U–Pb and Lu–Hf systematics of zircons from Sargur metasediments, Dharwar Craton, Southern India: new insights on the provenance and crustal evolution

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A study of U–Pb and Lu–Hf–Yb isotope data in zircons from metamorphosed psammopelite and quartzite from the type area of Archaean Sargur Group, Dharwar Craton, India is carried out. Two age populations are observed: an older population with concordant U–Pb ages between 2.7 and 2.8 Ga, and a younger population with ages in the 2.4–2.6 Ga age range. The εHf values of 0 to +2.0 for the older zircon population suggest that they were derived from juvenile crust formed at 2.7–2.8 Ga. Sub-chondritic εHf values for the younger population indicate metamorphism and/or crustal reworking at ~2.5 Ga. Metasedimentary enclaves in the Sargur type area are therefore part of the gneiss–supracrustal complex of different antiquities and may not have an independent stratigraphic status.

Keywords: Detrital zircon, high- and low-grade metamorphism, isotope analysis, supracrustal rocks.

IN the amphibolite to granulite facies high-grade metamorphic gneiss–granulite terrains of the Archaean cratons, metasedimentary and metavolcanic rocks typically occur as meso- to macro-scale enclaves in gneisses and granulites. Whether these enclaves of supracrustal rocks are remnants of the rock formations of greenstone belts in the deeper sections of the earth's crust, or they belong to a stratigraphic sequence older/younger than the ones preserved in the greenstone belts, has been a matter of debate in Archaean geology. According to Condie[1], one of the popular theories is that the low and high-grade Archaean terranes represent respectively, shallow and deep levels of the same crust. Even though this view has been supported by many workers[2–8], there is another proposition that the high-grade supracrustal rocks in gneiss/granulite may have developed in a different type of tectonic setting that had different rock-formation modes, prior to granite–greenstone terranes[9]. Shackleton[4] suggested that the high-grade terranes may even be younger than the granite–greenstone terranes and may represent uplifted mobile belts that evolved between greenstone belt terranes. U–Pb detrital zircon geochronology has been pursued extensively to resolve these complex relationships[10–15]. In polycyclic Archaean metamorphic assemblages, zircon grains may have grown during different geological processes and/or may have been affected by multiple alteration processes[16,17]. Combined U–Pb and Lu–Hf zircon datasets can provide new insights on the timing of primary and secondary events such as juvenile versus crustal remelting, magma sources or metamorphism[18,19]. The isotope data can also provide tight constraints on the timing of crustal growth and reworking[16].

In the Dharwar Craton, Archaean high-grade metamorphic rocks of the Sargur Group have been suggested to be older than the low-grade greenschist facies metamorphic rocks of the Dharwar greenstone belts – the Dharwar Supergroup[20]. In this study, we have performed *in situ* U–Pb and Lu–Hf isotopic analysis of zircons by laser ablation inductively coupled plasma mass spectrometer (LA-ICP-MS) to understand the ages of zircons in two metasedimentary enclaves from the type area of the Sargur Group, to infer the age of the juvenile and/or reworking/metamorphic history of the zircons. Implication of our findings for the lithostratigraphic division of the Archaean rocks in the Dharwar Craton into Sargur Group and Dharwar Supergroup is discussed.

In the Dharwar Craton of southern India, the Meso- to Neoarchaean lithostratigraphic sequence has been divided into the Sargur Group and the Dharwar Supergroup[20]. The Sargur Group has been considered by several workers as the oldest group in the Archaean sequence of the Dharwar Craton[21]; it is assigned to an age older than 3 Ga. The rocks of the Dharwar Supergroup, constituting the well-defined Dharwar greenstone belts (also referred to by different workers as schist belts or supracrustal

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belts) are considered to be younger and deposited between 3 and 2.55 Ga. On the basis of the first U–Pb SHRIMP zircon age data for the detrital zircons, separated from the quartzites of the Sargur Group exposed near Holenarasipur and Banavar, Nutman *et al.*[11] suggested that the sedimentary protoliths of quartzites were derived from a provenance with a minimum age of 3.0 Ga. Jayananda *et al.*[22] and Maya *et al.*[23] reported 3.35 and 3.15 Ga ages respectively, for the komatiitic ultramafic rocks of the Sargur Group. Trendall *et al.*[24] reported U–Pb SHRIMP zircon ages of 2.72 and 2.6 Ga for the metavolcanic rocks of the Bababudan and Chitradurga Groups respectively, of the Dharwar Supergroup. SHRIMP U–Pb geochronological studies of the felsic volcanic rocks have largely reinforced the view that the Dharwar greenstone belt volcanics are younger than 3 Ga (refs 25–27). Although the foregoing geochronological studies support the classification of supracrustal sequence in the Dharwar Craton into Sargur Group (older than 3.0 Ga) and Dharwar Supergroup (3.0–2.55 Ga), they contradict an alternative view that the Sargur Group rocks, which occur as enclaves in gneisses, are a complex that consists of supracrustal rocks of Dharwar Supergroup as well as of some older rocks[8,28]. Except for a recent attempt by Lancaster *et al.*[29], no combined U–Pb and Lu–Hf geochronological study of zircons from the metasediments of the type area of Sargur Group has been carried out to support either of these alternative points of view. The study of one quartzite sample by Lancaster *et al.*[29] yielded U–Th–Pb ages consistent with the interpretation that the Sargur Group rocks are older than 3.0 Ga. The timing of upper amphibolite to granulite grade metamorphism in the Sargur area and further south has been variously proposed as >3.0 Ga and ~2.6 Ga (refs 30–33). We note that the database for establishing a reliable age for the source rocks as well as subsequent events of metamorphism unequivocally for the metasedimentary supracrustals in the type area for the Sargur Group is still inadequate. New results on zircon U–Pb and Lu–Hf systematics are presented in this study for a further understanding of the minimum age of the provenance for the Sargur Group rocks, as well as the time of their post-depositional metamorphism.

