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Geology, Petrography and Classification of Commercial Granites of Jalore and Barmer Districts, Rajasthan

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ABSTRACT
Granite is an important dimensional and decorative stone. Being more resistant to wear and tear as well as weathering, granite is most sought-after stone to be used as building as well as decorative stone. Rajasthan is richly endowed with large reserves of different varieties of granites spread over in 23 districts of the state. Jalore and Barmer districts are the leading producer of commercial granites in the state. The granites in these districts belong to Neo-proterozoic age. Granites of the area show wide variation in colour, texture and mineralogy. The essential minerals of the granites of the area include potash feldspar (orthoclase or microcline), quartz and plagioclase. Accessory minerals are hornblende, reibeckite, biotite, aegirine, muscovite, apatite, zircon and opaques. Secondary minerals are chlorite and sericite. The mineralogy of the granites of the area reveals that granites of both the categories i.e. subsolvus and hypersolvus are present. However, majority of the granites are subsolvus i.e. two feldspar granites. The QAP diagram based on IUGS classification suggest that the all of the commercial granites of the area are not normal granites. Out of 27 granites, 12 granites are "Alkali – Feldspar Granites", 11 are "Syeno – Granites", 2 are "Monzo Granite" and one each is "Alkali – Feldspar Quartz Syenite" and "Granodiorite" respectively.
Keywords: Petrography, Classification, Commercial granites

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INTRODUCTION

Granite is an important dimensional and decorative stone. Technically granite refers to a light-coloured granulose plutonic rock composed essentially of potash felspars and quartz with minor amount of plagioclase and mafic minerals, such as, biotite, hornblende, pyroxene, iron oxides, etc. However, in commercial phrasing, the term granite has become synonymous with all those crystalline rocks which have pleasing colours, strength to bear the processes of quarrying and cutting and polishing and which are used commonly for decorative purposes. Being more resistant to wear and tear as well as weathering, granite is most sought-after stone to be used as building as well as decorative stone[2].

Commercial Granite is defined by the American Society for Testing and Materials [1] as a "visibly granular, igneous rock generally ranging in color from pink to light or dark grey, and consisting mostly of quartz and feldspars, accompanied by one or more dark minerals". According to Walle and Heldal [6], any igneous rock closely related to granite, granodiorite, porphyry, gabbro and dolerite and metamorphic rocks such as gneiss are considered as 'granite'. As per the definition given in Granite Conservation and Development Rules, 1999 [15] "Granite mean dolerites, granite gneiss, migmatites, gabbros, anorthosite, rhyolites, syenites, charnockites and any other igneous and metamorphic rock types which are (i) Amenable to be recovered as dimensional stone, (ii) Capable of taking polish and (iii) Commercially exploitable".

MATERIAL AND METHODS

Geological Setup of Granite Deposits :

Rajasthan is richly endowed with large reserves of different varieties of granites spread over in 23 districts of the state. More than 200 localities of granite have been identified so far. Important production centers are mainly spread in the districts of Jalore, Barmer, Pali, Sirohi, Barmer, Ajmer, Jaisalmer, Jhunjhunu and Jodhpur [5, 10]. Rajasthan experienced large number of scattered granitic emplacements different geologic time i.e. from Archean to Neo-Proterozoic age. However, majority of commercial granites belong to Meso to Neo Proterozoic age. Granites of the state are having diverse mineralogy, pertochemistry and emplacement history. Broadly the granites of the state can be sub-divided into five categories [7]:

1. Archean Granites
2. Paleo-Proterozoic Granites
3. Meso-Proterozoic Granites
4. Post – Delhi Granites
5. Neo-Proterozoic Granites

The commercial granites of Jalore and Barmer districts are to belong to Neo-proterozoic granites. These granites are considered as a part of Malani Igneous Province. There are 15 granitic plutons in the Malani Igneous Province. The granites of Malani Igneous Province are broadly classified into three types [4]:

- Jalore Granites (Jalore district)
- Siwana Granites (Barmer district)
- Malani Granites (Barmer district)

Bhushan [3] proposed the magmatic genealogy of Malani Igneous Province as under:

Marwar Supergroup
------*Unconformity*----------
Phase – III Dykes (Acid to basic dykes)
Phase – II Plutons and Ring Dykes (**Jalore, Siwana and other Granites**)
Phase – I Volcanics (Rhyolites, dacites, basalts etc.)
-------*Unconformity*----------
Basement Rocks (Delhi Supergroup)

