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Petrography and major element chemistry of mafic dykes in the Nagar Parkar Igneous Complex, Tharparkar, Sindh

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Abstract

The Nagar Parkar igneous complex consists of a variety of Late Proterozoic granitic rocks emplaced in a basement of amphibolitic rocks. These were intruded by mafic rocks that range from veins to dykes commonly no more than 300×5 m in surface exposures; but a few are thicker and longer, with one extending up to 2 km. The dykes can be divided into two groups: a possibly earlier one of amphibole-bearing rocks, and a later group of titanium augite-bearing rocks. The rocks are grey to black, fine- to medium-grained, and commonly porphyritic. In addition to amphibole or augite, they also contain zoned plagioclase (andesine-labradorite, commonly saussuritized), opaque oxides, apatite, sphene, and secondary minerals. Some of the augite-bearing rocks also contain olivine. The two groups of rocks are alkaline, similar in major element chemistry, and derived from differentiated magma(s).

Keywords: Nagar Parker; Late Proterozoic Granites; Mafic dykes; Alkaline

1. Introduction

Part of the Thar Desert in the SE of Sindh, Pakistan, comprises the Nagar Parkar uplifted block, covering some 500 km^2. Unlike the Thar Desert, which is mainly covered by sand dunes, this area exposes Precambrian bed rocks. The oldest of these comprise a suite of low-grade metamorphosed basic to intermediate rocks which constitute a basement to subsequent magmatism that is essentially granitic (Butt et al., 1994; Jan et al., 1997; Kazmi and Jan, 1997). The basement rocks are only sporadically exposed and occupy low lands between the granitic hills due, probably, to their greater susceptibility to erosion and weathering, and possible exposure for longer time. Detrital material, loess, and residual (laterite/kaolin) deposits derived from the igneous complex during the Quaternary are subordinate and local. The granitic rocks make locally bold hills and reach as high as 356 m in Karunjhar (Fig. 1). The igneous rocks were named as the Nagar Parkar igneous complex by Kazmi and Khan (1973). The complex has been, rather arbitrarily, regarded to be the western extension of the Indian Shield (Shah, 1977; Muslim et al., 1997). On the basis of lithological similarities with granitic rocks in Rajasthan, Laghari (2004) considered it to belong to the Malani igneous suite of Late Proterozoic age.

The Nagar Parkar igneous complex, according to Jan et al. (1997), comprises six major magmatic episodes of plutonic (abundant) to subvolcanic (subordinate) rocks, 1) basement rocks, 2) riebeckite-aegirine grey granite, 3) biotite-hornblende pink granite, 4) acid dykes, 5) rhyolite “plugs”, and 6) basic dykes. The plutonic and subvolcanic rocks in the Nagar Parkar igneous complex that post-date the basement rocks are dominated by the grey and pink granites with subordinate amounts of silicic and mafic dykes. The proximity and petrographic similarities suggest that the phase 2 to 5 rocks may belong to the Malani magmatism. Covering large areas in Rajasthan, the Malani suite has been dated as Late Proterozoic. Recently, Khan et al. (2007) have reported U-Th-Pb ages for a number of rocks from the Nagar Parkar complex. These Late Proterozoic ages span from 1000-1100 Ma (Karunjhar grey granite) to 700-800 Ma (pink and other granites).