Geological setting of the area

Type area for the Sargur Group is around Sargur town, which lies between the Dharwar greenstone–granite belt region in the north and gneiss–granulite region (charnockite region) in the south (Figure 1). While the rock formations in the Dharwar greenstone belts are metamorphosed under greenschist to low amphibolite facies, those of the Sargur Group are metamorphosed under upper amphibolite to lower granulite facies[34–36]. The metasedimentary supracrustal rocks of the Sargur Group in the type area comprise fuchsite and muscovite quartzites ± graphite, psammopelites (kyanite/sillimanite ± garnet ± graphite schists), calc-silicate rocks and marbles, and banded iron formation (BIF). They are associated with metamorphosed ultramafic rocks (some with komatiite composition), and gabbro and anorthosites[36]. These foregoing rock formations occur as meso- to macroscale enclaves in ortho- and paragneisses (the latter sometimes contains garnet, kyanite and corundum). At some places greasy patches of charnockite and mafic granulites are observed amidst gneisses.

For this study, we have collected samples from two locations close to Sargur: (1) metamorphosed psammopelite from the hillocks near Itna (12°01.046′, 76°23.817′) and (2) quartzite from the hill near Thumbasoge (12°01.994′, 76°23.837′). The metamorphosed psammopelite from Itna has abundant kyanite and is associated with muscovite mica, quartz and disseminated graphite. The quartzite from Thumbasoge is an impure micaceous quartzite with flakes of graphite.

Analytical methods

The samples were crushed into centimeter-sized chips and thoroughly washed after eliminating the weathered portions. The clean chips were pulverized to <250 μm using a stainless-steel piston and cylinder. After repeated washing, non-magnetic, high-density mineral grains were

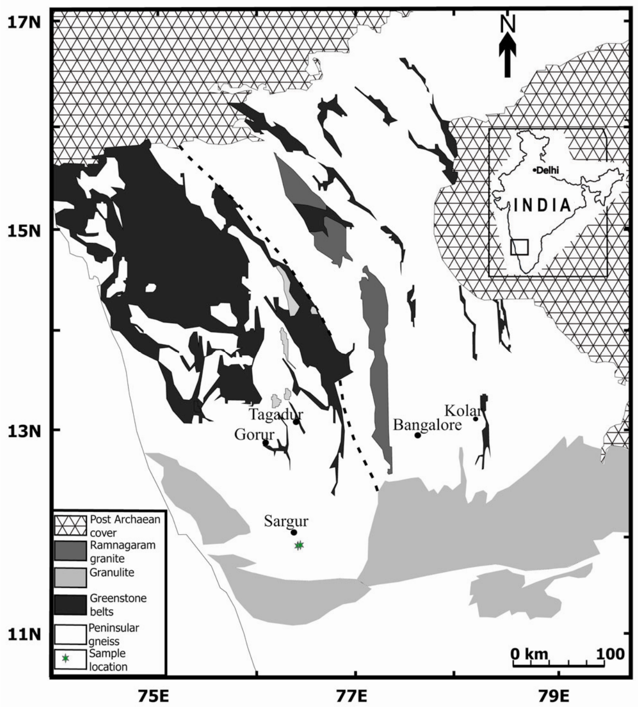

Figure 1. Geological map of the Dharwar Craton (modified from Chardon *et al.*[41]). Sampling sites are marked by filled green colour. Location of some important cities and towns is also shown (circle).

concentrated by density separation using aqueous sodium polytungstate solution (density = 3 g cm^{-3}) followed by magnetic separation using a Frantz isodynamic separator. For the kyanite-rich Itna samples, after following the standard technique, size separation was carried out at 90, 120, 150 and 200 μm. Zircon grains were handpicked using a binocular microscope. They were more abundant in the 120–150 μm size fractions. Clear, unfractured zircon grains were selected and mounted on a double-side adhesive tape, cast in epoxy and sectioned by polishing. Transparent zircons with simple internal structure were documented in detail. The grains recovered from the studied samples are inclusion-free, subhedral, colourless to brownish and some have metamict cores. Even though distinct overgrowths are present in a few zircons, our attempt to analyse the core–rim domains did not yield robust and reproducible age for the metamict cores. U–Pb and Lu–Hf isotope analysis was carried out at Goethe University, Frankfurt, Germany using a Thermo-Scientific Element II SF-ICP-MS and Neptune multicollector (MC)-SF-ICP-MS, both coupled to a New wave UP213 laser system. The analytical procedure adopted in this study is the same as described earlier in detail by Gerdes and Zeh[14].

