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Geology and petrography of the Nagar Parkar Igneous Complex, southeastern Sindh: the Wadhrai body

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Abstract

The Wadhrai igneous body occurs to the north of the Nagar Parkar town. This and other bodies constituting the Nagar Parkar Igneous Complex are an extension of the Malani Igneous Suite of western Rajasthan. The body is occupied by petrographically uniform granite composed of perthite, albitic plagioclase, quartz, and small quantities of biotite, opaque oxide and titanite. The rocks are sparingly porphyritic and contain dykes and veins of microgranite, aplite and quartz; pegmatites are rare and simple. In the southeastern part, the granite is invaded by parallel sheets and swarms of many mafic dykes, and rhyolite sheets. The mafic dykes are porphyritic to aphyric and consist of calcic plagioclase, hornblendic amphibole or clinopyroxene +/- olivine, ilmenite, titanite and a range of secondary minerals. Many of the mafic dykes are strongly altered, some totally, and a few beyond recognition. The rhyolite sheets are sparsely porphyritic, at places banded, and composed of perthite, quartz, albite, sodic amphibole, aegirine-augite, opaque oxide and titanite. The main rhyolite sheet extends for more than 2 km and attains a thickness of 30 m. While the felsic dykes are apparently related to the granite, the mutual relations between the granite, mafic and rhyolite sheets are yet to be deciphered, but the rhyolites may represent melts derived from the crust through underplating by mafic magma. This paper gives detailed petrography of the rocks, together with newly prepared geological maps.

Keywords: Nagar Parkar igneous complex, Wadhrai body, Sindh, Pakistan.

1. Introduction

The Nagar Parkar area covers about 500 km^2 at the junction of the Great Rann of Kutch and Thar Desert. It comprises mounds and bold hills of granitoids in a plain covered by sand, silt and salt. Karunjhar hill (356 m above sea level) is the principal geomorphic landmark of the desert in southeastern Pakistan. The area is an uplifted block of Precambrian igneous rocks named as the Nagar Parkar Igneous Complex (NPIC). The oldest of these comprise a suite of low-grade metamorphosed mafic to silicic rocks which constitute the foundation to Neoproterozoic granitoids. The foundation rocks are physiographically inconspicuous and, generally, occupy low ground. The granites occur in stocks, bosses and dykes that are accompanied by felsic to mafic dykes, and rhyolite plugs (Kazmi and Khan, 1973; Butt et al., 1994; Jan et al., 1997; Kazmi and Jan, 1997; Muslim et al., 1997). A simplified geological map of the area is shown in Figure 1.

The granitoids are represented mainly by aegirine-riebeckite grey (Karunjhar) granite, grey to pinkish granite, and biotite (with or without hornblende) pink granite (Jan et al., 1997; Ahmad and Chaudhry, 2008). Laghari (2004) equated the grey and pink varieties with their counterparts in Rajasthan. Proximity and petrographic similarities suggest that the igneous rocks may belong to the Malani Igneous Suite (MIS). Covering large areas in Rajasthan, the MIS has been dated as Late Proterozoic (Bhushan, 2000; Kochhar, 2004; Gregory et al., 2009; Ashwal et al., 2013). Khan et al. (2012) have reported U-Th-Pb zircon ages for a number of rocks from the NPIC. These Late Proterozoic ages span from 1100-1000 Ma (Karunjhar grey granite) to 800-700 Ma (pink and other granites).

Substantial details of the geology, mineral deposits, petrology, and geochemistry of the Nagar Parkar area have been presented (see references above and in Jan et al., 2014, 2016). This paper is one of a series by the authors that deals with geological mapping and systematic petrography of the major hillocks in the area. The Wadhrai igneous body is exposed 12 km north of Nagar Parkar (24º 20´ 40´´N, 70º 45´ 53´´E), and covers >10 km^2 area between Wadhrai, Jam Khan Jo Wandhio and Dotar villages. The body is composed of granite that is intruded by felsic and mafic dykes (Fig. 2). Scattered outcrops in the sand surrounding the granite suggest that it may be covering a much larger area.

