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–granulate 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 Condie1, 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 workers2–8, 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 terranes9. Shackleton4 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 relationships10–15. In polycyclic Archaean metamorphic assemblages, zircons may have grown during different geological processes and/or may have been affected by multiple alteration processes16,17. 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 metamorphism18,19. The isotope data can also provide tight constraints on the timing of crustal growth and reworking16.

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 Supergroup20. 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 Supergroup20. The Sargur Group has been considered by several workers as the oldest group in the Archaean sequence of the Dharwar Craton21; 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...
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.21 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 komatitic ultramafic rocks of the Sargur Group. Trendell 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 rocks8,28. 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 systems 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 postdepositional 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 facies24–36. 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 anorthosites26. 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 Inna (12°01’0.046”, 76°23.817’), and (2) quartzite from the hill near Thumbasoge (12°01’.994”, 76°23.837’). The metamorphosed psammopelite from Inna 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
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. Cathodoluminescence 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 metapelitic samples from the Sargur area

| Grain | 207Pb (cps) | 206Pb (ppm) | 208Pb (ppm) | Th/U (%) | 205Pb/204Pb | 206Pb/204Pb | 207Pb/204Pb | 208Pb/204Pb | U error (%) | 206Pb/235U | 207Pb/235U | 208Pb/235U | Concorance (Ma) | 206Pb/238U | 207Pb/238U | 208Pb/238U | Concorance (Ma) |
|-------|-------------|-------------|-------------|----------|--------------|--------------|--------------|--------------|-------------|------------|--------------|--------------|----------------|----------------|--------------|--------------|----------------|----------------|
| Z-124, Itna | | | | | | | | | | | | | | | | | | |
| A25 | 63,115 | 100 | 61 | 0.30 | 1.6 | 0.51250 | 1.7 | 13.27 | 21 | 0.1878 | 1.2 | 0.82 | 2667 | 38 | 2699 | 20 | 2723 | 20 | 99 |
| 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 | 2722 | 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 | 7.40 | 0.4 | 0.61670 | 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 | 83 | 0.02 | 4.6 | 0.38670 | 1.8 | 8.549 | 3.0 | 0.1640 | 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 |

- **Spot size = 23 µm; depth of crater = 15 µm.** 207Pb/235U error is the quadratic addition of the within run precision (2 SE) and the external reproducibility (2 SD) of the reference zircon, 205Pb/206Pb error propagation (207Pb signal-dependent) following Gerdes and Zeh [16]. 206Pb/235U error is the quadratic addition of the 205Pb/206Pb and 207Pb/235U uncertainty.
- **Within run background-corrected mean 206Pb signal in cps (counts per second).**
- **U and Pb content and Th/U ratio were calculated relative to GJ-1 reference zircon.**
- **Percentage of the common Pb on the 206Pb bd, Below detection limit.**
- **Corrected for background, within run Pb/U fractionation (in case of 206Pb/208Pb) and common Pb using Stacy and Kramers [42] model Pb composition and subsequently normalized to GJ-1 (ID-TIMS value/measured value).** 207Pb/235U calculated using 205Pb/206Pb (205Pb/206Pb; 1/137.88).
- **rheo is the 208Pb/235U, 207Pb/235U error correlation coefficient.**
- **Degree of concordance = 206Pb/238U age/206Pb/238U age < 100.**
- **Accuracy and reproducibility was checked by repeated analyses (n = 4) of reference zircon OIG, 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

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<th>176Lu/177Hf&lt;sup&gt;a&lt;/sup&gt;</th>
<th>±2σ</th>
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<th>±2σ</th>
<th>176Hf/177Hf&lt;sup&gt;c&lt;/sup&gt;</th>
<th>±2σ</th>
<th>Signif. (V)</th>
<th>176Hf/177Hf&lt;sup&gt;d&lt;/sup&gt;</th>
<th>±2σ</th>
<th>εHf(t)&lt;sup&gt;d&lt;/sup&gt;</th>
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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 Plesovice zircon. Accuracy and reproducibility were checked by repeated analyses (<i>n</i> = 30 and 20 respectively) of reference zircon GJ-1 and Plesovice (data given as mean with two standard deviation uncertainties).

<sup>a</sup>176Lu/177Hf = (176Yb/177Yb)meas × (176Yb/177Hf)meas/10, 176Hf/177Hf = ln((176Hf/177Hf)measured)/(176Hf/177Hf)measured); M is the mass of the respective isotope; 176Lu/177Hf was calculated in a similar way by using 176Lu/177Hf and γ(Yb).

<sup>b</sup>Mean Hf'signal (volts).

<sup>c</sup>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 deviations).

<sup>d</sup>Initial 176Hf/177Hf and εHf calculated using the apparent Pb–Pb age determined by LA-ICP-MS dating (see ), and the CHUR parameters: 176Lu/177Hf = 0.0382, and 176Hf/177Hf = 0.282785 (Bouvier et al.).

<sup>e</sup>Two-stage model age in billion years using the measured 176Lu/177Lu 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) 176Lu/177Lu and 176Hf/177Hf of 0.0384 and 0.28314 respectively.

<sup>f</sup>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 $\varepsilon$Hf(t) (Figure 5). Model ages of the analysed grains ranged between 2.88 and 3.05 Ga. $T_{\text{DM}}^{\text{Hf}}$ of these zircons in the two-stage model became apparently older with decreasing apparent age. Thus, for geological interpretation, only initial Hf model ages ($T_{\text{DM}}^{\text{initial}}$) can be used. It may be noted that model ages also do not always correspond to ‘real’ continental crust formation events37,38. 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 populations19.

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
and significant $^{176}\text{Hf}^{177}\text{Hf}$ and $^{176}\text{Yb}^{177}\text{Hf}$ ratios (Table 2). The evolved Hf isotope signatures of zircons ($\varepsilon\text{Hf}$ 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 Ina sample were characterized by juvenile crustal signature ($\varepsilon\text{Hf}$ value ranging between $+0.2$ and $+2$), whereas the 2.5 Ga zircon population was characterized by evolved Hf-isotope value ($\varepsilon\text{Hf} = -3.9$ 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.

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 ($\varepsilon\text{Hf}= -3.9$ to $-5.1$). $^{176}\text{Hf}^{177}\text{Hf}$ 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 $^{176}\text{Hf}^{177}\text{Hf}$ 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.

In the $^{176}\text{Hf}^{177}\text{Hf}_{\text{int}}$ versus apparent Pb–Pb age (Figure 4) diagram, similar $^{176}\text{Hf}^{177}\text{Hf}$ 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 polyametamorphic conditions. The horizontal arrays of the $^{176}\text{Hf}^{177}\text{Hf}$ 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 $^{176}\text{Hf}^{177}\text{Hf}$ signature.

As the type area of Sargur Group is in the amphibolite to granulate 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.22 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. $^{176}\text{Hf}^{177}\text{Hf}_{\text{int}}$ 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 RamaKrishnan28.

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 to 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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