Results

The zircon grains analysed in the study were short as well as long prismatic and poorly sorted in size. Cathodoluminesence images of zircon grains revealed clear core–rim relationships in some grains. The zircon cores show an oscillatory zoning, as is characteristic for magmatic rocks, whereas the rims show diffuse zoning pattern. Some grains show metamict cores. Figure 2 is representative back scattered electron and cathodoluminescence images of zircons.

Zircon U–Pb isotope analysis

U–Pb isotope analysis was carried out on 15 zircon grains separated from the Itna psammopelite sample (Z-124; Table 1). Data for two zircon grains (A38, A39) yielded discordant U–Pb ages (15% discordance). These were not considered further. Two distinct concordant age populations (95–105% concordance) were observed in the data of the other 13 grains. Four core ages (A25, A27, A29, A30) consistently yielded concordant ages in the range 2.72–2.81 Ga. Nine grains (A26, A28, A31, A32, A40, A41, A43–A45) were in the age range ~2.46 to 2.56 Ga. The weighted average age for the younger population was 2519 ± 9 Ma. Concordance level of all the ages was 95–102% (Figure 3).

Eleven zircon grains from the Thumbasoge quartzite sample (Z-103) were analysed (Table 1). Two grains (A47 and A48) were characterized by concordant older ages of 2.66 and 2.70 Ga respectively. Rest of the nine grains gave concordant ages ranging between 2.51 and 2.53 Ga, with a weighted average age of 2521 ± 9 Ma. The concordance level for all ages was between 95% and 101% (Figure 3).

Lu–Hf–Yb isotopic analysis

From Itna psammopelite eight Lu–Hf–Yb isotopic analyses were conducted on the grains having enough areas for the Lu–Hf analysis (Table 2). Some of the older 2.72–2.81 Ga zircons indicated chondritic to superchondritic nature (εHf values = +0.1 to +2.0) with Hf model ages between 2.88 and 2.99 Ga. The ~2.52 Ga younger zircons had sub-chondritic εHf values between −3.9 and −5.1. Initial ^{176}Hf/^{177}Hf ratios were calculated using the Lu–Hf isotopic data and the apparent Pb–Pb ages were obtained from the younger zircon grains. Majority of zircon grains having different apparent Pb–Pb ages showed similar initial ^{176}Hf/^{177}Hf values, indicating that the analysed younger zircon grains probably crystallized from the same source rock that yielded zircons of the older population. Identical initial ^{176}Hf/^{177}Hf, but large variation of their corresponding ^{206}Pb/^{207}Pb ages (see Figures 4 and 5) indicated that all these grains formed at the same time; however, several zircon domains were subsequently

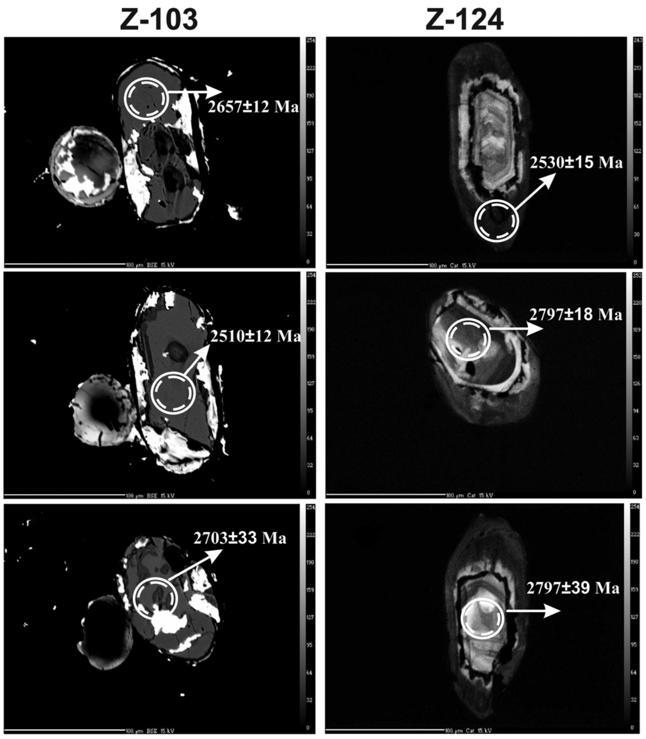

Figure 2. Representative back scattered electron (BSE) and CL images of the analysed zircons (Z-103 – Thumbasoge sample; Z-124 – Itna sample). The two marked circles are analysis spots for U–Pb (inside) and Hf (outside).