There are seven plutons of Jalore granites, covering an area of 17000 square kms. The largest pluton is at Jalore and the smallest is located at Salawas. Hill ranges composed of Jalore granites are seen around Jalore city. The Jalore Fort is located on this granite. The granite outcrops extend up to Bishangarh in North and Kankhi in NW. In South, the granites are seen up to Bhinmal. An intrusive contact with rhyolites can be seen at few places. There are six plutons of Siwana granites, covering an area of about 2000 square kms. There are four main localities of Siwana granites i.e. Siwana, Jasai, Mungeria and Baisala. At Siwana the granites occur as discontinuous elliptical ring shaped structure. At other three places the granites occur as curvilinear intrusions on either sides of volcanics. Small sized scattered bosses of Malani granites occur at Balera, Lunu and Suwala in Barmer district.

RESULT AND DISCUSSION

During the course of present study, intensive field visits were undertaken at different plutons and mines of Jalore and Barmer districts to study the nature of granite emplacement, field relationship between different granitic rocks and with other igneous rocks, textural and structural variations and collection of representative samples for petrological studies. Following observations were made with respect to geology, nature and field relationship, textural and structural characters of granitic rocks of the study area:

- The granitic rocks in the area are occurring as isolated plutons of variable in shape and size i.e. in form of stocks and boss (Photograph 1).
- The basement rocks are generally not exposed in the area however, at many places there is a sharp contact with Malani rhyolites, indicating that most of the granitic rocks are emplaced during post-Malani phase.

- At many places in Jalore area the intrusions of basaltic dykes are seen within the granitic rocks and showing chilling effect up to 5 meters both sides (Photograph 2).
- Granites of the area show wide variation in colour and texture. Generally each pluton has different type of colour and texture. Colours of granites are grayish white, light pink, dark pink, reddish brown, light yellow, yellowish brown, light green, green, grayish green etc. Similarly, the texture varies from fine to very coarse grained and equigranular to inequigranular. At places gradational contact between fine to medium/coarse grained granites is also seen (Photograph 3).
- Like texture, gradational contact between light and dark colours within the granites is commonly observed nature. Only at one place i.e. Devda in Jalore there is sharp contact between yellowish (Golden Pearl) and light green (Desert Green) variety (Photograph 4).
- At many places xenoliths of rhyolitic and mafic volcanics have been observed within the granites.
- Granites of the area shows various types of weathering features like exfoliation, spheroidal, pan hole, tuffoni etc. (Photograph 5).
- There is no visible sign of deformation in the granitic rocks of the area.
- Jointing is common structural element present in the granites. Two to three sets of jointing has been reported (vertical, horizontal and inclined). The jointing in these rocks plays a very important role in the formation of blocks for commercial use.
- At places the granitic rocks are fractured causing the deterioration in the commercial value (Photograph 6).

Petrography :

Petrography is the science of describing and classifying the rocks. A petrographic description includes identification of minerals, textural relation between grains and presence of structures etc. This not only helps in giving name of the rock but also helps in classification on the basis of volume percentage of various minerals (Philpotts, 1989). During the present course of work intensive field visits were undertaken to learn the field relationship and collection of representative samples for petrological and physico-mechanical studies. The random sampling was done on the basis of variation in colour, texture and field relationship. Total 28 samples of granites and associated volcanic rocks (rhyolites) were collected for the petrographic studies. Granitic rocks of the study area have variety in their textural and petrographic characteristics. Brief descriptions of the petrography of the rocks are given as under:

Texture and Structure: Commercial granites of the area exhibit both equigranular and inequigranular texture and varying in size from fine to very coarse grained (pegmatitic). However, majority of granites are medium to coarse grained and showing characteristic hypidiomorphic texture (Photographs 7 and 8). Few granites of the area do have structures like:

(i) Rapakivi structure: Here the large crystal of potash feldspar are rimmed by the plagioclase feldspar (Vorma, 1976). In one sample (JB-9) the rapakivi structure has been observed (Photograph 9).