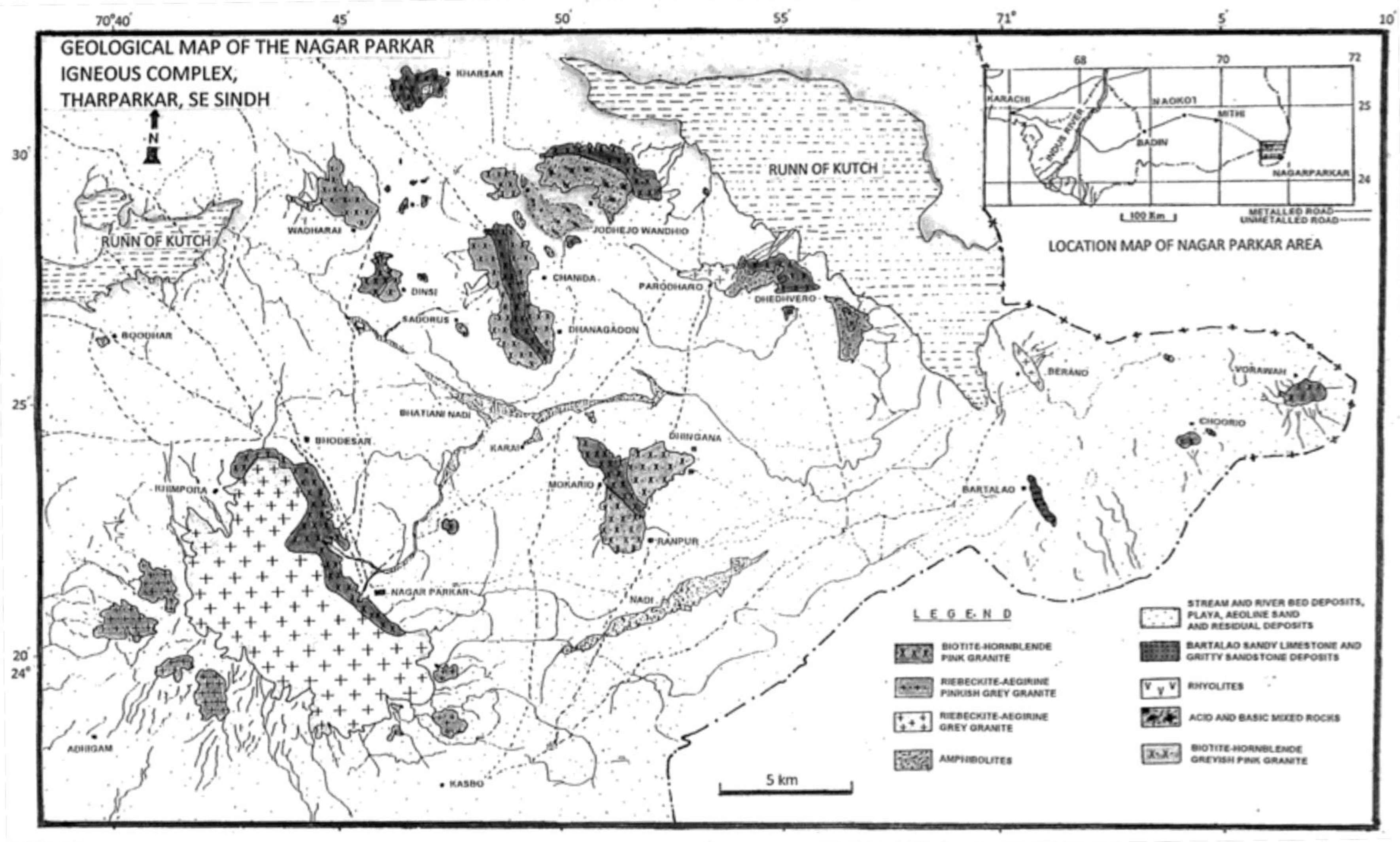

Fig. 1. Geological map of the Nagar Parkar Igneous Complex, southeastern Sindh (after Jan et al., 1997).

2. Mafic dykes

The Late Proterozoic granitic rocks of the Nagar Parkar area are intruded by many dykes of mafic composition. Like their host rocks, these are undeformed and metamorphosed, but some are strongly altered and contain solution pits. Most occur in veins to steeply dipping dyke sheets no more than 300×5m in surface exposures, but a few are thicker and much longer. The Ranpur granitic body has a number of prominent dykes, mostly trending NE, and extending up to 2km. In some places the dykes are quite common, locally forming swarms or networks of repeated injections, as in the Wadhrai body. It is not clear whether the mafic dykes are Late Proterozoic, related to a later (? Deccan) magmatic event or both, but Jan et al. (1997), Ahmad (2004), Ahmad et al. (2005) and Laghari (2004) favour the former possibility. In rare cases, both the thin mafic dykes and host granite show effects of plastic deformation, suggesting that the granite had not cooled down to solid state when the mafic dykes were emplaced. Some fierls aspects of the dykes are shown in Figure 2.

The dykes show some colour and textural variation in the field and range from fine- to medium-grained, and aphyric to subporphyritic to strongly porphyritic. Chilled margins are not uncommon in the case of relatively coarser grained dykes. The phenocrysts are commonly plagioclase and less than 0.5 mm long in most cases, but in the south-central part of the Ranpur body one mafic dyke contains up to 8 cm long euhedral to subhedral plagioclase that gets finer grained in the upper part. In the margins of some dykes, plagioclase phenocrysts show flow alignment (Fig. 2, bottom right). On the basis of the main mafic mineral content, Laghari (2004) classified the dykes into hornblende-bearing (appinitic) and pyroxene-bearing types. The former are far more abundant and appear to be older than the pyroxene-bearing type. Preliminary geochemical data show that both are alkaline and not different significantly in chemical composition. Our ongoing study suggests that at least one of the dolerite dykes in Dinsi contains biotite as a major mafic mineral; but we are not including this rock in the present description.

3. Petrography

3.1. Amphibole-bearing Dykes

These are aphyric to porphyritic and medium- to fine- grained, but a few have “spinifex” texture. In many cases, the margins of the dykes are finer grained than the centres, but variations from fine-grained to diorite-looking medium-grained may occur even in the interior. The rocks (Fig. 3) are commonly altered. Plagioclase, amphibole, and ilmenite-magnetite are their principal constituents. Plagioclase is zoned and commonly saussuritized and sericitized. In the porphyritic rocks, it is the sole or principal phenocryst phase and may contain inclusions of the matrix material. Amphibole is generally altered but, when fresh, is light brown hornblende that is locally zoned. The rocks commonly also contain a second generation green amphibole, some in distinctly elongated prisms, associated with chlorite, epidote, and biotitic mica. Accessories include sphene (mostly secondary), apatite and in rare cases, secondary quartz? The very fine-grained rocks are more intensely altered and essentially comprise cloudy plagioclase and chlorite.

3.2. Pyroxene-bearing Dykes

These are grey to dark grey in colour, fine- to medium-grained, aphyric to porphyritic, and fresh to variably altered. Most are doleritic, but gabbroic dykes are exposed in the Karunjhar, Karai, Jodhe-jo-Wandhio, Dedhvero and other areas. A medium-grained dyke near Karai shows some layering and cumulate texture. All are characterized by the presence of lilac to pinkish (probably titanium-bearing) augite, pointing to alkaline character of the rocks.

