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Geology, geochemistry and geochronology of the Archaean Peninsular Gneiss around Gorur, Hassan District, Karnataka, India

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Abstract. The Peninsular Gneiss around Gorur in the Dharwar craton, reported to be one of the oldest gneisses, shows nealy E–W striking gneissosity parallel to the axial planes of a set of isoclinal folds (DhF_1). These have been over printed by near-coaxial open folding (DhF_{1a}) and non-coaxial upright folding on almost N–S trend (DhF_2). This structural sequence is remarkably similar to that in the Holenarasipur schist belt bordering the gneisses as well as in the surpracrustal enclaves within the gneisses, suggesting that the Peninsular Gneiss has evolved by migmatization synkinematically with DhF_1 deformation.

The Gorur gneisses are high silica, low alumina trondhjemites enriched in REE (up to 100 times chondrite), with less fractionated REE patterns ($Ce_N/Yb_N < 7$) and consistently negative Eu anomalies ($Eu/Eu^* = 0{\cdot}5$ to $0{\cdot}7$).

A whole rock Rb–Sr isochron of eight trondhjemitic gneisses sampled from two adjacent quarries yields an age of 3204 ± 30 Ma with Sr_i of $0{\cdot}7011 \pm 6$ (2σ). These are marginally different from the results of Beckinsale and coworkers (3315 ± 54 Ma, $Sr_i = 0{\cdot}7006 \pm 3$) based on a much wider sampling. Our results indicate that the precursors of Gorur gneisses had a short crustal residence history of less than a 100 Ma.

Keywords. Archaean; trondhjemites; geochemistry; Rb–Sr geochronology; Peninsular gneiss; syntectonic emplacement; evolution of continental crust.

1. Introduction

Archaean gneiss complexes which host the greenstone belts are polycyclic in origin. Relicts of gneisses generated during early cycles rarely retain their identity because of superposed deformation, metamorphism and anatexis leading to migmatization which obliterates the memory of early events. The Peninsular Gneiss complex of southern India is one such polymigmatite-gneiss complex which has a long history of evolution from ~3300 to 2500 Ma ago (Beckinsale *et al* 1980; Taylor *et al* 1988). Three groups of Rb–Sr ages have been measured in the Peninsular Gneiss — 3300 ± 100 Ma, 3000 ± 100 Ma and 2500 ± 100 Ma (Pichamuthu and Srinivasan 1984). Relicts of 3300 Ma and older gneisses are rare in the Peninsular Gneiss terrane. They were first recognized in the gneisses exposed between Hassan and Gorur in the western part of Karnataka from a five-point whole-rock Rb–Sr isochron age of 3358 ± 66 Ma (Beckinsale *et al* 1980). Further dating of these gneisses based on a 34-point Rb–Sr whole-rock isochron and a 11-point whole-rock Pb–Pb isochron reconfirmed the earlier result at 3315 ± 54 Ma($Sr_i = 0{\cdot}7006 \pm 3$) and 3305 ± 13 Ma($\mu_1 = 8{\cdot}0$), respectively (Beckinsale *et al* 1982). Ancient gneisses of comparable age have subsequently been found in the Anmod Ghat region of Goa (Dhoundiyal *et al* 1987).

Monrad (1983) in his study of sialic terranes in the vicinity of Holenarasipur schist belt classified the gneisses into "Hassan gneisses" and "marginal gneisses". "Hassan gneisses" were described as gray, foliated, veined, folded, low alumina trondhjemite gneisses generally free of inclusions. They were further classified into high silica ($>75\%\,SiO_2$), high Zr (mean 557 ppm), low Rb (mean 1·3 ppm) and intermediate varieties. All of them show less fractionated REE patterns with negative europium anomalies. Their relation to the Holenarasipur schist belt is unknown. They yield Rb–Sr ages of 3162 ± 61 Ma(Sr_i 0·7020 ± 1), 3139 ± 31 Ma(Sr_i 0·7015 ± 3) and 3071 ± 67 Ma(Sr_i 0·7008 ± 10).

The "marginal gneisses" by contrast have been described to be generally massive, unfoliated high alumina trondhjemites intrusive into Holenarasipur schist belt. However, they have been found to be folded on N–S axis at least in one place. These inclusion-rich gneisses have yielded Rb–Sr isochron ages of 2959 ± 24 Ma (Sr_i 0·7019 ± 2) (Monrad *op. cit.*).

Several other trondhjemite plutons of about 3000 m.y. age have been found in western Karnataka (see Taylor *et al* 1984; Rogers and Callahan 1989).

The "Hassan Gneisses" of Monrad are from the same Hassan-Gorur region studied by Beckinsale *et al* (1980), but their ages differ from that of latter by more than experimental error. Further, the age relationship between the "Hassan gneisses" and the greenstone belt is not clear. In order to resolve the age discrepancy and gain some insight into the gneiss-greenstone relationship we have carried out a more focussed sampling of the Gorur-Hassan gneiss for their geochronology, after a careful study of its structural history in relation to that of the adjoining greenstone belt.

2. Geology and structural history

The Peninsular Gneiss of the Hassan-Gorur area is similar to many other Archaean gray gneiss complexes. Fresh outcrops of these gneisses are exposed in a number of quarries on either side of the Hassan-Gorur road to the south of Hassan. They form a part of the granite-gneiss terrane to the west of the Holenarasipur schist belt, one of the Dharwar schist belts. The schist belt as well as the gneisses have been invaded by 3·0 Ga old trondhjemites (Monrad 1983) about 3 km to the southeast of the study area (figure 1).

