International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081 (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jgee.htm
2014 Vol. 4 (3) September-December, pp. 244-258/Sreenivasulu et al.

Research Article

GRANITOIDS ADJOINING KADIRI SCHIST BELT, ANDHRA PRADESH, SOUTH INDIA: FIELD AND PETROGRAPHIC IMPLICATIONS

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ABSTRACT
The Kadiri Schist Belt lies in the eastern Dharwar craton and is in juxtaposition with granitoids on either side which include TTG, TGM, MS and Alkali Granites. The schist belt rocks and granitoids exhibit three phases of deformation. The granitoids are mainly medium to coarse grained and exhibit hypidiomorphic texture. Two important textural characters in thin sections are perthitic and myrmekitic intergrowths, which may be formed by exsolution or replacement. The order of crystallisation in the study area may be assumed as, TTG-TGM–MS–Post-orogenic Alkali granite sequences. The presence of the synplutonic microgranitoid dykelets and enclaves in the TGM suite indicate contemporaneous presence of mafic and felsic magmas and magma mingling and mixing processes. The granitoids are important for the search of porphyry type copper, molybdenum, gold, chromium, cobalt, nickel, platinum and related mineralization. They are also being quarried as dimensional stone granites.

Keywords: *Kadiri Schist Belt, Granitoids, Magma Mixing and Mingling, Dimension Stone Granites*

INTRODUCTION
The Indian shield is one of the several Precambrian shield areas where diverse rocks of early archaean to late proterozoic age are exposed in different tectonic settings. The area of present study where the rocks ranging in age from archaean to phanerozic are exposed forms a large segment in the eastern part of Dharwar Craton. The Dharwar Craton of South India consists of two parts; (1) the older Western Dharwar Craton (WDC; 3.3-2.7Ga), and (2) the younger Eastern Dharwar Craton (3.0-2.5Ga) (Chadwick *et al.*, 2000). The Eastern Dharwar Craton is made up of late archaean (2.6-2.5Ga) granites intrusive into subordinate amounts of older (2.9-2.7Ga) Tonalite Trondhjemite Granodiorite gneisses.

Greenstones in the EDC are confined to small, elongated belts which may represent terrane boundaries (Krogstad *et al.*, 1989; Chadwick *et al.*, 2000). The present work is taken up with a view to study in detail, the granitic rocks adjoining the Kadiri Greenstone Belt in parts of Anantapur and Chittoor districts of Andhra Pradesh along with the associated mineralization.

Kadiri Greenstone Belt which lies in the eastern tectonic block includes bimodal, mafic-felsic, volcanic association like many Archaean Greestone Belts (Barker and Peterman, 1974; Condie, 1981; Ayres *et al.*, 1985; Peate *et al.*, 1997). Bimodal volcanic rocks have been reported from various schist belts in the Eastern Dharwar Craton such as Sandur (Hanuma *et al.*, 1997), Hutti (Anantha and Vasudev, 1980; Giritharan and Rajamani, 1998) and Ramagiri (Mishra and Rajamani, 1999). The Kadiri Schist Belt is unique in having larger area occupied by meta-acid volcanics compared to basic volcanics and hence represents the higher stratigraphic level in the greenstone model of Anhaeusser *et al.*, (1969).

Geological Setting
The study area is confined to the granitoids adjoining the Kadiri Greenstone Belt which run for a strike length of over 80 km in an approximate North-South direction from Dorigallu (Lat. $14^0$25’30”; Long $78^0$02’) in the north to Gollapalli (Lat $13^0$44’; Long $78^0$09’30”) in the south. The width of the belt varies in different localities with a minimum of 0.8 km to a maximum of 4.8 km. It lies in the Government of India Toposheet Number 57J/3, 57J/4, 57K/1 and 57K/2) (Figure I).