The gabbroic rocks are mainly composed of plagioclase, olivine, augitic pyroxene and iron oxide, with small amount of biotite and apatite (Fig. 3, bottom right). Plagioclase shows albite and Carlsbad twinning, and partial alteration to sericite and epidote. Olivine grains are fractured, mildly altered, and enclosed in plagioclase. Pale brown augitic pyroxene occurs as phenocrysts, and in the groundmass. Chlorite and at least some biotite are alteration products. 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.

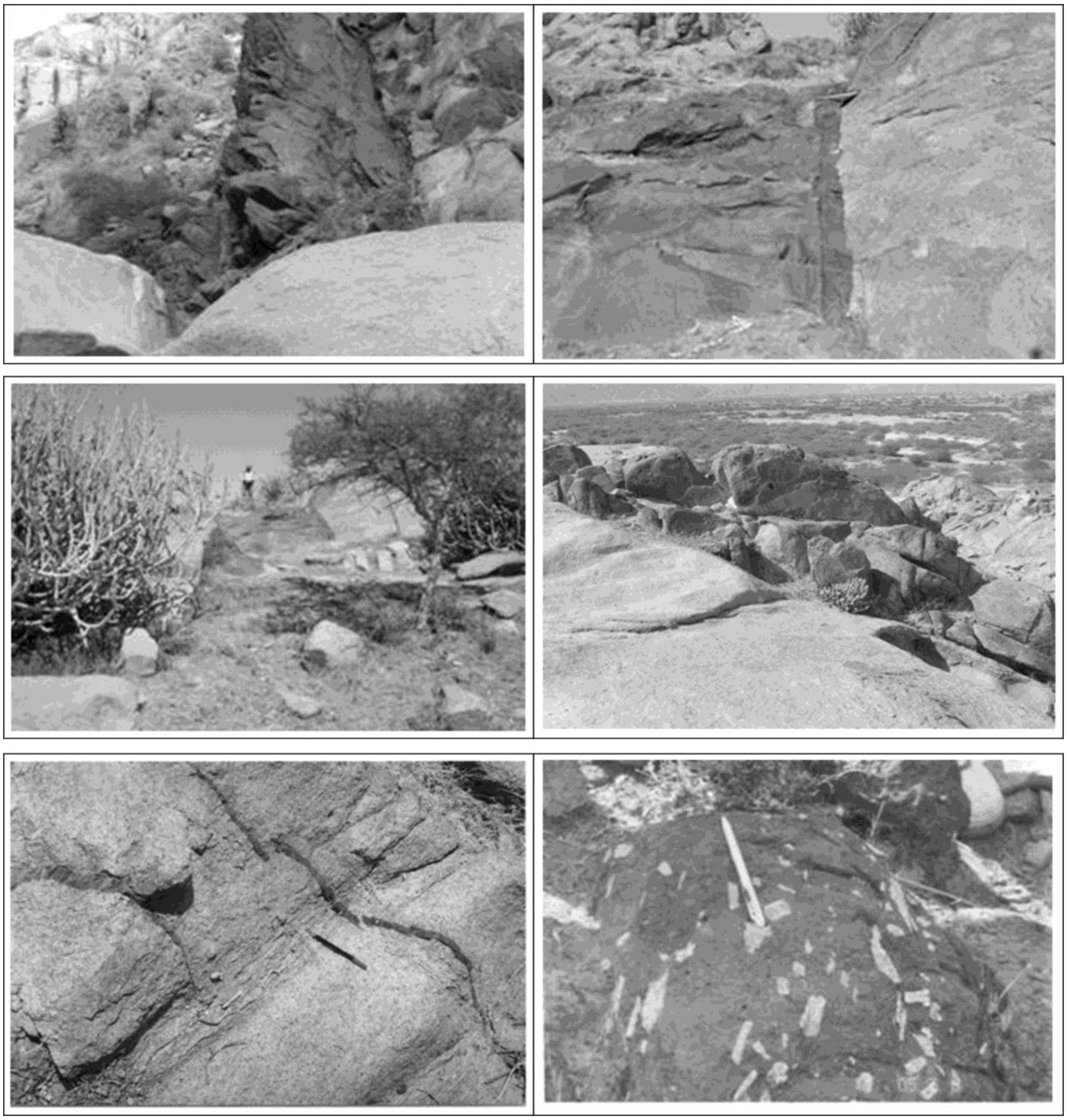

Fig. 2. Some field features of the mafic dykes in the Nagar Parkar Igneous Complex.

Top left: Two meters thick, steeply dipping dyke in the Pink Granite at the northeastern edge of Karunjhar Hill near Nagar Parkar.

Top right: Dyke in grayish pink granite, Kharsar body. The dark right-side of the dyke is either chilled or another dyke.

Middle left: Thick dyke in Kharsar granitic body. In this area, younger dolerite sheets may be emplaced conformably along the margins of the older dykes.

Middle right: Horblende-bearing mafic dyke in grayish white granite, Ranpur.

Bottom left: Mafic dyke in pink granite near Banbharunki Dongri. Note the displacements in the broken dyke are filled by undeformed host granite, suggesting emplacement of the dyke possibly before solidification of the host.