The gneisses are well-foliated and show thin banding. They are similar to "Hassan gneisses" of Monrad (1983). Amphibolites occur as several centimetre thick bands parallel to gneissosity. Irregularly-shaped ultramafic and anorthositic enclaves occur in these gneisses near Kattaya and to the east of Arakalgud respectively. Quartzofeldspathic veins (pegmatites and aplites) are generally parallel to the gneissic banding although some of them are seen to transect the foliation.

The gneissic foliation in this sector is nearly E–W in contrast to a major part of the Peninsular Gneiss terrane, where the strike of foliation ranges from N to NNW. This foliation is parallel to the axial planes of a set of isoclinal folds in quartzofeldspathic layers which constitute an integral part of these gneisses. Absence of any planar structure, coupled with the development of pinch-and-swell structures in these layers where they are subparallel to foliation~~,~~ and buckle folding when they are at high angles to foliation (figure 2), indicates that the quartzofeldspathic layers were emplaced late synkinematically with reference to the isoclinal folding. These isoclinal folds

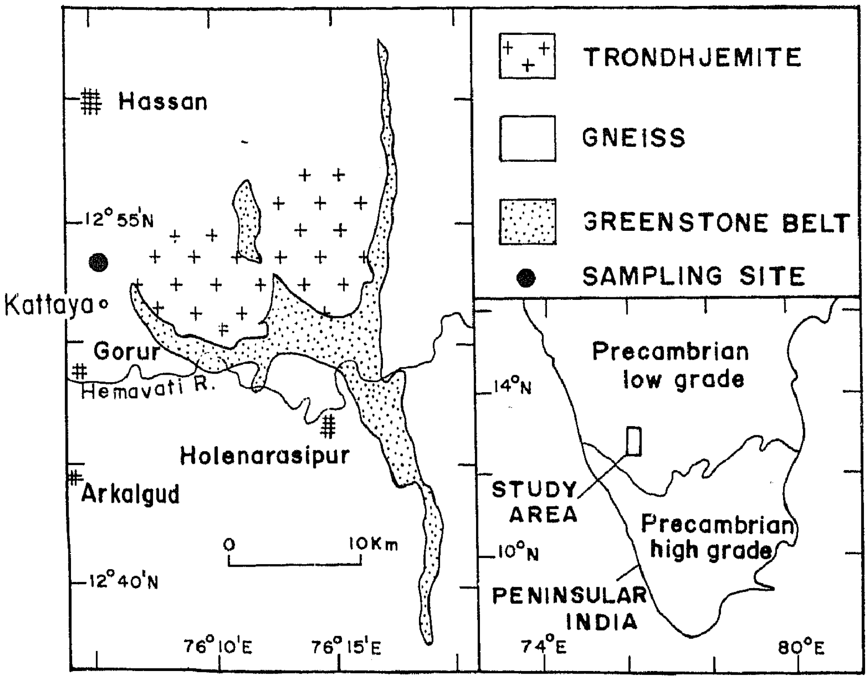

Figure 1. Geological sketch map of Hassan-Gorur region showing the Holenarasipur schist belt and the location of the quarries where the gneiss samples were collected.

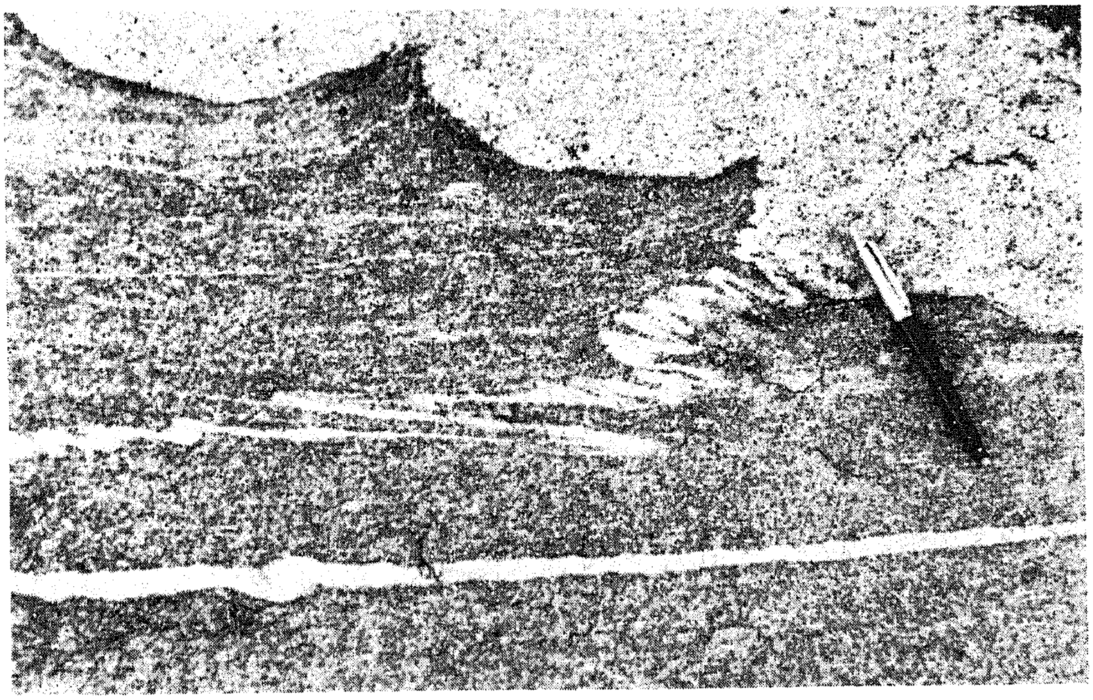

Figure 2. Development of pinch-and-swell structures and buckle folds in quartzofeldspathic veins depending on whether they are parallel or at high angles to the foliation. Quarry near 10 km marker on Hassan-Gorur Road.