Table 1. U–Pb data of the studied metapelite samples from the Sargur area

Grain	$^{207}Pb^{a}$ (cps)	U^{b} (ppm)	Pb^{b} (ppm)	Th^{b}/U	$^{206}Pbc^{c}$ (%)	$^{206}Pb^{d}/^{238}U$	±2σ (%)	$^{207}Pb^{d}/^{235}U$	±2σ (%)	$^{207}Pb^{d}/^{206}Pb$	±2σ (%)	rho^{e}	$^{206}Pb/^{238}U$	±2σ (%)	$^{206}Pb/^{235}U$	±2σ (Ma)	$^{207}Pb/^{206}Pb$	±2σ (Ma)	Concor-dance (%)
Z-124, Itna																			
A25	63,115	100	61	0.30	1.6	0.51250	1.7	13.27	2.1	0.1878	1.2	0.82	2667	38	2699	20	2723	20	98
A26	66,307	131	66	0.006	0.1	0.49190	1.6	11.34	1.8	0.1672	0.9	0.88	2579	34	2552	17	2530	15	102
A27	66,143	98	59	0.29	0.4	0.51460	1.6	13.94	1.9	0.1965	1.1	0.83	2676	35	2746	19	2797	18	96
A28	632,679	1285	652	0.13	0.0	0.47880	1.5	11.23	1.9	0.1701	1.1	0.82	2522	32	2542	17	2558	18	99
A29	47,066	60	37	0.36	0.4	0.53000	1.7	14.14	2.8	0.1935	2.3	0.61	2742	39	2759	27	2772	37	99
A30	31,913	43	27	0.30	0.3	0.53830	1.5	14.73	2.0	0.1984	1.2	0.79	2776	35	2798	19	2813	20	99
A31	850,106	1839	3052	7.43	0.0	0.46170	1.6	10.58	1.8	0.1663	0.7	0.91	2447	33	2487	17	2520	12	97
A32	66,679	130	64	0.01	0.2	0.48190	1.6	11.04	1.8	0.1661	0.9	0.86	2536	33	2526	17	2519	15	101
A38	97,766	203	86	0.02	4.6	0.38670	1.8	8.549	3.0	0.1604	2.4	0.60	2107	32	2291	27	2459	40	86
A39	40,241	78	39	0.18	3.0	0.42970	1.9	11.64	3.1	0.1964	2.4	0.63	2305	38	2576	29	2797	39	82
A40	69,035	146	71	0.006	0.1	0.48170	1.6	11.05	1.8	0.1663	0.8	0.88	2535	33	2527	17	2521	14	101
A41	73,674	147	72	0.012	0.1	0.48430	1.6	11.08	1.9	0.166	1.0	0.84	2546	34	2530	18	2517	17	101
A43	54,783	115	55	0.005	0.1	0.47670	1.7	10.83	1.9	0.1648	1.0	0.87	2513	35	2509	18	2506	16	100
A44	539,316	1131	548	0.14	0.0	0.45560	1.6	10.38	1.7	0.1653	0.5	0.94	2420	32	2469	15	2510	9	96
A45	503,182	1198	617	0.25	0.0	0.47010	1.5	10.75	1.6	0.1659	0.6	0.93	2484	31	2502	15	2517	10	99
Z-103, Thumbasoge																			
A46	460,032	858	415	0.01	0.0	0.47690	1.6	10.99	1.7	0.1672	0.6	0.93	2514	33	2523	16	2530	10	99
A47	54,601	147	82	0.13	0.5	0.51400	1.9	13.15	2.8	0.1856	2.0	0.68	2674	41	2691	26	2703	33	99
A48	111,386	189	102	0.13	0.4	0.50170	1.8	12.48	1.9	0.1804	0.7	0.92	2621	38	2641	18	2657	12	99
A51	157,973	296	143	0.02	0.0	0.47590	1.5	10.84	1.7	0.1653	0.7	0.90	2509	32	2510	16	2510	12	100
A53	202,691	401	194	0.02	0.1	0.47480	1.5	10.81	1.6	0.1651	0.7	0.90	2505	31	2507	15	2509	12	100
A54	161,928	444	226	0.06	0.4	0.48970	1.8	11.40	2.0	0.1688	0.8	0.91	2569	38	2556	18	2546	13	101
A55	115,900	221	111	0.11	0.4	0.47410	1.7	10.85	2.1	0.166	1.2	0.82	2502	35	2510	19	2518	20	99
A57	219,096	453	219	0.04	0.1	0.46990	1.6	10.75	1.8	0.1659	0.7	0.92	2483	34	2502	17	2517	12	99
A58	232,686	445	218	0.02	0.1	0.48060	1.5	10.95	1.7	0.1652	0.8	0.88	2530	31	2519	16	2510	13	101
A59	254,096	458	213	0.03	0.7	0.44840	1.7	10.29	1.9	0.1664	0.8	0.90	2388	35	2461	18	2522	14	95
A60	176,560	334	163	0.02	0.4	0.47720	1.7	10.98	1.8	0.1668	0.7	0.92	2515	35	2521	17	2526	12	100

Spot size = 23 μm; depth of crater ~15 μm. $^{206}Pb/^{238}U$ error is the quadratic addition of the within run precision (2 SE) and the external reproducibility (2 SD) of the reference zircon. $^{207}Pb/^{206}Pb$ error propagation (^{207}Pb signal-dependent) following Gerdes and Zeh[16]. $^{207}Pb/^{235}U$ error is the quadratic addition of the $^{207}Pb/^{206}Pb$ and $^{206}Pb/^{238}U$ uncertainty.