Bottom right: Strongly porphyritic dyke with euhedral to subhedral plagioclase phenocrysts in southeastern Ranpur mass. The phenocrysts show strong alignment in some parts of the 8m thick dyke.

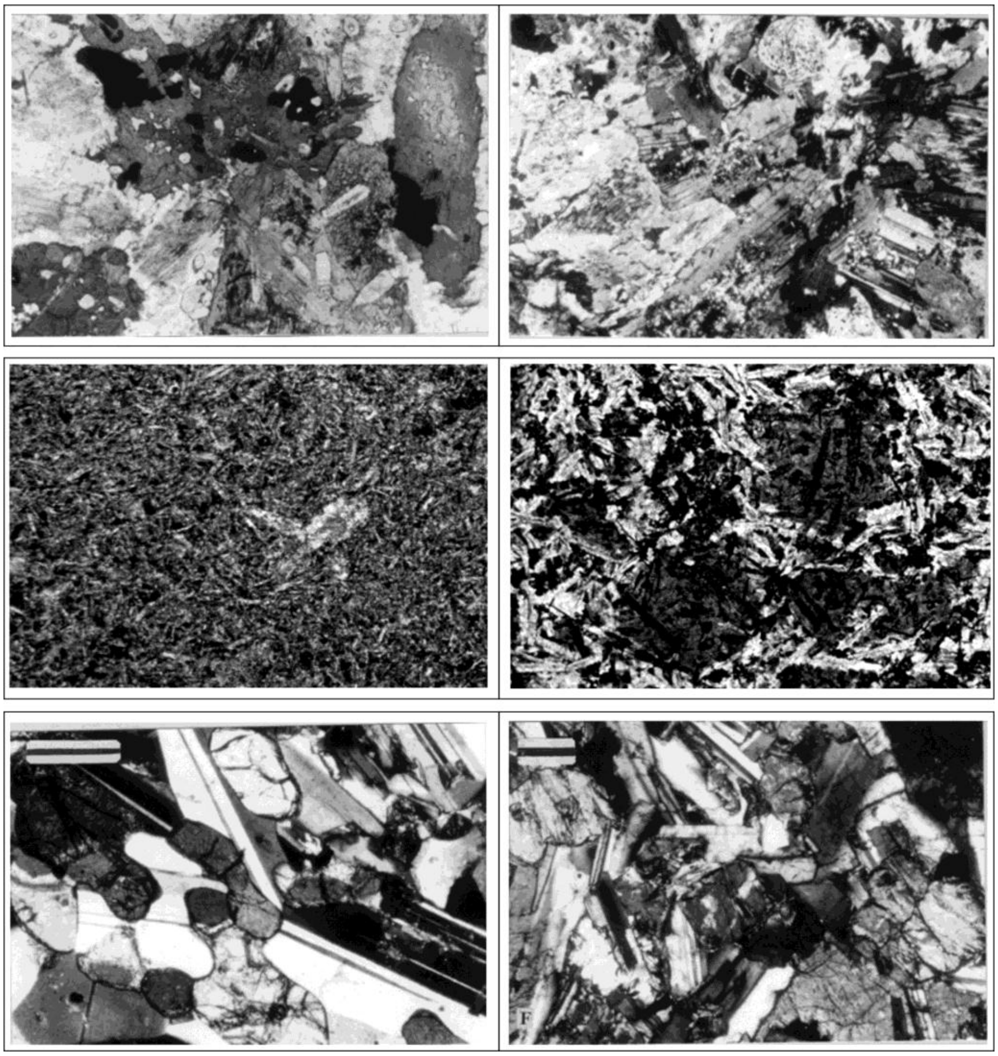

Fig. 3. Petrographic features of the mafic dykes. Length of all photographs is about 1.25 mm, and polars are crossed except in the top left.

Top left: Hornblende-bearing dyke containing hornblende (yellowish green), opaque oxide (black), plagioclase (white) and sphene (middle right). The amphibole grain on the right is zoned and contains colourless core of either clinopyroxene or another amphibole.

Top right: Mafic dyke from Jodh-jo-Wandhio. Plagioclase is well-twinned, and partially saussuritized in the interior. Hornblende (left and lower right) is also partially altered and contains secondary epidote in some margins. Biotite (small grains, upper middle) shows local alteration to chlorite.

Middle left: A 60 cm thick dyke in Kharsar mass, comprising sparse plagioclase microphenocrysts in altered groundmass of plagioclase, chlorite (likely after amphibole) and other secondary minerals, and devitrified glass.

Middle right: Porphyritic dolerite comprising plagioclase (An_{50}), pinkish augite with opaque oxide along fractures, devitrified glass (dark patches), and secondary minerals. From west-central part of Kharsar mass.

Bottom left: Fresh olivine gabbro dyke in basement from Karai. Labradoritic plagioclase is well-twinned and encloses olivine (fractured grains) and augite (smaller, non-fractured grains). The sample was collected from from a dyke that shows some crude layering.

Bottom right: Dolerite dyke in granite near Karunjhar. Plagioclase is fresh and mildly zoned. Clinopyroxene (titanian augite, upper left) is ophitic in habit. Olivine grains are fractured but generally fresh.

