Sm-Nd ages of two meta-anorthosite complexes around Holenarsipur: Constraints on the antiquity of Archean supracrustal rocks of the Dharwar craton

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Whole-rock Sm-Nd isochron ages are reported for two stratiform meta-anorthosite complexes emplaced into the Archean supracrustal-gneiss association in the amphibolite facies terrain around Holenarsipur, in the Dharwar craton, South India. While these metaperidotite-pyroxenite-gabbro-anorthosite complexes are petrologically and geochemically similar, they differ in the intensity of tectonic fabric developed during the late Archean (c. 2.5 Ga) deformation. They also differ in their whole-rock Sm-Nd isochron ages and initial Nd isotopic compositions: 3.285 ± 0.17 Ga, $\varepsilon_{\mathrm{Nd}} = 0.82 \pm 0.78$ for the Honnavalli meta-anorthosite complex from a supracrustal enclave in the low-strain zone, and 2.495 ± 0.033 Ga, $\varepsilon_{\mathrm{Nd}} = -2.2 \pm 0.3$ for the Dodkadnur meta-anorthosites from the high-strain southern arm of the Holenarsipur Supracrustal Belt (HSB). We interpret these results as indicating that the magmatic protoliths of both meta-anorthosite complexes were derived from a marginally depleted mantle at c. 3.29 Ga but only the Dodkadnur rocks were isotopically reequilibrated on a cm-scale about 800 Ma later presumably due to the development of strong penetrative fabrics in them during Late Archean thermotectonic event around 2.5 Ga. Our results set a younger age limit at c. 3.29 Ga for the supracrustal rocks of the HSB in the Dharwar craton.

1. Introduction

A general consensus is that the Archean gneiss-supracrustal associations of the Dharwar craton, southern India constitute a polyphase assemblage that developed between ~3.4 and 2.5 Ga ago (reviewed by Naqvi and Rogers 1987). However, aspects of spatial and temporal relationships between gneisses and supracrustals, and the antiquity of the supracrustal rocks remain ambiguous. The region encompassing the Holenarsipur Supracrustal Belt (HSB, figure 1) has long been recognised as one of the oldest crustal nucleii in the Dharwar craton based on the evidence for preservation of the ≤ 3.3 Ga tonalitic orthogneisses (Beckinsale *et al* 1980, 1982; Bhaskar Rao *et al* 1991; Meen *et al* 1992; Naha *et al* 1993; Peucat *et al* 1993). Geological and geochronological studies have been inconclusive on the temporal relationship between the spatially associated gneissic and supracrustal rocks. While some authors (e.g. Naqvi 1981; Hussain and Naqvi 1983) proposed that supracrustal rocks pre-date the gneisses, several others (e.g. Ramakrishnan and Viswanatha 1981; Monrad 1983; Meen *et al* 1992) suggested that the gneisses were older. U/Pb ages of detrital zircons from a quartzite-metapelite unit from the HSB indicate granitoid rocks as old as ~3.6 Ga in its provenance (Nutman *et al* 1992). Peucat *et al* (1995) reported a precise U/Pb age of 3.298 ± 0.007 Ga for zircons in a metarhyolite in the upper part of the stratigraphic sequence in the HSB implying that the entire supracrustal succession in this belt could be at least as old as the oldest dated (~3.3 Ga) Gorur gneiss nearby. In a different and complementary approach to the age of the supracrustal