(ii) Myrmekitic intergrowth: Myrmekite is an intergrowth of vermicular quartz and sodic plagioclase which occurs near the rim of a plagioclase crystal (Turner and Verhoogen, 1960). Few granite samples (JB-2, JB-5, JB-25, JB-26) of the area show the myrmekitic micro-structure (Photograph 10).

(iii) Graphic intergrowth: Graphic and micrographic structures are intergrowths of quartz in K-feldspar host (mostly orthoclase or microcline), which can be form (a) by replacement, (b) simultaneous crystallization at the eutectic point, or (c) crystallization from super-cooled liquids (Turner and Verhoogen, 1960, Best, 1986). Graphic intergrowth is observed in many granite samples (JB-2, JB-20, JB-21, JB-25, JB-26) of the area (Photograph 11).

Mineral Composition: The essential minerals of the granites of the area include potash feldspar (orthoclase or microcline), quartz and plagioclase. Accessory minerals are hornblende, reibeckite, biotite, aegirine, muscovite, apatite, zircon and opaques. Secondary minerals are chlorite and sericite.

Potash Feldspar: Potash feldspar is the dominant mineral phase in most of the granites of the area. The granites of the area are having variation in the size and type of potash feldspar i.e. few granites are having microcline while other are having orthoclase

(Photograph 12). However, perthic intergrowth is common in majority of the granites. The Exsolution lamellae of albite are well visualized with in the perthite. The perthites are of lamellar, string and braided type (Photograph 13). Alteration along grain boundaries is very common in these grains. Partial to complete sericitization was observed in the grains (Photograph 14).

Quartz : Quartz grains are variable in size and invariably anhedral with serrated margin. Quartz are unaltered and in few samples grains of strained quartz are also seen.

Plagioclase : In many granite samples plagioclase grains are also present as tabular laths. These grains show well marked albite twinning. They are comparatively less altered than the potash feldspar. At places zoned plagioclase are also present (Photograph 15).

Amphiboles : Reibeckite and hornblende are common amphiboles present in these granites. Both the minerals are subhedral and of variable size. They show distinct two sets of cleavages and pleochroism. Alteration is common in these minerals (Photograph 16).

Biotite : They are present as accessory mineral and showing well marked pleochroism. Biotite laths are having inclusions of apatite and zircon (Photograph 17).

Other minerals : In few granites muscovite, apatite, zircon, aegirine, iron oxides are present as accessory minerals (Photograph 18).

Categorization of Granites of Study Area:

A classification of granitic rocks based on the nature of the feldspar is proposed. The classification has two major divisions: (1) subsolvus, and (2) hypersolvus (Tuttle and Brown, 1958). In hypersolvus granites, crystallization at relatively low water pressures results in the formation of a single feldspar as opposed to subsolvus granites in which two distinct types of feldspar are present. The distinctive character of feldspar in hypersolvus granite is to present exsolution textures. That is because the high temperature feldspar was ternary (i.e. contained comparable parts of the Ca, Na, K components) and was later dissociated during the cooling phase into K-rich parts and Na-Ca-rich parts, within the initial crystal. The resulting texture is referred to as perthitic. In subsolvus or two feldspar granites crystallization occurs at high water pressures resulting in the formation of two types of feldspar. In the hypersolvus rocks all the soda feldspar is or was in solid solution in the potash feldspar whereas in the subsolvus rocks the plagioclase is present as discrete grains.

The mineralogy of the granites of the area reveals that granites of both the categories i.e. subsolvus and hypersolvus are present. However, majority of the granites are subsolvus i.e. two feldspar granites. Table 1 gives the categorization of the granites on the basis of feldspar.

Table 1: Categorization of the granites of the study area on the basis of feldspar

Hypersolvus Granites	Subsolvus Granites
JB-3 Rakhi Green, JB-4 Mokalsar Green, JB-7 Green Granite, JB-8 Golden Pearl, JB-13 Desert Green, JB-18 Merry Gold, JB-20 Mountain Green, JB- 28 Imperial Pink.	JB-2 Bala Flower, JB-5 Rosy Pink, (Medium), JB-6 Rosy Pink (Coarse), JB-9 Copper Silk, JB-10 Z. Brown, JB-11 S.R. Red, JB-12 Classic White, JB-14 Black Granite, JB-15 Chima Pink, JB – 16 Jeeraval White, JB-17 Royal Touch, JB-19 Sunrise Yellow, JB-21 Rosy pink (Dark), JB-22 Baltic Blue, JB-23 P.white, JB-24 Urban Classic, JB-25 Bala Flower, JB-26 Bala Flower, JB-27 Kharda Red.

