DISCUSSION AND REPLY

Detrital Zircons Reveal Evidence of Hadean Crust in the Singhbhum Craton, India: A Discussion

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Miller et al. (2018) discussed the isotopic composition and possible source of Hadean and Archean zircons extracted from Baitarani River modern-day sediments from the Archean Singhbhum craton, eastern India. They generated voluminous and significant U-Pb age and corresponding Lu-Hf isotope data of zircons with a large spectrum of age (i.e., Hadean to Neoarchean). Such excellent data were long overdue, and we must congratulate them for undertaking this study with detrital zircon that provides the opportunity to study zircons sourced from varied lithologies exposed over a regional area representing the oldest part of the craton. However, the stratigraphic implications of their valuable data and propositions about the source of the zircons will not be fully resolved until the following issues are discussed.

Miller et al. (2018, p. 543) wrote, "The only U-Pb single-zircon Eoarchean ages reported from the Singhbhum craton come from Cameca IMS-4f ion microprobe analysis of three grains with ages of 3628 ± 72, 3583 ± 50, and 3591 ± 64 Ma from an OMG [Older Metamorphic Group] orthoquartzite (Goswami et al. 1995)." This is, however, not the case, as Upadhyay et al. (2014) reported an Eoarchean U-Pb La inductively coupled plasma mass spectrometry age of 3611 ± 11 Ma, and Chaudhuri et al. (2018) reported two U-Pb SHRIMP concordant analysis spots with ages of 3670 ± 7 Ma and 3673 ± 7 Ma. All three of these ~3.6–3.7 Ga age data are reported from inherited cores from zircons extracted from Older Metamorphic Tonalitic Gneiss (OMTG). These observations substantiate that both OMG and OMTG incorporate a reworked Eoarchean crustal component. Hence, the statement "Paleoarchean ages dominate the Singhbhum craton zircon signal of every major unit and begin at ~3.5 Ga for all except the OMG" is out-of-date (Miller et al. 2018, p. 543).

Regarding the lower age limits of major Singhbhum units, the statement "Upadhyay et al. (2014) reported a 2790 ± 27 Ma average age for SG [Singhbhum Granite] phase I zircons" is ambiguous (Miller et al. 2018, p. 545). The actual crystallization age reported by Upadhyay et al. (2014) for SG-I is Paleoarchean (3350 ± 20 Ma), which is in reasonable agreement with other published works that report emplacement of SG-I to be between ~3.3 and 3.4 Ga (Saha 1994; Chaudhuri et al. 2018). The 2790 ± 27 Ma age basically dates the age of metamorphism of SG-I (Upadhyay et al. 2014).

Miller et al. (2018, p. 547) concluded, "Because the OMG, OMTG, SG, IOG [Iron Ore Group], and Mahagiri Quartzite all have >3.5 Ga U-Pb-dated zircon grains, the exact source of prismatic to subrounded 3.62–3.55 Ga (5%) grains and the anhedral 4015 Ma grain are unclear. However, BIF [banded iron formation] pebbles and cobbles were found in portions of the Baitarani River near our sampling site, indicating a potential IOG component." The oldest stratigraphic component in Singhbhum cra-