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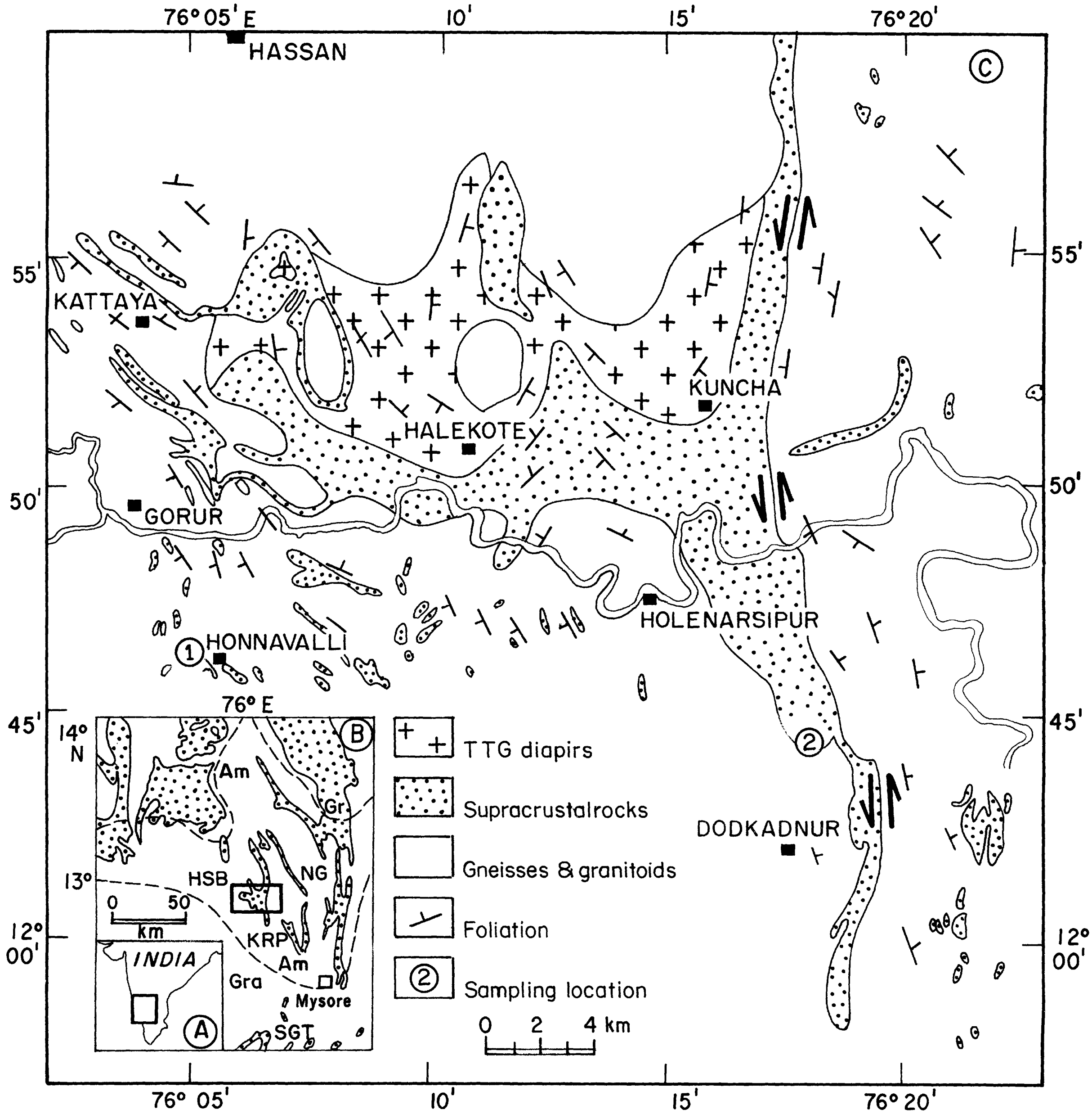

Figure 1. Generalised geological map of the Archean Holenarsipur Supracrustal Belt (HSB) and surrounding gneissic country showing location of the Honnavalli and Dodkadnur meta-anorthosite complexes (based on Hussain and Naqvi 1983). **Inset – B** shows the location of the HSB in the amphibolite (Am) – facies terrain of the western part of the Dharwar craton, south India which is bounded by greenschist facies (Gr) and Granulite (Gra) facies domains. Other supracrustal belts containing similar stratiform complexes include: Sargur (SG), Nuggihalli (NG) and Krishnarajpet (KRP).

sequence of the HSB, we have dated two isolated bodies of multiply deformed and metamorphosed stratiform periodite-gabbro-anorthosite suite from around Holenarsipur.

Many deformed stratiform dunite/periodite-pyroxenite-gabbro-anorthosite complexes are known from the lower sections of supracrustal belts such as the Holenarsipur, Nuggihalli, Sargur and Krishnarajpet in the western part of the Dharwar craton (WDC). Geology, petrology and geochemistry of these bodies have been described by Ramiengar *et al* (1978); Ramakrishnan *et al* (1978); Drury *et al* (1978); Naqvi and Hussain (1979); Ramakrishnan and Viswanatha (1981); Hussain and Ahmad (1982); Kutty *et al* (1984) and have been reviewed recently by Nijagunappa (1994). Structurally these bodies are identical to their host supracrustal and/or gneiss rocks suggesting their emplacement before the regional deformation and metamorphic events. Relative to the metarhyolite dated by Peucat *et al* (1995), the stratiform suites considered here occupy a much lower stratigraphic position in the supracrustal succession around Holenarsipur. Therefore, the primary (crystallisation) age of these stratiform suites would set a strict younger (minimum) limit to the age of the supracrustal rocks of the HSB.