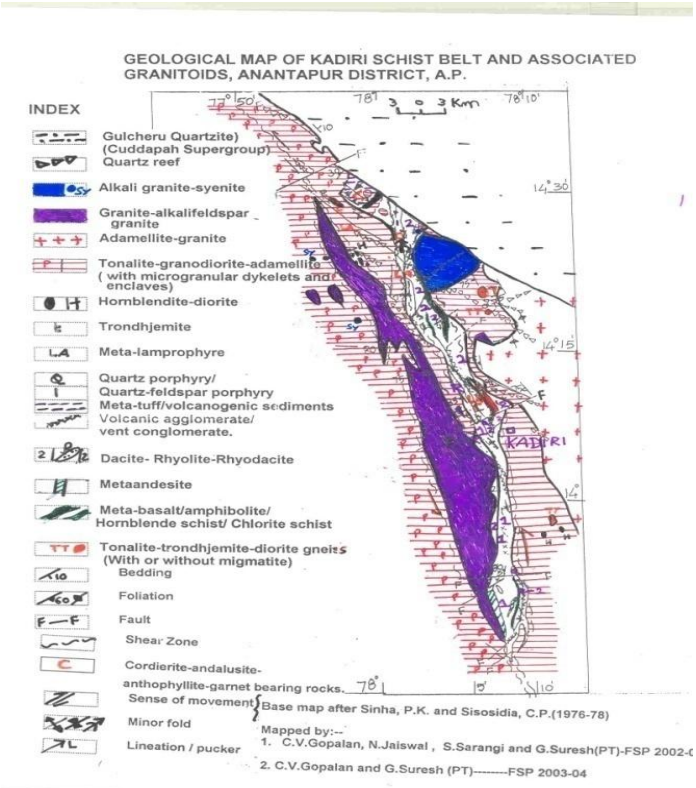

Figure 1: Geological map

The central portion of the study area constitutes the schist belt, which runs roughly in the NNW-SSE direction and comprises predominantly acid volcanic rocks with minor amounts of basic volcanics. It is in juxtaposition with granitoids on either side which include Tonalite Trondhjemite Granodiorite (TTG) suite, Tonalite-Granodiorite-Monzogranite (TGM) suite, Monzogranite-Syenogranite (MS) suite and Post-orogenic Granites (Alkali Granites). Acid volcanics are represented by rhyodacite, rhyolite, quartz porphyry and quartz feldspar porphyry while metabasalt, meta-andesite and basic tuffs constitute the basic volcanics. Impersistent bands of BIF within acid volcanics occur as minor intercalations. Impersistent but conspicuous volcanic conglomerate horizon occurs in conformable relationship with acid volcanics of the belt. The above litho-units are intruded by younger granitoids, dolerite and gabbro dykes, pegmatite and quartz veins.

A detailed description of the different granitoid units identified, as to their distribution, general characters and the nature of enclaves and other rocks associated with each unit is attempted in this paper.The contact relations are described and detailed assessment of the various structural elements in relation to the regional tectonic is given. Each of the four granitoid units are dealt with separately under subsections.

Tonalite Trondhjemite Granodiorite (TTG)

TT gneiss represents a distinct contrasting topography characterized by plain to low undulatory terrain dotted by linear hillocks and ridges. It is the oldest and intruded by TGM and MS suite of rocks. It is banded with poly phase/multi-compositions (diorite-tonalite – trondhjemite) and multi-migmatised. It is dominantly biotite bearing. Melanocratic band and biotite rich bands are minor while mesocratic tonalite and leucocratic trondhjemite (leuco-tonalite) bands are dominant (Figure 2). The remobilization of gneisses is characterized by the formation of second generation of gneisses which is synchronous with the second folding of gneisses and also emplacement of TGM suite synkinematic to it. TT gneisses contain linear bands/patches of supracrustal rocks like hornblendities, agmatised basic volcanic, quartizite. BIF/recrystallised BIF, sericite schists/ boitite schist, cordierite-sillimanite schists etc.

Figure 2: Researcher at TTG exposure

There are three generations of gneisses recorded in this area viz. oldest (mafic dioritic-amphibolitic gneisses with minor ultramafics, magnetite quartzite and trondhjemite), followed by tonalite-trondhjemite-granodiorite gneisses and finally by trondhjemite gneisses. The oldest dioritic/amphibolitic gneisses within early trondhjemites (migmatitic) occur as irregularly oriented enclaves in younger banded TT gneisses. The enclaves of basic volcanics present in the oldest gneisses could possibly represent equivalents of older schist belts or primordial simatic crust-differentiates of mantle.

The banded tonalite-trondhjemite gneisses and kadiri schist belt were together subjected to similar deformations and three phases of folding. Development of gneissosity in the gneisses and formation of schistosity/ foliation in schist belts is synchronous. The remobilized trondhjemites show clear-cut intrusive relationship with the banded TT gneiss and rarely as minor bands within schist belts and also subsequently folded. The last generations of trondhjemites were almost coeval with the emplacement of TGM suite and emplaced either at late stages of F1 folding or during early stages of F2 folding. It appears at places some of the hornblendites could be intrusives separating TT gneisses from younger trondhjemitic gneisses. But, the primary features like chilled margins, cross-cutting relationship with older gneisses etc. are not seen due to uniformity in metamorphism and deformation. Prior to gneiss formation, the volcanics of greenstones and felsic plutonic rocks existed together and deformed – folded together.

Within trondhjemites the older trondhjemites were associated with migmatised diorites basic volcanics. Nowhere the gneisses are grading into younger granites through migmatites. Different generations of trondhjemites noticed through repeated migmatisation. The contact of gneiss with basic volcanics is characterized by the presence of trondhjemitic melt. The youngest trondhjemites occur like plutons as seen to the SE of Pedda Timma Samudram (PTM) and to the SW of B. Kothakota. In many places the basic volcanics show agmatic/injection zones and appear to be included in to the older basement granitoids. Two types of basic volcanics are found granular and banded. They are also co-folded along with gneisses. The remobilized younger gneisses show intrusive relationship with the supracrustals and are discordant to the gneissosity of agmatised basic volcanics.

Profuse injections of trondhjemites into tonalite- diorite-basic volcanics gives banded structure. The remobilized td veins show folded structure (asymmetric Z or S folds) and also ptygmatic folds. Basic volcanics show invariably agmatitic structure locally grading into metatexitic stage. The earlier generation gneisses and basic volcanics occurring as enclaves show schleiren structure in later gneisses.

The trondhjemitic plutons show schleiren banding to nebulitic and associated fold structures. The insitu – migmatisation evidences are lacking except in basic volcanics. The diorite and tonalite gneisses show banding / layering to metamorphic differentiation accompanying incipient migmatisation.

