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Geology and petrography of the Nagar Parkar igneous complex, southeastern Sindh: the Dinsi body

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Abstract

Geological mapping and detailed petrography suggest that the Dinsi area is principally occupied by medium-grained porphyritic granite, and quartz monzonite which covers the western part of the outcrop area. The granite is composed of perthite, quartz, some plagioclase, opaque oxide, biotite and/or amphibole, and titanite, whereas the quartz monzonite comprises perthite, calcic oligoclase/andesine, quartz, and minor amount of mafic minerals similar to those of the granite. The two granitoids contain local bodies of the basement consisting of fine-grained doleritic to medium-grained dioritic rocks. The basement shows brittle deformation and low-grade metamorphic overprint that resulted in development of epidote, chlorite, albitic plagioclase, and actinolite before the emplacement of the granitoids. These rocks were cut by small dykes of granitic and aplitic rocks showing a range of texture and composition. They are of more than one generation and at places show complex relations, but many are related to the two main intrusions of the granitic rocks. The final phases of magmatism are represented by mafic and rhyolite dykes and their contemporaneous, rare microgranite dykes. The mafic dykes, reaching 500x3 m in size, can be divided into two broader groups one of which contains hornblende and the other augite as the characteristic primary mafic phase.

1. Introduction

The Nagar Parkar area covers about 500 km^2 at the junction of the Great Rann of Kutch and Thar Desert. It is connected to Mithi and Badin by a recently built metalled road. Surrounded on three sides by the Rann and the Indian territory. Unlike the Thar Desert, which is mainly covered by sand dunes, this area is characterized by mounds and bold hills of granitic rocks in an otherwise leveled territory comprising sandy, salty and salty plain. Karunjhar hill, the principal geomorphic landmark of the desert in southeastern Pakistan, attains a height of 356 m above sea level.

The area may be an uplifted block exposing Precambrian igneous rocks that have been named as the Nagar Parkar igneous complex (Kazmi and Rana, 1973). The oldest of these comprise a suite of low-grade metamorphosed basic to intermediate rocks which constitute a basement to Neoproterozoic magmatism that is essentially granitic (Butt et al., 1994; Jan et al., 1997; Kazmi and Jan, 1997). Butt et al. (1989) reinterpreted the gravity anomaly data of Farah and Jafree (1965) and suggested that the basic rocks of the basement underlie much of the Nagar Parkar area, whereas the granitic intrusions form thin, sheet-like masses.

The basement rocks are only sporadically exposed and physiographically inconspicuous. They generally occupy low ground between the granite hills due, probably, to their greater susceptibility to erosion and weathering, and possible exposure for longer time. The granites are undeformed and occur in stocks, bosses and dykes emplaced in the basement. There are several types of granites, of which the two prominent varieties are grey and pink in colour. The larger granite intrusions are accompanied and followed by younger granitic, aplitic, mafic and rhyolitic dykes. Detrital material and residual (laterite/kaolin) deposits derived from the igneous complex during the Quaternary are subordinate and local, but wind-blown sand and loess are common.

The Nagar Parkar igneous complex (Fig. 1), 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 granites are dominated by 2 and 3, along with quartz monzonite. Laghari (2004) equated the grey and pink varieties with their counterparts in Rajasthan. Indeed, 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 (Bhushan, 2000; Kochhar, 2004; Gregory et al., 2009). Recently, Khan et al. (2012) have reported U-Th-Pb zircon 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).

Substantial details of the geology, petrology, geochemistry and mineral deposits of the area have been presented by several workers (for references, see Jan et al., 1997; Muslim et al., 1997; Ahmad and Chaudhry, 2008; Khan et al., 2012), but we feel that the area requires additional field studies. The grouping of the rocks by Jan et al. (1997) and Ahmad and Chaudhry (2008), for example, is too simplistic and generalized. We, therefore, started afresh systematic and detailed study of individual bodies of the granites. This is the first of a series of accounts that we shall present for the area.

2. The Dinsi Body

It has been named after the village Dinsi, the body comprises a hill (122 m) and a mound to the east, the two separated by a few hundred meters of alluvium. The major component occurs in the hill in the north of the village and stretches for more than 2 km, whereas the mound to the east is much smaller. The outcrop area is covered by 1) isolated remnants of the basement, 2) porphyritic granite, 3) quartz monzonite, 4) dykes and veins of microgranite, aplite and rhyolite, and 5) mafic dykes. The contact relations of the quartz monzonite and porphyritic granite, the two principal lithologies, are not very clear. However, in one place north of the eastern basement, the porphyritic granite and a granitic dyke in it are clearly cut by the quartz monzonite, which also contains xenoliths of the granite. In the northern part also the porphyritic granite is cut by an quartz monzonite dyke. The geological map of the area, prepared during this investigation, is shown in Figure 2. Some field relations and photomicrographs are displayed in figures 3 and 4. In the following, the five units are described in some detail:

2.1. Basement

The basement rocks (Figs. 3.1-3.2) are exposed in three places. Two of the bodies occur along the contact of the medium-grained granite and quartz monzonite in the central and eastern parts of the main hill, and the third in the centre of the peneplained northern continuation of the hill. To avoid confusion, we shall call these as western, eastern and northern, respectively. The western body is 140 m long, and thins out in both directions from the centre that is 35 m wide. The eastern body stretches for 300 m, and attains a thickness of 50 m in the centre. The basement here is intruded by the two varieties of the granitic rocks, as well as (porphyritic) microgranite and aplitic dykes and veins. The northern body is occupied by diorite-looking rocks with patches and dykes of granite, dolerite and rare rhyolite. The rocks here also are fine-grained to medium-grained, and some have phenocrysts of plagioclase and hornblende. By and large, the basement rocks in Dinsi are not much different than elsewhere in the Nagar Parkar igneous complex (cf., Laghari, 2004).