A potential problem in using Sm-Nd whole-rock isochron method to date deformed and metamorphosed mafic-ultramafic rock systems is the mobility of rare earth elements during secondary geological processes, particularly those involving exchange reactions between rocks and hydrothermal fluids. However, adoption of a proper sampling strategy considering the scale of tectonic fabrics developed in the rocks could help retrieve primary age information irrespective of their metamorphic grade (Black 1988). Many examples where whole rock Sm-Nd isochrons yielded reliable primary ages for stratiform anorthosite complexes in Archean greenstone belts elsewhere have been reviewed by Ashwal (1993).

2. Geological setting

In a tilted cratonic block exposing an oblique cross-section of Archean rocks ranging in metamorphic grade from greenschist facies in the north to granulite facies in the south, the Holenarsipur region forms a central medium-grade (amphibolite facies) domain. The trident shaped HSB has narrow northern, southern and western arms. The southern part of the western arm and the entire southern arm are believed by some workers to comprise the lower part of the supracrustal succession described variedly as the > 3.0 Ga Sargur Group (Swami Nath *et al* 1976; Ramakrishnan and Viswanatha 1981), the oldest supracrustals (Naqvi 1981), and the Holenarsipur Group (Naqvi and Rogers 1987). This sequence is dominated by ultramafic schists of komatiite-tholeiite affinites, metapelites and minor quartzite, banded iron formation and numerous lensoid and/or sheet like bodies of stratiform dunite-periodite-pyroxenite gabbro-anorthosite. The northern part of the western arm and the northern arm contain a mafic metavolcanic-dominated sequence with rare spinifex textured komatiites. Minor felsic volcanic rocks occur in the upper stratigraphic level. The mafic volcanic rocks are interlayered with thin quartzite, argillite and a banded iron formation. This latter sequence was correlated with the < 3.0 Ga Dharwar Supergroup, the younger Archean supracrustal cycle of the Dharwar craton (Swami Nath *et al* 1976; Ramakrishnan and Viswanatha 1981). This two-fold subdivision of the supracrustal sequence in the HSB has been refuted by other workers (Hussain and Naqvi 1983; Naha *et al* 1986, 1993; Srinivasan 1988; Srinivasan and Naha 1996).

Tonalitic orthogneisses west and northwest of the HSB have yielded whole rock Rb-Sr, Pb-Pb and zircon U/Pb ages between 3.350 and 3.305 Ga (Beckinsale *et al* 1980, 1982; Monrad 1983; Taylor *et al* 1984; Bhaskar Rao *et al* 1991; Meen *et al* 1992; Naha *et al* 1993; Peucat *et al* 1993). The gneiss-supracrustal assemblage, including the stratiform complexes, is structurally concordant and bears evidence for two major and a minor episodes of deformation with metamorphism reaching up to amphibolite facies (Chadwick *et al* 1978, 1981; Naha *et al* 1986, 1993; Naqvi and Rogers 1987; Bhaskar Rao *et al* 1991). During the first episode (D_1 and D_{1a}) the rocks were isoclinally folded and co-axially refolded. An axial planar schistosity (S_1) was developed, and metamorphic conditions varied from greenschist facies in the north to amphibolite facies in the southern part of the HSB. Synkinematic tonalite-trondhjemite-granodiorite (TTG) diapirs invaded both the gneisses and supracrustal rocks. The distribution of L, L-S and S fabric dominated domains in the region is suggested to have been controlled by deformation associated with the rising TTG-diapirs (Bouhallier *et al* 1993, 1995). Several of these TTG suites have been dated at $\sim$3.0 Ga (Beckinsale *et al* 1982; Monrad 1983; Stroh *et al* 1983; Taylor *et al* 1984). The c. 3.0 Ga event was also associated with migmatisation, remobilization of large ion lithophile elements and re-equilibration of Rb-Sr and Pb-Pb isotopic systematics in the gneisses (Bhaskar Rao *et al* 1983; Naqvi and Rogers 1987; Meen *et al* 1992). The D_1-episode of deformation culminating at c. 3.0 Ga is generally believed to mark a strict younger age limit to the deposition and early deformation and metamorphism of the Holenarsipur supracrustal rocks. During a second major episode of deformation (D_2), the earlier isoclinal folds and axial planar schistosity were refolded into N-S upright folds with N-S striking axial planes. The D_2-folding is associated with development of a zonal crenulation cleavage, marked by micas in the northern part and amphibole in the southern arm of the HSB. The D_2-phase is also associated with strong transcurrent-shearing along N-S belts, such as the one along the eastern margin of the HSB that affected much of the southern arm (e.g. Drury *et al* 1984; Chadwick *et al* 1992; Bouhallier *et al* 1993, 1995). The N-S fabrics related to D_2 are weak along much of the western arm of the HSB, where the pre-D_2 structures and compositions are expected to be better preserved. Garnet-bearing amphibolites developed syntectonically with D_2 give consistent whole rock-garnet Sm-Nd isochron ages at $\sim$2.5 Ga (Bouhallier 1995). In a regional context, the D_2-episode coincides with a craton-wide late Archean tectonometamorphic event that culminated at c. 2.5 Ga with charnockite formation at deeper levels and widespread emplacement of K-rich granites at the shallow crustal levels (reviewed by Naqvi and Rogers 1987; Friend and Nutman 1991; Peucat *et al* 1993). Locally around the HSB, late warps (D_3) with E-W axial planes accentuated the plunges of the D_2-folds.

