are mostly leucocratic and equigranular in texture. They consist mainly of a fine-grained granular mixture of feldspar and quartz, with small amount of biotite, iron oxide, muscovite and sphene. Both sodic plagioclase and potassic feldspar are present. The latter may costitute more than half of the feldspar in the rocks. Patches of micrographic intergrowth of quartz and feldspar have also been noticed.

Phase-5 Rhyolite " Plugs"

These occur in two small, domal outcrops exposed near Sadorus and Boodhar. Their field relations with the rest of the granites could not be studied in detail but they may be an effusive phase genetically related to the granites.

The 1.0 × 0.3 km outcrop near Sadorus village is entirely occupied by rhyolite with rare thin aplite dykes. The rhyolite is dark grey to black, glassy-looking, with whitish bands up to a cm thick and extending for more than 2 m in N 20° W direction and dipping 60° SW. The southwestern part of the body is dominantly homogeneous, while the rest of the body is extensively banded. The banding has a consistant regional attitude but is extensively undulated and folded at outcrop scale. This banding is probably due to an uneven distribution of tiny bubbls and the folding is a consequence of upward migration or flow of a viscous magma. The rocks are fractured and jointed. A few of fractures and joints are filled with epidote. Locally, the rocks exhibit brownish red staining.

The rocks are fine-grained and porphyritc to subporphyritic. They contain phenocrysts of K-feldspar (mainly perthite) and quartz, with small amounts of plagioclase, embedded in a quartzo-feldspathic groundmass (Fig. 4D) (compare Pandit and Deep, 1994). The phenocrysts make upto 20% of the rocks, and are subhedral to anhedral in shape. Other minerals include Fe-oxide, sphene, biotite, epidote, muscovite and secondary carbonate. Zircon and apatite occur as accessory minerals. In one thin section, small grains of tourmaline and fluorite were also observed. The perthitic phenocrysts contain blebs and shreds of plagioclase. Independent grains of plagioclase (An 12-20) constitute 5-10% of the total phenocryts, and are frequently fresh, but locally cloudy due to sercitization and kaolinization. The Quartz phenocrysts are inclusion-free and often embayed. Limonite is developed throughout the rocks as a staining material. At places, the rocks show micrographic texture and there are spherulitic intergrowth of quartz and alkali feldspar. The spherulites may have developed due to quenching of the melt (Bhushan, 1985).

A 1.0 × 0.5 km rhyolitic body, trending in N 20° E direction, is exposed east of Boodhar village. It is generally homogeneous dark grey to black with greyish-white bands, fine-grained, porphyritic to subporphyritic, and contains xenoliths of basic rocks. These rocks are quite similar to the Sadorus rhyolites.

TABLE 4. MODAL ANALYSES OF REPRESENTATIVE SAMPLES OF ACID DYKES AND RHYOLITES

S.N	NP 63	W 8	NP 70	NP 217	W 18	W 40	E 41	E 64	NP 164	NP 170	NP 172	NP 190	NP 197	NP 198
PHENOCRYST (P)														
Prt	-	-	60	50	50	60	-	-	55	50	50	85	75	80
Pl	-	-	-	10	5	5	-	-	5	5	5	10	25	-
Qtz	-	-	40	40	45	30	-	-	40	45	45	5	5	20
GROUNDMASS (G)														
Felsic	92	97	88	83	86	79	89	84	86	82	95	82	83	82
Bt	3	-	-	-	2	1	-	-	T	-	-	5	-	T
Ms	1	T	2	-	-	1	-	-	-	-	-	-	-	-
Chl	-	-	T	-	1	2	-	-	T	-	-	T	3	-
Am	-	-	1	8	6	7	-	1	3	-	-	4	6	7
Pyx	-	-	T	-	-	-	-	-	-	-	1	-	-	2
Spn	-	T	1	2	2	2	-	-	1	2	T	1	1	1
Opq	3	1	4	3	2	3	10	10	10	10	3	6	2	6
Ep	-	1	1	1	T	1	T	T	T	5	T	1	2	1
Zrn	-	-	T	T	T	1	-	-	-	-	-	T	1	-
Ap	-	-	T	T	T	T	-	-	-	-	-	-	T	T
Fl	T	-	T	-	T	T	T	T	-	-	-	-	T	-
Car	-	T	2	-	-	1	-	4	-	-	-	-	-	-
Rt	T	-	-	1	-	-	-	-	-	-	-	T	-	-
Al	T	-	-	1	-	1	-	-	-	-	-	-	1	-
P%	-	-	25	30	40	35	-	-	25	22	20	15	30	20