The basement may be highly fractured, and is a mixture of fine- to medium-grained aphyric to inequigranular to porporphyritic rocks, with local pools of coarse medium-grained rocks. Petrographically, the rocks can be lumped under the broader heading of 'diorite', but they range from those with substantial hornblende to those with essential quartz (Figs. 4.1-4.2). Some of the fine-grained rocks are aphyric, but some are porphyritic, with 1-2 mm long plagioclase phenocrysts in a groundmass of plagioclase, amphibole, ore, etc. The rocks in the eastern body locally contain epidote-rich pools (some 25-30 cm across) and veins (up to 12 cm thick). One of these is made up of medium/fine-grained, xenomorphic assemblage comprising epidote, chlorite, titanite, quartz and albitic plagioclase.

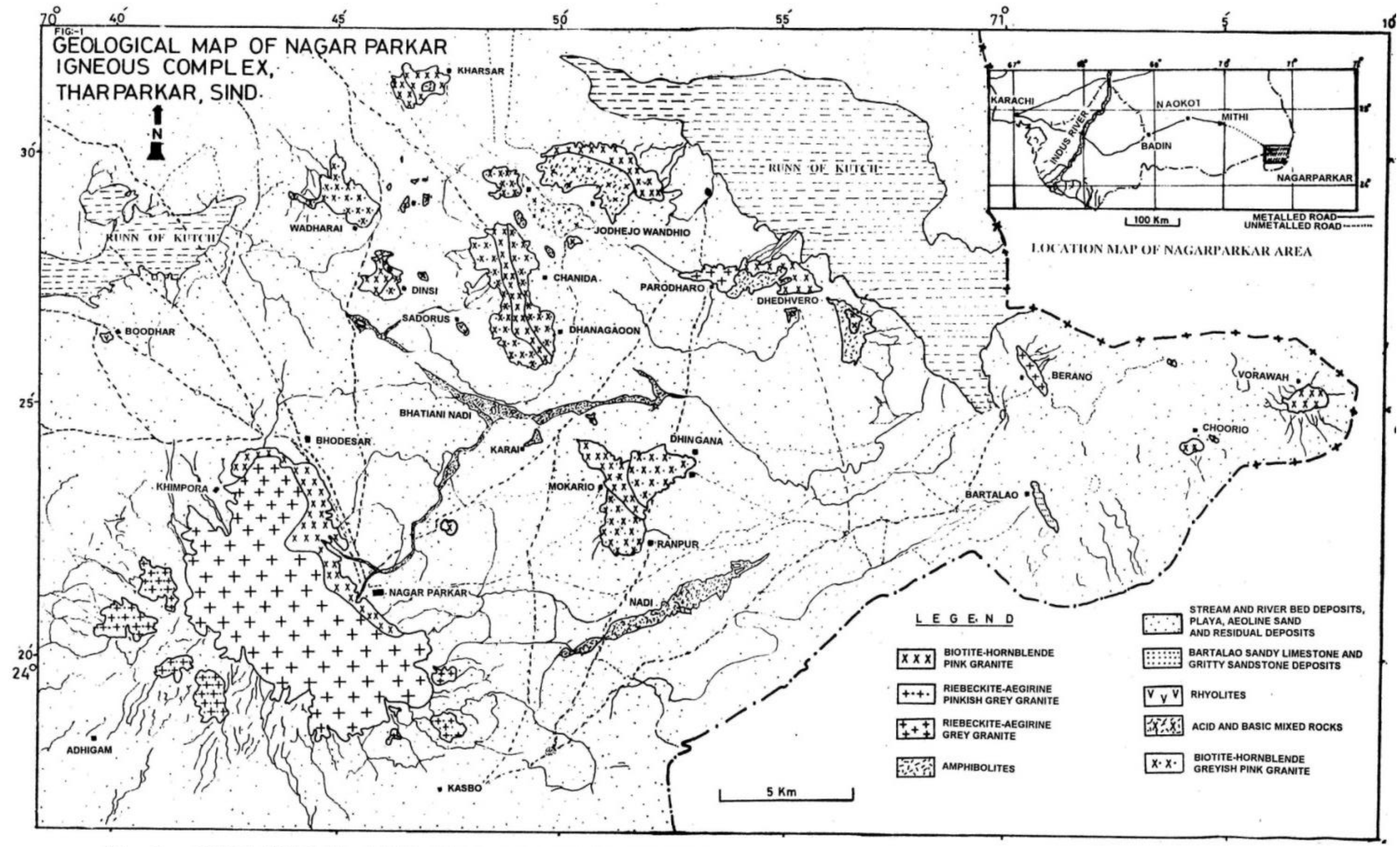


Fig. 1. Geological map of the Nagar Parkar igneous complex, southeastern Sindh (after Jan et al., 1997).