3. The stratiform meta-anorthosite complexes

The two bodies of deformed and metamorphosed stratiform peridotite-gabbro-anorthosite studied here are:

- the *Honnavalli meta-anorthosite*, at the Honnavalli village approximately 20 km west of Holenarsipur and 3 km south of Gorur and
- the *Dodkadnur meta-anorthosite*, located ~5 km south of Holenarsipur, ~3.5 km north of Dodkadnur (figure 1).

The Honnavalli meta-anorthosite, first described by Hussain and Ahmad (1982), is a ($\sim 50 \times 20$ m) oval shaped body included in banded tonalitic gneisses and associated with actinolite-tremolite-talc-antigorite schists. The meta-anorthosite with $> 90\%$ modal plagioclase grades into gabbroic anorthosite with 80–90% modal plagioclase. The rock is coarse to medium-grained with a feeble foliation defined by a crude alignment of clots rich in hornblende. The foliation strikes NNW and dips ~60–65° easterly which is parallel to foliation in the enclosing gneisses (also see Hussain and Ahmed 1982; Hussain and Naqvi 1983). Plagioclase (An_{92}) in the anorthositic rock is variably sassuritised. The anorthosites are conformably associated with a thin (20×2 m) band of schistose amphibolite containing largely hornblende and subordinate plagioclase (An_{70-85}). These can be interpreted as metagabbro (<30%, modal plagioclase) and anorthositic gabbro (70–80% plagioclase), zoisite, calcite, scapolite, titanomagnetite and chlorite are accessory minerals.

The Dodkadnur meta-anorthosite is exposed over a strike length of ~300 m. About a dozen other smaller, isolated bodies of meta-anorthosite are known approximately along its strike extension over a N-S zone of ~12 km. Detailed descriptions of the petrology and geochemistry of several of these bodies have been given by Drury *et al* (1978), Ramakrishnan *et al* (1978) Naqvi and Hussain (1979), Ramakrishnan and Viswanatha (1981) Kutty *et al* (1984). In the Dodkadnur complex, meta-anorthosite grades to metagabbro across strike. Locally, metagabbro grades to magnetite gabbro and a small band of titaniferrous magnetite. Elsewhere, ~8 km north of this body, gradations between metagabbro, metapyroxenite and metaperidotite/dunite were noted (Kutty *et al* 1984). Unlike the Honnavalli rocks, the Dodkadnur outcrops show a strong N-S gneissic foliation marked by alternate plagioclase and hornblende-rich laminae and a distinct lineation due to parallelism of hornblende. This foliation, parallel to the axial planes of large isoclinal folds (D_1), is refolded by open folds associated with well-developed NNW to N striking axial planes. Granulation and recrystallisation of the coarse polysynthetically twinned plagioclase into aggregates of fine untwined plagioclase is ubiquitous. The recrystallised domains show granoblastic polygonal equilibrium texture. Garnet has developed in some metagabbroic anorthosites and metagabbros. Typically the garnets are euhedral, up to 1 cm across, and show faces truncating foliation. Some contain abundant inclusions of fine aggregates of plagioclase and hornblende. The textures suggest that garnet growth outlasted D_2-deformation. Accessories include sphene and traces of apatite besides others noted for the Honnavalli rocks.