NP63, W8 aplites. NP70, NP217, W18, W40 porphyritic microgranites. E41, E64 trachyte dykes; NP164, 170, 172 rhyolites and NP190,197,198 are porphyritic rhyolite dykes.

They contain phenocrysts of K-feldspar, quartz and minor plagioclase in a spherulitic matrix with well-marked flow structure, and micrographic ground mass consisting of quartz and slightly altered feldspar. Accessory minerals include greenish blue amphibole (riebeckite), Fe-Ti oxide, aegirine, sphene, rutile, zircon, apatite, and secondary epidote and sericite (Table 4). The K-feldspar occurs as microperthite and spherulites depicting intergrowth with albite and quartz. At the boundary with microperthite and spherulite, the plagioclase is myrmekitically intergrown with quartz. These rocks may be the equivalent of the Malani rhyolites (Kochhar, 1984; Chandrasekaran and Srivastava, 1992; Rathore et al. 1996; Rathore and Venkatesan, 1996). According to Bhushan (1985), the Malani rocks range from tholeiitic to alkaline.

Phase-6 Basic dykes

These are discussed as a separate unit on the basis of their cross-cutting relationship with most of the rocks described here (Kazmi and Khan, 1973; Butt et al., 1994; Muslim et al., 1995). Most of the mafic dykes are younger than the granitic rocks but in a few places they themselves are apparently cut by granitic dykes. In Banbhan-ji-dungri, a broken dolerite dyke contains infilling of the matrix granite, suggesting that the dolerite intrusion took place before the cooling and solidification of the matrix granite. There are rare composite dykes consisting of mafic interior and granitic margins (see Kazmi and Jan, 1997). The dykes mostly have vertical attitude and range from thin veins to 5 m thick bodies (Kazmi and Khan, 1973). The basic dykes can be divided into two groups; a: lamprophyric diorite dykes, b: alkaline gabbro/dolerite dykes.

a. " Lamprophyric" dykes

These are fine-grained rocks, generally, subequigranular and, in rare cases, display some parallel (flow?) fabric. They are characterized by the presence of brown hornblende and show a distinct alteration (deuteric/late magmetic). Plagioclase, amphibole, and ilmenite-magnetite are their principal constituents. At least some rocks appear porphyritic with hornblende phenocrysts along with plagioclase (An 45-55), although some hornblende is poikilitic. In one rock, only plagioclase forms the phenocrysts. These rocks also contain a second generation of faintly green amphibole, with chlorite and epidote in many cases. Acecessories include sphene, apatite and, in some thin sections, quartz and/or K-feldspar locally intergrown graphically. Epidote and white mica are the alteration product of the plagioclase. In one studied rock, there are augite grains, commonly surrounded by brown hornblende.

b. Alkaline gabbro/dolerite dykes

These are generally fresh or mildly altered, and characterized by lilac titanian augite with olivine in most cases. These are probably of alkaline affinity. The gabbroic rocks are exposed near Karai, Jodhe-jo-Wandhio and Dedhvero areas. In the following, we describe the exposures near Karai as an example.