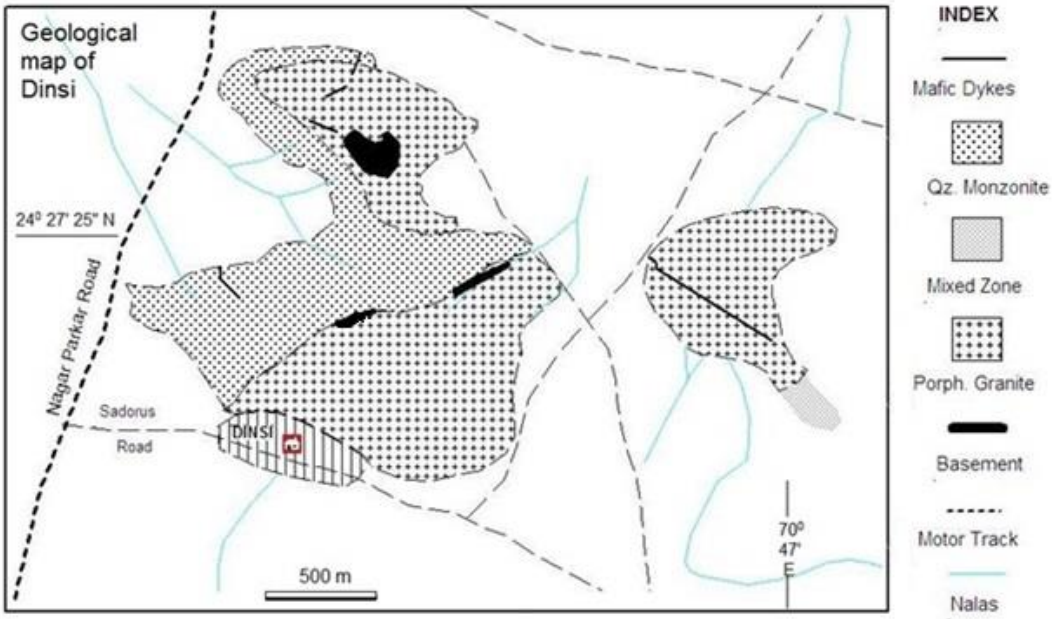


Fig. 2. Geological map of the Dinsi igneous body. Silicic and many mafic dykes are not shown because of their small sizes.

Most rocks under the microscope are medium-grained, hypidiomorphic to allotriomorphic, subequigranular, and composed of plagioclase, hornblendic amphibole, opaque iron oxide, quartz and, in some, biotite, titanite and rare perthite. The plagioclase looks zoned, and variably saussuritized, especially in the cores, but in some cases it appears to have fresh secondary (?) margins. These minerals are accompanied by plenty of secondary amphibole, chlorite, epidote (one or more of the three phases abundant in some rocks), titanite, and leucoxene. Primary amphibole is brown and altered to chlorite with or without epidote and secondary amphibole that is bluish green actinolite. In a few rocks, the primary amphibole is completely psuedomorphed by chlorite, with some epidote and titanite. The secondary minerals are locally also seen along fractures. In one case, trailers of calcite grains occur along 1-1.5 mm thick fractures. The presence of chlorite, epidote, actinolite and albite suggest that the rocks have passed through low grade metamorphism. Since these minerals occur in sheared as well as unsheared rocks, the metamorphism could have been static.

2.2. Porphyritic granite

This is the principal lithology in the Dinsi area (Fig. 2). It is a grey porphyritic rock containing coarse feldspar phenocrysts in a medium-grained matrix. Many of the phenocrysts are some millimeters to over a centimeter in length, reaching 2 cm in rare cases. The amount of the phenocrysts shows some variation across the body. Phenocrysts are particularly abundant in the eastern edge of the main body where the granite is also coarser grained, and near the contact with the basement in the western part where the granite is finer grained. The presence of widely spaced joints results in large exfoliated and spheroidally weathered blocks in the top of the hill to the north of the Dinsi village. In the southern edge of the body near the village, the rocks are a mixture of light pink and grey tones, turning reddish pink along some fractures. In this locality in particular, but also elsewhere, there are pseudotachylite veins up to 2 cm thick and over a meter long. Xenoliths of the basement (Fig. 3.3) and autoliths are common, at places abundant, and some showing the effect of baking. The frequency of the xenoliths generally increases towards the contact with the basement.






Fig. 3. Field aspects/relations of the rocks. Clock-wise from top left: 1) A part of the eastern basement body with thin dykes of pink microgranite (24º 27´ 23´´N; 70º 46´ 22´´E), 2) Eastern basement, showing network of leucogranite dykes in dioritic rocks (24º 27´ 22´´N; 70º 46´ 19´´E), 3) Xenoliths of basement rocks within porphyritic granite near the eastern basement (24º 27´ 25´´N; 70º 46´ 22´´E), 4) Contact between the main phases of intrusions, i.e., porphyritic granite on the left and quartz monzonite on the right (24º 27´ 24´´N; 70º 46´ 20´´E) close to eastern basement, 5) Thin, cross-cutting microgranite-aplite dykes in quartz monzonite (24º 27´ 23´´N; 70º 46´ 10´´E) just west of the above contact of the two granitoids, 6) Concentration of xenoliths within a quartz monzonite dyke in the porphyritc granite near the contact with the northern basement (24º 27´ 43´´N; 70º 46´ 06´´E), 7) Mafic dyke, 15 cm thick, cutting porphyritic granite in the northeastern part of the area (24º 27´ 21´´N; 70º 46´ 07´´E). The long dyke-like image in the right is that of a bamboo stick, and 8) Thin microgranite dyke cutting mafic dyke (which itself intrudes the porphyritic granite) in the eastern isolated mound (24º 27´ 15´´N; 70º 46´ 57´´E).

The porphyritic granite is intruded by small dykes of microgranite/aplite, generally less than half a meter thick and a few tens of meters in length. Near the eastern basement outcrop, the granite has quite a range of the minor intrusions: 15 to 60 cm thick dykes of quartz-biotite (with or without hornblende) monzonite; strongly porphyritic hornblende granodioritic dykes with up to 1 cm long plagioclase phenocrysts in a fine-grained dark matrix; and thin leucogranite dykes similar to those displayed in Figure 3.2. The Nagar Parkar granites are generally devoid of the occurrence of pegmatites, except sparingly. In Dinsi, there are only two small patches of feldspar-quartz pegmatite. One of these is near the above described dykes and the other is in the mixed zone. There are veins of green epidote and/or milky quartz in many places. Between the hill top and Dinsi village, the granite contains a 6 m long and 1cm thick vein comprising of quartz, green epidote, opaque oxide, with or without minor feldspar.