Modal Analysis and Classification

Modal analysis includes the determination of actual mineral content in a rock, measured in volume per cent. The International Union of Geological Sciences (IUGS) Sub-commission on the Systematics of Igneous Rocks suggested the use of the modal composition for nomenclature and classification of igneous rocks. A plutonic rock may be classified mineralogically based on the actual proportion of the various minerals of which it is composed (called the mode). For the granitic rocks the modal analysis requires the determination of the relative abundance of three minerals i.e. quartz, alkali feldspars and plagioclase. A modal classification is based on arbitrarily defined boundaries between classes on a ternary diagram [11, 8].

In the present study the determination of the mineral composition and their relative proportions in the various types of granitic rock exposed in the area were carried out to differentiate and classify the granite types on the basis of their mineralogy. Table 2 gives the modal analysis of 27 commercial granites of the study area. Table 3 gives the modal percentage of quartz (Q), alkali feldspar (A) and plagioclase feldspar (P) of these granites samples for classification and nomenclature as per the IUGS classification.

From the Table 2 it has been found that except in the Black granite and Platinum White granite, the alkali feldspar is the dominating mineral in most of the granitic rocks of the area. The concentration of alkali feldspar is ranges from 6.3% to 73.64%. Quartz is another leading mineral in these rocks which ranges from 17.43% to as high as 38.03%. Plagioclase is also present in majority of granites but the concentration is highly variable. Few granites are devoid of plagioclase while in other the concentration ranges from 1.4% to 43.12%. Amphiboles and mica are invariably present in these granites in minor concentration.

For the petrological classification and nomenclature as per IUGS classification scheme, the modal percentage of quartz (Q), alkali feldspar (A) and plagioclase (P) of these granites were used and recalculated to 100%. The QAP diagram (Figure 1) based on IUGS classification suggest that the all of the commercial granites of the area are not normal granites. Out of 27 granites 12 granites are “Alkali – Feldspar Granites”, 11 are “Syeno – Granites”, 2 are “Monzo Granite” and one each is “Alkali – Feldspar Quartz Syenite” and “Granodiorite” respectively. The classification and nomenclature of the commercial granites of the area on the basis of IUGS – QAP diagram is given in Table 4.

Table 2 : Modal analysis of commercial granites of Jalore and Barmer districts

Sample No	Commercial Name	K-F%	Q%	Plag%	Amp%	Pyr%	Mica%	Other%
JB – 2	Bala Flower	31.43	62.35	3.25	1.25	0	1.32	0.4
JB – 3	Rakhi Green	18.94	73.64	0	6.8	0	0.6	0.1
JB – 4	Mokalsar Green	17.43	73.01	0	8.36	0	0	1.2
JB – 5	Rosy Pink (Fine)	28.4	64.22	4.23	1.6	0	1.2	0.35
JB – 6	Rosy Pink (Coarse)	26.2	62.0	8.7	1.2	0	1.7	0.2
JB – 7	Green Granite	23.5	62.9	0	4.2	2.4	6.8	0.2
JB – 8	Golden Pearl	21.2	71.5	0	4.9	0	0	0
JB – 9	Copper Silk	33.5	38.5	18.9	4.3	0	3.5	1.3
JB - 10	Z.Brown	22.5	64.7	1.4	4.2	3.2	2.8	1.2
JB - 11	S.R. Red	24.4	66.8	4.7	2.3	0	1.8	0
JB - 12	Classic White	20.5	53.97	18.9	1.23	0	5.1	0.3
JB - 13	Desert Green	21.23	66.82	0	10.4	0	1.34	0.21
JB - 14	Black granite	19.28	6.3	43.12	15.8	0	12.9	2.6
JB - 15	Chima Pink	24.26	38.5	24.27	7.97	0	4.25	0.75
JB - 16	Jeeraval White	25.4	48.35	18.3	2.5	0	4.8	0.65
JB - 17	Royal Touch	29.7	56.88	4.7	3.8	0	4.2	0.72
JB - 18	Merry Gold	32.36	59.39	0	4.9	0	2.6	0.75
JB - 19	Sunrise Yellow	28.4	42.05	18.9	4.3	0	5.7	0.65
JB - 20	Mountain Green	38.03	53.47	0	3.8	0	4.7	0
JB - 21	Rosy Pink (Dark)	26.12	48.58	12.8	4.9	0	6.3	1.3
JB - 22	Baltic Blue	29.31	45.05	6.12	3.1	0	16.1	0.32
JB - 23	Platinum White	35.08	30.5	19.01	2.5	0	11.5	1.4
JB - 24	Urban Classic	34.15	42.71	17.11	0	0	6.03	0
JB - 25	Bala Flower	28.05	54.37	7.15	3.1	0	5.3	2.03
JB - 26	Bala Flower	31.1	51.1	6.5	4.2	0	5.6	1.5
JB - 27	Kharda Red	34.05	40	17.15	3.5	0	4.1	1.2
JB – 28	Imperial Pink	31.38	58.21	0	4.85	0	4.35	1.10