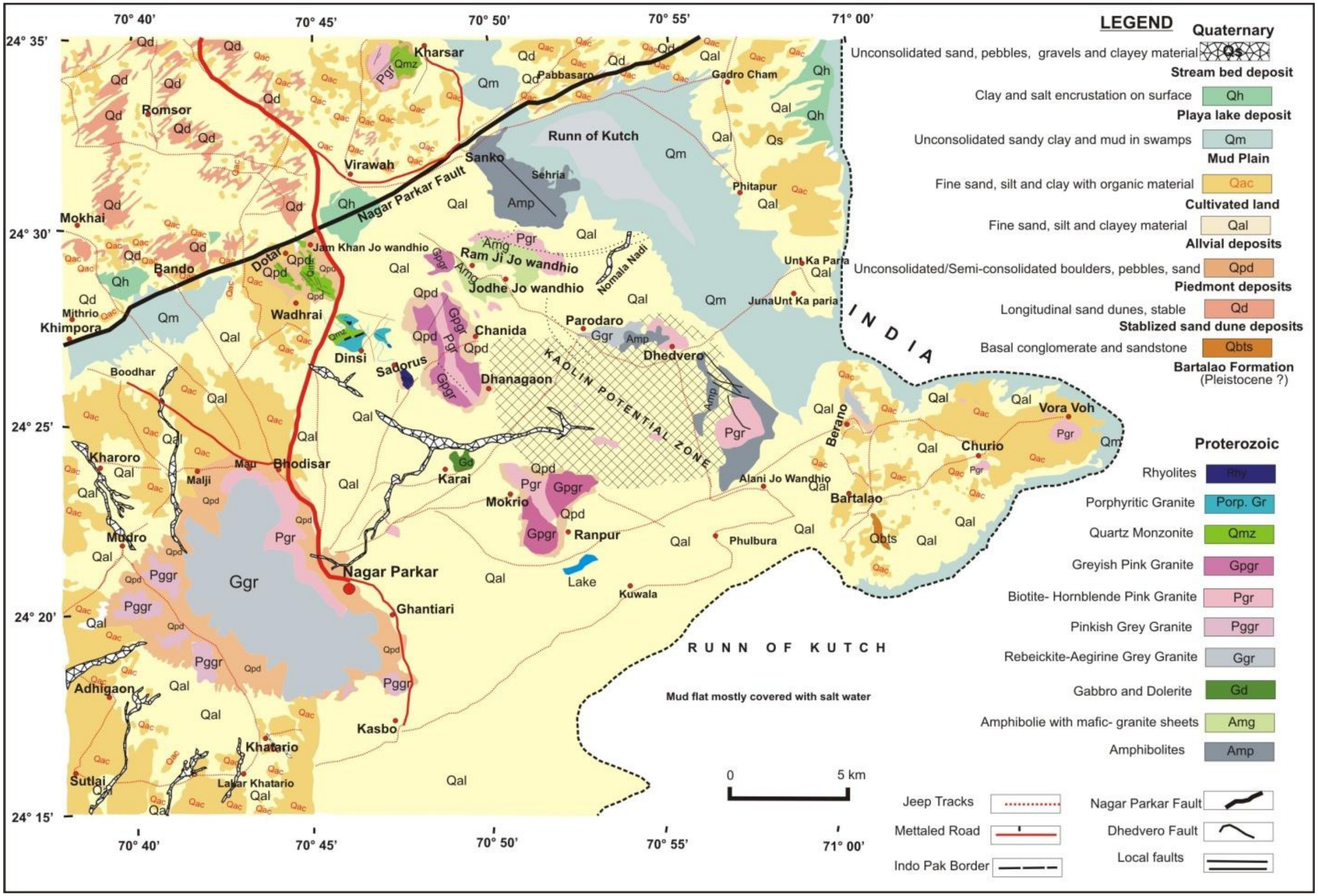

Fig. 1. Geological map of the Nagar Parkar area (bed-rock geology modified after Kazmi and Khan, 1973, Jan et al., 1997, Muslim et al., 1997, Rizvi et al., 2006; Quaternary geology during present work).

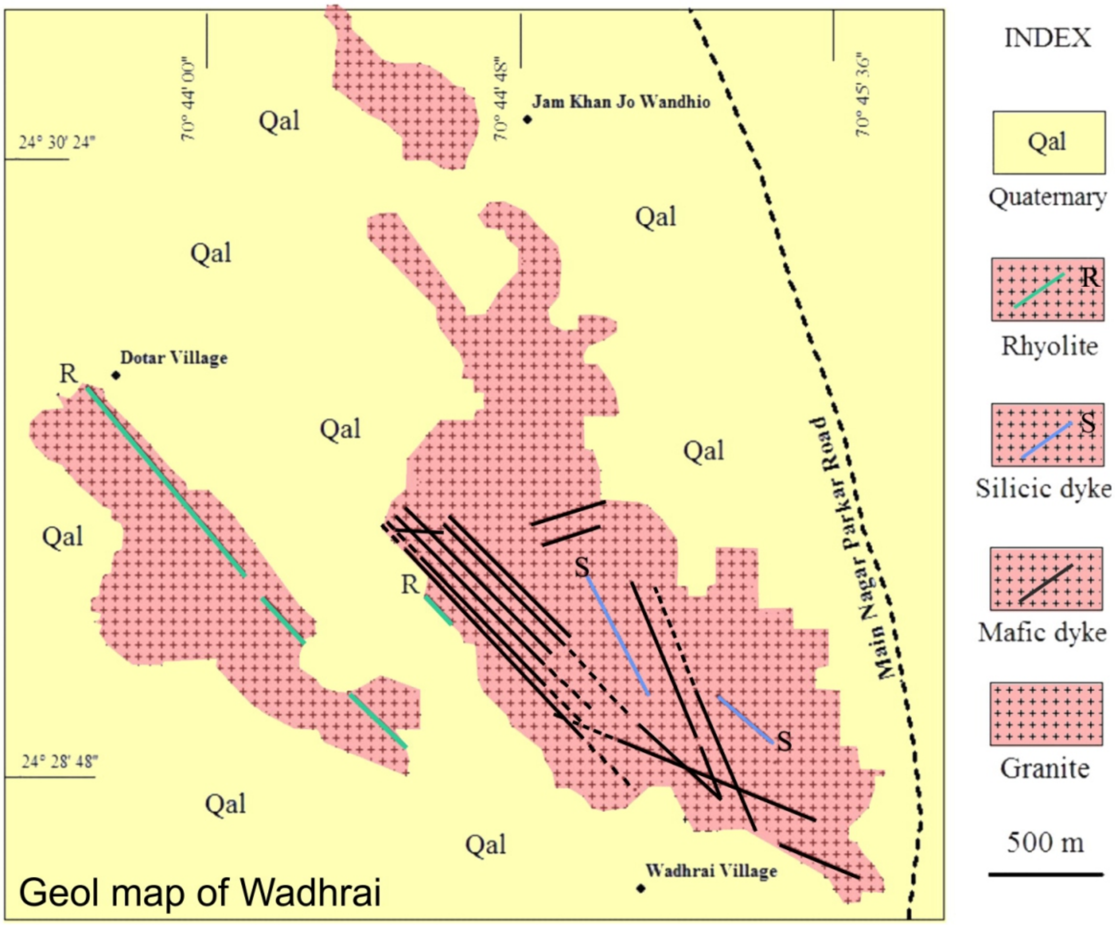

Fig. 2. Geological map of the Wadhrai-Jam Khan Jo Wandhio-Dotar area, prepared during this work. Only major dykes are shown.

2. The Wadhrai Granite

The Wadhrai body comprises spheroidally weathered, granite of light grey colour, locally having pinkish hue. The granite is uniform in appearance and dark or light schlierens are rare. In the northeastern part, it contains a few N-S shears that range from 30 cm to several meters in width and tens of meters in length. The rocks are mostly medium-grained, but locally fine- or coarse-grained, and sparingly porphyritic. The body is intruded by felsic dykes (microgranites, aplite and rare pegmatite), mafic dykes, rhyolite sheets, and contains quartz veins and rare secondary calcite veins up to 7 cm thick. Widely-spaced jointing is useful in extracting large blocks of this attractive rock suitable for use as decorative stone; some extracted blocks measure up to 15x7x5 m.