The available major and trace element compositions (data from Drury *et al* 1978; Naqvi and Hussain 1979; Hussain and Ahmad 1982; Kutty *et al* 1984 and our unpublished results) indicate that the Dodkadnur and Honnavalli meta-anorthosite suites are geochemically similar among themselves and to many other anorthosite complexes of the Archean greenstone belts (e.g., Henderson *et al* 1976; Phinney *et al* 1988; Ashwal 1993). The most significant feature of the present set of rocks is their extremely low abundance of K, Rb, Sr, Y and REE, even in the garnet-bearing samples. This is consistent with their mineral composition which is devoid of light rare earth element (LREE)-rich accessory phases like zircon, allanite, and monazite. The meta-anorthosites and gabbroic anorthosites show a marginal enrichment of LREE in their chondrite-normalised REE pattterns ($Ce_N/Yb_N = 1$–2.6), low REE (4–$9 \times$ chondrite) and variable positive Eu-anomalies (Eu/Eu* between 1.8 and 7.2). Kutty *et al* (1984) described that the compositional variations within the Dodkadnur complex resulted from low-pressure fractionation of a tholeiitic magma. They suggested distinct fractionation trends controlled by separation of olivine, clinopyroxene, plagioclase and magnetite. Hussain and Ahmad (1982) also suggested a similar magmatic evolution for the Honnavalli suite. The samples analysed here are limited mostly to a narrow compositional window where fractionation of clinopyroxene and plagioclase is important.

4. Sm-Nd geochronology

4.1 *Experimental techniques*

3–5 kg samples were collected from fresh outcrops within an area of $\sim 30 \times 20$ m (Honnavalli) and $\sim 200 \times 70$ m (Dodkadnur). Fresh interior fragments or slabs ~ 1.5–2.5 cm thick, 6×5 cm on a face, were prepared along foliation. In the case of samples, YBL-19, 20B and 21A, blocks of ~5 kg each was processed. All samples were powdered to ~200 mesh using a steel jaw crusher and a ring mill.

Sm-Nd isotopic analysis of the Dodkadnur samples was carried out at the NGRI, Hyderabad while that of the Honnavalli samples at the IPGG, St. Petersburg. Analytical procedures were broadly similar and involved dissolution of ~100 mg powders in $HF + HNO_3$ in screw capped teflon (Savilex) vials. Clear solutions were split for isotope dilution (ID) and isotopic composition (IC) measurements. Chromatographic separations of Nd and Sm followed procedures described by Richard *et al* (1976) with minor modifications. Isotopic compositions were measured on

Table 1. *Sm-Nd isotopic data for Holenarsipur meta-anorthosite complexes.*

Sample (rock type)	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd^a$ (atomic)	$^{143}Nd/^{144}Nd^b$ (atomic)	T^c_{CHUR} (Ga)	T^d_{DM} (Ga)
Honnavalli						
O8-19 (LA)	0.64	2.30	0.1381	0.51143 ± 5	3.12	3.32
YBL-20B (LA)	0.61	2.27	0.1449	0.51155 ± 5	3.18	3.42
O8-19-4 (MA)	1.06	4.22	0.1518	0.51171 ± 5	3.13	3.38
O8-19-3 (S)	0.90	3.28	0.1651	0.51202 ± 5	2.95	3.31
YBL-21A (H)	2.10	7.46	0.1707	0.51204 ± 5	3.40	3.69
O8-19-2 (H)	1.60	5.27	0.1839	0.51239 ± 5	–	–
YBL-19 (H)	1.63	5.44	0.1880	0.51254 ± 5	–	–
Dodkadnur						
M-11 (MA)	0.535	2.432	0.1318	0.511447 ± 15	2.78	3.11
M-3-2 (Gt.A)	0.418	1.708	0.1478	0.511729 ± 15	2.82	3.26
M-18 (LA)	0.420	1.706	0.1486	0.511716 ± 15	2.90	3.33
M-13 (S)	0.250	0.785	0.1922	0.512431 ± 15	–	–
M-4 (H)	3.231	8.907	0.2187	0.512886 ± 15	–	–

LA = leucocratic meta-anorthosite, **MA** = mesocratic meta-anorthosite (gabbroic anorthosite), **S** = Serpentinite (metaperdotite/pyroxene), **H** = Hornblendite (pyroxenite-gabbro), **Gt. A** = garnet bearing leucocratic meta-anorthosite.
Errors are 2 sigma of mean. [a] Error in $^{147}Sm/^{144}Nd$ ratios is 0.15% for Dodkadnur samples and 0.5% for Honnavalli samples. [b] normalised to $^{146}Nd/^{144}Nd = 0.7219$. [c] CHUR model ages calculated using: $(^{143}Nd/^{144}Nd)_{CHUR}$ 0.512638; $(^{147}Sm/^{144}Nd)_{CHUR}$ = 0.1967; [d] T_{DM} calculated using the equation of DePaolo (1981) for samples with $^{147}Sm/^{144}Nd < 0.17$.