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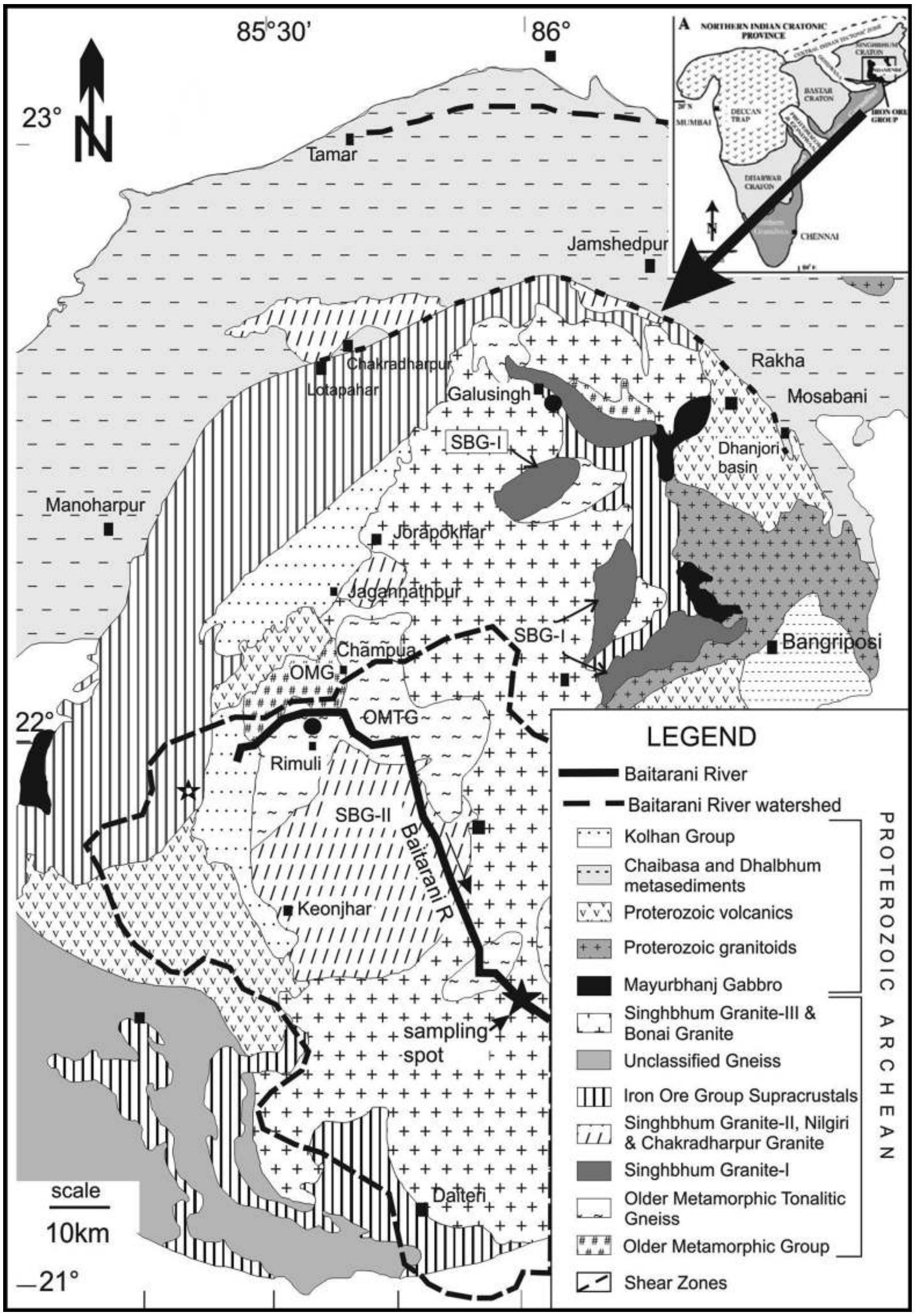

Figure 1. Geological map of Singhbhum craton (modified after Chaudhuri et al. 2018). Black dot and black star indicate sample site of Hadean zircons and Hadean-Archean zircons by Chaudhuri et al. (2018) and Miller et al. (2018), respectively. The thick black line denotes the Baitarani River, and the dashed black line delineates the Baitarani River watershed (after Miller et al. 2018 and references therein). The white star denotes the sample location of 2.8 Ga Tamperkola granite after Bandyopadhyay et al. (2001). OMG = Older Metamorphic Group; OMTG = Older Metamorphic Tonalitic Gneiss; SBG-I = Singhbhum Granite-I; SBG-II = Singhbhum Granite-II.