(DhF_1) are affected by near-coaxial open folding (DhF_{1a}) (figure 3) followed in turn by upright folding with the nearly N–S striking axial planes (DhF_2) (figure 4). A penetrative axial planar schistosity has developed with the DhF_2 folding at some

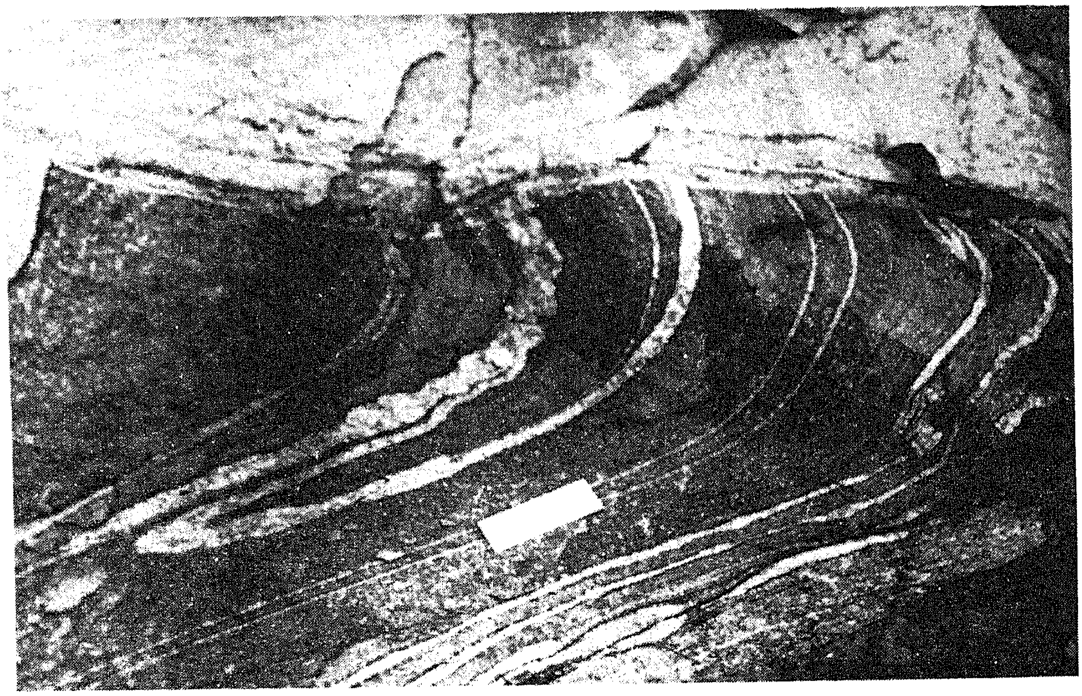

Figure 3. Peninsular Gneiss of Hassan-Gorur region showing DhF_1 isoclinal folds involved in coaxial refolding in DhF_{1a}. Quarry near 10 km marker on Hassan-Gorur Road.

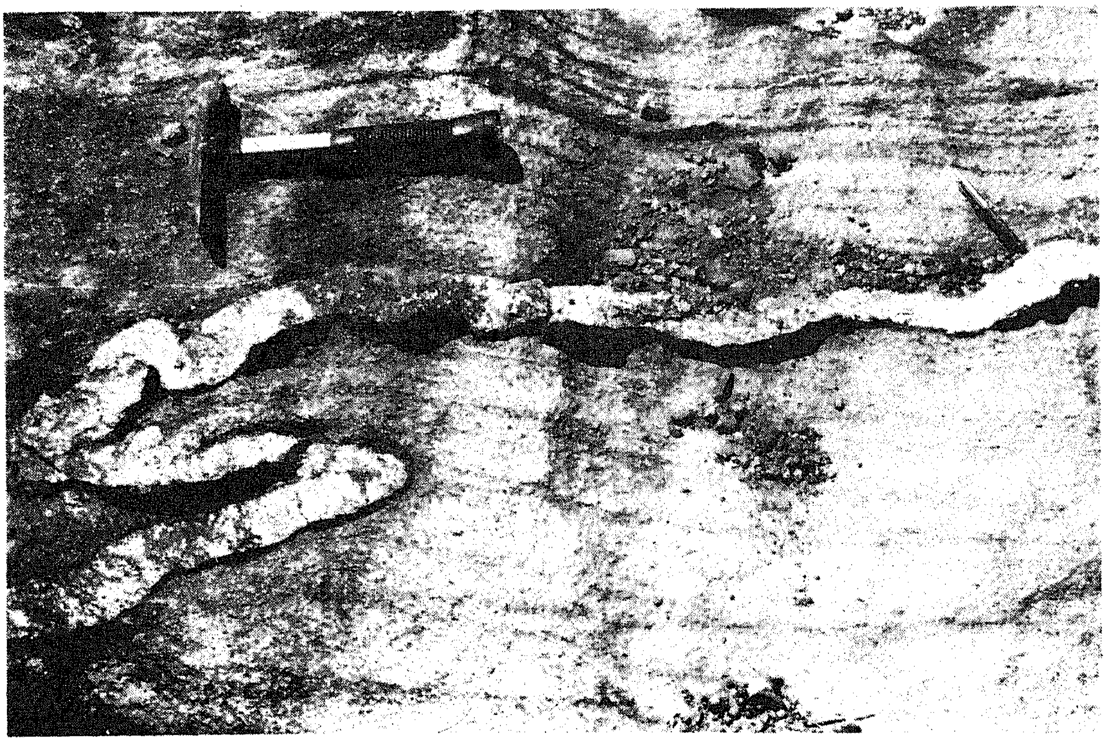

Figure 4. DhF_2 upright open folds with N–S axial planes affecting the limbs of isoclinally folded quartzofeldspathic veins (location as in figure 2).

places. However, this later schistosity is very weak or nearly absent in the Peninsular Gneiss of Hassan-Gorur sector.