Figure 3: Synplutonic Microgranitoid enclave

Figure 4: Microgranitoid dykelet

***Tonali – Granodiorite – Monzogranite* (TGM):** Tonalite – Granodiorite – Monzogranite group is mainly distributed in the contact of the Kadiri greenstone belts. TGM forms a compositionally diverse suite of rock with large variation in the proportion of the mineral constituent. The TGM form relatively flat country rocks with bouldary outcrops and low rock mounts. TGM suite is mainly hornblende bearing suite characterized by the presence of synplutonic microgranitoid enclaves (Figure 3) (Didier and Barbarin, 1991), small scale plutonic micogranitoid dykelets (Frost and Mahmood, 1987) (Figure 4) associated with hornblendite-diorite-tonalite-granodiorite and monzogranite which indicate contemporaneous presence of mafic and felsic magmas and magma mingling and mixing processes. The group is readily identifiable in the field by its visibly coarse grained granular nature, shades of grey colour with pale greenish tinge due to alteration of plagioclase feldspars (except the pale pink monzogranite), spotted appearance due to the presence of considerable amount of mafics, their even distribution and the grain size comparable to the other minerals, and the abundance of the hornblendite-diorite series of rocks and microgranitoid enclaves and dykes associated with the group. It is mainly hornblende bearing cal-alkaline expanded suite characterized by presence of a wide spectrum of rock types ranging in composition from diorite to granite with microgranitoid enclaves (spindle to cuspate shaped) and dykelets which indicate contemporaneous presence of mafic and felsic magmas and magma mingling and mixing processes. Dominantly the vast area is occupied by megacrystic to porphyritic granodiorite forming a table land with thick red soil. The mafic rocks are hornblendite-diorite units occurring mostly as linear dyke/ lense like bodies with magmatic-breccia zones consisting profuse injections of leucodiorite / pegmatite / quartzofeldspathic / quartz veins etc resembling pseudoagmatites.In the southern and southeastern part of Kadiri schist belt, The intrusive TGM is dominantly made up of monzogranite

syenogranite which forms hills as seen to the SE of Kandukuru, Ankireddipalli and Tanakallu. The compositions vary gradationally from tonalite to monzogranite /syenogranite through granodiorite. Biotite starts appearing progressively in younger differentiated granitic phases though hornblende is main mafic mineral. The early different compositional phases occur as schlierens / bands in later phases. Primary structures are phase banding, flow banding defined by alignment of phenocrysts and schleirens, irregularly oriented phenocrysts, layering / banding due to differentiation from hornblende to quartz diorite, fine grained and chilled nature of microgranitoid enclaves / dykelets, intrusion related magmatic breccias etc.

The various enclaves recognized in the TGM granitoids are metabasalt, BIF, TT gneisses, hornblend diorite series of rocks and microgranitoids. The microgranitoids enclaves are fine grained rocks of granitic composition ubiquitously present throughout the TGM area as enclaves whose dimensions range from less than one cm to about 50 cm across and upto about a meter or two in length. The smaller sized enclaves are more common. They are mesocratic and hence darker in color than the host granitoids in which they are included. The enclaves are hereafter referred to as mafic rich microgranular enclaves (MME) following Didier and Barbarin (1991). They have compositions of granodiorite, tonalite, quartz monzodiorite, quartzdiorite, diorite and are generally fine grained equigranular, although medium grained and porphyritic types are not uncommon. A positive correlation between the mafic and plagioclase contents of the enclaves and that of the host granitoid is observed. Also, the enclave population decreases with decreases with decrease in the plagioclase and mafic content in the host TGM. The MME are spheroid to disc shaped or lenticular with variable degree of flattening. Spindle shaped MME are characteristically noticed in the granodiorites of Tanakallu area It has been suggested that such microgranular enclaves of igneous origin which are so common in many granites are formed as a result of the complex process of mingling and mixing when a hotter and relatively small amount of mafic or intermediate magma is injected into a crystallizing and cooler granitic magma (Reid *et al.*, 1983; Vogel *et al.*, 1984; furman and Spera, 1985; Didier, 1987; Frost and Mahmood, 1987; Vernon *et al.*, 1988; Lorenc, 1990; Poli and Tommasini, 1991, Barbarin, 1991, Elburg and Nocholls, 1995; Mass *et al.*, 1997). The mafic-intermediate magma arrives late, coexists with the partly crystalline felsic host magma, mingles with it as disaggregated magma blobs, cools faster and becomes completely crystalline even before the host magma is totally crystallized. In certain conditions, depending upon the amount of magma and timing of its arrival vis-à-vis the host interaction and mixing ensues between the two. In this context, the fine grained margin in the medium grained enclave as seen in is an important feature indicating chilling of enclave magma against the cooler host granitoid.

Microgranitoid dykes which are similar in composition and texture to that of fine grained MME and designated as MMD, also occur as small scale dykes distributed sporadically throughout the TGM. They range between a few cm and a few tens of cm (rarely upto 2 meters) in thickness and maximum of 20 meters in length. The microgranitoid dykes crosscut the foliation in the host; they themselves have foliation which is parallel to their margin and less prominent in the central part than close to the margins. Some dykes display back-veining of granitic material from the host leading to net-vein structures and even to disaggregated structures. The dykes show curved and lobate margins. Back-veining and lobate margin indicate the synplutonic nature of the microgranitoid dykes and form part of the magma mingling structures (Marshall and Sparks, 1984; Hyndman and Foster. 1988. Sutcliffe, 1989).

From B. Kothakota to the southern tip of Kadiri Schist Belt, the porphyritic granodiorite/tonalite grades to monzogranite and to syenogranite. Progressively, biotite is enriched and MMD an MME decrease. At place, the clots of MME are only present. Similarly, porphyritic granodiorite grades into monzogranite between Tanakallu and Papaghni River. The porphyritic monzogranite consists of synplutonic microgranitiod dykelets. The presence of synplutonic microgranitoid dykelets and enclaves indicate magma mingling-mixing evidences in TGM suite.