K-F = Potash Feldspar, Q = Quartz, Plag = Plagioclase, Amp = Amphiboles, Pyr = Pyroxene

Table 3 : Modal percentage of commercial granites

Sample No.	Commercial name	Q %	A %	P %
JB - 2	Bala Flower	32.39	64.25	3.34
JB - 3	Rakhi Green	20.45	79.54	0
JB – 4	Mokalsar Green	19.27	80.72	0
JB - 5	Rosy Pink (Fine)	29.32	66.3	4.36
JB - 6	Rosy Pink (Coarse)	27.03	63.98	8.97
JB - 7	Green Granite	27.1	72.8	0
JB - 8	Golden Pearl	22.86	77.13	0
JB – 9	Copper Silk	36.85	42.35	20.79
JB - 10	Z. Brown	25.39	73.02	1.58
JB - 11	S.R. Red	25.44	69.65	4.9
JB - 12	Classic White	21.95	57.8	20.24
JB - 13	Desert Green	24.11	75.88	0
JB - 14	Black granite	28.06	9.17	62.76
JB - 15	Chima Pink	27.87	44.23	27.88
JB - 16	Jeeraval white	27.59	52.52	19.88
JB - 17	Royal Touch	32.53	62.31	5.14
JB - 18	Merry Gold	35.26	64.73	0
JB - 19	Sunrise Yellow	31.78	47.06	21.15
JB – 20	Mountain Green	41.56	58.43	0
JB – 21	Rosy Pink (Dark)	29.85	55.52	14.62
JB – 22	Baltic Blue	36.41	55.97	7.6
JB – 23	P. White	41.48	36.06	22.47
JB – 24	Urban Classic	36.34	45.46	18.2
JB – 25	Bala Flower	31.31	60.7	7.98
JB – 26	Bala Flower	35.06	57.6	7.3
JB – 27	Kharda Red	37.33	43.85	18.8
JB-28	Imperial Pink	35.02	64.97	0