The structural sequence observed in the gneisses is identical with that in the

Holenarasipur schist belt to the east. Just as in the Gorur gneisses, the western arm of the Holenarasipur schist belt displays isoclinal early folds with E–W striking axial planes (DhF_1). The axial planes of these folds as well as the foliation parallel to them have been refolded almost coaxially during DhF_{1a}. A set of upright folds with N–S striking axial planes has been superimposed on the earlier structures (DhF_2). It is significant that the enclaves of amphibolites, ultramafic rocks and anorthosites in the gneisses also record the same structural history. This structural similarity between the gneisses and schist belts and lithological similarity of the schist belt and enclaves in the gneisses suggest that the Peninsular Gneiss around Gorur is a product of migmatization synchronous with the earliest deformation.

3. Petrography

The quartzofeldspathic constituents of the foliated gneisses of the Gorur area still retain xenomorphic or hypidiomorphic granular fabric. Except for minor undulose extinction, slightly bent twin lamellae in plagioclase, and gentle bending of cleavages in biotites, the rocks show little evidence of post-crystalline deformation. Besides these features, Monrad (1983) cited clear plagioclase, normal zoning and lack of 120° junctions among minerals showing a generally intergranular fabric as evidence for the absence of significant recrystallization. The foliation in these gneisses is parallel to DhF_1 axial planes.

Plagioclase and quartz are the most dominant minerals. Plagioclase (oligoclase) is characterized by complex twinning (albite-ala). Minor amount of microcline is invariably present in all the samples examined. Although microcline occurs as patch perthite in plagioclase, it is mainly observed as discrete grains without any replacement relation with plagioclase. Therefore it is interpreted to be primary. Biotite occurs as rectangular tablets showing mainly green pleochroism. Biotites with dark brown pleochroic colour are also present. They exhibit pleochroic halos around allanite inclusions. In rare instances hornblende breaking down into biotite-sphene assemblage can be seen. Sphene is the dominant accessory. Apatite, zircon, magnetite and epidote are other accessory minerals. Most feldspar grains are fresh, with near complete absence of saussuritization or sericitization. However, rare instances of development of white mica after plagioclase have been noted.

The amphibolites interbanded with gneiss show schistose granoblastic fabric with minerals showing polygonal outline. They are composed of blue green amphibole, with biotite developed usually at their margin. Sphene and epidote are usually associated at such sites. In an amphibolite that transects the DhF_1 foliation, porphyroblasts of garnet show sieve texture. They consist of inclusions of quartz of the same size as those found outside the garnet grains. No evidence of rotation of garnets has been observed. The garnets are clearly post-tectonic. Evidence of post-crystalline deformation is very weak in amphibolites as in the associated quartzofeldspathic gneisses. It is restricted to undulose extinction and slightly bent cleavages. In rare instances penninitic chlorite interbanded with biotite has been seen. In this association no clinozoisite or epidote was observed.

4. Petrochemistry

4.1 *Analytical methods*

Powders for analysis were prepared from 7 to 10 kg size samples. Major and minor elements were analysed by X-ray fluorescence using lanthanum-doped fused beads with an accuracy of about 2%. Na_2O was analysed by atomic absorption spectroscopy (AAS). Trace elements including REE were determined on an inductively coupled plasma mass spectrometer (ICP–MS) with an accuracy of better than 5 per cent for most elements.

For Rb and Sr isotopic analysis, about 100 mg of sample powder was digested in hydrofluoric and nitric acid mixture. Rb and Sr fractions were separated by cation exchange chromatography following spiking with ^{87}Rb and ^{84}Sr-enriched tracers. Isotopic measurements were carried out on a VG 354 thermal ionization mass spectrometer. Total process blanks for Sr and Rb were about 0·8 ng and 0·3 ng respectively. Mean of 24 measurements of the Sr standard SRM-987 was 0·71024 ± 4 ($2\sigma_m$). Analytical precision for Sr and Rb was better than 0·2% and 0·8% respectively.

A program after Provost (1990) was used for calculation of Rb–Sr isochron slope and intercept using a blanket error of 1% in $^{87}Rb/^{86}Sr$ and 2σ analytical error in each $^{87}Sr/^{86}Sr$ measurement. ^{87}Rb decay constant used was $1{\cdot}42 \times 10^{-11}\,y^{-1}$. The errors in age and initial Sr isotopic composition (Sr_i) are two standard deviations of the mean.

4.2 *Chemical characteristics of gneisses of Gorur region*

Major, trace and rare earth element data for the gneisses and the associated amphibolite are given in table 1. The K_2O/Na_2O ratio in gneisses ranges from 0·07 to 0·39 which is typical of tonalites and trondhjemites. In the normative Or–Ab–An diagram of O'Connor (1965) modified by Barker (1979), their trondhjemitic composition is evident (figure 5). The Gorur trondhjemites with more than 75% SiO_2 are similar to the siliceous gneisses of the Ancient Gneiss Complex of Swaziland (Cf. Hunter *et al* 1978 and Hunter 1979). TiO_2 ranges from 0·31 to 0·68% which at the observed level of SiO_2 is high for orthogneisses. Werner (1987) distinguished ortho- from para-gneisses in a P_2O_5/TiO_2 vs MgO/CaO plot. The wide range of P_2O_5/TiO_2 ratio from 0·2 to 0·6 against MgO/CaO variation between 0·2 and 0·94 suggests that these rocks are orthogneisses. The low initial $^{87}Sr/^{86}Sr$ ratio given later also does not support a sedimentary precursor. With less than 13% Al_2O_3, the Gorur gneisses are classified as low alumina trondhjemites of Barker (1979). Monrad (1983) also observed the low alumina character of the "Hassan gneisses". Low alumina trondhjemites are relatively less common in Archaean gneiss complexes (Condie 1981, p. 188). Webb Canyon gneiss in the United States and parts of Ancient gneiss complex of Swaziland (Hunter 1979) are some other examples of such low alumina Archaean trondhjemites. In the FMA plot (figure 6), despite a trondhjemitic composition, the Gorur gneisses follow a tholeiite trend similar to the Amitsoq augen gneisses, oceanic plagiogranites and continental and Red sea granophyres (see Collerson and Bridgwater 1979; Coleman and Donato 1979). Compared to the oceanic plagiogranites, however, their K_2O content is much higher. Rb varies from 22 to 52 ppm except in one case (7 ppm), Sr from 41 to 147 ppm with one exception of 580 ppm. Rb/Sr ratio varies from 0·04 to 1·24. In Rb vs Sr plot (figure 7) most of the samples fall in the range of granophyres