Monzogranite – Syenogranite (MS) Suite:

The MS suite forming huge hills occur to east and also to the west of the schist belt (Figure 5) are extensive to make up the major part of the area. All the other groups of granitoids and the greenstone belt

rocks occur enclosed within the vast country formed by MS suite. The MS suite is exposed on the eastern part as major hill ranges. This suite is polyphase type with typical magmatic features like alignment of phenocrysts, biotite schleirens banding/phase banding, flow folds etc. Primary banding in these younger granites is thrown into folds indicating magmatic affinity.

Figure 5: Large batholiths of M. S Suite

Injections of different phases, i.e. interaction cause complex patterns (looking at places like migmatites). This suite does not contain microgranular enclaves and dykelets. Three major phases are found in this suite namely (1) megacrystic to very coarse grained porphyritic monzogranite (2) medium grained porphyritic monzogranite and (3) medium to fine grained syenogranite. Earlier phase occurs as bands schlierens while later phase occurs as an injection. They show ENE to WNW trends with moderate to steep dips. The compositional variation is imperceptibly gradational between monzogranite and syenogranite. Pegmatites and aplites of different dimensions are omnipresent throughout the MS suite. The contact between younger granite suite and adjacent TT gneisses and megacrystic granodiorite is sharp and wavy. At many places this is marked by injections of pegmatite. The linear oval shaped granite pluton located to the east of Mulakalacheruvu Railway Station shows E-W trending southern contact at the southern side. The enclaves present in the MS suite are those derived from the pre-existing country rock, incorporated as solid blocks (xenoliths). They include metabasalts, besides these enclaves the early formed granitic phases of the same suite also occurs as enclaves/bands. Interaction of granitic magma with early phases and also with the enclaves of TGM has resulted into the formation of schlierens/bands of these xenoliths/enclaves. The MS suite have sharp contact with the country rocks namely, the greenstone belt and TGM suite. The contacts are generally straight on the regional scale and follow the regional structural trend. In the MS suite rocks of Kadirikonda, a small, faulted dykelet is exposed over a length of about 10 meters.

The syenite bodies occur as minor bodies / veins confined to hornblendite-diorite body exposed to the NNE of Reddipalle (57 J/4) (Suresh *et al.*, 2010); in MS suite along E-W trending Mudigubba – Bukkapatnam lineament and also in youngest minor differentiated gabbro-granophyre-syenite association as seen to the NNE of Dorigallu. Syenites range in composition from monzonite to syenite.The pegmatites and aplites occur either as outcrop scale segregations or as veins within the granitoids. The veins are seen as sheet-like bodies with sub-vertical dips. Some of the pegmatites have aplite at the contact with the host granite. The pegmatite and aplite veins have also intruded the older country rocks. Locally, major quartz reefs are exposed all along the shears.

Alkali Granite:

Alkali granites are pink in colour intrusive into sheared and silicified metabasalt and tonalite of TGM. At the contacts, within the granite, ENE-WSW trending silicified fractures are noticed. To the east of Dorigallu, an oval shaped coarse, prophyritic and medium grained post orogenic granite pluton is found with exfoliated dome/sheeting tars- castle, koppe (Figure 6) varying in composition from monzogranite to alkali –feldspar granite with porphyritic coarse to medium grained phases and occurs as brittle shear controlled plutons.

Figure 6: Koppe structures in Alkali Granites

Structure:

The Kadiri greenstone belt rocks and the TT gneiss were subjected to three phases of deformation namely D1, D2, D3. The D1 is represented by the penetrative foliation/ schistosity (S1) which is well developed in the greenstones. The S1 schistosity is further deformed producing the mesoscopic asymmetrical low plunging folds related to D2. Subvertical cleavage (S2) trending in NNW-SSE direction and axial planar to the second generation folds is also present. The Tonalite–Granodiorite-Monzogranite group is a syntectonic intrusive emplaced during the second deformation. It displays primary magmatic flow structures which are parallel to and continuous with the S2 fabric in the greenstone belt and TT gneiss. Late D2 ductile shearing resulted in the development of the regional shear zones. The MS also exhibits primary magmatic flow related fabric modified partly due to this deformation. The post MS brittle deformation is manifested in the form of NW trending cataclastic zones. The last phase of deformation, the regional D3 event is represented by broad warps with axial traces trending ENE-WSW to ESE-WNW through E-W direction in Alkali Granites. Near vertical axial planar fractures are developed due to deformation. Some of the D3 related fractures further developed into regional fault zones occupied by quartz reefs. They extend upto the Cuddapah basin and offset its margin as observed in the satellite imageries.

Petrography of Granitoids:

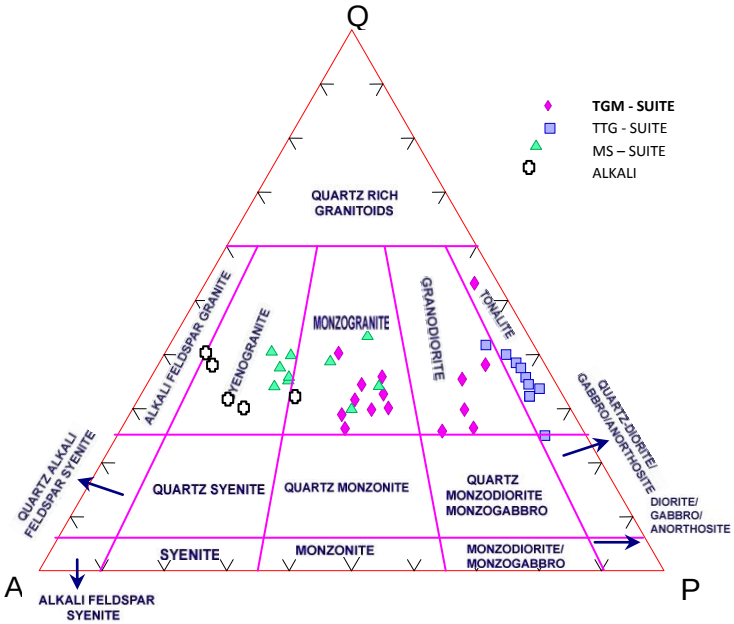

Figure 7: Modal Quartz – K-Feldspar – Plageoclase (QAP) ***(After Streckeisen, 1976)***