[a]Within run background-corrected mean ^{207}Pb signal in cps (counts per second).

[b]U and Pb content and Th/U ratio were calculated relative to GJ-1 reference zircon.

[c]Percentage of the common Pb on the ^{206}Pb. bd, Below dectection limit.

[d]Corrected for background, within run Pb/U fractionation (in case of $^{206}Pb/^{238}U$) and common Pb using Stacy and Kramers[42] model Pb composition and subsequently normalized to GJ-1 (ID-TIMS value/measured value); $^{207}Pb/^{235}U$ calculated using $^{207}Pb/^{206}Pb/(^{238}U/^{206}Pb*1/137.88)$.

[e]rho is the $^{206}Pb/^{238}U/^{207}Pb/^{235}U$ error correlation coefficient.

[f]Degree of concordance = $^{206}Pb/^{238}U$ age/$^{207}Pb/^{206}Pb$ age × 100.

[g]Accuracy and reproducibilty was checked by repeated analyses (n = 4) of reference zircon OG, Plesovice and 91,500; data given as mean with two standard deviation uncertainties.

Table 2. LA-MC-ICPMS Lu–Hf isotope data of zircon for the Sargur samples

	$^{176}Yb/^{177}Hf^{a}$	±2σ	$^{176}Lu/^{177}Hf^{a}$	±2σ	$^{178}Hf/^{177}Hf$	$^{180}Hf/^{177}Hf$	Sig_{Hf}^{b} (V)	$^{176}Hf/^{177}Hf$	±2σ[c]	$^{176}Hf/^{177}Hf_{(t)}^{d}$	εHf(t)[d]	±2σ[c]	T_{NC}^{e} (Ga)	Age[f] (Ma)	±2σ
Z-124, Itna															
25	0.0347	40	0.00167	13	1.46718	1.88687	11	0.281125	20	0.281038	0.2	0.7	2.92	2723	20
26	0.0000	47	0.00214	13	1.46720	1.88660	9	0.281120	24	0.281017	–5.1	0.8	3.05	2530	15
27	0.0657	218	0.00267	52	1.46713	1.88706	9	0.281183	26	0.281039	2.0	0.9	2.88	2797	18
29	0.0499	70	0.00232	18	1.46722	1.88664	10	0.281127	27	0.281004	0.1	0.9	2.96	2772	37
30	0.0127	30	0.00082	8	1.46720	1.88675	7	0.281023	24	0.280979	0.2	0.9	2.99	2813	20
32	0.0491	58	0.00171	16	1.46714	1.88697	9	0.281132	24	0.281050	–4.2	0.9	2.99	2519	15
40	0.0728	103	0.00232	24	1.46716	1.88705	10	0.281167	22	0.281055	–3.9	0.8	2.98	2521	14
41	0.0445	46	0.00199	13	1.46717	1.88675	10	0.281134	21	0.281038	–4.6	0.7	3.02	2517	17
Z-103, Thumbasoge															
46	0.0345	141	0.00473	29	1.46714	1.88701	9	0.281171	22	0.280942	–7.7	0.8	3.20	2530	10
47	0.0589	37	0.00123	8	1.46716	1.88694	9	0.281049	23	0.280985	–2.2	0.8	3.03	2703	33
48	0.0483	33	0.00112	7	1.46716	1.88690	9	0.281066	19	0.281009	–2.4	0.7	3.01	2657	12
51	0.0575	50	0.00151	10	1.46715	1.88696	8	0.281077	25	0.281004	–6.0	0.9	3.09	2510	12
53	0.0898	66	0.00177	14	1.46715	1.88709	9	0.281103	21	0.281018	–5.5	0.7	3.06	2509	12
54	0.0000	41	0.00132	9	1.46716	1.88697	9	0.281108	23	0.281044	–3.7	0.8	2.99	2546	13
57	0.0246	47	0.00130	10	1.46716	1.88686	8	0.281080	27	0.281017	–5.4	1.0	3.06	2517	12
58	0.0000	36	0.00108	9	1.46716	1.88692	8	0.281053	21	0.281001	–6.1	0.8	3.09	2510	13
60	0.0752	42	0.00145	9	1.46718	1.88676	9	0.281069	21	0.280999	–5.8	0.8	3.09	2526	12

Quoted uncertainties (absolute) relate to the last quoted figure. The effect of the inter-element fractionation on Lu/Hf was estimated to be about 6% or less based on analyses of GJ-1 and Plesovičе zircon. Accuracy and reproducibilty were checked by repeated analyses ($n = 30$ and 20 respectively) of reference zircon GJ-1 and Plesovičе (data given as mean with two standard deviation uncertainties).