Table 1. Major element (wt.%) and trace element (ppm) compositions of representative samples of the Gorur gneisses.

	Gorur Trondhjemites													Amphibolite
Sample	YBL-68	YBL-77	YBL-78	YBL-81	YBL-86	YBL-87	YBL-88	YBL-90	PG87–130	PG87–131	PG87–133	PG87–137	PG87–138	PG87–127
SiO_2	75·52	77·66	74·84	77·25	75·18	76·63	75·75	75·04	76·69	76·29	78·63	80·15	78·97	47·62
TiO_2	0·34	0·68	0·66	0·68	0·67	0·65	0·63	0·31	0·65	0·64	0·63	0·68	0·64	1·62
Al_2O_3	12·28	12·04	11·95	12·14	12·42	12·31	12·02	15·12	11·79	11·27	10·85	11·90	12·10	13·26
Fe_2O_3·T	3·90	3·08	3·00	2·97	3·14	3·22	3·15	1·82	3·20	3·31	3·31	3·49	2·45	15·57
MnO	0·05	0·06	0·04	0·04	0·04	0·04	0·05	0·01	0·02	0·07	0·04	0·08		0·21
MgO	0·58	0·43	0·55	0·03	0·43	0·54	0·79	0·55	0·72	0·61	0·42	0·25	0·56	5·53
CaO	0·85	1·87	1·55	1·37	1·31	1·41	1·50	2·06	1·57	1·20	1·46	1·23	1·85	9·40
Na_2O	4·19	3·20	3·49	3·66	2·75	3·02	2·99	4·23	3·27	2·76	3·05	3·38	3·35	1·89
K_2O	1·48	0·83	0·89	0·89	0·99	0·92	1·18	1·55	0·63	1·33	1·19	0·73	0·23	0·76
P_2O_5	0·01	0·03	0·02	0·04	0·03	0·03	0·04	0·06	0·05	0·03	0·05	0·02	0·03	0·19
Total	99·20	99·88	96·99	99·07	96·96	98·77	98·10	100·75	98·59	97·51	99·63	101·91	100·18	96·05
Sc	4		13		12		11	2		16		15	14	26
V	11		3		2			5		279		0		431
Cr	19		18		187		186	144		298		188	11	195
Co	53		45		5		1	4		2		2	68	42
Ni	4		5		8		4	8		8		4	1	97
Zn	167		56		150		60	52		72		58	19	203
Ga	22		19		20		20	19		22		20	21	19
Rb	52		38		51		34	41		43		23	7	10
Sr	42		105		134		89	581		57		82	147	148
Y	85		81		108		109	11		134		131	105	27
Zr	404		267		323		260	99		380		411	432	33
Nb	15		18		21		21	3		24		25	24	5
Ba	91		51		70		64	194		54		75	16	21
Hf	8		4		6		5	1		5		12	6	0·
Ta	1		1		1		1	0		1		1	1	0
Th	3·8		3·8		3·8		3·8	2·2		4·4		4·4	3·8	6·8
U	4·1		2·7		2·7		2·7	1·4		4·1		2·7	1·4	1·4

(*Continued*)

Table 1. *(Continued)*

				Gorur		Trondhjemites								Amphibolite
Sample	YBL-68	YBL-77	YBL-78	YBL-81	YBL-86	YBL-87	YBL-88	YBL-90	PG87–130	PG87–131	PG87–133	PG87–137	PG87–138	PG87–127
La	24·3		21·4		24·2		25·0	11·7		25·1		27·5	20·8	5·5
Ce	56·2		49·0		56·1		60·7	23·2		56·6		59·5	47·0	12·5
Pr	6·4		5·4		6·4		6·8	2·3		6·8		7·3	5·4	1·6
Nd	29·6		25·5		27·9		30·0	10·7		30·8		31·2	25·3	7·8
Sm	8·8		7·5		8·0		9·2	2·1		8·1		7·9	6·9	2·3
Eu	1·7		1·6		1·7		1·8	0·3		2·0		1·7	1·3	1·0
Gd	8·5		8·1		9·1		10·7	1·7		9·3		10·8	7·7	2·7
Tb	1·5		1·2		1·5		1·5	0·1		1·5		1·6	1·3	0·4
Dy	8·4		7·7		10·5		11·4	0·9		10·4		11·8	7·8	2·3
Er	4·6		4·1		6·4		7·3	0·6		6·5		7·0	4·8	1·4
Tm	0·7		0·6		1·1		1·1	0·1		0·9		1·1	0·7	0·2
Yb	5·1		0·7		7·8		8·4	0·8		7·5		8·4	5·9	7·2
Lu	0·8		0·7		1·2		1·2	0·1		1·2		1·1	0·8	0·2
K_2O/Na_2O	0·35	0·26	0·26	0·24	0·36	0·30	0·39	0·37	0·19	0·48	0·39	0·22	0·07	0·40
K/Rb	240·14		200·09		165·55		292·32	312·43		264·55		256·18	290·88	678·97
Sr/Ba	0·46		2·06		1·92		1·39	2·99		1·05		1·10	9·40	6·92
Rb/Sr	1·24		0·36		0·38		0·38	0·07		0·75		0·28	0·04	0·07
[Ce/Yb]n	2·87		18·67		1·86		1·87	7·24		1·95		1·84	2·06	0·45
[La/Sm]n	1·73		1·80		1·91		1·71	3·58		1·95		2·19	1·89	1·52
[Gd/Yb]n	1·36		9·64		0·94		1·03	1·61		1·01		1·05	1·06	0·30
Eu/Eu*	0·60		0·62		0·61		0·54	0·55		0·71		0·55	0·54	1·23