metal-ion species using the automated, multicollector thermal ionization mass spectrometers, VG 354 at the NGRI and Finnigan MAT 261 at the IPGG, as described in detail elsewhere (Anil Kumar *et al* 1996 and Kotov *et al* 1995). $^{143}Nd/^{144}Nd$ ratios were normalized to $^{146}Nd/^{144}Nd = 0.7219$ and weighted mean of $^{143}Nd/^{144}Nd$ for a La Jolla Nd standard were 0.511861 ± 14 (2σ) at the NGRI (13 measurements) and 0.511845 ± 4 (2σ) at the IPGG (31 measurements). Ages were calculated using the two-error regression method of Williamson (1968) in a computer program after Provost (1990). ε_{ND} were calculated by the method of Fletcher and Rossman (1982). All errors on age and initial Nd isotopic compositions (Nd_i) reported in this article are quoted at 2σ.

4.2 *Results*

Sm-Nd data for the two meta-anorthosite complexes are given in table 1 and plotted in figures 2(a) and 2(b). The samples from both the Honnavalli and Dodkadnur suites show a good mutual spread in their $^{147}Sm/^{144}Nd$ ratios–from 0.1381 to 0.1880 in the former and from 0.1318 to 0.2187 in the latter. Both sets define very good linear arrays as evident from MSWDs of 0.53 and 0.78, respectively. If these straight lines are interpreted as isochrons (see next section), they give distinct ages and initial Nd ratios for the two suites: 3.285 ± 0.170 Ga, $\varepsilon_{Nd} = 0.82 \pm 0.78$ for the Honnavalli rocks and 2.493 ± 0.033 Ga, $\varepsilon_{Nd} = -2.2 \pm 0.03$ for the Dodkadnur rocks. However, T_{DM} model ages (DePaolo 1981) for rocks with $^{147}Sm/^{144}Nd < 0.15$ from either suite are quite consistent (3.11 to 3.42 Ga) with their mean being indistinguishable from the older isochron age of ∼3.3 Ga.

5. Discussion

Three important lines of evidence show that the linear arrays (figures 2(a) and 2(b)) are indeed isochrons and not mere mixing lines without time significance. Firstly, the data in either case do not show a linear correlation between $^{143}Nd/^{144}Nd$ and 1/Nd that would be expected for a mixture of just two arbitrary components (Faure 1986). Secondly, as argued by previous workers, e.g., Kutty *et al* (1984), petrological and geochemical data indicate that the meta-anorthosite suites formed by crystal-melt fractionation processes from a homogeneous parent magma of tholeiitic composition. The observed differentiation trends are consistent with early segregation of olivine + pyroxene, closely followed by plagioclase and a middle stage precipitation of magnetite. Finally, the T_{DM} model ages of the rock samples are concordant not only among themselves but also with the older isochron age of 3.3 Ga. This would not be the case if these samples were mixtures of two genetically unrelated components.

So, the two isochrons indicate that the Honnavalli samples evolved as closed systems for ∼3.3 Ga from a common initial Nd ratio of $\varepsilon_{Nd} = 0.82 \pm 0.78$, whereas the Dodkadnur rocks evolved for ∼2.5 Ga from a common initial ratio of -2.2 ± 0.03. But the good agreement of the T_{DM} model ages between the two compositionally similar suites together with the older Sm-Nd isochron age of ∼3.3 Ga argues that both crystallized from a homogeneous parental magma close to 3.3 Ga ago. The two complexes may be either isolated intrusions of compositionally very similar parental melts or segments of a large tectonically dismembered stratiform complex.