[a] $^{176}Yb/^{177}Hf = (^{176}Yb/^{173}Yb)_{true} \times (^{173}Yb/^{177}Hf)_{measured} \times (M_{173(Yb)}/M_{177(Hf)})^{\beta(Hf)}$, $\beta(Hf) = \ln(^{179}Hf/^{177}Hf_{true}/^{179}Hf/^{177}Hf_{measured})/\ln(M_{179(Hf)}/M_{177(Hf)})$; M is the mass of the respective isotope. $^{176}Lu/^{177}Hf$ was calculated in a similar way by using $^{175}Lu/^{177}Hf$ and $\beta(Yb)$.

[b] Mean Hf signal (volt).

[c] Uncertainties are quadratic additions of the within-run precision and daily reproducibility of the 40 ppb-JMC475 solution. Uncertainties for the JMC475 quoted at 2SD (two standard deviation).

[d] Initial $^{176}Hf/^{177}Hf$ and εHf calculated using the apparent Pb–Pb age determined by LA-ICP-MS dating (see [f]), and the CHUR parameters: $^{176}Lu/^{177}Hf = 0.0336$, and $^{176}Hf/^{177}Hf = 0.282785$ (Bouvier *et al.*[43]).

[e] Two-stage model age in billion years using the measured $^{176}Lu/^{177}Lu$ of each spot (first stage = age of zircon), a value of 0.0113 for the average continental crust (second stage), and a juvenile crust (NC) $^{176}Lu/^{177}Lu$ and $^{176}Hf/^{177}Hf$ of 0.0384 and 0.28314 respectively.

[f] Apparent Pb–Pb age determined by LA-ICP-MS.

affected by multiple Pb-loss that caused the resetting of the U–Pb system, but left the zircon Hf isotope system unaffected (see Zeh *et al.*)[19]. A positive correlation was seen between apparent zircon Pb–Pb ages and εHf(t) (Figure 5). Model ages of the analysed grains ranged between 2.88 and 3.05 Ga. T_{Hf}^{DM} of these zircons in the two-stage model became apparently older with decreasing apparent age. Thus, for geological interpretation, only initial Hf model ages (T_{DM} initial) can be used. It may be noted that model ages also do not always correspond to 'real' continental crust formation events[37,38]. Zircons preserved Hf-isotope signatures from all significant sources that contributed to parental melts of these minerals. Model ages of zircons that are produced from mixed sources (e.g. melting of heterogeneous basement or mixed crust and mantle-derived source) will only show a geologically meaningless average age of all sources from which these zircons were produced. Zircon Hf model ages can be used with confidence for determining ages of crust formation when only supported by other lines of evidence, e.g. matching U–Pb zircon age populations[19].

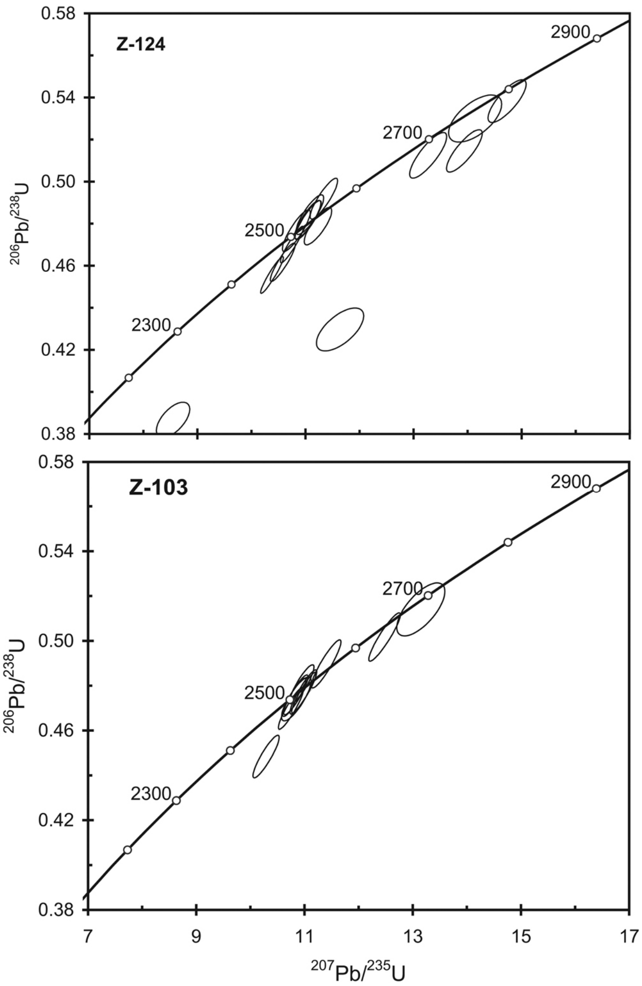

Figure 3. Concordia diagram of the studied samples.