The dolerite dykes are mostly 1 to 3 m thick and extend for 10 to 300 m. Such dykes are also reported to occur in the Malani igneous suite (Srivastava et al., 1989; Pandit and Deep, 1994). The rocks are fine- to medium-grained and porphyritic, with plagioclase phenocrysts up to 7 mm in length. Some dykes show an alignment of plagioclase in the quickly cooled margins. The pyroxene is intergranular to subophitic, but in some rocks grains of other minerals may be poikilitic in habit. The rocks comprise plagioclase, lilac augite, biotite, opaque oxide(s), apatite, and secondary chlorite, epidote, sphene, carbonate and muscovite. A few rocks contain olivine and secondary amphibole. The plagioclase shows zoning and partial alteration to sericite and epidote. Some of the chemically analyzed samples contain substantial amounts of K_2O, and the possibility of the presence of K-feldspar in these cannot be ruled out.

4. Geochemistry

The major oxides were determined by using a combination of Pye Unicom Sp 190/191 Atomic absorption spectrophotometer and Sp8-400 UV/ Visible Spectrometer at the National Centre of Excellence in Geology, University of Peshawar.

Major element analyses, CIPW norms, oxide ranges and means are listed for the two groups of dykes in Tables 1 and 2. The rocks are characterized by restricted variation in silica content. Fourteen of the 15 analyses are olivine-normative, with six also containing nepheline. Analysis W-16 contains a small amount of normative quartz, suggesting the possibility of overestimation of SiO_2 in it. Corundum is totally absent from the norms.

Table 1. Major element analyses and norms of the amphibole-bearing dykes from Nagar Parkar.

Elements	**NPE-45**	**NPE-75**	**NP-43**	**NP-79**	**NP-204**	**NP-249**	**NPW-16**	**Range**	**Mean**
SiO_2	50.30	50.02	49.32	46.12	51.21	50.00	52.12	46.12–52.12	49.87
TiO_2	1.30	2.27	2.33	2.34	1.80	2.01	2.06	1.30 – 2.34	2.02
Al_2O_3	16.92	15.76	15.62	14.72	16.38	15.79	16.38	14.72 – 16.92	15.94
Fe_2O_3	8.92	10.49	11.65	11.10	8.17	8.51	10.35	8.17 – 11.65	9.88
MnO	0.17	0.18	0.26	0.22	0.17	0.15	0.19	0.15 – 0.26	0.19
MgO	6.63	5.74	6.20	6.90	4.85	5.88	4.08	4.08 – 6.90	5.75
CaO	10.00	8.59	8.45	11.86	9.28	8.94	6.05	6.50 – 11.86	9.09
Na_2O	2.88	4.25	3.39	3.52	4.62	4.04	3.64	2.88 – 4.62	3.76
K_2O	1.29	0.90	1.28	0.90	0.65	0.90	1.97	0.90 – 1.97	1.17
P_2O_5	0.20	0.56	0.49	0.44	0.31	0.47	0.80	0.20 – 0.80	0.47
L.O.I	1.89	1.86	2.36	2.41	2.70	2.47	2.27	1.86 – 2.70	2.28
Total	100.50	100.62	101.35	100.53	100.44	99.16	100.36		
C.I.P.W. norms									
Quartz	0	0	0	0	0	0	2.43	0.0 – 2.43	0.0
Orthoclase	7.79	5.43	7.72	5.47	5.78	5.54	11.97	5.43 – 11.97	7.10
Albite	24.90	36.73	29.26	13.84	34.78	35.61	31.67	13.84 – 36.73	32.69
Anorthite	30.05	21.71	24.08	22.31	21.77	23.20	23.16	21.71 – 30.05	23.78
Nepheline	0	0	0	9.10	2.97	0	0	0.0 – 9.10	-
Diopside	15.64	14.72	12.58	28.60	19.14	15.98	3.82	3.82 – 28.60	15.78
Hypersthene	10.36	2.20	9.71	0	0	4.85	18.15	0.0 – 18.15	-
Olivine	5.86	10.53	7.74	10.01	7.53	7.21	0	0.0 – 10.53	8.64
Magnetite	2.31	2.88	3.17	3.08	2.28	2.42	2.82	2.28 – 3.17	2.71
Ilmenite	2.52	4.40	4.51	4.57	3.52	3.98	4.02	2.52 – 4.57	3.94
Apatite	0.45	1.25	1.09	.99	0.70	1.07	1.80	0.45 – 1.80	1.05

Dedhvero: NPE-45; Karai: NPE-75; Karunjhar: NP-43, NP-79, NPW-16; Cahnida: NP-204; Jodhe-jo-Wandhio: NP-249

Table 2. Major element analyses and norms of the Pyroxene-bearing dykes from Nagar Parkar.