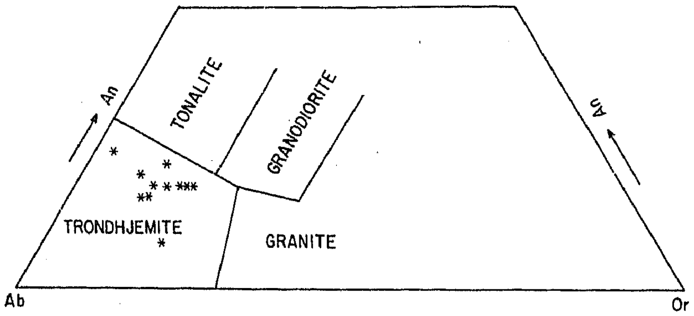

Figure 5. Normative Ab–Or–An diagram [after O'Connor (1965) modified by Barker (1979)] for Gorur gneiss samples. Shows that all the samples are trondhjemitic in composition.

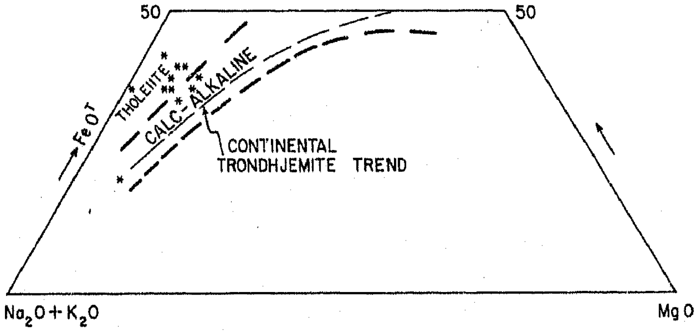

Figure 6. A F M diagram for the Gorur gneiss samples showing that they follow a tholeiite line of descent.

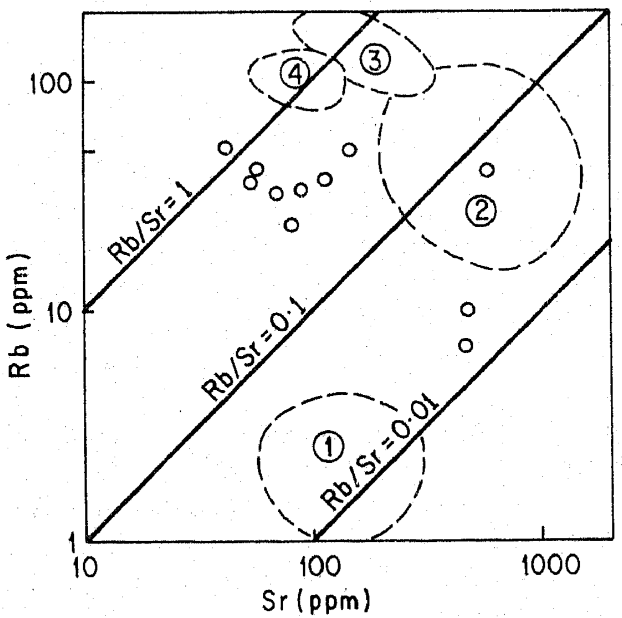

Figure 7. Log Rb against log Sr variation showing the fields of: 1—oceanic plagiogranites; 2—continental trondhjemites and quartzdiorites; 3—continental granophyres and Iceland rhyolites; and 4—Red sea granophyres (fields are from Coleman and Donato 1979). Most Gorur gneiss samples plot close to the fields of granophyres. However, their average Rb/Sr ratio is similar to those of continental trondhjemites.

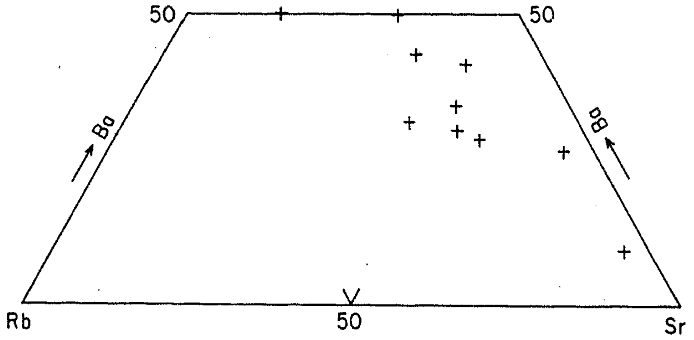

Figure 8. Ternary Rb–Ba–Sr diagram showing that the Gorur gneiss samples are characterized by a wide range of Ba/Sr but are low in Rb.

rather than continental trondhjemites, although their average Rb/Sr ratio of 0·24 is akin to that of continental trondhjemites.