Modal Compositions are best suited for the descriptive study and classification of the granitic rocks. Some of the earlier researchers Johnsen (1932), Chayes (1952, 1957) and Bateman (1961) proposed classification of granitic rocks based on their modal composition, each one has suggested his own limits to the parameters. In order to maintain uniformity, the IUGS sub-commission proposed systematic classification of igneous rocks (Streckeisen, 1976) which has been taken as standard classification for all the granitic rocks.

The granitoids of the study area are classified based on the Streckeisen classification. The modal values of quartz, plagioclase and potash feldspars are recalculated to 100 and plotted in the Streckeisen (1976) trilinear diagram (Figure 7). In this diagram, the granitoids fall in the tonalite, granodiorite, monzogranite and syenogranite fields.

Tonalite-Trondhjemite-Granodiorite Gneiss Suite (TTG): They are grey in colour, banded with melanocratic to leucocratic exhibiting both schistose and granulose textures. Each band shows specific compositions ranging from quartz diorite to tonalite to trondhjemite.

Quartz and plagioclase feldspars are major minerals with negligible amounts of potash feldspars. Multi-grain formation and xenoblastic textures are common. Mafic minerals are mostly biotite. The leucocratic trondhjemites are also biotite bearing and rich in soda feldspars. Locally the potash influx into trondhjemite leads to formation of granodiorite. In TTG suite, recrystallisation and granoblastic features are commonly seen (Figure 8).

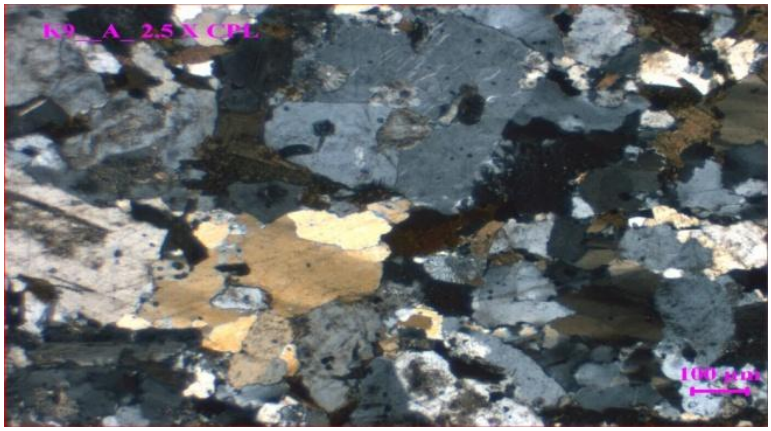

Figure 8: Granoblastic texture in TTG suite

Mafic rich and leuco rich banding due to differentiation by metamorphism is observed. Banding is imparted due to trondhjemite injections or incipient migmatisation accompanying deformation. The quartz-biotite rich leucocratic bands and hornblende-plagioclase rich mafic bands with gradational nature is conspicuous.

Recrystallisation of quartz is common. The rimming of mafics around plagioclase feldspars and segregation of leucocratic bands resulted into streaky gneisses is another phenomenon. Potash feldspar proportion is very minor or almost absent in TTG. Plagioclase feldspars are invariably saussuritised/epidotised and untwined.

In trondhjemites plagioclase feldspar is unaltered but untwined to feebly twin. Youngest trondhjemites are medium grained and locally porphyritic with the presence of potash feldspars. Biotite-muscovite-opaques form as accessory phases. Tonalites show hypidiomorphic granular textures.

The older trondhjemites show strong foliation. The petrographic account indicates quartz, plagioclase feldspar, hornblende, biotite, epidote, sphene and opaques with negligible potash feldspar for tonalite gneisses. The trondhjemite suite reflects the presence of dominantly quartz and plagioclase feldspar with traces of biotite and potash feldspar. At places, the influxes of potash feldspar transform it into granodiorite. The modal analyses of the rocks are given in the Table – 1.

Table 1: Modal Composition of TTG, TGM, MS and Alkali Granites

Rock No.	**Quartz**	**K-Feldspar**	**Plagioclase**	**Mafics**	**Rock No.**	**Quartz**	**K-Feldspar**	**Plagioclase**	**Mafics**
Tonalite Trondhjemite Granodiorite gneiss suite					**Monzogranite Syenogranite**				
PSV 92	34	4	57	5	PSV 172	39	39	20	2
PSV 94	35	4	52	9	PSV 176	33	40	21	6
PSV 99	30	5	58	7	PSV 178	28	33	33	6
PSV 102	36	4	56	4	PSV 181	34	30	24	2
PSV 104	35	4	51	10	PSV 182	31	26	34	9
Tonalite Granodiorite Monzogranite suite					Alkali Granites				
PSV 125	39	31	27	3	PSV 204	36	52	10	2
PSV 130	31	33	34	2	PSV 209	39	39	20	2
PSV 134	32	8	44	16	PSV 212	32	53	12	3
PSV 136	23	15	49	13	PSV 214	32	50	14	4
PSV 139	32	28	38	2	PSV 218	34	52	9	5