The porphyritic granite is coarsely medium-grained, and hypidiomorphic to locally allotiomorphic. It is essentially composed of perthite and quartz, with smaller to trace amounts of plagioclase, biotite, amphibole (not in all), opaque oxide, titanite, apatite and zircon. In some samples, perthite and quartz also occur in graphic intergrowths. The feldspars are fresh to slightly cloudy and sparingly show mantles of plagioclase around perthite (rapakivi-type) or vice versa. Amphibole is blue green to yellow brown, but in one sample it is violet to greenish blue (sodic?). Biotite displays the normal brown-red colour, but is strong orange-red in a fracture in one of the samples. Chlorite has developed at the expense of some biotite and amphibole. Wet chemical analysis of a sample (Laghari, 2004) is given in Table 1. It is a typical granite with rather higher than usual amounts of $Na_2O + K_2O$ (8.8 wt%) and contains small amounts of diopside, acmite and hypersthene in the CIPW norms that are dominated by albite, quartz and orthoclase.

Table 1. Chemical analyses (in wt%) of granite and quartz monzonite from Dinsi.

	P177	P178	CIPW Norms	P177	P178
SiO2	75.80	71.51	q	29.73	22.65
TiO2	0.29	0.43	c	0.00	0.13
Al2O3	12.34	14.92	Or	21.81	18.86
Fe2O3	1.73	1.75	ab	42.92	49.05
MnO	0.06	0.08	an	0.00	5.30
MgO	0.28	0.37	ac	0.52	0.00
CaO	0.80	1.15	di	3.40	0.00
Na2O	5.14	5.74	hy	0.98	2.64
K2O	3.69	3.16	mt	0.09	0.36
P2O5	0.00	0.07	il	0.55	0.82
LOI	0.54	0.61	ap	0.00	0.15
Total	100.67	99.79	(From Laghari, 2004)		

2.3. *Quartz Monzonite*

In the Nagar Parkar complex, these rocks have been referred to as adamellite by Laghari (2004) and Ahmad and Chaudhry (2008). In this and subsequent papers, we have used the preferred equivalent name ‘quartz monzonite’, following Le Maitre et al. (2002). The western part of the main Dinsi body is occupied by medium-grained quartz monzonite similar to that of the Wadhrai body to the north of the Dinsi hill (Muslim et al., 1997). Field relations suggest that the body is younger than the porphyritic granite (Fig. 3.4). It is equigranular to subequigranular, but locally porphyritic, and shows some grain size variation from fine-grained to coarse /medium-grained. Porphyritic variants occur near Dinsi, where larger grains of plagioclase are set in medium-grained matrix of pink perthite, plagioclase, quartz, epidote, ore and biotite. The rocks in the NW edge of the outcrops near the main road are subporphyritic, with 6-8 mm whitish phenocrysts. Some spheroidal weathering and solution pits occur at places, and there are local enclaves of xenoliths and autoliths. In the western part of the plain near the neck-shaped peneplained outcrops, the quartz monzonite contains local phenocrysts of plagioclase, reaching 1.5 cm in length, in a medium-grained quartzo-feldspathic groundmass that also contains hornblende and biotite.

The rocks range in colour from pinkish to grey. To the north of the Dinsi village, in a 70x150 m zone, they are turned orange to red. This place is highly fractured and contains at least three fracture zones. It forms a saddle due to rapid erosion associated with fractures and closely-spaced joints. In general, joints are rather closely-spaced in most of the quartz monzonite, which results in breaking of the rocks into small blocks that do not display pronounced spheroidal weathering.

The quartz monzonite are medium-grained, hypidiomorphic and, as said, locally porphyritic rocks of rather uniform mineral composition. They are essentially composed of perthite, plagioclase and quartz, at places in equal proportions, and in a few rocks inter-grown locally in bold graphic pattern. Biotite, opaque oxide, titanite, apatite, zircon and, in some, amphibole are the other primary minerals. The rocks are generally fresh or show a minor degree of alteration. Plagioclase is cloudy to saussuritized in some rocks, especially in the more calcic cores but, where fresh, it is of intermediate anorthite content (calcic oligoclase to andesine). In one rock sample, some of the plagioclase grains are surrounded by perthite rims. Biotite and blue-green or brown-yellow amphibole may show alteration to chlorite, titanite and epidote, and opaque oxide to titanite or leucoxene. However, not all the titanite is secondary. This composition is in conformity with chemical analysis (Table 1) of a sample of the rock carried out by Laghari (2004). The CIPW norms of the rocks are dominated by sodic plagioclase, followed by quartz, albite, minor hypersthene, etc.

2.4. *Dykes and veins of microgranite, aplite and rhyolite*

2.4.1. Silicic dykes

Both the porphyritic granite and quartz monzonite of Dinsi are intruded by many dykes and veins of microgranite/aplite. These range from less than a centimeter to tens of centimeters (rarely 1.5 m or more) in thickness and up to many meters in length (Figs. 3.1-3.2, 3.5). Most of these are fine-grained to fine medium-grained and subequigranular to sparingly porphyritic, but the aplites may be equiganular. Photomicrographs of three samples are shown in figures 4.3-4.5. A few of the dykes in the granite are described in the earlier section; some others are worthy of special mention.

1) A set of some closely spaced leucogranite/aplite dykes, a few cm thick and running parallel in the southern part of the quartz monzonite north of Dinsi, comprise quartz, plagioclase, pink K-feldspar, ore and amphibole.
2) At the junction of the Dinsi hill with the flat ground to the north occurs the largest of the granitic dykes. This E-W trending 3 m thick dyke of grey colour is modally similar to its host quartz monzonite and extends for about 130 m.
3) An 8 cm x 4 m felsic dyke of grey colour in the northwestern part of the eastern mound is very unusual. It is full of feldspar megacrysts (some over 7 cm long) in a granitic groundmass. The rock has associated crystals of black tourmaline more than a centimeter in length.
4) In the northeastern part of the area to the south of the small village, a set of dykes shows complex relations. The porphyritic granite here is cut by over a meter thick and tens of meters long pinkish quartz monzonite. Both these are cut by a dark quartz monzonite dyke full of inclusions. The dyke is medium-grained with up to 7 mm long phenocrysts of plagioclase in a matrix of two-feldspars, quartz, ore, chlorite, biotite and/or amphibole. Some 40 m to the southwest, there are a few meters across patchy intrusions of this rock in the porphyritic granite. These contain sugary autoloiths(?), meter size blocks of the host, and darker xenoliths that may be derived from the basement (Fig. 3.6). The margin of the granite in the northwestern edge of the area also contains a similar dyke full of xenoliths ranging from grey to black, fine- to medium-grained and mafic to dioritic in composition, as well as autoliths of a porphyritic microgranitoid.