Elements	NP-52	NP-53	NP-161	NP-218	NP-219	NP-224	NP-271	NPW-57	Range	Mean
SiO_2	49.02	46.12	48.12	46.40	48.10	50.50	45.12	50.01	45.12 – 50.50	47.92
TiO_2	1.55	3.42	2.03	2.12	0.58	1.81	3.07	2.73	0.58 – 3.42	2.16
Al_2O_3	17.68	15.02	17.34	17.58	18.32	15.32	17.43	15.11	15.02 – 18.32	16.73
Fe_2O_3	9.94	11.03	9.81	7.22	7.38	9.58	12.08	12.76	7.22 – 12.76	9.98
MnO	0.16	0.25	0.17	0.13	0.14	0.16	0.20	0.24	0.13 – 0.25	0.18
MgO	6.22	7.34	5.66	10.12	9.79	5.62	4.81	4.75	4.75 – 10.12	6.79
CaO	9.77	11.70	8.32	11.3	11.21	11.05	6.29	7.68	6.29 – 11.70	9.66
Na_2O	3.39	3.05	4.28	2.80	2.75	3.67	3.91	4.40	2.75 – 4.40	3.53
K_2O	0.45	0.89	1.02	0.36	0.30	0.50	1.45	1.22	0.30 – 1.45	0.77
P_2O_5	0.35	0.45	0.33	0.35	0.30	0.29	0.53	0.70	0.29 – 0.70	0.41
L.O.I	1.32	1.99	3.18	1.00	0.62	1.88	4.55	2.37	0.62 – 4.55	2.11
Total	99.95	101.26	100.26	99.38	99.22	100.38	99.44	101.97		
C.I.P.W. norms										
Orthoclase	2.72	5.35	6.26	2.18	1.80	3.02	9.12	7.31	1.80 – 9.12	4.68
Albite	29.36	15.84	27.19	14.38	23.68	31.78	27.18	37.77	14.38 – 37.77	24.34
Anorthite	34.42	25.05	06.04	35.09	37.39	24.39	27.37	18.12	18.12 – 37.39	28.28
Nepheline	0	5.63	5.65	5.33	0	0	4.38	0	0.0 – 5.65	-
Diopside	12.08	24.89	11.87	15.75	13.78	24.23	1.78	13.11	1.78 – 24.89	14.90
Hypersthene	8.74	0	0	0	1.37	4.95	0	3.34	0.0 – 8.74	-
Olivine	8.17	10.25	12.98	16.72	18.24	4.77	16.11	9.90	4.77 – 18.24	13.77
Magnetite	2.60	3.26	2.75	2.11	1.80	2.57	3.56	3.48	1.80 – 3.56	2.76
Ilmenite	3.01	6.60	4.0o	4.12	1.12	3.52	6.21	5.26	1.12 – 6.60	4.22
Apatite	0.78	1.00	0.75	0.78	0.67	0.65	1.23	1.55	0.65 – 1.55	0.85

Karunjhar: NP-52, NP-53, NPW-57; Boodhar: NP-161; Karai: NP-218, NP-219, NP 224; Wadharai: NP-271

The amphibole-bearing basic dykes display a variation of 46.1 to 52.1 weight per cent in SiO_2, 1.3 to 2.3 wt % TiO_2, and 4.2 to 5.6 wt % total alkalis. SiO_2 in the pyroxene-bearing rocks ranges from 45.1 to 50.5 wt %, TiO_2 from 0.6 to 3.4 wt %, and total alkalis from 3.0 to 5.6 wt%. The greater variation in the TiO_2 and total alkalis contents of the latter is due probably to the effect of cumulate minerals. Some of the samples were collected from meters-thick dykes showing some degree of in situ differentiation (layering).

Following SiO_2 vs. total alkalis classification schemes of Cox et al. (1979), and Le Bas et al. (1986), the basic dykes classify as basalt (Fig. 4). The use of De La Roche (1980) classification scheme enables evaluation of silica saturation of the dykes, which is not clear from the Cox et al. (1979) classification. In conformity with the CIPW norms, use of the R1-R2 parameters of De La Roche (1980) also classifies 14 of the dyke analyses as undersaturated and only one (W-16) as silica-oversaturated. In terms of nomenclature, all the studied basic dykes, except W-16, classify as basalt (Fig. 5).

Both the petrographic data and chemical analyses suggest that the two groups of the basic dykes are alkaline in character. The abundance of hornblende, and the presence of not very calcic plagioclase (An 45–55), ilmenite and sphene characterize the hornblende-bearing dykes. The pyroxene-bearing dykes are characterized by the presence of lilac to pinkish (titanian) clinopyroxene and in some cases olivine, accompanied by labradorite. The chemistry of the rocks is supportive of these observations. The majority of the analyses are characterized by high contents of TiO_2 and total alkalis, they contain olivine in the norms, together with nepheline in six. Average compositions (Tables 1 and 2) for both the series are typically alkaline with > 2% TiO_2, and > 4.2% total alkalis. The molar 100Mg/(Mg+Fe) content of the analyses is <40 (except in a couple of cases possibly representing cumulates), hence the dykes are a product of differentiated rather than primary magma.