Tonalite-Granodiorite-Monzogranite Suite (TGM): The granitoids of TGM group are characterized by the predominance of igneous microstructures and textures, as a wide range in the modal content of the different mineral constituents. They are chiefly made up of plagioclase feldspar, k-feldspar, quartz, hornblende and biotite in different proportions. The accessory phases include sphene, opaques, apatite and zircon in the decreasing order of abundance. As per the IUGS – Streckeisen classification (Pitcher, 1997) they fall in the categories of tonalite, granodiorite and monzogranite with successive decrease in the plagioclase feldspar ratio. A general increase in mafic content towards tonalite end is discernible. However, the variation in mafic content is also independent of two-feldspars ratio. The mafic content is hornblende dominant towards tonalitic end and biotite dominant towards monzogranite end in conformity with the increase in k-feldspar.

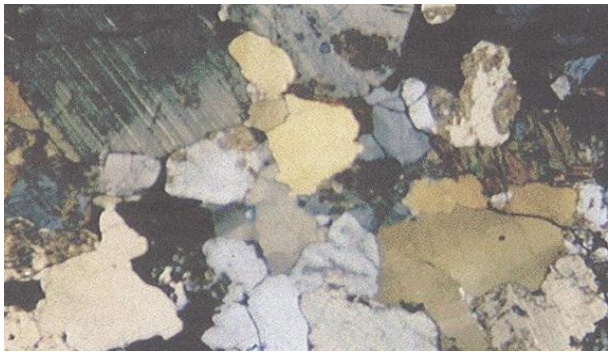

Figure 9: Hypidiomorphic texture

All the components of the group are medium to coarse grained equigranular, hypidiomorphic to inequigranular. Plagioclase feldspar forms subhedral grains with a tendency to assume euhedral shape. The mineral is anhedral to subhedral, the later being more common with the larger crystals. It occurs as smaller interstitial grains in tonalites showing hypidiomorphic textures (Figure 9) and as larger grains in k-feldspar dominant rocks such as granodiorite and monzogranite in which it forms the main constituent along with other feldspars. The multiple twinning present is according to combination of albite and Carlsbad and percline laws; bent twin lamellae of plagioclase are observed in a few sections of granodiorite. Normal to oscillatory zoning is common, though rather imperfectly developed. Some larger plagioclase feldspar grains carry small euhedral crystals of plagioclase feldspar indicate two stages of crystallization. The coarse tartan twinning is sometimes developed in the patched amidst the less distinct portions of the fine twinning. The megacrystic granodiorite contains large crystals of orthoclase which is partially converted to microcline. Potash feldspar grains are invariably perthitic wherein, braid, string and patch perthitic patterns are common. Zoned and twinned amphiboles with skeletal quartz and plagioclase at the centre are seen in monzodiorite; microcline perthite replaces plagioclase and apatite needles are present in some sections.

Hornblende forms short prismatic subhedral grains and less commonly it occurs as euhedral to anhedral grains. It is pleochroic to yellowish green, green and brownish green. Some of the hornblende grains in the mafic facies or TGM suite have number of inclusions of quartz and feldspar sometimes giving rise to skeletal structure. Biotite flakes are pleochroic in shade of yellowish green to greenish brown. It occurs as separate grains in association with hornblende or as patches along the prismatic cleavage within hornblende. The hornblende grains are sparsely distributed in monzogranite and in some leucotonalite and leucogranodiorite samples.The accessory minerals present in the decreasing order of abundance are sphene, opaques, apatite and zircon. Sphene occurs as spindle to rod shaped inclusions within the hornblende. Opaques and euhedral apatite are also present in independent grains as well as inclusions with in the mafics and feldspars. The modal compositions of the rocks are given in the Table 1.

Monzogranite-Syenogranite Suite (MS): Potash feldspar, plagioclase feldspar and quartz constitute the essential minerals in all the phases of MS group. Biotite is a minor constituent and hornblende is rare. The accessories are sphene, zircon, apatite and opaques. Monzogranite is medium to coarse grained, light greenish-pink coloured, holocrystalline and massive. It exhibits hypidiomorphic granular texture. The felsic constituents are plagioclase, orthoclase, quartz and k-feldspar. Microcline is the dominant k-feldspar and the other is orthoclase which is partly inverted to microcline. Biotite is the minor mafic constituent and hornblende is rare. Accessory minerals are apatite, zircon, ilmenite, sphene and opaques. Although the compositional range of monzogranites is small, it defines a differentiation trend that is essentially controlled by biotite and plagioclase fractionation. In general the texture is similar to granodiorites, with zoned subhedral plagioclase and euhedral microcline and quartz. However, microcline is commonly perthitic with fine grained plagioclase and quartz. Medium grained subhedral muscovite grains are observed. The textural modifications due to the deformation recorded are; subgrain formation to recovery recrystallisation of quartz grains and peripheral granulation of mineral grains and myrmekite development at the feldspar margins.

