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The Geology of Goa Group: Revisited

A. G. DESSAI
Department of Earth Science, Goa University, Taleigao Plateau, Goa - 403 206
Email: ashokadessai@gmail.com

Abstract: The supracrustals that constitute the Goa Group of Gokul et al. (1985) can be divided into two lithostratigraphic sequences namely the Barcem Group and the Ponda Group. The former comprises predominantly greenstones (metabasalts) and rests on a basement of the 3300-3400 Ma Anmode Ghat trodhjemite gneiss with a crudely developed quartz-pebble conglomerate at the base, and shows lithological similarities with the lower part of the Bababudan Group. The younger sequence is dominated by clastics, and is assigned to a new stratigraphic group formally termed the Ponda Group which is equivalent to the Chitradurga Group of the Dharwar Supergroup. This group rests on a basement of the 2700-2900 Ma Chandranath granite gneiss with a distinct unconformity marked by a polymict, granite-clast metaconglomerate. The conglomerate displays many similarities with the Talya conglomerate that occurs at the base of the Chitradurga Group. It is overlain by a psamolitic sequence which is followed in ascending order by the chemogenic sediments that host the BIF and by the deep water turbidite sequence (argillite-graywacke association) with intercalations of mafic volcanics. The supracrustal sequence is intruded by the Bondla layered mafic-ultramafic complex along a major shear zone (NW-SE) that largely controls the course of the northwesterly flowing tributary of River Mandovi. The late intrusive, Canacona potassic granite marks the culmination of the sedimentation in the Shimoga-Goa basin.

Keywords: Goa Group, Supracrustals, Anmode Ghat trondhjemite gneiss.

INTRODUCTION

The southern portion of the Indian shield particularly the granite-greenstone terrain of the Dharwar craton is a complex amalgamation of the Western and the Eastern Dharwar cratons (WDC, EDC) respectively. The intricate relationship between the gneisses and supracrustals from parts of the Dharwar craton continues to be debated (e.g. Swami Nath and Ramakrishnan, 1981; Naqvi and Rogers, 1987; Ramakrishnan, 1994; Radhakrishna and Vaidyanadhan, 1997; Ramakrishnan and Vaidyanadhan, 2008). The same is true for the gneissic rocks that belong to various episodes that have been broadly included under the Peninsular Gneissic Complex. A systematic study of the gneissic complex and its relationship with the greenstones from critical areas can yield significant information on the Precambrian crustal evolution and the palaeo-tectonics of this region.

Goa is situated in the northwestern part of the WDC where the Shimoga-Goa supracrustal belt extends contiguously until it is concealed beneath the Arabian Sea and the Deccan Traps in the north. The belt possibly continues beneath the Traps up to the Narmada, where the Narmada-Son lineament terminates this supracrustal belt.

The Shimoga-Goa belt extends NNW-SSE over a length of approximately 250 km and has a maximum width of about 120 km at Dharwar. The western margin of the belt is marked by large domal masses of gneissose rocks such as the Chandranath granite gneiss and the Canacona granite. The eastern margin is faulted, whereas the southern section appears to have been deposited in shallow waters. The latter is associated with subaerial mafic volcanic rocks at Kumbharwada, and north of Karwar and Ankola. The thickest accumulation of mafic volcanics of this schist belt is, however, centred at Bababudan and Kudremukh which forms the southern extensions of this belt (Harinadha Babu et al. 1981a). A thick sequence of greywackes occupy the northern section of the basin. The southern section in general, is characterized by orthoquartzite/basic lava association that denotes subaerial environments and intermittent volcanic activity in a coastal sand environment under stable conditions. The limestone-iron-manganese ore sequence of Goa and north Kanara (Castlerock band) in the northern part (Maclaran, 1904) of the Shimoga belt is in physical continuity with that in the southern part and serves as the marker horizon to show the continuity of the rocks over the entire length of the belt.

The granitic-gneisses from Goa were assigned either a syntectonic or post-tectonic status (Harinadha Babu et al.

1981a; Gokul et al. 1985) in relation to the deformational episodes exhibited by the supracrustals. However, there is a considerable lack of clarity as regards the interrelationship among the granitic gneisses on the one hand and between the gneisses and the supracrustal greenstones on the other. The supracrustal sequences in particular, consist of metavolcanics and clastics each with peculiarities of its own, yet both have been included under one stratigraphic group namely the Goa Group (e.g. Gokul et al. 1985).

PREVIOUS STUDIES

The lithounits from Goa were geologically examined by Fermor (1909) and later by Dunn (1942). A formal stratigraphic classification was, however, provided by Oertal (1958) who divided the rocks into two groups: (i) the lower infraconglomerate group and (ii) the upper metalliferous group. The granitic rocks occurring at Quepem, Canacona and Dudhsagar were considered by him to be intrusive into the schistose rocks. The Goa region in general, is largely occupied by schistose rocks (Pascoe, 1950; Dhepe, 1954) but for the northeastern corner of the State where Deccan Traps (late Cretaceous to Eocene) overlie the Dharwar metasediments.