Compared to the average chromium content of 8 ppm in the Archaean low-alumina trondhjemites (Condie 1981, p. 190), the Gorur gneisses are strongly enriched in chromium, a feature characteristic of southern Indian gneisses. Their Ni content is however similar to the gneisses of other Archaean terranes. Condie (1981) observed that Archaean trondhjemites are fairly enriched in Ba with Ba and Sr in about equal proportions. This does not appear to be true for the Gorur gneisses which show a very wide range of Ba and Sr as evident from Ba–Rb–Sr plot (figure 8). The U content varies from 1 to 3 ppm and the Th from 1 to 9 ppm. The range exhibited by these elements, especially Th, is much higher than found by Callahan and Rogers (1987) and Rogers and Callahan (1989) in the gneisses of the western Dharwar craton. Zr abundances range from 99 to 432 ppm. With such a wide range in Zr and Rb, this suite of rocks does not conform to any particular subclass of the "Hassan gneisses" proposed by Monrad (1983).

Chondrite-normalized REE patterns for the Gorur gneisses are given in figure 9. Barring one sample, LREE are about 60 to 100 times chondrite and the HREE 20 to 40 times. All of them have Yb_N greater than 8 typical of low-alumina trondhjemites. In the Al_2O_3 vs Yb plot after Arth (1979), the rocks fall in the field of oceanic or island arc trondhjemites. Arth (1979) pointed out that low alumina, high Yb trondhjemites originate in an oceanic environment, whereas the high alumina and low Yb ones in a continental milieu. The La_N/Sm_N ratios ranging from 1·71 to 3·58 and Gd_N/Yb_N between 0·94 and 1·36 (with the one exception of 9·64) show that there is no strong depletion of heavy rare earth elements. All of them are characterized by negative europium anomalies (Eu/Eu* 0·55–0·71). In the gneisses of Gorur region, there is no continuum of composition from mafic to felsic end members. The association is more like a bimodal mafic-felsic assemblage with the mafic end member represented by amphibolites (the metabasalts) and the felsic by trondhjemites. There is no significant compositional spread in the Harker's variation diagrams. These observations on the Gorur trondhjemites favour a partial melting model rather than fractional crystallization for their origin. Genesis of tonalites/trondhjemites by partial melting of metabasalts is now well established. There is no field evidence to support a sedimentary parentage such as graywacke for these rocks. Partial melting of metabasalts is therefore the preferred mode of origin. Hanson and Goldich (1972), Arth and Hanson (1972, 1975), Arth and Barker (1976), Arth (1979) and Drummond

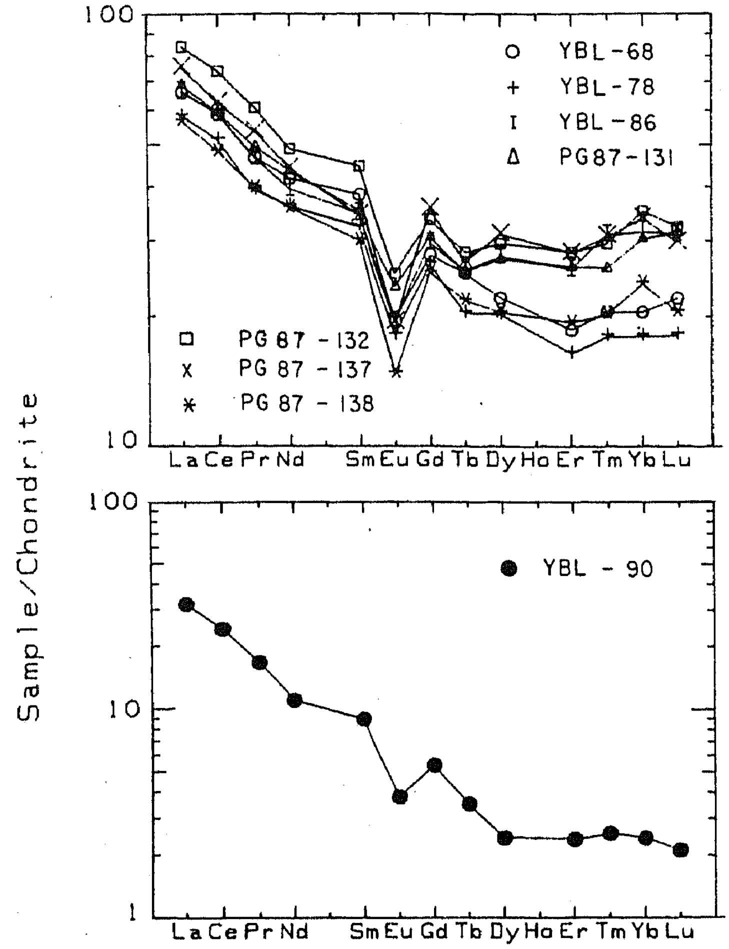

Figure 9. Chondrite normalized REE patterns for the Gorur trondhjemitic gneisses (normalized against Cl chondrites, Taylor and McLennan 1986, pp. 493), showing a narrow range of total REE for most samples which show consistent low Ce_n/Yb_n, Gd_n/Yb_n and negative Eu-anomalies.

et al (1986), have all discussed the origin of tonalites and trondhjemites. Interpreted in the light of these studies, the relatively flat REE patterns, especially in the HREE region, rule out the possibility of garnet or hornblende in the residum while the characteristic negative europium anomaly suggests that plagioclase is significant in the residual phase. Since plagioclase is not stable below a depth of 40 km (10 kbar), shallow level processes are indicated. Barker and Arth (1976) postulate that tonalite liquids produced under low total pressure, *a* H_2O and percentage of partial melting are low in Al_2O_3 and leave a plagioclase residue.