A porphyritic quartz latite dyke near the xenolithic quartz monzonite dyke cuts not only the host porphyritic granite but also terminates a 1.5 m thick, medium-grained granitic dyke in it. The quartz latite is about 20 m long, and 15 m thick in the centre, where it shows a bend from N10°E trend in the northern part to N40°E in the southern part. Sequential relation of the rhyolite and the xenolithic quartz monzonite could not be deciphered because direct contact between the two was not observed. But from our experience of the Kharsar body (15-20 km north of Dinsi), it is likely that the quartz latite is younger (Jan et al., preparation). The rock is devoid of enclaves, contains veins with Fe-stains, many solution pits, and at least three sets of joints. Further south and west, there are small exposures of the quartz latite. One of these is cut by a centimeter thick aplite vein.

In conclusion, the small granitic dykes are of several generation and at places cross-cut each other. It appears that they were related to both the two main types of the granitic rocks, because some in the porphyritic granite are truncated by the quartz monzonite and are, thus, related to the former. Finally, there are local veins of quartz and epidote, as well as mafic dykes. Like the porphyritic granite, the quartz monzonite also contains enclaves of grey to greenish black and black colour and variable grain size, locally abundant, as near Dinsi. Many of these appear to belong to the basement, but some may be derived from the porphyritic granite, yet others may be autoliths. Some of the xenoliths show baking effect and are reddish on margins. The autoliths are of granitic mode, and consist of pink feldspar, milky feldspar, quartz and amphibole. Locally, the xenoliths contain large grains (up to 6 mm) of pink feldspar, possibly resulting from metasomatism.

2.4.1a. Petrographic features of the silicic dykes:

These dykes in both the porphyritic granite and quartz monzonite are fine- to medium grained, hypidiomorphic to allotriomorphic and subequigranular to porphyritic. Phenocrysts are small but, in rare cases, reach 3.5 mm or more in length. The rocks range from granite to granodiorite and quartz monzonite in composition, and are essentially composed of quartz and (meso)perthite, with or without plagioclase, depending upon the composition of the rock. Many are leucocratic, with less than four volume percent of mafic minerals. These include opaque oxides, in some biotite and/or amphibole, and rarely zircon, titanite and tourmaline. In one rock, perthite seems to have exsolved grains of quartz, in addition to plagioclase which may reach 1 mm in size. The amphibole shows variation in pleochroic colours, depending upon the degree of alteration. The rocks may be mildly altered, with cloudy plagioclase, and secondary chlorite, titanite, epidote and calcite in some. Fe staining, in brown to pink and red colours, is not uncommon. The quartz latite dyke described above is composed of phenocrysts of plagioclase, quartz and perthite in a very fine-grained crystalline, quartzo-feldspathic matrix that also contains small quantities of opaque oxide, greenish blue (sodic?) amphibole, biotite, and titanite.

2.4.2. Mixed zone

This small area is very complicated, and made up of a range of lithologies. Some rocks are greyish coloured granitoids that are fine-grained to fine medium-grained, and subequigranular to porphyritic. These comprise perthite, quartz, plagioclase, amphibole and/or biotite, opaque oxide, with or without titanite, apatite and zircon, and are quartz monzonite. One rock may also have traces of astrophyllite. Some of the rocks contain graphic and myrmekitic intergrowths of quartz and feldspar. The amphibole is pleochroic in shades of green to (pinkish) brown. The rocks are fresh, but the amphibole and biotite may show local alteration to chlorite, and the opaque oxide to leucoxene. These are cut by a pegmatite vein (<30 cm thick and 4 m long) that contains up to 6 cm long ash grey feldspar crystals and quartz. Another 4 m long pegmatite contains pink feldspar reaching 11x7 cm in size. A 4 m long, medium-grained granophyre dyke in one of the porphyritic dykes consists of perthite, quartz, amphibole, opaque oxide and biotite.

The granophyre dyke is cut by a 10-30 cm thick darker and coarser dyke, which is locally in networks. This dyke is compositionally granite, comprising perthite, quartz, opaque oxide, and small amounts of amphibole, plagioclase, titanite and epidote. It is medium-grained, and hypidiomorphic, but locally granophyric. Some of the plagioclase grains surround the perthite in rapakivi fashion. Most of the amphibole is green, but there are needles of a violet to greenish blue amphibole shot through the biotite. This granite contains meter long xenoliths of a fine-grained, sugary and greenish rock that does not seem to belong to the basement. The granite and granophyres are the predominant rock types in the northern part of the mixed zone. The granite dyke looks similar to the main porphyritc granite, and such rocks cover much of the mound to the north.