Recent geological mapping (GSI, 1996) has shown that the basal sequences are made of metavolcanics with intercalations of metasediments overlain by a larger proportion of clastics, dominated by greywackes. In these respects, they are similar to the Dharwar-type greenstones of Radhakrishna and Vaidyanadhan (1997). Gokul et al. (1985) proposed a modern scheme of stratigraphic classification and grouped the lithounits of Goa into four formations. The stratigraphic succession proposed by Gokul et al. (1985) is presented in Table 1 along with the proposed revision. In their scheme of classification all the granitic gneisses and the granites from Goa were considered coeval and intrusive into the metasediments (e.g. Harinadha Babu et al. 1981b; Gokul et al. 1985). The basement for the supracrustal sequence was not clearly identified. The Goa Group typically has a greenstone dominated sequence at the base which is overlain by a metaconglomerate over which rests a dominantly clastic sequence. The metaconglomerate (tilloid) was assigned the status of a para-conglomerate. The granitic gneisses in Goa are exposed at four different localities and are referred to as (i) Chandranath granite gneiss, (ii) Tamdi felspathic gneiss, (iii) Dudhsagar granite, and (iv) Canacona granite. They are all considered as intrusives into the supracrustals (greenstones) by Gokul et al. (1985). The Chandranath granite gneiss was considered to be syntectonic with the first phase of folding, the Tamdi felspathic gneiss and the Dudhsagar granite were considered to be synkinematic with the second phase, whereas the Canacona granite was considered to be post-tectonic (Gokul et al. 1985). In the light of the recent work (Dhoundial et al. 1987; Devaraju et al. 2007, 2010; Dessai et al. 2009) especially on the granitic gneisses, greenstones and the intrusive granites from representative sections, it is proposed to revisit the classification of the greenstones from this area. The Goa Group of Gokul et al. (1985) needs to be integrated (see also Devaraju et al. 2010) with the contiguous Dharwar Supergroup of WDC, as otherwise it would give an erroneous impression of forming a separate stratigraphic entity within the Dharwar craton. The Goa Group (e.g Gokul et al. 1985) denotes a local classification confined to Goa and is here devided into two groups namely the Barcem Group and the Ponda Group which correspond respectively to the Bababudan and Chitradurga Groups of the Dharwar Supergroup in the unified regional classification. The proposed stratigraphic scheme is listed in Table 1.

CHARACTERISTICS OF GNEISSIC ROCKS

***Anmode Ghat Trondhjemite Gneiss**:* The gneiss is exposed at Anmode (Tamdi felspathic gneiss of Gokul et al. 1985) along the Panaji-Belgaum National Highway (NH 4A) and is amongst the oldest gneisses from India that has yielded an Rb/Sr whole-rock age of 3400±140 Ma (Dhoundial et al. 1987). Recent Sm-Nd and U-Pb work has provided ages of about 3300 Ma (Devaraju et al. 2007). Temporally the gneiss is nearly equivalent to the Gorur Gneiss from Hassan district of Karnataka [34 point Rb/Sr isochron age of 3315±54 Ma (Beckinsale et al. 1980); with very low $^{87}Sr/^{86}Sr$ ratio of 0.7006] that has yielded an equally older age. These grey gneisses, that are older than 3,000 Ma, are included along with the younger ones (~ 2600 Ma) under the Peninsular Gneissic Complex. It consists of a complex assemblage of migmatites, gneisses and granitoids and forms a back-drop for the schist belts scattered within the gneisses. Most workers agree to its polyphase and polymigmatitic nature, which has been supported in recent years by isotope studies and radiometric dating. The Anmode Ghat gneiss is fine grained, granulated and has a metamorphic fabric. The foliation trends N-S and dips 60-70^{o} west. Petrographically it varies in composition from trondhjemite, tonalite to granodiorite (TTG). It is essentially an orthogneiss as shown by low initial strontium ratios ($^{87}Sr/^{86}Sr$) of 0.7016±0.0005, low potassium (K_2O: <1 wt%; Na_2O/K_2O: 2.63) content, negative ε_{Nd} : -7 (Devaraju et al. 2007) and by the morphology of the accessory zircons.

The trondhjemite-tonalite gneisses (TTG suite) are also

Table 1. Lithostratigraphic classification of rocks from Goa (*after* Gokul et al. 1985; and the proposed revision)

After Gokul et al. (1985)			Proposed Revision		
			Basic Intrusives		Metadolerite/Dolerite
			Canacona Granite	2395±390 (?) Ma	Porphyritic potassic granite
			Mafic-ultramafic layered complex	Peridotite-Gabbro	Dunite-peridotite-gabbro complex and equivalents
		Metadolerite		Vagheri Formation	Metabasalt Argillite and metagreywacke
Basic Intrusives		Dolerite, Gabbro	Ponda Group (≡ Chitradurga Group)	Bicholim Formation	Banded ferruginous quartzite Manganeferous chert breccia with pink ferruginousphyllite Limestone Pink ferruginous phyllite Quartz-chlorite-amphibolite-schist
Chandranath Granite Gneiss	2600±100 Ma	Granodiorite		Sanvordem Formation	Metagreywacke Argillite,quartzite,tilloid
	Vagheri Formation	Metabasalt Argillite and metagreywacke	~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ Unconformity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~		
Goa Group	Bicholim Formation	Banded ferruginous quartzite Manganiferous chert breccia with pink ferruginous phyllite Limestone Pink ferruginous phyllite Quartz-chlorite-biotite-schist	Barcem Group (≡ Bababudan Group)	Barcem Formation	Matagabbro Peridotite, talc-chlorite schist Quartzite, quartz-sericite-schist Red Phyllite Quartz porphyry Massive, schistose and vesicular metabasalt
	Sanvordem Formation	Argillite, quartzite, tilloid	~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ Unconformity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~		
	Barcem Formation	Metagabbro Peridotite, talc-chlorite-schist Quartzite, quartz-sericite-schist Phyllite Quartz-porphyry Massive, schistose and vesicular basalt	Chandranath Granite Gneiss	2700-2900 Ma	Granodiorite
Basement: not identified			Anmode Ghat trondhjemite gneiss	3300-3400 Ma	Basement: trondhjemite-tonalite-granodiorite