The granite contains sparse enclaves (locally abundant), commonly no more than a few centimeters, but a few are up to a third of a meter. These range from mafic xenoliths (probably derived from the foundation), to greyish granitic/aplitic autoliths themselves containing dark enclaves in rare instances. Some of the mafic enclaves have 1-3 cm thick orange colour halos. There also are cavities left after removed enclaves that may be margined by hardened shells of the host granite. Some field features of the rocks are shown in Figure 3A-C.

2.1. Petrography

The granite displays medium-grained, hypidiomorphic to, less commonly, allotriomorphic, subequigranular to equigranular, and sparingly granophyric fabric. Locally, as near Jam Khan Jo Wandio, it is porphyritic with feldspar phenocryst up to a centimeter in length. The rocks comprise plagioclase, perthite, quartz, and small amounts of biotite, opaque oxide, titanite, rare allanite, and secondary chlorite (after biotite), leucoxene and epidote. Some plagioclase and quartz grains are strained. In the pinkish parts, iron stains are common along fractures. The plagioclase is commonly zoned, at places oscillatory, with much altered cores containing white mica and zoisite granules, and ranges from sodic andesine to albite. In some rocks, the perthite is poikilitic and encloses plagioclase and quartz grains. Both the feldspars are cloudy but not intensely. The titanite appears to be primary but at places it is intermixed with ilmenite. Some tiny grains of biotite, commonly associated with chlorite and opaque oxide, may be secondary in origin. Micro-veins of epidote and of calcite traverse the rocks sparingly. Petrographic aspects of the rocks are shown in Figure 3.

2.2. Geochemistry

Analytical data are available for ten samples of the granite. Laghari (2004) presented major element analyses of two samples, together with trace and rare earth elements for one (Table 1). Ahmad and

Fig. 3. Field and petrographic aspects of the Wadhrai granite.A: Typical, fresh granite from northern part of the body, with a dark enclave in the middle. B: Granite from east-central part showing orange-brown stains, exfoliation, and enclaves (X). The dark one is possibly derived from the mafic foundation, whereas the grey with darker outer shell may be an autolith. C: Spheroidal weathering N of Wadhrai. D, E: Naturally carved sculptures in central part, resulting from jointing, exfoliation, weathering, and erosion. Iron staining results in orange pink coloration in D. F: WD-17 (northern part, under crossed polars-XP), contains cloudy sodic plagioclase (Pl), perthite (Prt), quartz (Qtz), opaque oxide, chloritized biotite (Bt), and primary titanite (Spn). The plagioclase is zoned with some grains having cloudy cores and clear margins. G: WD-18, northern middle part, XP, cloudy feldspar (Prt, Na-Pl, rare microcline), quartz, biotite, and opaque oxide. The euhedral perthite shows Carlsbad twinning. Biotite is chloritized along cleavages, contains inclusion of opaque oxide, and has locally associated muscovite. H (plane polarized light (PL)), I (XP):WD-20, east-central part, perthite, quartz, zoned plagioclase showing alteration, partly chloritized biotite and opaque oxide.Photomicrographs are 2.5 mm long. Mineral symbols are mostly from Winter (2010). Precise locations of the samples can be obtained from one of us (MHA). Many pictures display rounded air bubbles and dust trapped during covering of the thin sections.

Chaudhry (2008), and Khan et al. (2012) published major, trace and rare earth element data for six and two samples, respectively. These data are used here only for the purpose of classification of the granite.

On petrographic basis, Laghari (2004) and Ahmad and Chaudhry (2008) classified the rocks as adamellite. However, the major element chemistry does not support this. The classification of the analyses on normative Anorthite–Albite–Orthoclase ternary diagram of O'Connor (1965) is shown in Figure 4. In this diagram, and according to the classification scheme of De la Rouche et al. (1980, not shown here), all the ten analyses classify as granite. The Wadhrai granite analyses plot in alkaline field on the SiO_2 vs. $(Al_2O_3 + CaO + Na_2O + K_2O)/(Al_2O_3 + CaO + Na_2O – K_2O)$ diagram of Middlemost, 1994, (figure not shown). Further details of the geochemistry of the Wadhrai granite will be presented in another paper.

3. Felsic dykes

These rocks comprise pink to light grey, some brownish, microgranite and aplite; pegmatites are rare and simple in composition. Most of the dykes do not exceed 1 m in thickness and 150 m in length; some are vein-like and less than 10 m in length (Fig. 5 top). They have steep dips and are variable in strike. In the outcrops near the main road, for example, small micrograniti̇c dykes occur in three orientations, and were probably emplaced along a set of joints. The dykes are locally displaced for a meter or two by faults. They are older than and cut by the mafic dykes, and locally the two may form composite sheets. In the ridge north of Wadhrai, a highly altered mafic dyke of chocolate colour is flanked on both sides by pink granite sheets. It appears that the felsic dykes are related to the main granite, however, in rare cases the mafic dykes contain microgranite veins.

To the northwest of Wadhrai, a pink to yellow brown dyke extends for 150 m. Trending N80^{o} W with steep northerly dip, it is about 50 cm thick in the eastern part, but thins westward to 30 cm in the centre and steadily disappears in the host granite at its western end. A quartz vein runs along the centre of the dyke for a few meters. This dyke is made up of a subequigranular rock containing brownish feldspar, larger grains of quartz, and small quantities of amphibole and opaque oxide. In the east central part of the area, a microgranitic dyke runs for over 300 m in N30-35^{o} W direction. It is 1-2 m in the southeastern part, but for much of its length it maintains a thickness of 2 to 4 m. This is a well jointed, equigranular, chocolate brown rock that turns yellow at places.