5. Rb–Sr geochronology

Earlier Rb–Sr studies in the Gorur region were carried out on a variety of rock types collected from a wide area, typically a few square kilometres. Since such a wide sampling may not ensure a uniform initial Sr composition, we have concentrated on cluster sampling within two adjacent quarries midway between Hassan and Gorur. In addition, we selected a set of 8 samples with very similar composition for Rb–Sr

Table 2. Rb–Sr isotopic compositions of Gorur trondhjemitic gneisses (whole rocks).

Sample No.	^{87}Rb/^{87}Sr	^{87}Sr/^{86}Sr (2σ errors)
YBL–90	0·204	0·71062 ± 0·00006
PG87–137	0·823	0·73977 ± 0·00008
YBL–78	1·056	0·75034 ± 0·00006
YBL–86	1·107	0·75091 ± 0·00014
PG87–143B	1·398	0·76509 ± 0·00004
PG87–132	1·971	0·79624 ± 0·00008
PG87–131	2·183	0·79977 ± 0·00006
YBL–68	3·634	0·87370 ± 0·00007

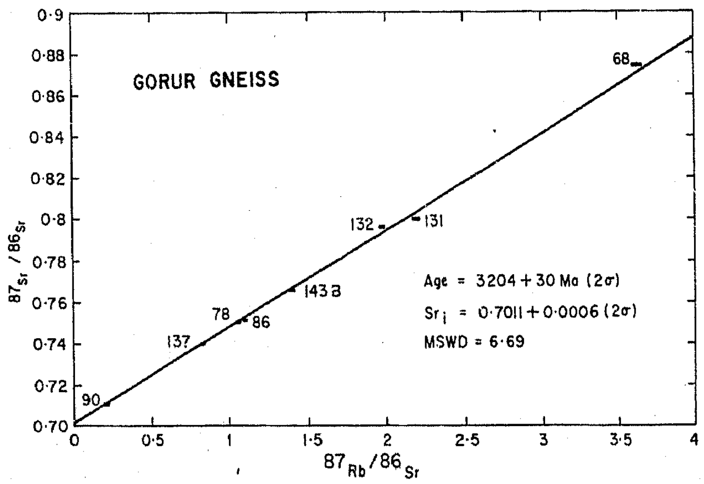

Figure 10. Whole rock Rb–Sr isochron for Gorur trondhjemitic gneisses. The isotopic data are given in table 2.

isotopic analysis. The isotopic data are presented in table 2 and depicted in figure 10. In spite of the restricted variation in major element composition, the 8 whole-rock samples of Gorur gneisses show a good spread in wide range of ^{87}Rb/^{86}Sr ratio from 0·2 to 3·6, which is larger than in the samples studied by Beckinsale *et al* (1980) and Monrad (1983). Separate regression calculations for samples from each quarry give a close agreement in age and Sr_i as evident from the following results: 3190 ± 83 Ma ($\mathrm{Sr}_i = 0{\cdot}7014 \pm 60$) and 3200 ± 44 ($\mathrm{Sr}_i = 0{\cdot}7011 \pm 8$). Regression of all the eight samples yields an age of 3204 ± 30 Ma and Sr_i of 0·7011 ± 6 with a MSWD of 6·69 (figure 10). Two samples PG/87/131 and YBL/86 show slight deviation from the best fit. Elimination of these two samples from the regression reduces the MSWD to 3·77, but gives essentially the same results for age and intercept (3246 ± 36 Ma and Sr_i 0·7008 ± 6). Since we have no petrographic or geochemical criteria to eliminate these samples from calculation, we have retained them. Though our result yields slightly older ages than that reported by Monard (1983) for the "Hassan gneisses", they agree within the extreme limits of error. On the other hand, our result differs from the age reported by Beckinsale *et al* (1980 and 1982), the differences being slightly beyond the extreme error limits.

6. Discussion and conclusions

The structural history of the gneisses of Hassan-Gorur sector is identical with that of the adjoining Holenarasipur schist belt. The gneisses show evidence of ductile deformation. There is no evidence of post-crystalline deformation and recrystallization. The foliation banding in the gneisses is axial planar with reference to DhF_1 folds. Although this foliation has been involved in later refolding, metamorphic recrystallization accompanying the later deformations did not affect them. These observations lead to the inference that the Gorur gneisses were formed synkinematically with the first deformation affecting supracrustal rocks in the schist belt and remained petrologically unaffected since then. We therefore relate the 3200 Ma age to the time of first deformation episode common to the Gorur gneiss and related schist belts and to the time at which Sr isotopes in the precursors of the Gorur gneisses were equilibrated to 0·7011.

If the ultrabasic and basic rocks of the Holenarasipur schist (greenstone) belt were the parent rocks as indeed suggested by the presence of their inclusions in the gneisses and the higher Cr abundance in gneisses, the low initial Sr ratio of 0·7011 would imply a very short crustal residence time (< 100 Ma) for the source material. An age of about 3300 m·y for the source rocks is supported by the fact that the zircons from the metapelites (in which the ultramafic-mafic rocks are emplaced in the Holenarasipur belt) have yielded a mean Pb-Pb age of 3309 ± 5 Ma (2σ) by the direct evaporation technique (A Kroner, private communication). This interpretation is consistent with the general veiw that (i) the mafic and ultramafic rocks of greenstone belts are precursors to the Archaean trondhjemites (Glikson 1979), and (ii) the intervening stages are very brief (cf. Peterman 1979).

The marginally older age of 3315 ± 54 Ma (Rb–Sr) and 3305 ± 13 Ma (Pb–Pb) respectively reported by Beckinsale *et al* (1982) would, according to our interpretation, imply the presence of an earlier generation of gneisses in the same area from which our rock suite was collected. However, before one considers such a possibility seriously, one has to critically examine whether the marginal difference is not due to the effects of slight but significant differences in the initial Sr ratios of their samples spaced rather widely in a gneissic terrane with a complex evolutionary history.

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