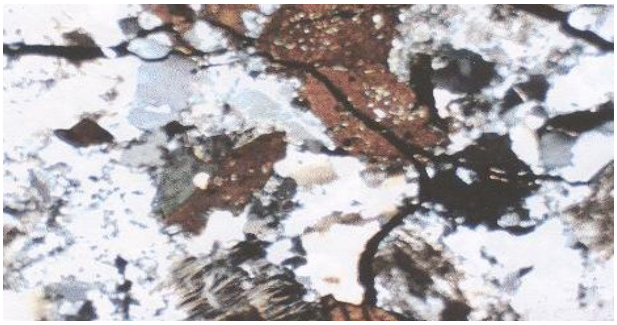

Figure 10: Perthitic texture in MS suite

Syenogranite in MS suite is medium to coarse grained, mesocratic and pink. The mineral constituting the rocks are Quartz, k-feldspar, plagioclase feldspar, biotite and hornblende. Under the microscope, it shows hypidiomorphic granular texture with occasional foliation defined by preferred orientation of biotite flakes. Feldspars are subhedral and of medium size. K-feldspar is interstitial, replacement perthitic and contain relict grains of plagioclase (Figure 10). Orthoclase mostly occurs as stringes and vein perthites. K-feldspar at places shows a little cloudy appearance due to the presence of dusty limonite and anatase; otherwise it is almost free from alteration. It rarely contains inclusions. At places, plagioclase is zoned along the periphery. It is slightly sericitised and has a little corroded appearance. Quartz shows moderate wavy extinction, and is slightly elongated confirming the trend of foliation. Biotite occurs as short discontinuous bands and show preferred orientation. It also shows slight bleaching and occasional chloritisation. Pleochroic haloes are commonly noticed around inclusions of zircon in biotite. Hornblende, sphene, apatite, zircon, anatase, rutile are chiefly noticed along the cleavage traces of biotite in minor segregations.

Based upon texture, modal mineralogy on QAP plot (after Streckeisen, 1976) the unit is classified as monzogranite-syenogranite suite. As per the IUGS –Streckeisen classification, majority of the MS group of rocks fall in the monzogranite and syenogranite (combined granite) fields. The modal compositions of the rocks are given in the Table -1.

*Alkali Granites***:** They are medium to coarse grained, pink coloured and massive. The rocks exhibit hypidiomorphic granular texture and comprise strain shadowed anhedral quartz, subhedral feldspars, microcline and plagioclase as common major minerals. Accessories are opaques, sphene, epidote, sericite, chlorite, apatite and flourite. Modal composition indicates monzogranite to syenogranite to alkali feldspar granite fields. As per the IUGS – Streckeisen classification, these rocks fall in the monzogranite field. The modal compositions of the rocks are given in the Table -1.

Petrogenisis and Tectonic Setting of Granitoids:

As the studies on the granitoids are restricted only to field and petrography in this paper, an attempt is made to utilize the field and petrographic data in identifying the processes involved in the magma generation and its evolution that resulted in the manifestation of the four suites of granitoids in the study area.

The different theories have been proposed on the origin of granites and their related rocks. The rocks of the study area are mainly batholiths. Wyllie (1984) advocated that siliceous granitic rocks of batholithic dimensions are not derived from the primary magmas from mantle or subducted oceanic crust but they represent the end products of subsequent stages. Mafic magmas derived from mantle source may differentiate and may give rise to enormous tonalites. In some regions where the continental crust is thick, the mafic magma may assimilate the crustal components and fractionate to give rise to voluminous siliceous end products. It is envisaged that melting to produce granites is the result of regional metamorphism above subduction zones as a result of invasion of mantle generated heat and fluids.

Mineralogical and Textural Evidences: The order of crystallisation in the study area may be assumed as, TTG-TGM–MS–Post-orogenic granite sequences. This sort of crystallisation of more basic rocks ahead of the acidic ones imply some sort of differentiation compatible with that of the Bowen's reaction principle. Two important textural characters are noticed in thin sections namely perthitic intergrowth and myrmekitic intergrowth.

The perthitic intergrowth is generally developed in two ways, i.e., by exsolution or by replacement. If the belbs in the host feldspar are confined to the centre of the grain without having any connection with outside plagioclase, it may be considered that the belbs are evolved during slow cooling. Normally the composition of such grains will be more acidic or albitic than the discrete plagioclase, as is the case in the present instance. Sometimes the evolved belbs coalesce and form bigger grains and migrate outside the K-feldspar due to deformation. This apparently gives connection with the external plagioclase which will be more acidic. But if the discrete plagioclase replaces K-feldspar, it becomes basic. The perthitic intergrowth in the present instance seems to be related to exsolution as the plagioclase belbs are confined to the central portions leaving the portions of K- feldspar clear.

The myrmekitic formation is also explained in two ways, one by replacement and the other by exsolution. The advocates of replacement origin derive the required quartz by the replacement of plagioclase by potash feldspar or vice versa (Binns 1966; Drescher, 1948 and Osterwald, 1955).

Petrographically, granitoids of the study area show hypidiomorphic granular texture frequently. According to Turner and Verhoogen (1960) the hypidiomorphic granular texture combines some features inherited by magmatic crystallisation with others impressed by at least minor post-magmatic recrystallisation.

Magma Mingling – Mixing Evidences in TGM Suite: Mingling and mixing by mechanical and chemical interaction of the co-existing mafic and felsic magmas has attracted the attention of the granite petrologists since the early 1980's, although such interaction was postulated earlier dating back to late 19th century (Pitcher, 1997) injection of mafic magma into a crystallising granitic magma (Poli and Tommasini, 1991) of underplating of mantle derived mafic magma at the base of the granitic magma chamber and subsequent mingling, mixing/interaction has been recognized as an important process in bringing about the compositional heterogeny in many orogenic granites or the granites at the plate margins (Pitcher, 1997). The recognition of field and petrographic evidences indicative of the coexistence of mafic and felsic magmas are important for considering the role of magma mixing in the evolution of granites (Reid *et al.*, 1983; Marshall and Sparks, 1984; Bacon 1986; Didier and Barbarin, 1991) (Gopalan and Suresh, 2004).