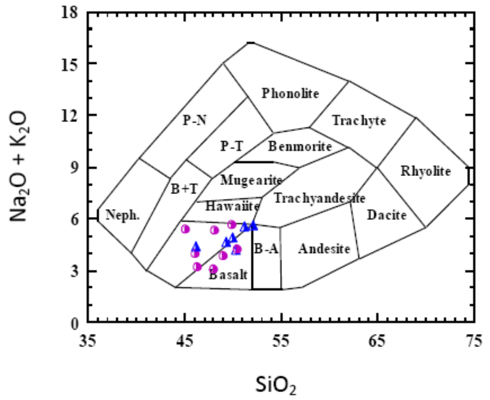

Fig. 4. Plots of the Nagar Parkar analyzed mafic dykes (▲ Amphibole-bearing, ◐ Pyroxene-bearing) in the classification diagram of Cox et al. (1979). B-A: basaltic andesite; B+T: basanite and tephrite; Neph.: nephelinite; P-N: phonolitic nephelinite; P-T: phonolitic tephrite

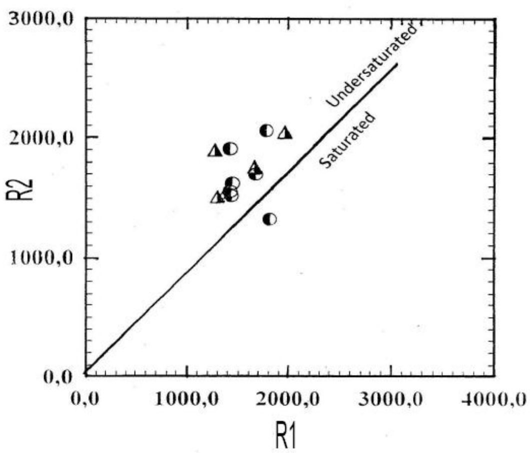

Fig. 5. Classification of the analyzed rocks using the parameters R1 and R2 of De La Roche et al. (1980), calculated from millication proportions.

R1 = 4 Si – 11 × (Na + K) – 2 × (Fe + Ti)

R2 = 6 Ca + 2 × (Mg +Al).

▲ Amphibole-bearing

◐ Pyroxene-bearing

This is further supported by comparison of the dyke analyses with rocks from other areas. Figure 6 shows the plots of the dykes analyses on Na_2O+K_2O vs. SiO_2 basis. Also shown are the boundaries between alkaline and subalkaline rock series (after Irvine and Baragar, 1971; Miyashiro, 1978), and Hawaiian alkaline and tholeiitic rock series (after McDonald and Katsura, 1964). In a rock without mafic minerals, the anorthite-albite join would separate compositions with normative nepheline (above) from subalkaline compositions (below) (McBirney, 1987). It is worth noting that on the basis of Irvine and Baragar (1971) and Miyashiro (1978) divisions, the hornblende-bearing dykes classify as alkaline whereas the pyroxene-bearing rocks plot in both the alkaline and adjacent area of subalkaline fields. It is significant that in one case, two samples from the same dyke body classify differently. This can only be explained on the basis of cumulate effect. However, when the alkaline-subalkaline division of the Hawaiian rocks is applied, the Nagar Parkar dykes classify as alkaline. It is, thus, concluded that both the dyke types are alkaline in character.

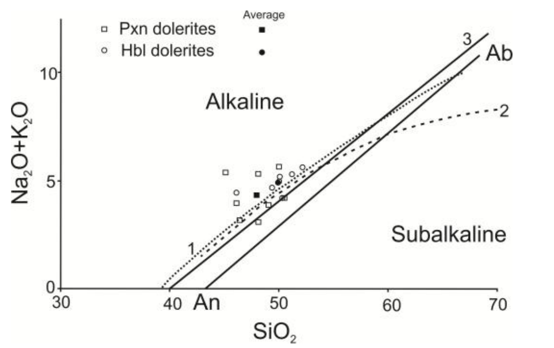

Fig. 6. SiO_2 vs. Na_2O+K_2O plot for the mafic dykes. Boundaries separating alkaline and subalkaline rocks have been extrapolated after (1) Irvine and Baragar, 1971, (2) Miyashiro, 1978, and (3) McDonald and Katsura (1964, for Hawaiian rocks). Note that in rocks without mafic minerals the An– Ab join would separate composition with normative nepheline (above) from subalkaline composition (below) (McBirney, 1987)

4.1. Major element variations

Binary variation diagrams using MgO as abscissa are used to evaluate inter-relationship between the dyke samples in terms of fractionation (Fig. 7). MgO and SiO_2 define a trend marked by increasing SiO_2 with decreasing MgO. Three samples of the pyroxene-bearing dykes plot off the trend, with two (NP-218 and NP-219) having MgO > 10 w%. These samples appear to have cumulus character. Indeed, 218 and 219 were collected from a layered dyke. In the rest of the binary plots, CaO shows an increase and Na_2O, P_2O_5 and, to some extent, K_2O show decrease with increase in MgO. From these trends, it appears that fractionation of clinopyroxene, in addition to olivine, has controlled the variation. Depletion of CaO without simultaneous depletion of Al_2O_3 (ignoring the two samples) and Na_2O support involvement of clinopyroxene instead of plagioclase in fractionation; whereas increase in silica with falling MgO may suggest olivine fractionation. But keeping in view the hydrous nature of the amphibole-bearing dykes, the possibility of hornblende fractionation cannot be ruled out.