exposed in the south at Chauri, Palolem and Agonda in the Canacona *taluka* along a WNW-ESE belt that attains a width of over 5 km towards the coast in the west and pinches out in the east. These gneisses are heterogeneous, polyphase gneisses/migmatites that consist of both the mafic and felsic (tonalitic) palaeosomes, and felsic neosomes (granodiorite-granite-pegmatite) reminiscent of the Londa migmatite gneiss (Ramnagar granitoids of Devaraju et al. 2007). At places, the gneiss contains lenticular enclaves of schistose amphibolites that are likely restite after the extraction of partial melt that formed the TTG suite. The hornblende within the schistosity defines a preferred WNW-ESE lineation within the plane of foliation. Two generation of felspars are seen. Quartzofelspathic augens are seen along the planes of foliation, some of which show replacement by the late K-feldspar (microcline) which is indicative of the activity of metasomatic fluids from the intrusive granites. The gneiss is compositionally similar to the Anmode gneiss and in particular also contains low abundance of K_2O [(<1-2 wt%), author's unpublished data] like the latter, however, its correlation with the Anmode gneiss could be confirmed from isotope systematics. The TTG suite is flanked by greenstones of the Barcem Formation both to the north and south. The gneisses are intruded by late granites (Canacona Granite) described later. The pods and lenses of hornblende are replaced by biotite indicating retrogression. The gneisses display a foliation that trends WNW-ESE and dips by 70° NNE.

A crudely developed quartz-pebble conglomerate horizon is exposed at Nagargali in Karnataka. It rests on the trondhjemite gneisses and is overlain by metavolcanics and metasediments of the Barcem Formation of Gokul et al. (1985). At places the gneiss occurs as metre long inliers within the supracrustal assemblage and forms the basement for the latter. The conglomerate is possibly the equivalent of the Walkunje and the Kalaspura conglomerates at the base of the Bababudan Group in the Dharwar craton. Dhoundial et al. (1987) described it as a meta-arkosic conglomerate.

***Chandranath Granite Gneiss*:** It is exposed at Paroda, Quepem (Gokul and Srinivasan, 1976) and extends in general E-W from Sanguem in the east to Colva-Banaulim in the west over a length of more than 22 km and is over 11 km wide. It is well foliated, the foliation trends NE-SW and dips by 50° east. Gokul et al. (1985) and Dhoundial et al. (1987) considered it to be intrusive, synkinematically with the first phase of folding of the metasediments. However, distinct intrusive relationship between the gneiss and the metasediments is no where available for observation (also Ramakrishnan, *per.comm.*).

It is a grey granitic gneiss that varies in composition from granodiorite to quartz-diorite. The Rb/Sr age obtained for it is 2650±100 Ma (Dhoundial et al. 1987). Recent Sm-Nd isotope studies provide model ages of about 2900 Ma (Devaraju et al. 2007) indicating that the protoliths are either younger than the trondhjemites or are less enriched in light rare earth elements. A similar gneiss exposed along the eastern border of the State and referred to as the Londa migmatitic gneiss is considered to be contemporaneous with the Chandranath granite gneiss. The recent age data (e.g. Devaraju et al. 2010) suggest that these gneisses are distinctly younger that the basement trondhjemite gneisses from the Dharwar craton. They form the basement for the Sanvordem Formation of the Ponda Group. The relationship between the gneiss and the supracrustal assemblage is best exposed to the east of Sanvordem railway station where the metaconglomerate with granite-clast unconformably rests on the gneiss and contains stretched pebbles of granitic gneiss along with those of vein-quartz in a chlorite-rich matrix. Devaraju et al. (2007) also describe the conglomerate as resting on the basement of Chandranath granite gneiss.

***Layered Intrusion*:** The emplacement of the Chandranath granite gneiss was followed by the intrusion of gabbroic rocks (e.g. Jena, 1980, 1985) which were later identified to form a layered peridotites-gabbro complex (e.g. Balakrishnan et al. 1992; Dessai et al. 2009). Dessai and Peshwa (1982) have shown that the complex is intruded along a major shear zone that runs NW-SE. It consists of a series of at least four plutons that provide evidence for the north-south continuity of the complex. The outcrops occur at Pernem, Valpoy, Bondla, and Canacona. The well exposed ones are those at Bondla and Canacona, both of which show ultramafic rocks at the base followed by mafic gabbros, leucogabbros and rarely by granophyric rocks at the top. The ultramafic zone consists of cumulates of chromitite layers alternating with those of olivine (Dessai et al. 1995). The mafic zone shows uniform layering (Dessai et al. 2009). These layered intrusives were placed stratigraphically higher than the 'intrusive' Chandranath granitic gneisses (Gokul et al. 1985). However, according to Devaraju et al. (2010) the complex is enclosed within the supracrustal rocks and as such was emplaced during the early stages of the basin formation and prior to the deposition of the supracrustals.