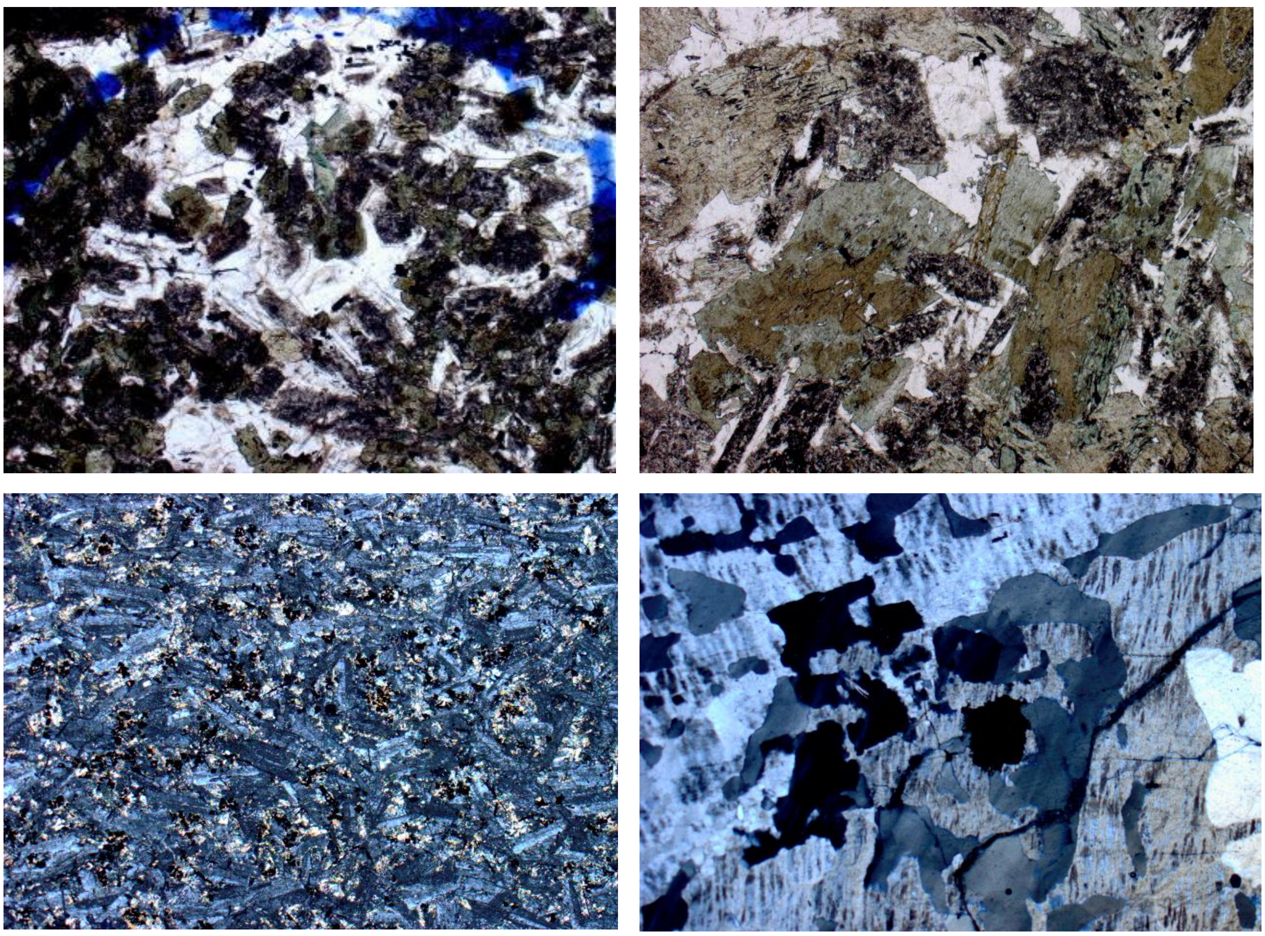
2.5. Mafic dykes

The two main granitic rocks and the basement are intruded by dykes of mafic rocks (Fig. 3.7-3.8). Some are dark grey to black, but the coarser ones look dioritic. The dykes are generally tens of centimeters to a couple of meters thick and some meters to 100 m in length, but the largest one in the eastern mound is half a kilometer long and 2.5-3 m thick. This is a fine-grained porphyritic rock, with chilled margins looking like chert. The dyke is highly fractured, but maintains a constant thickness and trends N65-70ºW, with 65ºN dip. It contains spots of, and fractures filled with, epidote and pink to white material. The spots are up to 1 cm and some have epidote rich interior and pink carbonate margins. There also are smaller mafic dykes in this area, up to 100 m in length, some parallel to and some across the trend of the main dyke.

The mafic dykes are fine-grained to (rarely) medium-grained and many have chilled margins. They are frequently porphyritic, with plagioclase phenocrysts up to a centimeter long in some cases. In the northern part of the area, one N75ºW trending mafic dyke in the quartz monzonite contains up to 4 cm long plagioclase phenocrysts. A 200 m long and 3 m thick dyke in the western part of the area (shown on map) contains up to 1 cm long, randomly distributed plagioclase phenocrysts. However, in the outer 6-12 cm chilled margins the phenocrysts are shorter and show some alignment. On the western side in this body, or another dyke of similar composition adjacent to it, the phenocrysts get smaller in size (1-2 mm) even in the interior of the body.

Many, but not all dykes are sheet-like, and some are disrupted or segmented by faults. In the very northern part of the area, a dioritic dyke containing plagioclase and hornblende extends N75°W for more than 150 m. It is dark greenish, fine- to medium-grained, porphyritic, and contains solution pits. To its southeast, a medium-grained dioritic dyke is cut by a 15 cm x 8 m fine-grained doleritic one.

The dykes can be classified mineralogically into two types: hornblende-bearing and pyroxene bearing (Fig. 4.6-4.8), as elsewhere in the Nagar Parkar complex (Laghari et al., 2013). Based on field relations, the former appear to be older than the latter. The *hornblende-bearing* rocks are made up of plagioclase, hornblendic amphibole, opaque oxide, in some biotite, and secondary chlorite, epidote, titanite and rare calcite. Plagioclase (calcic andesine to labradorite) is commonly zoned and occurs as phenocrysts and groundmass; in some the amphibole may also form phenocrysts. Some of the rocks show partial to complete alteration, resulting in development of saussurite/epidoe after plagioclase, chlorite after amphibole and leucoxene/titanite after skeletal ilmenite. In one dyke there are pseudomorphs of fine-grained serpentine looking material. In another, the plagioclase phenocrysts do not appear to be in equilibrium with the matrix that embays or cuts them.