A small (1.5 km^2), isolated exposure of a gabbroic body has been observed at Karai (24° 23′ 55″ N, 70° 47′ 24″ E). Kazmi and Khan (1973) described a gabbro (probably this one) containing plagioclase, augitic pyroxene and iron oxide from this area. These rocks are dark grey to black, medium-grained, aphyric to porphyritic, with rounded phenocrysts of pyroxene over a centimeter long. These rocks also contain quartz inclusions reaching up to 2.5 cm or even longer. They are extensively banded, with bands up to 3 cm thick and extending more than 30 cm in N 20° W direction, dipping 85° SW. Several dolerite dykes cut the gabbroic body and are themselves locally cut by granitic veins that are greyish white to pink and up to 1.5 m thick. Some dolerite dykes are oblique to the trend of "shearing" in the matrix and gabbros, and are displaced by the shears. In most of the places, the gabbros are highly sheared, weathered, jointed and fractured.

The gabbros are mainly composed of plagioclase, olivine, augitic pyroxene and iron oxide, with small amount of biotite and apatite, and show intergranular to subophitic mosaic. Plagioclase (An 50-64) occurs as laths with albite and Carlsbad twinning, and showing partial alteration to sericite and epidote. Subhedral, equant olivine crystals are enclosed in plagioclase. Narrow brown rims of iddingsite are formed at the margin of olivine due to hydration and oxidation. Pale brown augitic pyroxene usually occurs as phenocrysts and, rarely, also in the groundmass. It shows exsolution lamellae and partial alteration to hornblende. A few of the pyroxene grains contain relics of olivine. Biotite and chlorite are probably produced due to alteration of augite, as they form rims around the latter. At places vermicular intergrowth of iron oxide and titanium-augite have also been noticed. Thin rims of epidote around the iron oxide have grown due to reaction with plagioclase (Fig. 4E). Opaque minerals occur as inclusions within plagioclase and augite, and as discrete tiny grains in the groundmass. At places, these are altered to hematite along the grain boundaries. In one thin section, the presence of a small amount of pyrite was also noted.

Dolerite dykes of similar petrographic characteristics are widespread and intrude most rocks in the area. These are commonly 1 to 3 m thick and extend for 10 to 60 m. Similar dykes have also been reported in the Malani igneous suite (Srivastava et al., 1989; Pandit and Deep, 1994). These dykes are fine- to medium-grained and porphyritic. The pyroxene is commonly subophitic but in some rocks grains of other minerals may be poikilitic in habit (Fig.4F) The rocks contain phenocrysts of plagioclase, olivine and titanian augite in a groundmass of hornblende, biotite, chlorite and opaque oxide. Accessories include epidote, sphene, carbonate, iddingsite, muscovite and apatite (Table 1). The plagioclase shows zoning and partial alteration to sericite and epidote. The clinopyroxene may display a lilac colour, typical of titaniferous augite of alkaline rocks. Butt et al. (1994) noted that the augite can be divided into two groups: i) rounded, with olivine inclusions and lighter-colour margins, ii) euhedral, devoid of olivine and marginal zones. Whether the former represents xenocrysts is not clear. In some thin sections, there is a narrow, brown rim of iddingsite around magnetite cores. This feature is probably formed by hydration and oxidation of olivine. Symplectite texture has locally developed and consists of iron ore and pyroxene. At places, the augite contains exolution lamellae and shows partial alteration to hornblende. Chlorite has also developed due to the alteration of augitic pyroxene.

DISCUSSION AND CONCLUSION

The Nagar Parkar igneous complex is a part of the western Indian shield (Pathan and Ahmed; 1975-76, Shah, 1977; Muslim and Akhtar, 1995). The Indian shield as a whole consists of three major cratons, a) Dharwar craton, which is located west of Cudapah basin and is comprised of Archean to Early Proterozoic rocks, b) Singhbum craton is present in eastern India and consists of Archean granites, older metamorphic rocks, gneisses and metasediments overlain by Proterozoic volcanics and sediments, and c) Aravalli craton, occupying the northern portion of the shield region and consisting of Archean Bhilawara supergroup (banded gneissic complex) and three Proterozoic supergroups, i.e., the Aravalli, Delhi and Vidhyan (Murthy, 1987). The Aravalli Mountain Range of western India runs almost NE-SW and bends eastward at the southern end as a result of major drag fault along the Narmada-Son lineament (West, 1962; Crawford, 1978). Radiometric dates of 1,100 to 1,900 Ma were suggested for the metamorphic evolution of the Delhi rocks in the Aravalli mountain range (Crawford and Compston, 1970).