Q = Quartz, A = Alkali feldspar, P = Plagioclase

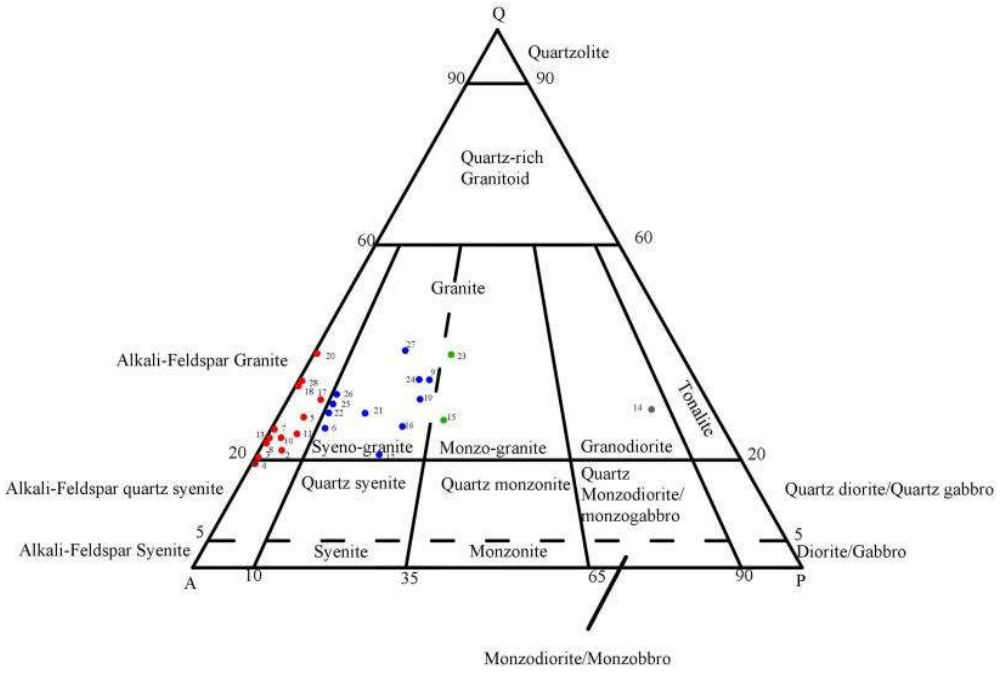
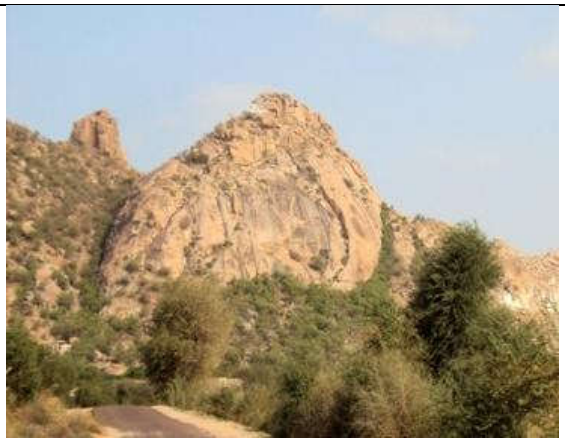
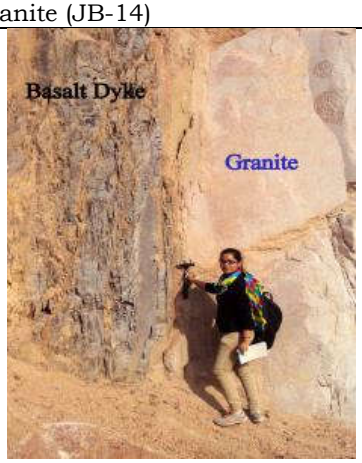
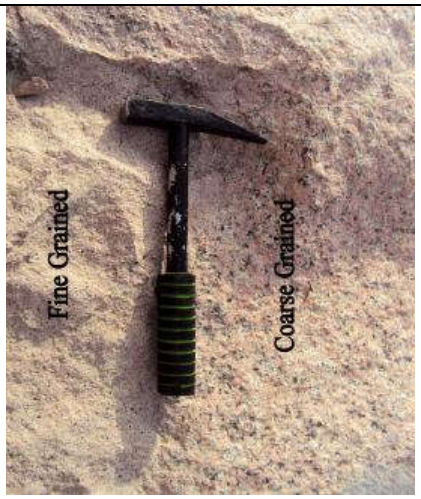
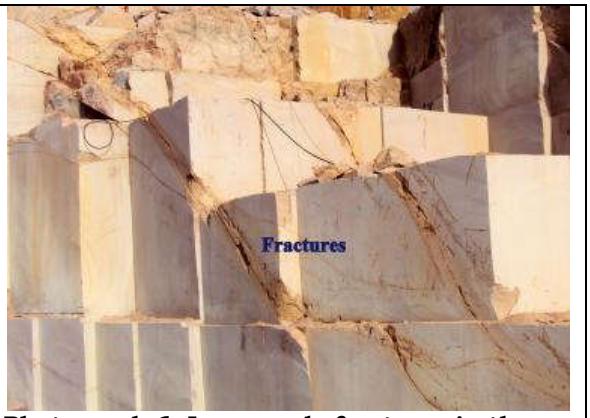


Figure 1 : IUGS – QAP diagram for the commercial granites of the area

Table 4: Classification and nomenclature of the commercial granites of the study area