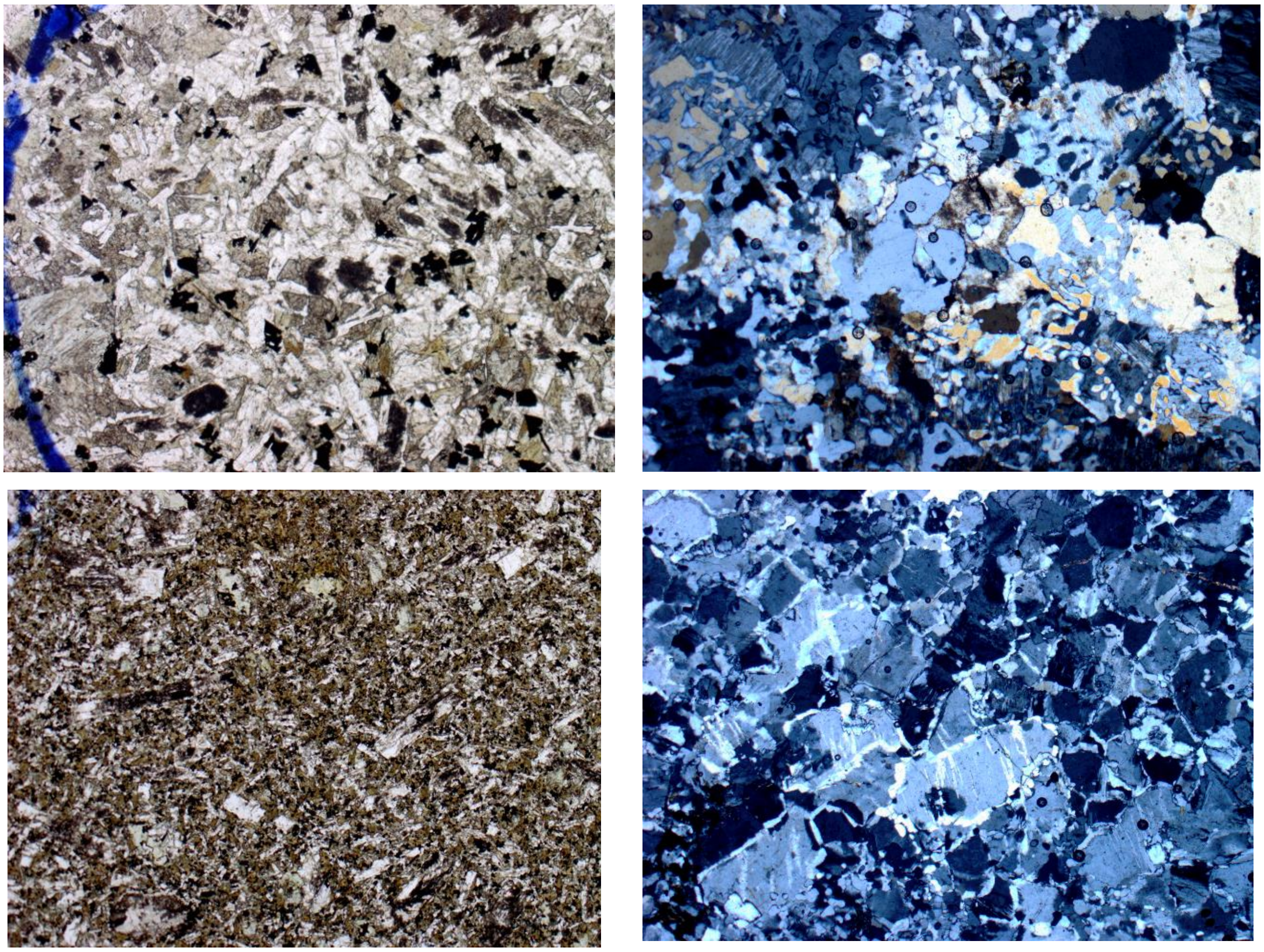


Fig. 4. Photomicrographs of the rocks of Dinsi area. In all eight, length of the photograph is 4.6 mm. Clockwise from top left: 1) Undeformed quartz diorite from sheared western basement block. Plagioclase is saussuritized, amphibole (centre and bottom) is zoned, quartz is also clear and mostly in spaces between these minerals and opaque oxide granules. Arc in the upper half is pen mark, 2) Undeformed quartz diorite from the eastern basement body. Hornblendic amphibole (centre) is abundant and replaced by green amphibole (actinolite?) and chlorite (top left). Plagioclase (dark) is saussuritized, but has clear margins (of metamorphic albite?). Opaque oxide granules are scattered and an elongated titanite grain occurs near the centre. White areas are quartz, except those around saussurite, 3) Dyke in porphyritic granite in the northern part of the eastern mound. It essentially comprises perthite and quartz, with traces of opaque oxide and amphibole. The dark grains in the centre are extinct quartz. Lower right shows an iron oxide/hydroxide filled fracture. The outcrop contains >7 cm long feldspar megacrysts and 1 cm long tourmaline, 4) Leuco-granophyre dyke in the mixed zone, comprising perthite, quartz, and minor plagioclase (twinned grain in upper right), 5) Leucogranite dyke in granite of the mixed zone. The dyke consists of perthite, quartz, and, locally, their granophyric intergrowth, 6) Hornblende dolerite from the western part of the quartz monzonite, not far from No. 7. Plagioclase phenocrysts (some cloudy in the centres) lie in a very fine-grained matrix of plagioclase laths, brown amphibole (grey), and opaque oxide, 7) Pyroxene dolerite dyke in western part of the quartz monzonite (shown in Fig. 2). Plagioclase is mostly clear but locally cloudy (centre), augite (along with tiny grains of amphibole) is grey, and opaque oxide is black and partly skeletal. The arc in the left is pen mark. The outcrop contains plagioclase phenocryst up to 7 mm in length. This dyke occurs within a few meters of the hornblende-bearing dyke 6), and 8) Pyroxene dolerite in southwestern part of the northern basement. Plagioclase (white and grey) shows some flow alignment. Clinopyroxene, opaque oxide (skeletal and partly altered to leucoxene/titanite, and biotite are interstitial. The rock contains up to 6 mm long plagioclase phenocrysts.