Four major tectonic, magmatic, and metamophic events have since been recognised in the Aravalli range. These events represent the approximate closing ages of 3,000 Ma for Archean, 2,000 Ma for Aravalli orogeny, 1,450 Ma for Delhi orogeny, and 850-750 Ma for Post-Delhi tectonic/ anorogenic magmatic event (Roy, 1988). The range contains many granites of Late Proterozoic age (Pascoe, 1959 ; Srivastava, 1988). Of these, the Mount Abu, Jalore, Siwana, Erinpura granites, and Malani igneous suite occur on the convex side of the dragged area of the range. The Rb-Sr age of the Malani and Mount Abu suites is the same (i.e., 740 $\pm$ 20 Ma). The igneous activity might have resulted due to the sinistral shear along the Narmada-Son lineament (Crawford, 1975).

The Nagar Parkar exposures occur no more than 130 km SSW of the volcanic and granitic exposures of the Malani igneous suite in Rajasthan. The intervening area is covered by sand (Butt et al., 1994). These granites have been encountered at shallow level in several test holes to the southeast of Chachro, 80 km north of the Nagar Parkar (Fasset et al., 1994). They display a general similarity with those of Siwana and Jalore. The later have recently yielded slightly younger Rb-Sr ages (698 and 728 $\pm$10 Ma, respectively) than the Malani volcanics (Rathore and Venkatesan, 1996). The Nagar Parkar rocks also share common features with the Malani igneous suite, e.g., both are locally alkaline and contain rhyolitic and younger basic dykes (Srivastava et al., 1989). We, thus, conclude that the Nagar Parkar granites may be a southwesterly extension of the post-Delhi magmatism towards the end of the Proterozoic as already suggested by us (Butt et al., 1994; Kazmi and Jan, 1997). Geochemically, the granitic rocks of Nagar Parkar (Butt et al., 1994) and their presumed equivalents in Rajasthan (Kochhar, 1984; Bhushan and Mohanty, 1988) are considered to be intracontinental. They may have been generated during a period of extension (domal uplift or rifting). Such an origin has also been suggested for the Malani igneous suite by Srivastava et al. (1989). Their host amphibolites are metamorphosed and show a distinctly higher degree of deformation. They probably represent a basement of an older age that underwent a tectono-metamorphic event before the emplacement of the granitic plutons.

From the present study, we conclude that the Nagar Parkar igneous complex is a product of several distinct batches of magma. The basement contains an early set of dykes possibly related magmatically to their host amphibolites. These range from gabbro through diorite and quartz diorite to hornblende-biotite granodiorite. These rocks may represent a tholeiitic association that was deformed and metamorphosed before granite magmatism. The latter began with grey granites clearly derived from a sodic alkaline magma, followed by pink leucogranites possibly per-aluminous in character. However, there are several types of acidic dykes the nature and emplacement history of which is still to be deciphered. The end of magmatism is mostly marked by mafic dykes which appear to be derived from two magma compositions one of which had a lamprophyric characteristic and the other an alkaline-olivine basalt characteristic. The mutual relation of these two is not clear at this stage. (All the young mafic dykes were collected with the bias that they are uniform in composition). In rare instances, field relations suggest that (1) these mafic dykes were emplaced before the host granites were totally solidified, and (2) the mafic alkaline dykes were followed by some acidic dykes. There is, thus, evidence that the area experienced a bimodal magmatism in the end. The magmatic story of the area may well be far more complicated than hitherto realised

Acknowledgement: This work was funded from the NCE field grant. We are thankful to the technical staff of the centre, and the

generous support of Police, Mr. Ghulam Mustafa Khoso, and other officials during the field work.

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