So, we do not emphasize much on our limited zircon Hf model age dataset. It may be noted that zircons with core–rim morphology consistently yielded core ages of ~2.8 Ga, whereas the rims were much younger, ~2.5 Ga. The analyses also revealed that most of the cores yielded higher Th/U (>0.2) than the rims (Th/U < 0.1). Judging from the combined CL and U–Th–Pb analyses, it could be inferred that the cores are derived from magmatic source, whereas the rims formed during metamorphic overprint.

For the Thumbasoge sample Lu–Hf–Yb analyses conducted on nine grains with younger ages showed complex

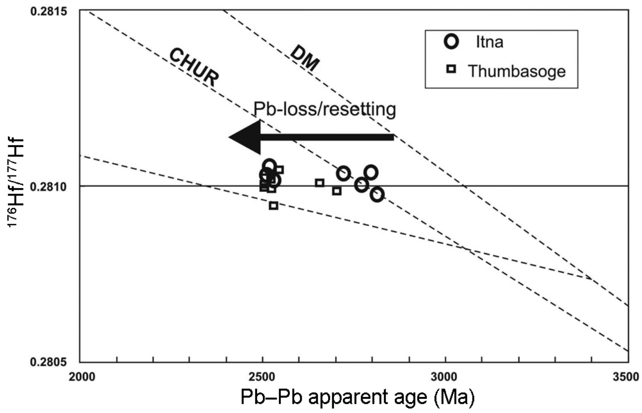

Figure 4. ^{176}Hf/^{177}Hf versus Pb–Pb age plot of the studied Sargur samples with the depleted mantle and bulk earth (CHUR) reference lines.

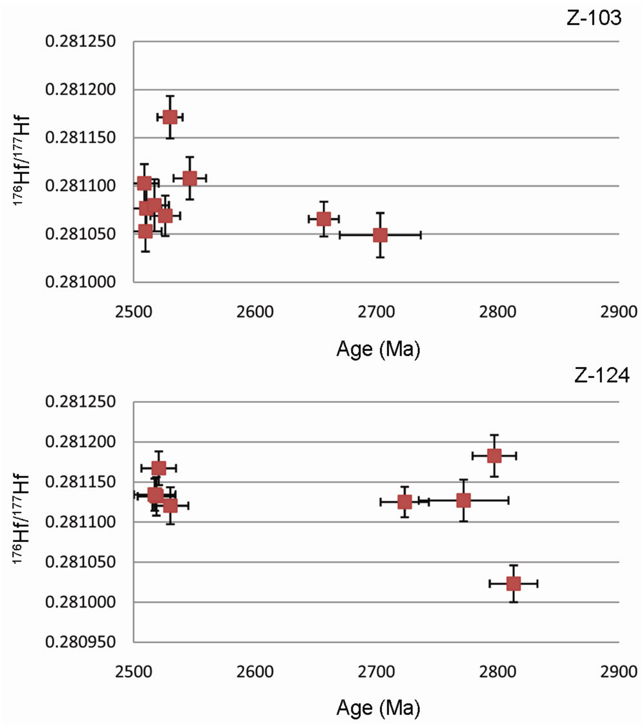

Figure 5. ^{176}Hf/^{177}Hf versus Pb–Pb age plot of the studied Sargur samples.

and significant $^{176}Hf/^{177}Hf$ and $^{176}Yb/^{177}Hf$ ratios (Table 2). The evolved Hf isotope signatures of zircons (εHf between –2.2 and –7.7) indicate reworking of older crust or geological event with Hf model ages varying between 2.99 and 3.20 Ga.

The U–Pb ages and Hf isotope data of psammopelite and quartzite samples, obtained in this study, show broad overlap. Zircon grains with ages ranging between 2.7 and 2.8 Ga in the Itna sample were characterized by juvenile crustal signature (εHf value ranging between +0.2 and +2), whereas the 2.5 Ga zircon population was characterized by evolved Hf-isotope value (εHf –3.9 to –5.1), indicating signature of reworked older crust or metamorphism.

Discussion

Earlier workers have considered that the Sargur Group rocks are all older than 3 Ga (refs 20, 29). U–Pb and Lu–Hf–Yb isotopic data presented here show that even the older population zircons in the quartzites and psammopelites of Sargur type area were derived from a juvenile magmatic crustal source whose age was in the range 2.7–2.8 Ga. Lu–Hf isotopic systematics for the older population zircons in the Sargur Group samples, also suggest an age younger than 3 Ga. Our data, therefore, do not support the view that the Sargur Group supracrustals, as a whole, were derived from >3 Ga crust[29].