Table 1. Analyses of two Wadhrai granite samples

Oxide %	P267	P268	Tr& REE ppm	P267
SiO_2	75.20	75.50	S	72
TiO_2	0.30	0.27	Ba	644
Al_2O_3	12.78	12.32	Zr	63
Fe_2O_3	1.14	1.97	Cr	5
MnO	0.08	0.08	Ni	5
MgO	0.32	0.32	Rb	41.6
CaO	0.89	0.36	Th	11.5
Na_2O	5.02	4.92	Ta	1.1
K_2O	3.45	3.19	Nb	6.2
P_2O_5	0.03	0.04	Hf	3.5
L.O.I	0.8	0.88	Y	53.6
Total	**100.01**	**99.85**	La	38.1
C.I.P.W. norms			Ce	70.8
Q	30.71	32.91	Pr	9.2
C	0.00	0.21	Nd	42.9
Or	20.52	19.08	Sm	8.4
Ab	42.86	42.14	Eu	1.4
An	2.15	1.54	Tb	1.3
Di	1.76	0	Gd	8.2
Hy	1.04	3.08	Dy	8.4
Mt	0.24	0.40	Ho	1.8
Il	0.57	0.52	Er	5.5
Ap	0.07	0.09	Yb	5.7

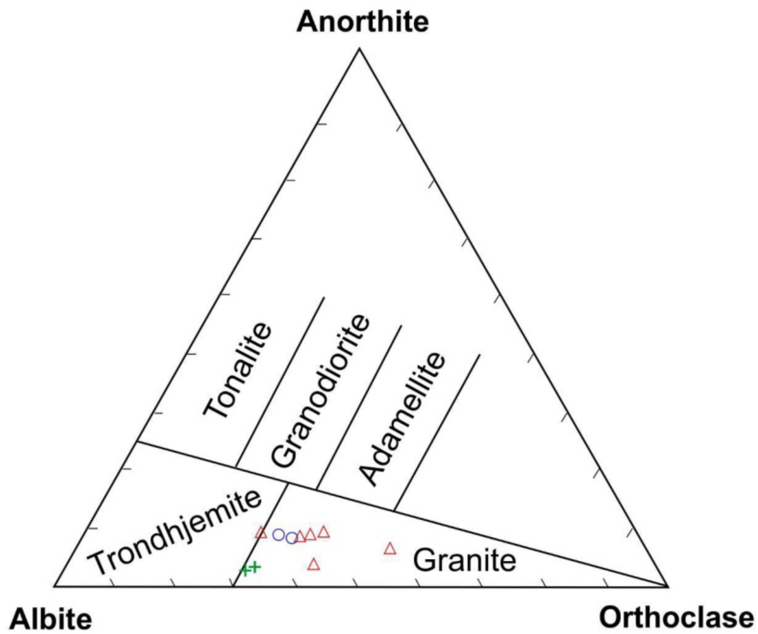

Fig. 4. Normative anorthite-albite-orthoclase ternary diagram of O'Connor (1965), showing fields of various granitioids. The analyses of the Wadhrai granite plot exclusively in the granite field. Sources of data include this study, Ahmad and Chaudhry (2008) and Khan et al. (2012).

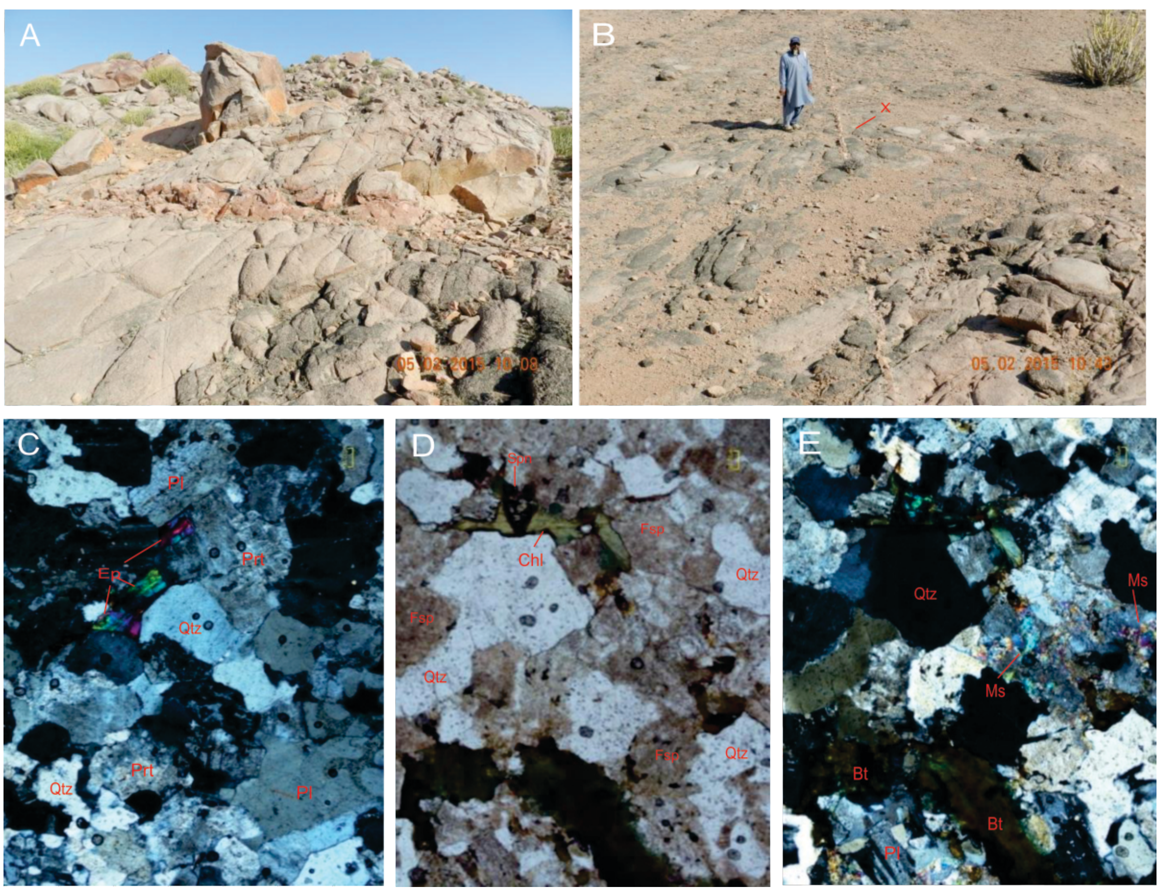

Fig. 5. Field and petrographic features of the felsic dykes. A: Pinkish dykes in the Wadhrai granite. B: Thin dykes showing cross-cutting relations near man's feet (X). Both A and B are from south-eastern part. C: WD-9, from south-eastern edge of the body, XP. Leucocratic dyke containing cloudy perthite (Prt), albite (Pl), quartz (Qtz) and euhedral (igneous?) epidote (Ep). D (PL), E (XP): Felsic dyke N of Wadhrai, containing cloudy feldspar, quartz, chloritized biotite (Chl, Bt) and titanite (Spn). Secondary muscovite (Ms) replaces some feldspar. Length of photomicrographs is 2.5 mm.