Canacona Granite: It is exposed at Char Rasta-Chauri, Palolem and Agonda, in Canacona *taluka* (Srinivasan and Gopalakrishnan, 1985). Harinadha Babu et al. (1981b) and Gokul et al. (1985) have included this granite as equivalent to the Chandranath granite gneiss. As per the latest geological and mineral map of Goa (GSI, 1996), the granite is depicted as intrusive into the TTG gneisses. It has been dated at 2395±390 Ma (e.g. Dhoundial et al. 1987), however, due to the large error factor, the age data are rather suspect. The granite is distinctly late, unfoliated, and exhibits a discordant relationship with the WNW-ESE foliation of the older TTG gneiss/migmatite (Fig. 1). It is potassic in comparison with the host gneiss/migmatite which is strongly foliated, and relatively sodic. Exposures at Palolem and Agonda occur as bosses and plutons. The contacts are sheared, patches and shreds of older gneiss can be traced on either sides of the younger intrusive phase. The granite is coarse to very

Fig.1. Discordant relationship between the foliation of the TTG gneiss/migmatite and the younger intrusive granite, at Palolem, Canacona. In the vicinity of the contact zone relicts of the host gneiss are seen. Note the homogeneous, even grained, structureless, leucocratic granite (foreground) cuts across the foliation of the gneiss. The rock bears textural similarities with the Ramnagar migmatite described by Devaraju et al. (2007).

coarse grained compared to the gneiss, grey to pinkish grey in colour and contains relict phases from the host TTG gneiss. The gneiss in the vicinity of the granite, contains K-felspar megacrysts that have grown along and across the foliation. The megacrysts are bent and fractured providing evidence of plastic and brittle deformation. The granite can be traced up to Palolem sea shore in the west and continues north up to Agonda. In the south it occurs discontinuously up to Polem and even beyond to Sadashivgarh and Karwar in Karnataka. Enclaves and rafts of metasediments are invariably intruded by aplite-pegmatite veins.

The rock is often porphyritic with megacrysts and phenocrysts of microcline, perthitic feldspar and plagioclase in a groundmass dominated by quartz, biotite and hornblende. Felspar megacrysts surround and include plagioclase and biotite of older generation. New K-felspar (microcline) has grown and it is interconnected with similar phases probably indicating melt injection. The rock is high in K (2.91-3.7 wt% K_2O; Na_2O/K_2O: 0.57), Rb (103-162 ppm) and moderate Sr (118-250 ppm) (author's unpublished data). According to Gokul et al. (1985) it is synkinematic with the second phase of folding. Dhoundial et al. (1987) have dated this granite at 2395±390 Ma, but the dates cannot be considered definitive. However, considering its late intrusive nature and distinct compositional identity, it is suggested that it may be a late phase of the Closepet granite (~2500 Ma).

Two small outcrop of hornblende granite (~ 7 sq km) are exposed around Dudhsagar railway station. The rock consists of quartz, plagioclase, K-felspar and hornblende. It is a high-K rock that varies in composition from adamellite, granodiorite to quartz-monzonite (Devaraju et al. 2007). The contact zone of the granite with the quartz-chlorite-schists is migmatised. It is considered to be synkinematically intrusive (Gokul et al. 1985) into the metavolcanics and metasediments. However, Dhoundial et al. (1987) consider it to be a late to post-tectonic intrusion. The granitic rocks are intruded by quartzofelspathic pegmatites and by quartz veins that in general trend NW-SE and WNW-ENE. In the light of Sm-Nd isotope systematics, Devaraju et al. (2007) suggest that the granite is as old as the Chandranath granitic gneiss.

The LIL-enriched character coupled with field relations and textural characteristics suggest an anatectic origin for the granite; the melt having derived either at the expense of the host gneiss itself or from a mixture of greywacke-argillite (e.g. Dhoundial et al. 1987). Devaraju et al. (2007), however, consider it to be a part of the basement. The WNW-ESE gneiss-granite belt is flanked by the greenstones of the Barcem Formation which rests on a basement of the trondhjemitic gneiss (Dhoundial et al. 1987). A poorly developed (patchy) conglomerate is seen exposed at the base of the metavolcanics. Intrusive relationship of the gneiss with the metavolcanics of the Barcem Formation is conspicuously absent.

PROPOSED REVISION OF THE GOA GROUP

In the light of the aforesaid, a revision of the classification of the Goa Group (e.g. Gokul et al. 1985) is warranted. The lithological characteristics of the supracrustal rocks permit the subdivision of the Goa Group (e.g. Gokul et al. 1985) into two sequences of greenstones (Fig.2). The lower sequence that rests on the TTG gneisses with a quartz-pebble conglomerate is largely dominated by mafic volcanics with intercalated clastics. It was designated as the Barcem Formation of the Goa Group by Gokul et al. (1985). This sequence is elevated to the status of a 'Group' which is formally named as the Barcem Group. The 'Group' as per the provisions of international stratigraphic guide (Hedberg, 1976, p.34) should consist of more than one Formation. However, considering the lithological and the facies variation within the Barcem Formation, it is felt that detailed mapping may eventually lead to its division into more than one Formation. It bears many similarities with the lower part of the Kalaspura Formation of the Bababudan Group.