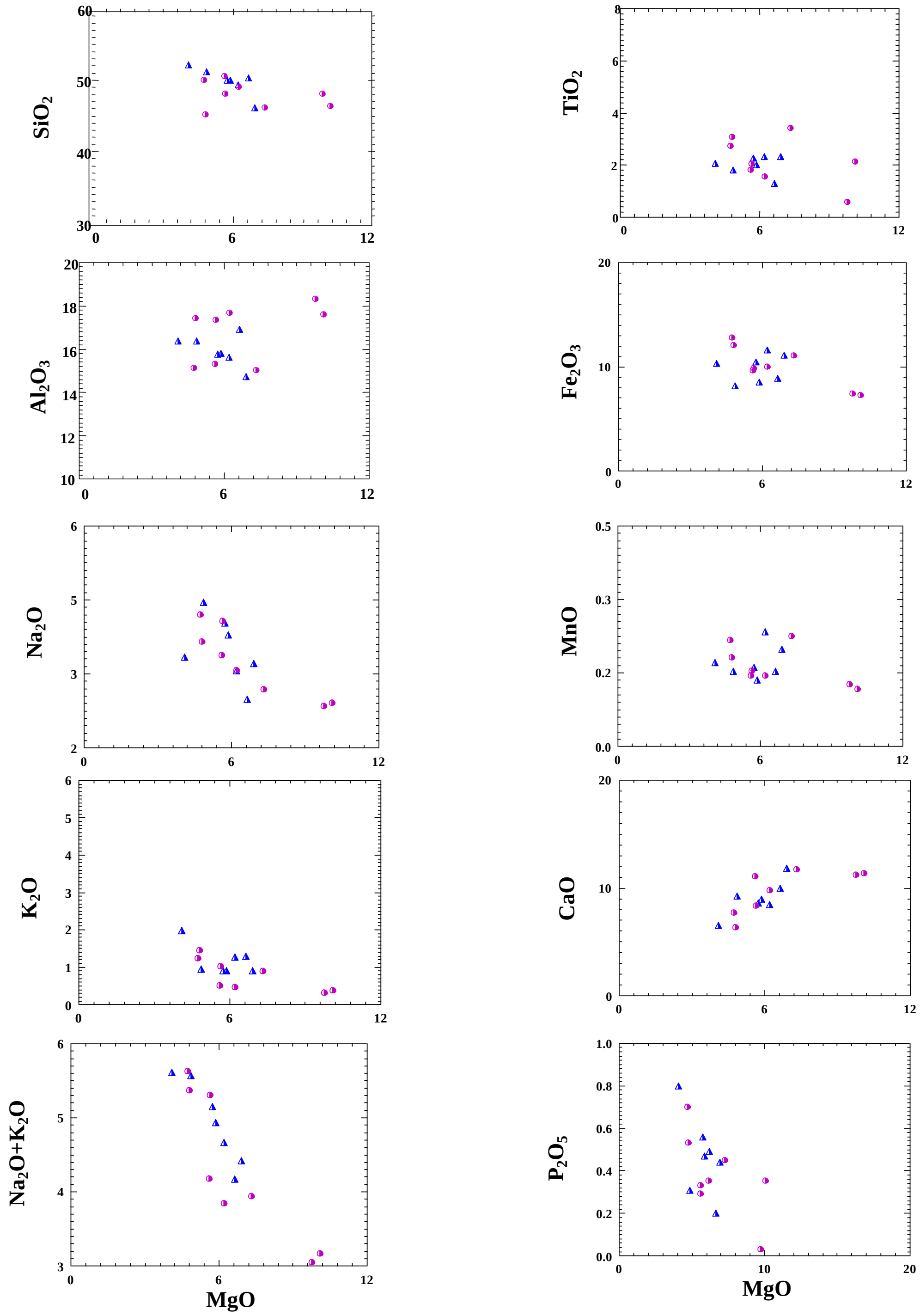

Fig. 7. Binary plots showing variation of major elements against MgO in the analyzed mafic dykes from Nagar Parkar. ▲ Amphibole-bearing ◐ Pyroxene-bearing

5. Discussion

The Nagar Parkar igneous complex is a product of several distinct batches of magma. The basement comprises an early set of mafic to granodiorite dykes possibly related magmatically to their host amphibolites. These rocks appear to belong to an island arc magmatic association, and were metamorphosed and deformed before the emplacement of a variety of granitic rocks. The latter began with grey granites (abundant) derived from a sodic alkaline magma, followed by pink leucogranites possibly peraluminous in character (Laghari, 2004). However, our recent studies show that each granitic mass is characterized by the presence of several types of granitic plutons and dykes, the nature and emplacement history of which are still to be deciphered. The Nagar Parkar Igneous Complex is indeed complex! The end of the Nagar Parkar magmatism was considered by earlier workers to be marked by the mafic dykes, but Jan et al. (1997) noted that at least some of these dykes were emplaced when their host granites were in plastic state and not fully solidified. We have recently seen minor granitic dykes that post-date the dolerite dykes. Are these youngest granites a result of partial melting of the country rocks by the rising mafic magma or did the waning phases of the granite magmatism overlapped with mafic magmatism?

The late mafic dykes in Nagar Parkar are divisible into two groups: amphibole-bearing and pyroxene-bearing. The age relationship of the two is not clear, but on the basis of rather weak field evidence the amphibole-bearing ones appear to have preceded the pyroxene-bearing ones. Interestingly, both are alkaline, have high amounts of TiO_2 and Na_2O+K_2O, and are olivine +/- nepheline normative. The dykes, thus, appear to be derived from two magmas of rather similar composition, one of which possibly had an appinitic character and the other an alkaline-olivine basalt character. Additional field work, trace element and REE geochemistry and isotopic studies are required to know the mutual relations of the two magmas and their relation to the younger granitic dykes.

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