3.1. Petrography

The felsic dykes are subequigranular to, locally, subporphyritic, hypidiomorphic, and fine- to fine medium-grained. They range from micogranite (abundant) to aplite, pegmatite and quartz porphyry, but the latter two are rare. Some look like the host rocks, except for finer grain size, and many are leucocratic. Perthite, albite, quartz, and sparse microcline are accompanied by small quantities of opaque oxide, with or without biotite, titanite and secondary minerals (Fig. 5). Pegmatites are rare and small. A 15 m long and 5 cm thick simple (quartz-feldspar) pegmatite occurs in the northern part of the area near Jam Khan Jo Wandio. It contains a central "spine" of discontinuous quartz. Like their host granite, the felsic dykes are fresh to slightly altered. As a result, the feldspar may be cloudy and/or replaced locally by white mica, the biotite may be chloritized and the opaque oxide partially replaced by leucoxene. In rare cases (Fig. 5C), the rocks contain euhedral epidote of possibly igneous origin.

4. Mafic dykes

Scattered throughout, mafic dykes are particularly abundant in the central southern part of the granite body (Figs. 2 and 6). They are commonly fine-grained, but locally medium-grained. Some are medium fine-grained in the centre and chilled fine-grained in the margins. They range in size from thin, short veins to bodies > 1 km in length and 10 m in width. Many trend NW-SE, but some extend NE-SW and appear to cross-cut the NW trending ones. Most dykes maintain a steady thickness or show gradual change from one end to the other, but some show considerable swelling within short distances. The swelling occurs mostly at the crossings of the dykes, but at places the swelled parts contain septa of the host granite. Some of the dykes display high degree of fracturing and weather brown to chocolate in colour; a few of the jointed ones show exfoliation (Fig. 6D).

The mafic dykes contain xenoliths of the granite some of which have been weathered out to leave behind rounded potholes and cavities. Commonly up to 2 cm across, these are filled with quartz, with or without mafic minerals. The dykes contain up to 1.5 cm thick epidote, quartz, and calcite veins, the latter locally along closely spaced fractures. Some calcite veins are several centimeters thick and more than a meter in length.

The dykes are often in parallel sets, separated by meters to tens of meters of the host granite. Near the northern part of the Wadhrai village, there is a set of three parallel to locally crosscutting greenish dykes, < 1 to 1.5 m thick and only a few meters apart. The set extends N60^{o} W for about 300 m and bends gently to N80^{o} W. A little north, there are four thin (<50 cm) dykes within a distance of 20 m; these also trend N60^{o} W and extend variably for 60 m. In the west central part of the area, there are repetitions of meters-thick and hundreds of meters long sheeted dykes at intervals of a few tens of meters in the host granite (Fig. 6A). We counted eight dykes, < 1 to 8 m thick, in a distance of 200 m. One of these, a medium-grained gabbroid, contains up to 3 cm long phenocrysts of plagioclase.

Composite dykes, comprising mafic and felsic sheets, occur locally. In the ridge N of Wadgrai, there is a 350 m long and a few to some meters thick composite dyke comprising up to 2 m thick reddish pink granite sheets flanking a dark doleritic rock on both sides. The presence of the granite xenoliths in the doleritic rock suggests that the latter is younger. The granite is leucocratic, shows colour variation and at places is a mixture of yellow, brown and black. The dolerite is black, but weathers chocolate and buff, at places mottled, and contains pits.

4.1. Petrography

The mafic dykes in Wadhrai show considerable variation in texture and modal composition from distinctly porphyritic to aphyric, medium to (mostly) fine-grained, and fairly fresh to completely altered (Fig. 7). Some of the latter contain plagioclase phenocrysts nearly totallysaussuritized (epidote + white mica), with or without altered mafic minerals including biotite, in an altered groundmass of cloudy/saussuritized plagioclase, amphibole, chlorite, biotite, ilmenite, +/– titanite/

leucoxene, calcite (abundant in a few), quartz, and rare serpentine, chalcedony(?) and devitrified glass. A few of the dykes look to contain amygdules comprising abundant calcite, and small amounts of chlorite, amphibole, quartz, and chalcedony, locally in concentric arrangements.

One of the greenish black dykes with light grey surface, occurring near Wadhrai, is worth special mention (Fig. 7I). This fine-grained altered rock comprises three components: 1) the matrix is light green, clear, and isotropic to having low interference colour, possibly chlorite or chlorophaeite. It contains up to 0.3 mm long, grey, locally brown, worm-like grains (with inclusions of opaque granules) that may be surrounded by clear halos of calcite/sericite, 2) the phenocrysts appear to be prismatic, but are totally replaced either by calcite, calcite-chlorite with brown Fe-stains on margins and across, chlorite-muscovite?, or chlorite-opaque oxide. Opaque oxide also seems to form rare phenocrysts, and 3) up to 1.5 mm rounded to elliptical pools of secondary minerals grown in concentric shells that display the following disposition from core to margin: chlorite–calcite–amphibole–chlorite, opaque grains+ calcite–calcite–chlorite with discrete grains of amphibole, and chlorite–discrete grains of titanite–calcite. These appear to be amygdules, suggesting that the dyke may be a subvolcanic (shallow) intrusion.

The fresh ones, as elsewhere in NPIC (Laghari et al., 2013) are characterized by either clinopyroxene or amphibole as the principal mafic mineral. In these the phenocrysts are mostly of plagioclase (labradorite with up to 70% An) that commonly range in length from <1 to 5 mm, but reach up to 3 cm in a couple of the medium-grained dykes. In a few clinopyroxene-bearing gabbroid dykes the plagioclase phenocrysts form clusters up to 2.3

Fig. 6. Field features of the mafic dykes. A: West central part of the Wadhrai body showing a series of W-trending mafic dykes (dark grey, low relief) in host granite. B: Mafic dyke in the granite, containing an angular xenolith of the latter below the yellow pen. C: Thin mafic dykes and patches in the granite. Yellow staff in the middle is 1.2 m long. D: Spheroidally weathered dolerite dyke in central part.

mm across (Fig. 7C). Small quantities of either clinopyroxene or hornblendic amphibole may occur as an additional phenocryst phase.