Nomenclature and Classification based on IUGC – QAP	Commercial Granite of the Class
Alkali – Feldspar Granite	Bala Flower (JB-2), Rakhi Green (JB-3), Rosy Pink Fine (JB-5), Green Granite (JB-7), Golden Pearl (JB-8), Z. Brown (JB-10), S.R. Red (JB-11), Desert Green (JB-13), Royal Touch (JB-17), Merry Gold (JB-18), Mountain Green (JB-20), Imperial Pink (JB-28)
Syeno - Granite	Rosy Pink Coarse (JB-6), Copper Silk (JB-9), Classic White (JB-12), Jeeraval White (JB-16, Sunrise Yellow (JB-19), Rosy Pink Dark (JB-21), Baltic Blue (JB-22), Bala Flower (Jb-25), Bala Flower (JB-26), Kharda Red (JB-27)
Monzo – Granite	Chima Pink (JB-15), P. White (JB-23)
Alkali – Feldspar – Quartz Syenite	Mokalsar Green (JB-4)
Granodiorite	Black Granite (JB-14)
 **Photograph 1: Granite exposure in Jalore area**	 **Photograph 2: Vertical basaltic dyke within the granitic rocks at Village Dhawla, Jaolre**
 **Photograph 3: Gradational contact between fine and medium grained granite (Fine at Left and Medium at Right)**	 **Photograph 4: Contact between Desert Green and Golden Pearl granite, Devda village, Jalore**

Photograph 5: Weathering in granites (Tuffoni caves)

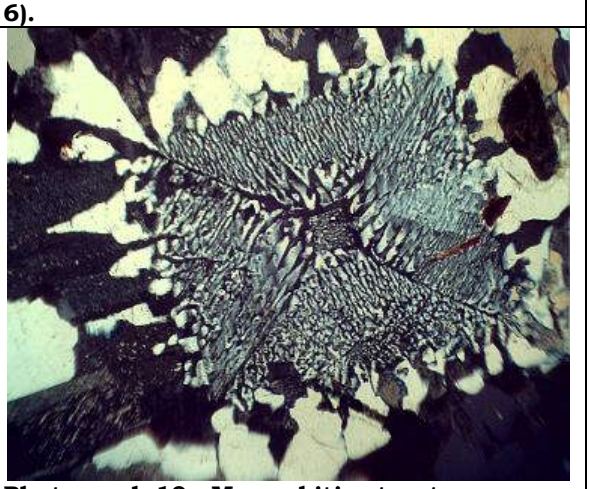


Photograph 6: Large scale fractures in the granites causing difficulty in block formation

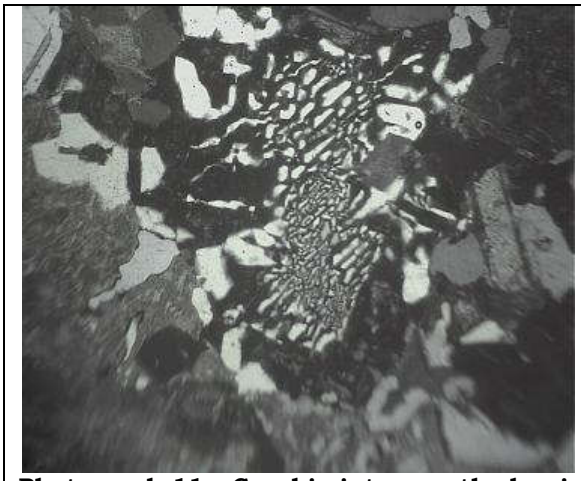
Photograph 7: Showing the Fine grained, equigranular variety of granite (Sample JB-5).

Photograph 8: Showing the Coarse grained, equigranular variety of granite (Sample JB-6).

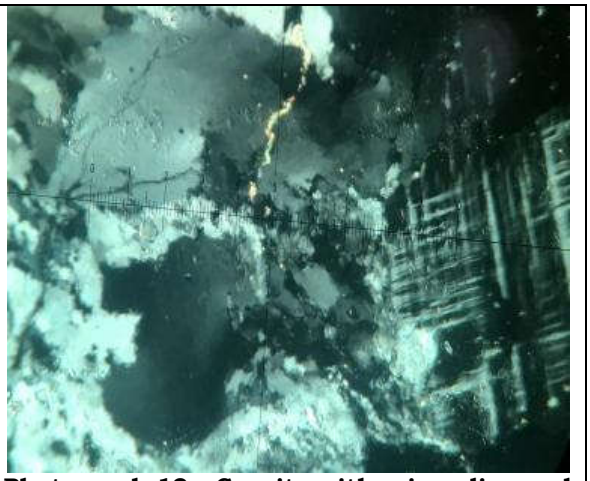
Photograph 9: Showing the inequigranular texture with Rapakivi structure (Sample JB-9).