The upper sequence of supracrustals, that makes up the three formations namely the Sanvordem, Bicholim and

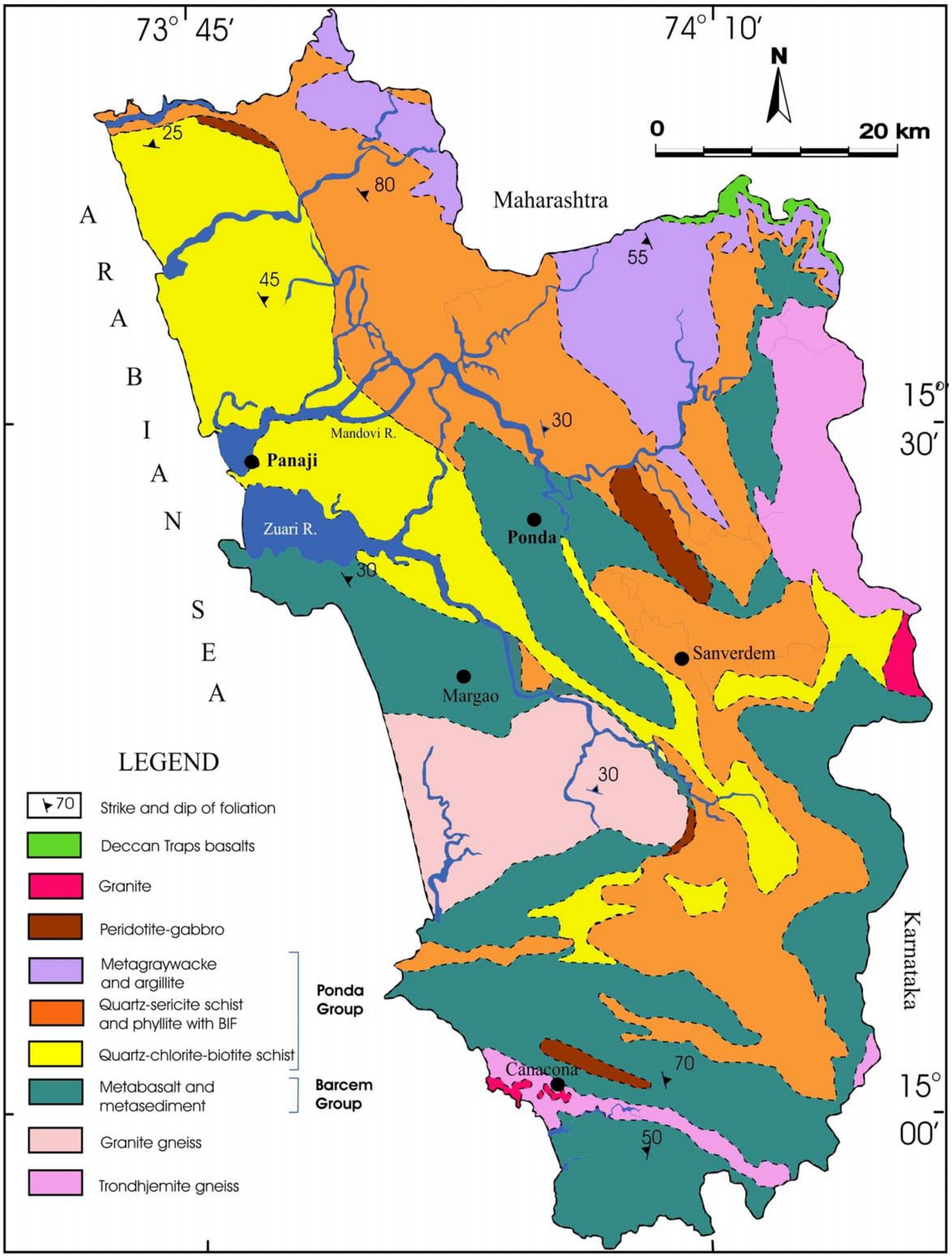

Fig.2. Geological map of Goa (revised after GSI, 1996, by integrating arguments based on the field, petrological, geochemical and isotope data following the works of Dhoundial et al. 1987; Devaraju et al. 2007; 2010; Dessai et al. 2009).

Vagheri, is assigned to a new stratigraphic group for which the formal term Ponda Group is proposed. This seems to be appropriate and reasonable. Moreover, the correlation of this group with the Chitradurga Group of the Dharwar Supergroup is justified in agreement with Gokul et al. (1985). The characteristics of the lithounits are described below.

Barcem Group

The newly identified Barcem Group is best developed to the southeast of Barcem village and account for a thickness of over 2 km, however, in the northwest between Margao and Vasco-da-Gama the rocks attain a thickness of about 2.5 km (Ram Das and Ramprasad Rao, 2001). It has a quartz-pebble conglomerate at the base and the lithounits consist of metavolcanics with intercalations of quartzites and pelites. The volcanics are represented by basic and felsic (?) lavas, agglomerates and tuffs. The metasediments consist of quartzites, quartz-sericite-schists, quartz-chlorite-schists and minor phyllites.

Non-vesicular metabasalts are exposed around Astagal, Polem, Padi and Subdalem in the south and Tisk (Usgao)-Dharbandora in central Goa. Vesicular metabasalts are exposed to the north of Gulem, at Barcem and along the Saleri-Vagon road in Canacona *taluka*. At places phyllitic intercalations are noticed. These probably represent the metamorphosed tuffs. Well preserved pillow lavas are described from Gokuldem-Maina section (Gokul et al. 1985). The basalts at the base of the Mormugao headland are schistose and at places vesicular. Those from Bogmalo are vesicular, amygdaloidal and are dominated by pyroxene and at places contain olivine (Devaraju et al. 2010). The basalts in general, consist of saussuritised plagioclase and uralitised pyroxene forming actinolite, chlorite, epidote, clinozoisite along with opaques.

Metavolcanics that could be silicic lavas or pyroclasts are exposed at Barcem. They are represented by quartz-sericite-schists and quartz porphyry. At places they are crushed and contain porphyroclasts of quartz in a pulvurised quartz-sericite matrix.