The groundmass in these rocks comprises plagioclase (calcic andesine to sodic labradorite), clinopyroxene or brown primary amphibole, biotite, ilmenite, olivine relics in some pyroxene-bearing dykes, rare pyrite in the amphibole-bearing types, and minor quantities of a range of secondary minerals as in the altered rocks. A few of the amphibole-bearing dykes also contain quartz. Rarely, the groundmass seems to contain intersertal glass. The lilac colour of the clinopyroxene is suggestive of the presence of titanium. Titanium augite of pink to lilac colour is typical of alkaline basalts (William et al., 1954). In the Wadhrai dykes, the olivine is partly or completely replaced by serpentine, magnetite and possibly some biotite (Fig. 7A). Thin veins of epidote-prehnite-chlorite occur in a few hornblende-bearing dykes. Additional details of the petrography can be seen in photomicrographs and captions to them in Figure 7.

5. Rhyolite sheets

There are a few thin dykes and two large N35° W trending sheets of rhyolites. One of these extends for over 2 km and is the most prominent of its type in the entire NPIC. These dykes are very fine-grained, hard, and locally display conchoidal fractures and banding (Fig. 8). The rocks are dark grey to almost black, but grey, bluish grey, greenish grey, earthy to buff or orange on weathered surfaces. The smaller of the two main dykes maintains a more or less uniform thickness of 3 to 4 m, tapering in SE to 2 m under alluvium. At places, it shows columnar joints developed against its trend, closely-spaced platy shears and, rarely, swarms of mm thick quartz veins. In the northwestern part across the fields, however, the main dyke gets much thicker (16-30 m), and contains up to 3 m thick granite septa. Both the dykes and the septa are sheared parallel to the length of the dyke. Due to displacement by a fault oriented at a high angle to its length, the thickness of the dyke reduces to 4-5 m and remains as such for 200 m before it disappears near Dotar. This end is a greenish grey, blocky and solid mass.

No cross-cutting relations have been observed between the mafic and rhyolite dykes, but they may be a product of bimodal magmatism as in the Kharsar hillock in northern Nagar Parkar (Jan et al., 2016). Bimodal mafic-felsic magmatism has been reported from several areas of the world (Winter, 2010). Underplating of the crust by mafic magma can lead to partial melting and production of felsic magma. Kochhar et al. (1995) also suggested ponding of the crust by basaltic magama, coupled with extensional tectonics, for bimodal magmatism in Jalor area of Rajasthan.

5.1. Petrography

The rhyolites are typically fine-grained and sparsely porphyritic. They display a fairly uniform modal composition and consist of feldspar, quartz, amphibole, clinopyroxene, and small quantities of opaque oxide, titanite, allanite, and rare epidote, tourmaline and (?) olivine. The phenocrysts (Fig. 8C-H) consist of up to 1mm long grains of feldspar, accompanied in rare cases by quartz and/or clinopyroxene and olivine. The feldspar is essentially perthitic; albite occurs in small quantities. The amphibole is greenish to brownish to blue, and in some rocks looks like typical riebeckite. The clinopyroxene is greenish pleochroic, and may range from aegirine augite to aegirine. While quartz and feldspar grains are mostly anhedral, the amphibole and clinopyroxene are subhedral, and form distinctly elongated grains that appear as slender prisms in thin sections, commonly < 0.5 mm in length.

Most of the rocks are characterized by abundant granophyric intergrowths (Fig. 8F-I) between quartz and feldspar, commonly making half or more of the thin sections. In a few cases these intergrowths are cut through by prismatic amphibole and clinopyroxene. The latter two minerals also occur in spherules (Fig. 8J-K) that are common but not abundant. In many rocks, the clinopyroxene and amphibole are located within feldspar grains, locally in pools, and appear to have grown late during crystallization. In a few rocks, the clinopyroxene seems to have grown earlier than amphibole. Details of textures and mineral