The longest dyke in the eastern body also belongs to this type, but it shows a considerably higher degree of alteration. It is subporphyritic, very fine-grained, and composed of plagioclase, abundant epidote, biotite, chlorite, ilmenite and calcite. Some plagioclase and opaque grains are larger than the rest. The plagioclase is not strongly epidotized, so the presence of the epidote pools is confusing. Biotite occurs mostly in independent grains, but some are associated with the ore. It occurs in tiny grains only locally chloritized. The chlorite also replaces completely some mineral, possibly amphibole, which formed larger grains than the biotite. A sample collected from a loose block in the vicinity of the dyke contains more chlorite and calcite and less epidote. It also has elongated pseudomorphs, possibly again after amphibole, comprising chlorite and some epidote and calcite. The rock contains up to a centimeter rounded to ellipsoidal amygdule-like masses. One of these, measuring 6 mm across, comprises a 3 mm wide core of coarser calcite, followed outward by shells of 1) calcite and epidote with or without opaque oxide, 2) finer grained epidote, and 3) coarser epidote and calcite.

The long dyke is accompanied by a smaller dyke of rhyolite, like the association in the Kharsar body (Jan et al., in preparation). The rhyolitic rock is porphyritic and fine-grained to spherulitic in texture. It shows banding that is defined under the microscope by variation in the amount of opaque granules. The phenocrysts in the rhyolite consist of perthite, quartz and plagioclase (?). They are euhedral to subhedral, but a few are resorbed by the matrix. The latter comprises quartzo-feldspathic material, ore, and secondary epidote, leucoxene and white mica. Spherules are abundant and comprise quartz-feldspar intergrowth. Some spherules have grown around perthite phenocrysts, but quartz phenocrysts also may be surrounded by the quartz-feldspar intergrowth.

The pyroxene-bearing dykes are generally fine-grained and porphyritic to subequigranular. The phenocrysts are mostly plagioclase. The dykes comprise plagioclase, augite, opaque oxide, and secondary chlorite, biotite and, in some, calcite. Of the six thin sections of these rocks that we studied, only one contains small amounts of brown primary amphibole and green secondary amphibole. A characteristic feature of these rocks is that the clinopyroxene is lilac in colour, possibly due to the presence of titanium. Biotite is reddish brown, and opaque oxide (ilmenite) tends to be skeletal. The plagioclase (fresh to cloudy and saussurritized) occurs as phenocrysts (commonly zoned), but also is the most important component in the groundmass. It is particularly abundant in a rock that contains no more than 25 volume percent mafic minerals. The smaller amount of mafic minerals than what is typical of mafic rocks suggests that the pyroxene-bearing dyke may be compositionally equivalent to hawaiite/mugerite (for definitions, see Le Maitre et al., 2002).

A 15 cm thick and 8 m long dyke in dioritic basement in the north is a little different from the rest of the dykes. This is a fine-grained rock showing spinifex texture. It consists of plagioclase, brown to orange devitrified glass and ilmenite. It contains local ammygdules comprising chlorite, with or without calcite and red iron oxide/hydroxide. A N5ºW trending, 25x1.5 m dyke to its south is segmented by two E-W trending faults. This comprises a mat of strongly zoned and fresh labradorie-andesine, with interstices comprising secondary reddish brown material and calcite that have completely replaced some mineral, and small amounts of hydroxidized opaque mineral, chlorite/amphibole, and biotite.

3. Summary and conclusions

Geological mapping and detailed petrography suggest that the Dinsi hill and its adjacent eastern mound are principally occupied by two types of granitic rocks. Much of the area is covered by a medium-grained porphyritic granite containing phenocrysts of feldspar in a groundmass of perthite and quartz, with smaller amount of plagioclase, and minor amounts of opaque oxide, biotite and/or amphibole, and titanite. This was followed by the emplacement of quartz monzonite which covers the western part of the outcrop area. The quartz monzonite comprises perthite, calcic oligoclase/andesine, quartz, and minor amount of mafic minerals similar to the porphyritic granite. Some samples contain oligoclase mantles around perthite (rapakivi texture) or vice versa. Both the rock-types turn pink due to iron-staining, particularly where sheared.

Within these granitoids occur local bodies of the basement comprising dark, fine-grained doleritic to medium-grained (quartz) dioritic rocks. The basement exposures show brittle deformation and are commonly fractured, but some parts are undeformed. The rocks are composed of plagioclase, hornblende, opaque oxide, biotite, with or without quartz. They are variably altered, and contain second generation of actinolite, chlorite, epidote (in some abundant), titanite and leucoxene, suggesting low-grade metamorphic overprinting before the emplacement of the granitic intrusions.

The granite bodies contain silicic dyke showing a range of textures and composition. These are fine-grained to fine medium-grained and porphyritic, but some are aphyric and subequigranular to equigranular. Rare varieties include those with coarse megacrysts, and simple pegmatites. Most of these are granitic in composition, but they range from quartz monzonite to granodiorite, leucogranite, aplite and rhyolite. Field relations suggest that these dykes are related to the two principal bodies of granites; those related to the earlier porphyritic granite are truncated by the younger quartz monzonite. But at places they comprise several phases showing complex relations, as in the mixed zone and in the northeastern edge of the peneplained area. The final phases of magmatism in the area are recorded by the occurrence of mafic dykes, and rare silicic dykes that may be contemporaneous with, or even post-date, the mafic dykes. One of mafic dykes is over 500 m long and 3 m thick. The mafic rocks can be divided into two broader types, one of which contains hornblende and the other clinopyroxene as characteristic primary mafic mineral. They are commonly fine-grained and aphyric to porphyritic.

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