Ponda Group

The Ponda Group is best developed around Ponda town where most of the lithologies are well exposed. It comprises three formations which in ascending order are the Sanvordem Formation, Bicholim Formation and the Vagheri Formation, all of which are dominated by clastics with very subordinate mafics only in the Vagheri Formation. Around Ponda, the total thickness of this group is about 8.8 km (Ram Das and Ramprasad Rao, 2001).

Sanvordem Formation: The Sanvordem Formation rests on the Chandranath granite gneiss with a polymict metaconglomerate at the base and comprises metagreywacke, and argillites. The conglomerate consists of stretched and elongated pebbles of quartzite and gneiss in a schistose chlorite matrix. The proportion of lithologies varies considerably from place to place, so much so that one single lithology may be present to the complete exclusion of the other members. The best section of this formation is exposed along the railway tract between Sanvordem railway station and Periudoc. In this section it has a thickness of over 1.2 km. To the east of Kalay railway station the lithounit is a metagreywacke which containds intercalations of metaconglomerate. It is also well exposed between Bati and Keri south of river Tiracol. Exposures occur at Ribandar in the vicinity of Panaji where it consists of metagreywacke with subordinate metaconglomerate. The exposures across River Mandovi between Aguada and Baga are dominated by thinly bedded (laminated) argillites. The meta-conglomerate consists of stretched lenticular pebbles and boulders of quartzite and granite gneiss (particularly at Sanvordem) that vary in size from 10 x15 x 25 cm along the longer dimension and are enclosed in a schistose matrix dominated by chlorite.

The metagreywackes are faintly schistose and show graded bedding. The rock consists of sub-angular quartz, plagioclase and lithic fragments in a matrix of sericite, chlorite and quartz. The argillites are light to deep grey and consist of quartz in a sericite-chlorite matrix with opaques. Rarely biotite has formed at the expense of chlorite. A detailed account of the petrography of the conglomerates is available in Devaraju et al. (2010).

Bicholim Formation: This Formation can be traced over the entire length of Goa (~ 185 km) in a NW-SE direction from Naibag in the northwest to Salgini in the southeast. The average true thickness of the Formation is about 1.4 km (Gokul et al. 1985). It consists of amphibole schists, ferruginous and manganiferous phyllites, limestones and banded ferruginous quartzites (BHQ) that occur as intercalations within the phyllites. The BHQs serve as the protores for the iron ore deposits that are extensively developed in this formation. The BHQs are thinly laminated and consist of alternate laminae of hematite/magnetite and chert. Magnetite is invariably martitised. The banded iron formation (BIF) consists of two subfacies- the haematite sub-facies and the magnetite sub-facies, both of which show interdigitated relationship. The hematite sub-facies predominates in the northwestern and central part (from Advalpal to Dharbadora) of the State whereas the magnetite sub-facies is largely confined to the central and the southeastern part (Costi to Barazana-Villiena). Calcareous (carbonate facies of BIF) and carbonaceous (sulphide facies) intercalations are common. Manganese being an inseparable associate of iron in almost all BIF the world over, both these exhibit a zonal distribution pattern. Broadly the iron-rich protores are confined to the northern part of the formation, northwest of Sanguem, whereas the manganese-rich protores are confined to the southern part of the State, largely to the south of Sanguem between Rivona and Salgini.

The dominant lithology is represented by quartz-chlorite-tremolite schists followed by ferruginous phyllites which is a ubiquitous lithology of this formation. The rock consists of tremolite and chlorite with quartz and opaques as accessories.

Limestone exposures are rare and occur to the northeast of Goa. Calcareous intercalations also occur in association with the phyllites and are encountered in bore holes below the manganiferous phyllites. They are also intercalated by cherts. The rock consists of calcite and dolomite with some tremolite.

Vagheri Formation: The topmost formation of this Group is represented by Vagheri Formation which conformably overlies the Bicholim Formation. It is best exposed to the northeast of Valpoy. It comprises metagreywacke-argillite with intercalated metabasalts. The metagreywackes are grey to greyish green, compact and exhibit poorly developed schistosity. The rock consists of angular to sub-angular crystic- and lithic-fragments in a fine grained mesostasis made up of quartz, feldspar and chlorite. The rocks are immature with poorly sorted angular and sub-angular clasts of andesitic tuffs (Devaraju et al. 2010).

The metabasalts occur as narrow, lenticular intercalations within the metagreywacke and exhibit a poorly developed foliation at places. The rock is grey to greenish grey, hard, compact and has faint schistosity. It consists of chlorite, tremolite/actinolite, plagioclase, epidote, zoisite, opaques and quartz which may be secondary. The revised classification is presented in Table 1 and the justification is outlined in the following section.

DISCUSSION

Rationale for the Identification of the Barcem Group

Although the Goa Group of Gokul et al. (1985) is considered younger, similar to the Chitradurga Group (e.g. Gokul et al. 1985), it lacks the polymictic granite-clast conglomerate at the base, as seen for example in the Chitradurga and Shimoga schist belts, where the Talya and Kaldurga conglomerates respectively, mark the base of the depositional sequence. A conglomerate, similar to the Talya conglomerate does occur within the Goa Group, however, it is not basal for the latter Group, but occurs above the Barcem Group, and at the base of the overlying Sanvordem Formation.