The synplutonic microgranitoid dykelets and enclaves present in the TGM suite are medium to fine grained hornblende rich and show chilled margins/fine grained nature. The phenocrysts of multigrain hornblende and plagioclase feldspars are found in both these rock and associated host tonalite. Plagioclase feldspars show reverse zoning. The mixed zones comprise multigrain hornblende and enhedral crystals in tonalite. Compositions vary from diorite to granodiorite. Back veining is characteristic. Mixed zones form skeletal hornblende. Poikilitic potash feldspar crystals gradually increase towards monzogranite of TGM and hornblendite – diorite bodies are very coarse grained, locally show fractionation into mafic poor and plagioclase rich parts. Hornblende crystals are found to occur as porphyritic grains. Relict pyroxenes are formed at places. Plagioclase feldspars are more calcic rich and altered to epidote with or without calcite. The leucovariants locally contain interstitial myrmekitic grains. Potash feldspars occur as poikilitic grains replacing plagioclase feldsplars. Dioritic variants show gabbroic textures.

The hornblende proportion in TGM vary drastically over short distances, i.e., from mafic rich to mafic poor. Similarly, grain size variations vary drastically. The mafic rich early tonalitic phases are typically hornblende bearing while the fractionated portions like monzo to syenogranites are medium to fine grained and biotite is dominant. Potash feldspar is almost nil in early tonalitic phases while it is almost dominant in younger granitic variant. Similarly, quartz proportion increases. The hornblendite – diorite bodies are injected by variety of leucosomes like potash rich pegmatites to plagioclase rich diorite and leucotonalite/trondhjemite veins, quartzo – feldspathic veins and quartz – veins.

Rotation of enclaves and biotitisation at the peripheries (reaction feature) and formation of quartzo-feldspathic patches unmixing these enclaves (haloes) is another feature at places formed in granitoid suites. At places, swarms of microgranitoid enclaves with oval shaped rounded nature are noticed. The compositionally expanded calc alkaline TGM suite with synplutonic microgranitoid dykelets and enclaves indicating magma mingling & mixing and fractional crystallization differentiation (Sreenivasulu and Padmasree, 2014). Thus the petrogenetic and tectonic aspects of the Kadiri Schist Belt and surrounding granitoid suites point to validity of existence of different tectonic blocks on either side of the belt.

***Economic Importance*:**

At many places in the study area, the trondhjemite bodies, hornblende-diorite bodies, leucogranite, medium grained granites of M.S. Suite and alkali granites are being quarried for dimension stone purpose. The deposits worth mentioning are trondhjemites of B.Kothakota, Pedda Timma Samudram (PTM), alkali granites of Dorigallu, granites from Thummala area, granites of Burrakayalakota, granites from southern part of Kadiri Schist Belt to the south of Gollapalli, east of Kokkanti cross, east of Mulakalacheruvu, hornblendite bodies from south of Tanakallu, west of Thummala and west of Panthulacheruvu.

The calc-alkaline granitoids (granodiorite) are important for the search of porphyry type copper, molybdenum and gold mineralization. The hornblendite-diorite and gabbro-anorthosite enclaves associated with TGM suite are worthy for the search of chromium, cobalt, nickel, platinum and related mineralization. The pegmatites related to alkali granites intrude into sheared metavolcanics and at places contain tourmaline. The shear planes in the contact area of granite, at some places, comprise copper and molybdenum sulphide besides presence of flourite Thus in the study area sweet green, black, madanapalli white and yellow granites are being quarried as dimensional stone granite.

CONCLUSION

Based on intensive field and petrographic studies it has been concluded that polyphase polymigmatised TTG gneisses comprising mafic-ultramafic bands indicate existence of older simatic crust which upon migmatisation and intrusion of differentiated mafic melts gave rise to different sialic crust in the marginal basin environment. The migmatisation at different periods gave rise to different generations of trondhjemites, the youngest event is synonymous with the emplacement of TGM suite as synplutonic microgranitoid dykelets of TGM suite are also found in trondhjemites. The TTG crust which forms the basement for Dharwars shows structural unity with the Dharwars and formation of gneissosity and schistosity is synchronous. The TTG crust also participated co-folding along with schist belt and comprises in-folded volcanic remnants with it and porphyries are intrusives suggesting presence of feeder dykes to overlying volcanics.

In the TGM Suite, presence of synplutonic microgranitoid dykelets and enclaves points to magma mingling & mixing and fractional crystallization differentiation. The homophanous to leucocratic variants of MS suite of granitoids show intrusive character and range in composition from monzogranite-syenogranite. The main characteristic feature of this suite is absence of microgranitoid dykelets and enclaves. In the last phase, thickening of the crust and the melting of mantle resulting into generation of alkali magmas which were emplaced as alkali granites along deep seated crustal fractures (lineaments) in a tensional tectonic regime.

ACKNOWLEDGEMENT

The authors are indebted to Dr. G. Suresh, Director, GSI, Hyderabad for his constant encouragement sand valuable suggestions. They are also grateful to the scientists of GSI, Southern Region, Hyderabad and NGRI, Hyderabad for their valuable help and suggestions on the contents of this paper.

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