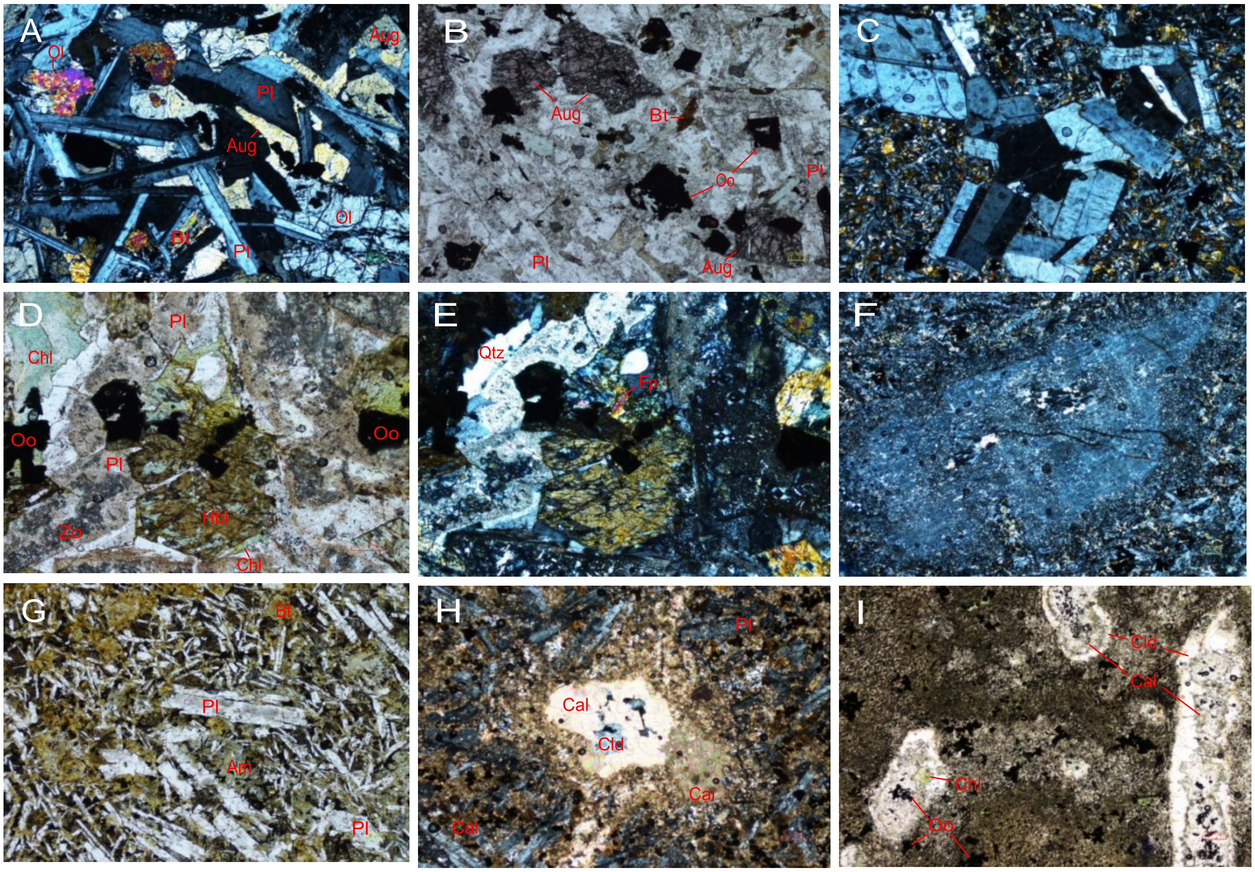

Fig. 7. Petrographic features of the mafic dykes. Photomicrographs D and E are 1.25 mm long; others are 2.5 mm long. A: Olivine (Ol)-augite (Aug) dolerite WD-25a from the western part of the main body, XP); labradorite (Pl) is well-twinned and not much zoned, augite is ophitic,olivine shows minor alteration to serpentine and magnetite along fractures, biotite (Bt) is slightly chloritized,and opaque oxide grains are fresh. B: 2-3 m thick dyke (WD-19, mid eastern part of the main body, PL), comprising calcic plagioclase, intergranular clinopyroxene (Aug), opaque oxide (Oo) and biotite. The plagioclase is zoned and partly saussuritized, especially in some cores, and biotite is partially chloritized. The clinopyroxene is lilac, and shows alteration along abundant fractures. Opaque oxide grains range from euhedral to spongy. Needles of apatite are common whereas secondary calcite and white mica occur locally. C: Augite dolerite dyke (WD-22, southwestern part of the main body, XP) showing a cluster of fresh, euhedral plagioclase (An69) in a matrix of plagioclase (An50), clinopyroxene, opaque oxide and biotite.D (PL) and E (XP): Diorite-looking dyke WD-23, near 22, containing euhedral hornblende (Hbl), plagioclase, and opaque oxide. The hornblende is partly replaced by chlorite, and plagioclase is cloudy to intensely saussuritized in the cores some of which, with high relief and anomalous blue interference, may be zoisite (Zo). Note secondary epidote, quartz and light green chlorite patches. F: (WD-14, NW of Wadhrai, XP), resorbed and embayed phenocyrst of plagioclase, showing oscillatory zoning and partial alteration, in a matrix of plagioclase, opaque oxide and secondary calcite, chlorite, amphibole and biotite. G: Mafic dyke (WD-10, N of Wadhrai, PL) with phenocrysts of sodic labradorite, sparse biotite (stained yellow green) and hornblendic amphibole in an altered matrix of plagioclases, opaque oxide, amphibole, chlorite, calcite, quartz and white mica. The plagioclase is saussuritized, hornblende is altered to chlorite and secondary amphibole, biotite is chloritized and opaque oxide (some skeletal) is partly replaced by titanite. Note some parallel arrangement in the plagioclase phenocrysts. H: Strongly altered dyke (WD-13, NW of Wadhrai in central part of the body)containing plagioclase, calcite (Cal), opaque oxide + leucoxene, chlorite, albite, chalcedony (?), and secondary amphibole. The photograph is focused on a swelled part of a vein containing chalcedony (Cld) cores in calcite that is surrounded by granules of calcite with discrete grains of amphibole. I: Highly altered mafic dyke (WD-8, southeastern edge of the main body) consisting of light and dark patches (probably after plagioclase and mafic minerals, respectively) comprising calcite, zoisite, chlorite, amphibole, opaque grains, white mica, albite, chalcedony(?), zeolite(?) and unidentified minerals, including elongated black and light colour grains spread throughout the rock. Rounded, ellipsoidal and elongated amygdules show zonal disposition of magnetite, calcite, chlorite, albite, chalcedony, zeolite, etc. Those in the picture consist of opaque oxide cores enclosed in calcite (high relief) with or without chlorite, and outer shell of chalcedony and or zeolite (milky). Further details of these can be seen in the text.