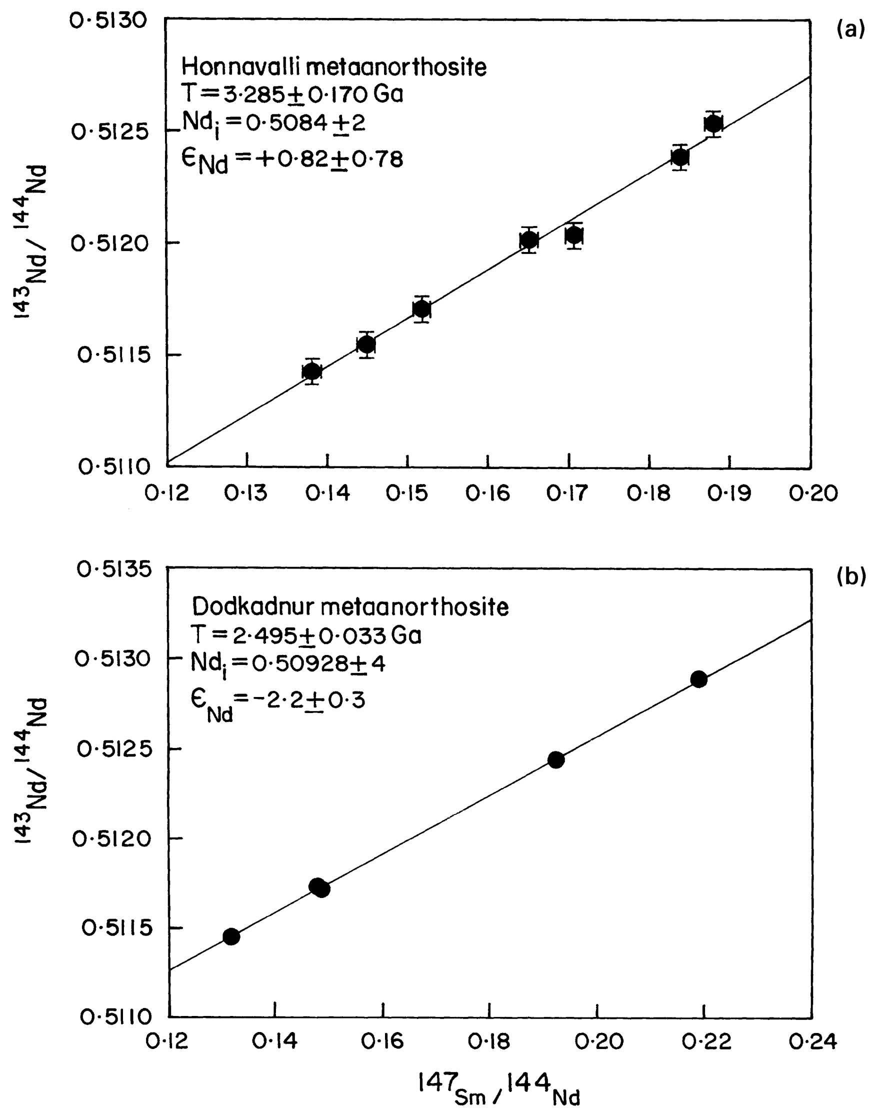

Figure 2. Sm-Nd whole rock isochron diagrams for the Honnavalli and Dodkadnur meta-anorthosite complexes around Holenarsipur.

If the Dodkadnur complex was originally coeval with the Honnavalli complex, its whole rock Sm-Nd isochron age of ∼2.5 Ga implies that the rocks of this complex were re-equilibrated in their Nd isotopes to a common value of $\varepsilon_{\rm Nd} = -2.2 \pm 0.03$ in a secondary event about 2.5 Ga ago. Assuming that the mean ^{147}Sm/^{144}Nd ratio of the five Dodkadnur rocks itself represent that of their parental magma, the Nd ratio of the latter 3.3 Ga ago can be calculated from the present day mean ^{147}Sm/^{144}Nd ratio of 0.1678 and its ^{143}Nd/^{144}Nd ratio of 0.50928 ± 4 ($\varepsilon_{\rm Nd} = -2.2 \pm 0.3$) 2.5 Ga ago. As the calculated ratio of 0.50838 ± 4 ($\varepsilon_{\rm Nd} = 0.65 \pm 0.3$) is well within the errors of the initial ratio of the Honnavalli rocks, the Nd isotopic compositions of the sources of both suites of rocks are quite similar, if not identical. In fact a regional event leading to generation of magmatic rocks and metamorphic resetting of pre-existing rocks at 2.5 Ga has been extensively documented (see reviews Naqvi and Rogers 1987; Friend and Nutman 1991; Peucat *et al* 1993). More specifically, a mica schist and an amphobolite from the southern arm of the HSB both containing garnets that developed syntectonically during the D_2-event gave whole rock-garnet isochrons of essentially the same age as the Dodkadnur rocks—2.473 ± 0.010 Ga, $\varepsilon_{\rm Nd} = -6.1 \pm 0.5$ and 2.527 ± 0.034 Ga, $\varepsilon_{\rm Nd} = -8.7 \pm 0.4$ (Bouhallier 1995). What is then surprising about the Dodkadnur rocks is that they were isotopically re-equilibrated not on a mineral scale (as in the case of the metapelite and amphibolite) but on a scale of a few tens of centimeters, whereas the Honnavalli rocks were not. Since the only major difference between these two complexes is in the intensity of tectonic fabric developed in them, we believe that this may be responsible for the differential response of the two complexes to the secondary or metamorphic event at 2.5 Ga. The Dodkadnur complex is located within the southern arm of the HSB, which is more intensely deformed than the western part of the region hosting the Honnavalli complex—resulting in the development of strong D_2-penetrative planar and linear mineral fabrics (Bouhallier *et al* 1993, 1995). The Dodkadnur rocks also show significant syntectonic recrystallisation accompanied by growth of garnets in some rock types. Evidence of sensitivity of Sm-Nd and Rb-Sr systematics to the intensity of deformation and the scale of penetrative fabric development in rocks rather than the intensity of the causative metamorphic event has indeed been found from studies elsewhere on multiply deformed and metamorphosed terrains (Black 1988).