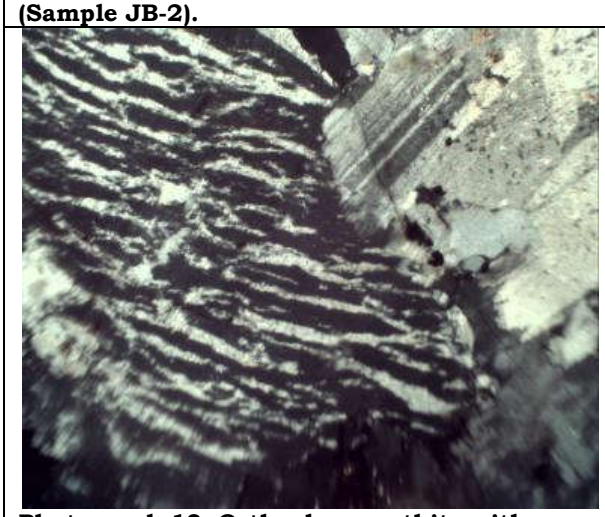
Photograph 10 : Myrmekitic structure showing intergrowth of quartz and plagioclase (Sample JB-5)



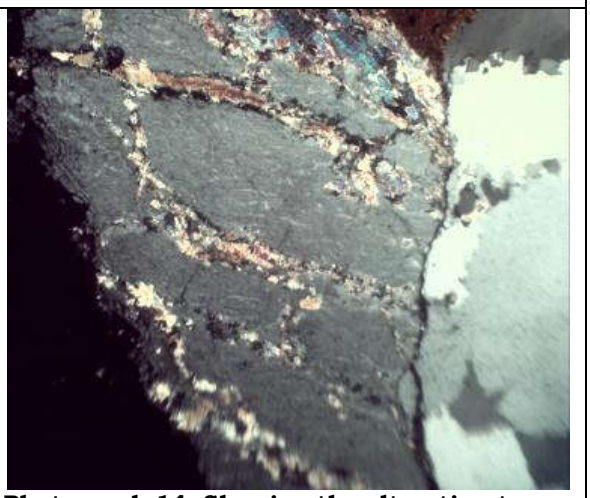
Photograph 11 : Graphic intergrowth showing intergrowth of potash feldspar and quartz (Sample JB-2).



Photograph 12 : Granite with microcline and anhedral quartz (Sample JB-24).

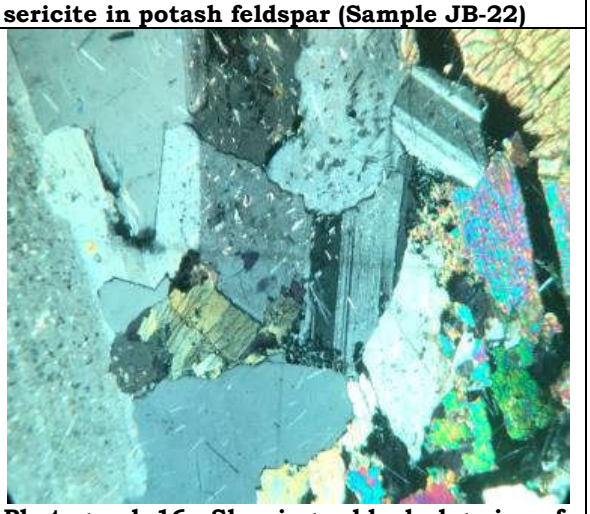


Photograph 13: Orthoclase-perthite with exsolution lamellae of albite (Sample JB-27).



Photograph 14: Showing the alteration to sericite in potash feldspar (Sample JB-22)

Photograph 15: Zoned plagioclase in granite (Sample JB-16).



Photograph 16 : Showing subhedral grains of altered perthite, plagioclase and reibeckite (Sample JB-15)

Photograph 17 : Inclusion of apatite and quartz within the biotite grain (Sample JB-14)

Photograph 18 : Inclusion of zircon grain within the hornblende grain (Sample JB-21).

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