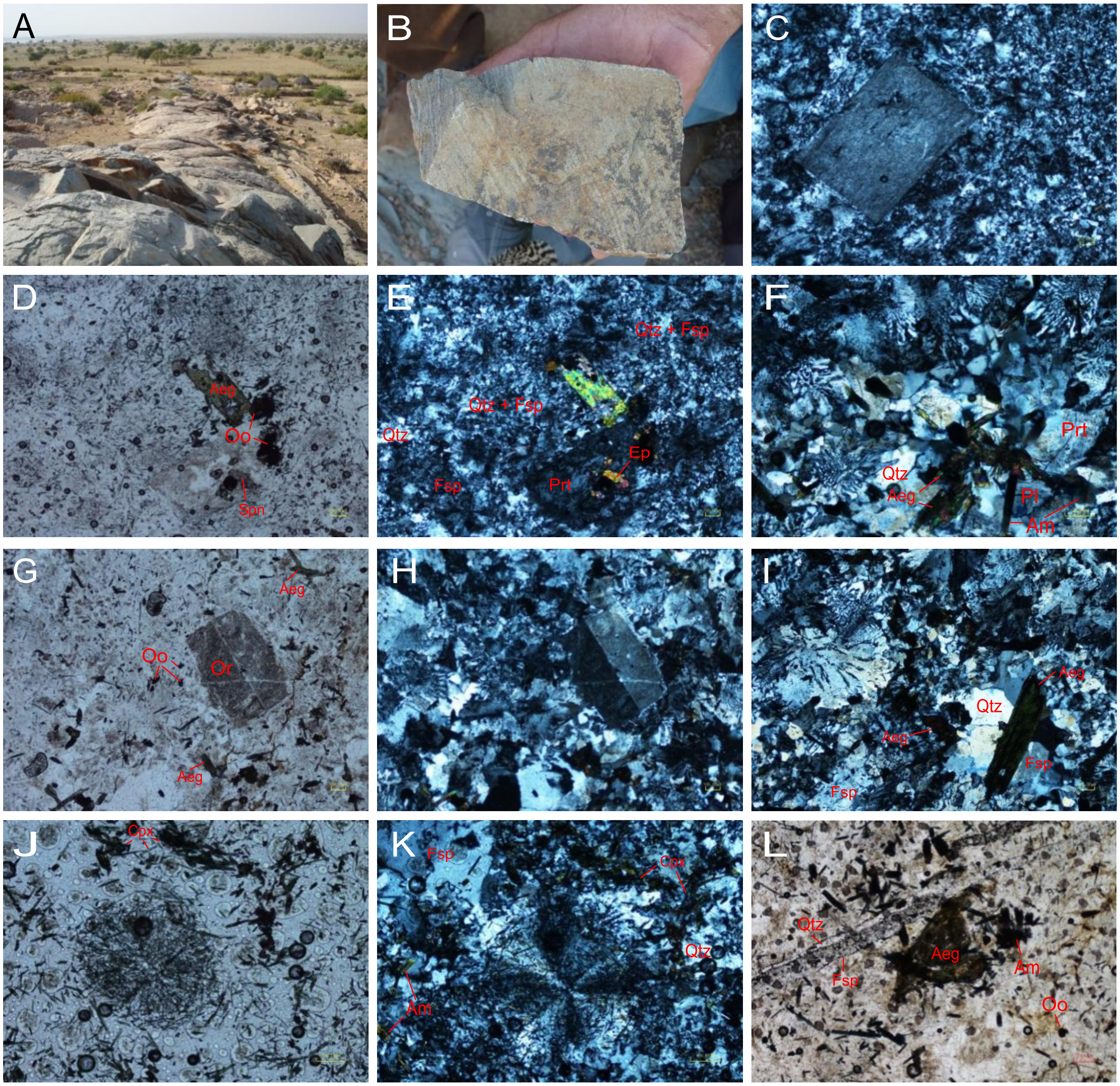

Fig. 8. Rhyolite dykes. Length of the photomicrographs is 2.5 mm, except in J and K where it is 1.25 mm. A: The smaller dyke (WD-26) shown in Fig. 2, disappearing in the fields NW of Wadhrai. B: Banding and manganese or iron dendrites in a specimen of dyke A. C: WD-26,XP, euhedral phenocryst of perthite in a groundmass comprising feldspar, quartz, acicular to prismatic sodic amphibole and clinopyroxene, and opaque grains. Much of the feldspar and quartz occurs in spherules or granophyric intergrowths. D (PL) and E (XP) Rhyolite WD-26: Perthite and sodic clinopyroxene phenocrysts, opaque oxide and associated epidote(?) in feldspar, quartz, sodic amphibole and pyroxene, titanite and opaque oxide groundmass. The clouded areas in D appear to be spherules of feldspar, quartz and amphibole. Rounded objects are air bubbles. F: Rhyolite WD-27B, W of 26, XP), showing a cluster of sodic clinopyroxene and amphibole in feldspar (mildly cloudy), quartz and abundant granophyre; G (PL) and H, XP) WD-28, NW of 26, showing orthoclase phenocryst with Carlsbad twinning, and clinopyroxene grains (lower left) in a predominantly granophyric groundmass, containing needles of clinopyroxene, amphibole and opaque grains. I: WD-16, from NW of the long dyke, XP). Larger grains of aegirine, quartz and feldspar in a groundmass of these, sodic amphibole, opaque oxide, titanite and epidote or olivine. Most of the groundmass is composed of graphic intergrowths some of which are shot through radially by acicular sodic amphibole; J (PPL) and K (XP), showing very fine-grained rhyolite (WD-32, main dyke) with spherulitic growth, alkali amphibole, some clinopyroxene, and opaque oxide. The spherules contain abundant tiny prisms of amphibole and the feldspar in the spherules is longer than that in the matrix; L: (WD-27 from central part of the smaller dyke, PPL) showing a cluster of aegirine augite near a quartzo-feldspathic vein. Other minerals are quartz, mildly cloudy feldspar, sodic amphibole and clinopyroxene.

contents can be seen in Figure 8 and captions.

6. Conclusions

- The Wadhrai granitoid body of the NPIC is an extension of the Neoproterozoic Malani Igneous Suite of western Rajasthan.
- The plutonic body stretches between the Wadhrai, Jam Khan Jo Wandio and Dotar villages, and covers more than 10 km^2 area. Scattered outcrops in the alluvium, particularly on the north-eastern side, suggest it is much larger.
- The body is occupied by a rather uniform, medium-grained, and mostly aphyric rock of light to locally pinkish colour. It is locally porphyritic, with 1 cm long feldspar phenocrysts.
- The rocks are generally fresh or mildly altered, have widely-spaced joints, and are suitable for extraction as decorative stone.
- Ten analyses of the granitoid classify as granite of alkaline character.
- Many dykes and veins of leucocratic microgranite, aplite, quartz, rare pegmatites, dolerite and rhyolite are emplaced in the granite.
- In the south-central part, there are sheets and networks of aphyric to porphyritic mafic dykes many of which are strongly altered, with a few beyond recognition. The less altered dykes are mostly hornblende-bearing but, as elsewhere in the complex, there also are pyroxene-bearing dykes some of which contain olivine. The lilac colour of clinopyroxene may be due to Ti, and the rocks may be alkaline. These appear younger than the hornblende-bearing variety. The degree of alterationand variations in texture and modal composition make the dolerites a complex group of rocks. They may belong to more than one episode of intrusive activity.
- Locally, the mafic dykes occur in composite intrusions with microgranite and aplite.
- Sheets of sodic alkaline rhyolite occur in the western part of the area. One of these, the largest of its type in the entire NIPC, attains a thickness of 30 m and extends for more than 2 km.
- While the felsic dykes appear to be related to the granite, and are older than the mafic dykes and rhyolite sheets, the emplacement order of the latter two is not clear.
- We do not have sufficient data at hand to postulate the petrological relations between the mafic and rhyolitic dykes, but the latter may represent melts derived from the crust in response to underplating by mafic magma.

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