Recent work has shown, that the basal part of the greenstones (e.g. Gokul et al., 1985), namely the newly established Barcem Group is characterized by a quartz-pebble conglomerate overlain by mafic rocks (with clastic intercalations), some of which show pillow structures whereas others are vesicular (also see Devaraju et al. 2010). The presence of a quartz-pebble conglomerate and greenstones dominated by mafics, show their similarity to the basal lithologies of the Bababudan Group. The Group also rests on a basement of trondhjemite gneiss. The newly identified Group, however, differs from the Bababudan in not having a well developed BIF horizon above the mafic rocks, that in fact is a hallmark of the Bababudan sequence in the type area. As these two groups are not exactly identical, the Barcem Group could be viewed as a 'truncated' sequence of the Bababudan-type sedimentation.

The overlying three Formations of the newly formed Ponda Group are, however, lithologically similar to those of the Chitradurga Group. The existence of a gneissic basement for the sedimentary sequence, larger proportion of clastic sediments than the volcanics and the presence of a limestone-iron-manganese marker horizon show their likeness to the Chitradurga Group sediments with which they are correlated (e.g. Gokul et al. 1985).

The clastics of the Sanvordem Formation rest on the granite-clast conglomerate which consists of pebbles of quartzite and gneiss (some of the pebbles may have been derived from aplites and pegmatites) in a schistose chlorite-rich matrix. This unit could be treated to be equivalent to the Talya and Kaldurga conglomerates from the Chitradurga and Shimoga schist belts. The overlying Bicholim Formation is dominated by chemogenic sediments that contain the BIF and is equivalent to the Vanivilas Sub-group of the Chitradurga Group. The Vagheri Formation overlies the Bicholim and consists of argillites and metagreywacke with volcanic intercalations. This formation broadly corresponds to the Ranibennur Sub-group of the Chitradurga Group.

Thus the mafic volcanism in the case of Chitradurga Group and the Ponda Group occurred towards the terminal phase of sedimentation whereas in the case of the Bababudan and also the Barcem Group the dominant volcanism preceded the deposition of the clastics and chemogenic sediments (e.g. Swami Nath and Ramakrishnan, 1981; Naqvi and Rogers, 1987; Ramakrishnan, 1994; Radhakrishna and Vaidyanadhan, 1997; Ramakrishnan and Vaidyanadhan, 2008). Thus the correlation of the newly identified Barcem Group with the Bababudan and that of the Ponda Group with the Chitradurga Group is justified.

Palaeoenvironmental Considerations

The mafic volcanics at the base of the Barcem Goup indicate volcanic activity both under subaerial and subaqueous conditions in a nascent basin. Possibly recognizing this fact, Oertal (1958) included the lower sequence of mafic rocks under the 'lower infraconglomerate group'. The basinal conditions at the time of deposition of the Ponda Group were different than these. The metaconglomerate indicates shallow water deposition, proximal to the basinal uplift whereas the volcaniclastics represent distal deposits. The BIF of the Bicholim Formation is suggestive of chemogenic precipitation under quieter conditions in relatively deeper parts in closed environments. Lateral variations with the haematite sub-facies in the north progressively grading into the magnetite sub-facies in the central and south Goa represents platformal-type of deposition. Minor limestones and silica suggest presence of algal activity. A change from shelf facies to deeper water facies is indicated by the presence of the manganese-carbonate marker horizon and by the greywacke-argillite association (with intercalated volcanics) of the Vagheri Formation. This unit was deposited under turbidite conditions as evident from abundant turbitite structures seen at Aguada.

The supracrustal assemblage was intruded by the layered mafic-ultramafic complex. The intrusion of the Canacona granite possibly marked the close of sedimentation of this group. Thus, although the Goa rocks in general show characteristics typical of the 'Dharwar-type' sedimentation, strictly the Goa Group of Gokul et al. (1985) conforms neither to the Bababudan nor to the Chitradurga Groups but share peculiarities of both. Hence the division of the supracrustal rocks into two stratigraphic groups, that are distinctly unconformable on their respective basements, is justified.

CONCLUSIONS

The greenstones of the Goa Goup of Gokul et al. (1985) are divisible into two stratigraphic groups. The older group formally named the Barcem Group, has a poorly developed quartz-pebble conglomerate at the base. The Group consists of metavolcanics with intercalations of metasediments and rests on a basement of 3300-3400 Ma Anmode Ghat trondhjemite gneiss. This group is unconformably overlain by the Ponda Group which is a clastics-dominated sequence lithologically similar to the Chitradurga Group and rests on a basement of 2700-2900 Ma Chandranath granite gneiss with a distinct polymict, granite-clast conglomerate at the base. It consists of three formations namely the Sanvordem, Bicholim and the Vagheri (e.g. Gokul et al. 1985) in ascending order. The supracrustal sequence is intruded by the Bondla layered mafic-ultramafic complex which is strongly controlled by a major NW-SE trending shear zone. The post-tectonic Canacona granite distinctly intrudes the trondhjemite-tonalite gneisses and marks the close of sedimentation in the Goa basin. It is an anatectic, potassic granite which is temporally equivalent to the late phases of the Closepet granite activity.

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References

Balakrishnan, S., Abbas, M. H., Vidyadharan, K.T. and Raghunandan, K.R. (1992) Chromite and sulphide mineralisation in the mafic-ultramafic complex of Usgao, Goa. Indian Minerals, v.41, pp.303-322.

Beckinsale, R.D., Drury, S.A. and Holt, R.W. (1980) 3360 Ma old gneisses from the south Indian craton. Nature, v.283, pp.469-470.