Based on Rb-Sr data of 10 whole rock samples from the Dodkadnur complex, Kutty *et al* (1984) proposed that this complex was emplaced 3095 ± 58 Ma ago. Our Sm-Nd results indicate not only a much earlier time of emplacement but also the imprint of a strong secondary thermotectonic event much later. We believe the large scatter in their Rb-Sr data could be due to open system behavior of the whole rock Rb and Sr during the 2.5 Ga event.

The general agreement of T_{DM} ages with the Sm-Nd isochron age precludes significant crustal contamination of the magma parental to the meta-anorthosite complexes. This is further supported by the absence of LREE enriched refractory accessory minerals, extremely low abundances of K, Rb, Zr, Y, and LREE, and the restricted range of contamination-sensitive Rb/Sr and La_N/Sm_N in different members of the anorthosite-gabbro complexes. The ε_{Nd} of 0.82 ± 0.78 therefore reflects that of the magma parental to the rocks. So their mantle source is either chondritic or marginally depleted with a maximum ε_{Nd} of $+1.5$. This is in general agreement with the finding that other Archean stratiform complexes in greenstone-gneiss and granulite-gneiss terrains were derived from mantle sources with a long term depletion in LREEs (summarised by Ashwal 1993). What is perhaps of more significance is the similarity of the mantle source ($\varepsilon_{Nd} = 1.86 \pm 0.16$) for the 2.94 Ga old Sittampundi anorthosite complex at the southern margin of the craton (Bhaskar Rao *et al* 1996).

The age of deposition of the supracrustal rocks in the HSB, especially its basal section, is crucial to the understanding of its relationship with the spatially associated ~3.33–3.0 Ga old orthogneisses, and to the resolution of the debate on its two-fold subdivision into an older Sargur Group and a younger Dharwar Supergroup. In the HSB, both the Sargur (> 3 Ga) and Dharwar (< 2.9 Ga) rocks are believed to be in juxtaposition over a fairly large area with the former exposed only in the southern and western arms and the latter mainly in the northern arm (Ramakrishnan and Viswanatha 1981). But for the differing views on the nature of the contact (intrusive or tectonic) between the ~3.0 Ga old TTG plutons and the supracrustals in the northern part, the HSB sequence would have long been accepted as a single unbroken sequence older than 3.1 Ga. The first direct indication that the sequence could be as old as 3.3 Ga came from magmatic zircons in metarhyolites, which gave a precise age of 3298 ± 7 Ma. Since these zircons are interpreted as magmatic and not detrital, and the metarhyolite occurs in the upper part of the sequence close to the trondhjemite-supracrustal contact in the northern sector of the HSB, Peucat *et al* (1995) concluded that the entire sequence is as old, arguing that the younger Sm-Nd isochron age of ~2.6 Ga for basaltic rocks (Drury *et al* 1987) in the same location is ambiguous.

Although the Sm-Nd data from ultrabasic-basic rocks from the southern part of the HSB are far less coherent than for the metabasalts of the northern part, Drury *et al* (1987) concluded that the so-called southern 'Sargur' rocks are also not older than 3.0 Ga. The meta-anorthosite rocks we have dated now occur in the southern and western parts and at lower stratigraphic levels than the ~3.3 Ga metarhyolite in the northern part dated by Peucat *et al* (1995). Since the stratiform complexes are believed to be intrusives, their age of 3.285 ± 0.170 Ga shows that the southern part of the sequence was also deposited before 3.30 Ga ago. Considered together with the age of 3298 ± 7 Ma for zircons in metarhyolite in the upper levels of the northern part, our results would further imply that the entire supracrustal succession in the HSB is a single unbroken sequence deposited not later than 3.0 Ga ago. Peucat *et al* (1995) have further proposed that the surrounding gneisses differ only marginally in their age relative to the supracrustal rocks and so were accreted at the same time as the accumulation of sediments in adjacent basins. But, from the presence of detrital zircons as old as 3.6 Ga in the supracrustal rocks (Nutman *et al* 1992) it is equally conceivable that the protoliths of the existing or otherwise gniesses could be as old as 3.6 Ga and their erosion provided the sediments before all of them were deformed in a region wide event.

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