The ages reported here overlap the SHRIMP U–Pb zircon ages (2.72 Ga) of felsic volcanic rocks of the Bababudan Group of the Dharwar Supergroup reported by Trendall *et al.*[24]. Lu–Hf isotopic systematics of the younger (2.5 Ga) population of zircons in this study are characterized by evolved Hf-isotope value (εHf–3.9 to –5.1). $^{176}Hf–^{177}Hf$ of the younger population apparently show relatively minor variation and are identical to the older zircons within the error limits (Figure 5). This suggests that the observed array can be interpreted to reflect resetting of the U–Pb systematics, while preserving the initial $^{176}Hf–^{177}Hf$ incorporated during magmatic crystallization. However, there is a gap of almost 150–200 million years between the older and younger age populations zircons. Therefore, resetting during magmatic crystallization as the cause for younger U–Pb ages is a difficult proposition. This resetting may have been caused by later metamorphism that has affected the rock formations of the area. The possibility that the U–Pb isotope systematics in some of the older detrital zircons might have been reset during the reported 2.5 Ga granulite metamorphism has been suggested by some workers[33,39]. In the $^{176}Hf–^{177}Hf_{int}$ versus apparent Pb–Pb age (Figure 4) diagram, similar $^{176}Hf–^{177}Hf$ ratio suggested that the studied zircon ages could have been reset during subsequent geological events. However, magmatic and metamorphic zircon domains maintained their primary hafnium isotopic signatures even during high-grade polymetamorphic conditions[16,19]. The horizontal arrays of the $^{176}Hf–^{177}Hf$ isotope data can be interpreted to result from post crystallization metamorphic alteration, which caused single or multiple Pb-loss events but did not change the primary $^{176}Hf–^{177}Hf$ (see refs 16, 19).

As the type area of Sargur Group is in the amphibolite to granulite transition zone in southern India, the possibility that younger age population of zircons represents metamorphic resetting of ages ca 2.5 Ga cannot be ruled out. However, the older core ages ranging between 2.66 and 2.80 Ga have not undergone resetting. The Th/U ratio of the younger rims were much lower than the unaltered cores. The results obtained in this study suggest that the 2.66–2.81 Ga juvenile magmatic zircons, found as detritus in Sargur Group sediments, were subjected to metamorphic resetting at ca. 2.50 Ga. Based on Pb–Pb isotopic study of marbles from the type area of Sargur Group, Sarangi *et al.*[32] also did not obtain evidence of metamorphism older than 2.5 Ga; the age of metamorphism was the same as recorded by Russel *et al.*[40] in the marbles of Dharwar Supergroup. Hokada *et al.*[27] have reported 3.08 Ga monazite age as probable for metamorphism of the Sargur Group. Our zircon age data do not support this view. $^{176}Hf–^{177}Hf_{int}$ versus apparent Pb–Pb ages (Figure 4) suggests that all zircons were formed during the same geological event, but were subjected to Pb-loss or resetting of different intensities. It is possible that in the Sargur area there are supracrustal enclaves in gneisses, some of which are older than 3 Ga, as exemplified by quartzites studied by Lancaster *et al.*[29], and others younger than 3 Ga. While the latter may represent torn/detached remnants of Dharwar granite–greenstone succession (Dharwar Supergroup), the former may be of rocks predating the Bababudan Group of the Dharwar Supergroup. Sargur Group is, therefore, a complex of rocks of different ages, a view conceded to by Ramakrishnan[28].

The present zircon U–Pb geochronological study of the high-grade metamorphosed supracrustal rocks of Sargur Group from the Dharwar Craton shows that in the Archaean gneiss–granulite terrains, there can be inclusions of supracrustal rocks of greenstone belts in the deeper crust. It is possible that the Sargur Group is a complex of rocks of more than one age, some predating the Dharwar Supergroup and others of the same age as those of Dharwar Supergroup. Therefore, the metasedimentary enclaves in the type area of Sargur Group have no independent stratigraphic status. They are part of gneiss–supracrustal complex of different ages and antiquities. Although the new geochronological results obtained in this study are limited, they underscore the need for further zircon geochronological and Hf-isotopic study to resolve the complex stratigraphic relationships of high-grade supracrustal rocks in the gneiss–granulite terrains in relation to the low-grade supracrustal rocks in the Dharwar greenstone belts.

Conclusion

The results of combined U–Pb and Lu–Hf isotopic studies on the zircons of Sargur supracrustal rocks from the type area may be summarized as follows: (i) The zircons belong two age populations of concordant U–Pb ages; an older population with ages ranging between 2.66 and 2.81 Ga, and a younger population ~2.5 Ga. (ii) Lu–Hf isotopic systematics of the zircons provides evidence that 2.66–2.81 Ga juvenile rock components also supplied sediments to the protoliths of Sargur supracrustals. (iii) Regional metamorphism at ~2.5 Ga affected the U–Pb systematics in some of the zircons in the Sargur Group metasediments. (iv) The metasedimentary enclaves in the type area of Sargur Group, as they are composed of sediments older as well as younger than 3 Ga, may not have an independent stratigraphic status.

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