Dessai, A.G., Arolkar, D.B., French, D. Viegas, A. and Viswanath, T.A. (2009). Petrogenesis of the layered mafic-ultramafic complex, Usgao, Goa. Jour. Geol. Soc. India, v.73, pp.697-714

Dessai, A.G. and Peshwa, V.V. (1982) Manganese mineralization in the tropical forest area of Goa, India. *In:* D.J.C. Laming and A.K. Gibbs (Eds.), Hidden Wealth: mineral exploration techniques in tropical forest areas. Proc. Seminar of the Association of Geoscientists for International Development, Caracas, Venezuela, pp.170-175.

Devaraju, T.C., Huhma, H.C., Kaukonen, R.J. and Allapieti, T.T. (2007) Petrology, geochemistry, model Sm-Nd ages and petrogenesis of the granitoids of the northern block of western Dharwar craton. Jour. Geol. Soc. India, v.70, pp.889-911.

Devaraju, T. C., Sudhakar, T.L., Kaukonen, R. J., Viljoen, R.P., Alapieti, T.T., Ahmed, S.A. and Sivakumar, S. (2010) Petrology and geochemistry of graywackes from Goa-Dharwar sector, western Dharwar craton: implications for volcanoclastic origin. Jour. Geol. Soc. India, v.75, pp.465-487.

Dhepe, P.D. (1954) A note on the geology, iron and manganese ore deposits of Goa, Poona Univ. Jour. Sci. Tech., v.4, pp 28-29.

Dhoundial, D. P., Sarkar, D. K., Trivedi, J. R., Gopalan, K. and Potts, P. J. (1987) Geochronology and geochemistry of Precambrian granitic rocks of Goa, southwest India. Precambrian Res., v.36, pp.287-302.

Dunn, J.A. (1942) Manganese ore. Rec. Geol. Surv. India, v.76, pp.1-53.

Fermor, L.L. (1909) Manganese ore deposits of India, Mem. Geol. Surv. India, v.37, pp.1-371.

Geological Survey of India (GSI) (1996) Geological and Mineral Map of Goa. Government of India.

Gokul, A.R. and Srinivasan, M.D. (1976) Chandranath Granite, Goa, Rec. Geol. Surv. India, v.107, pp.38-45.

Gokul, A. R., Srinivasan, M. D., Gopalkrishnan, K. and Vishwanathan, L.S. (1985) Stratigraphy and structure of Goa, Proc. Sem. Earth Resources for Goa's Development. Geol. Surv. India, 1-13.

Gopalkrishnan, K. (1976) Canacona granite and its relation to the schistose rocks, Canacona taluka, Goa, Proc. Sem. Precambrian Geology of the Peninsular India, Geol. Surv. India Misc. Publ., v.23, pp.375-379.

Harinadha Babu, P., Ponnuswamy, M.D. and Krishnamurthy, K.V. (1981a) Shimoga Belt. *In:* J. Swami Nath and M. Ramakrishnan (Eds.), Early Precambrian Supracrustals of southern Karnataka. Mem. Geol. Surv. India, v. 112, pp.199-218.

Harinadha Babu, P., Vidyadharan, K.T. and Jayaprakash, A.V. (1981b) Geology and mineral resources of Karnataka and Goa. Misc. Publ. Geol. Surv. India, v.30, pp.1-68.

Hedberg, H.D. (1976) IUGS International stratigraphic guide, John Wiley and Sons, New York, 200p.

Jena, B.K. (1980) Basic intrusives in Pernem taluka. Jour. Geol. Soc. India, v.21, pp.142-145.

Jena, B.K. (1985) Usgao ultramafic-gabbro complex. Jour. Geol. Soc. India, v.26, pp.492-495.

Maclaran, J. M., (1904) General Reports Rec. Geol. Surv. India, v.34, pp.96-131.

Naqvi, S.M., and Rogers, J.J.W. (1987) Precambrian of India. Oxford Monograph on Geology and Geophysics, Oxford Univ. Press, v.6, pp.57-81.

Oertal, G. (1958) A geologia do districto de Goa, Communicacao do Servico Geologico de Portugal, Lisboa, pp.1-40.

Pascoe, E.H. (1950) A Manual of Geology of India and Burma, Govt of India, New Delhi, v.1, 485p.

Radhakrishna, B.P. and Vaidyanadhan, R. (1997) Geology of Karnataka. Geol Soc. India, Bangalore, 353p.

Ramdas, G. and Ramprasad Rao, I. B. (2001) Gravity, magnetic and electrical resistivity studies along the Jadcherla-Panaji subtransect. Workshop on Geoinvestigations along Jadcherla-Goa sub-transect, Department of Geology, Usmania University, pp.4-9 (Extended Abstracts)

Ramakrishnan, M. (1994) Precambrian mafic magmatism in the western Dharwar craton. Jour. Geol. Soc. India, v.73, pp.101-116.

Ramakrishnan, M. and Vaidyanadhan, R. (2008) Geology of India. Geol. Soc. India, Bangalore, v.1, 556p.

Srinivasan, M.D. and Gopalakrishnan, K. (1985) Geology of Canacona area, with special reference to Canacona granite. Proc. Sem. Earth Resources for Goa's Development, Geol. Surv. India, pp.601-602 (Abstract).

Swami Nath, J. and Ramakrishnan, M. (1981) Early Precambrian supracrustals of southern Karnataka, Mem. Geol. Surv. India, v.112, pp.1-350.

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