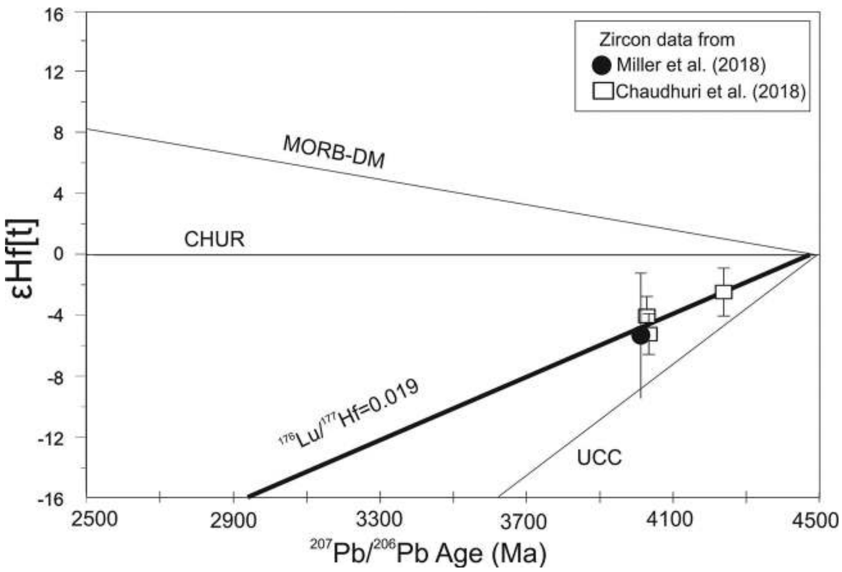

Figure 2. Age (Ma) versus εHf^t plot of Hadean zircons reported from Singhbhum craton, India (data from Chaudhuri et al. 2018; Miller et al. 2018). Note that all the age spots follow a source Lu/Hf = 0.019 array. CHUR = chondrite uniform reservoir (after Bouvier et al. 2008); MORB-DM = mid-ocean ridge basalt–depleted mantle (after Blichert-Toft and Putchel 2010); UCC = upper continental crust (after Rudnick and Gao 2003).

ton is OMG, which is intruded by a Paleoarchean tonalite-trondhjemite-granodiorite suite locally called OMTG, considered the oldest felsic intrusive component of Singhbhum craton (Saha 1994; Mukhopadhyay 2001). The ~3.5–3.6 Ga age spots from OMG zircons (Goswami et al. 1995) and ~3.6–3.7 Ga xenocrysts in OMTG (Upadhyay et al. 2014; Chaudhuri et al. 2018) indicate that a crustal component probably existed before deposition of OMG sediments that was recycled by OMG sandstones and was also reworked by parent magma of OMTG before deposition of IOG greenstone belt sediments. Hence, the probable origin of the Hadean-Eoarchean zircons is more likely to be this oldest, pre-OMG-OMTG crust. Alternatively, this early crustal component may eventually be recycled by IOG sediments (western IOG) that can also contribute such old zircons in Baitarani River sediments.

Miller et al. (2018, p. 547) interpreted that the ~2.8 Ga zircon grain "could be from the SG, the OMTG, or a minor unit such as the Dhanjori volcanics (Misra and Johnson 2005; Acharyya et al. 2010; Upadhyay et al. 2014)." With no Th/U ratio of zircon and cathodoluminescence (CL) and/or backscattered electron images provided corresponding to the ~2.8 Ga age spot in the article, there is no way to determine whether this represents crystallization or a metamorphic resetting age. However, if this age represents the crystallization age, we would like to point out ~2.8 Ga Tamperkola granite (21°50′N, 84°45′E; Bandyopadhyay et al. 2001) as a possible source located at the western fringe of the Singhbhum craton (fig. 1) that was not considered by the authors. The Dhanjori basin, located at the northeastern fringe of Singhbhum craton (fig. 1), is far beyond the drainage area of Baitarani River and hence cannot contribute any zircon in Baitarani River sediments. On the contrary, if this Mesoarchean spot represents a metamorphic age, the possibilities are rather wide and can be contributed by SG, OMTG, western IOG supracrustals, or even younger sediments (Kolhan Group) exposed in the studied area (fig. 1).

Finding Hadean zircon (4015 Ma) from Singhbhum craton is indeed an important discovery by the authors. However, speculation about its source warrants more clarification than presently stated. The finding of negative εHf^t in Hadean zircon invariably indicates an enriched source reservoir but not necessarily the presence of felsic crust. For example, Hadean Jack Hill zircons with negative εHf^t values indicate a reworked mafic source with a source Lu/Hf ratio between 0.020 (Kemp et al. 2010) and 0.022 (Amelin et al. 1999). In a time-integrated εHf^t plot, the 4.015 Ga age spot with εHf^t −5.1 coincides with other Hadean age spots reported from the Singhbhum craton (Chaudhuri et al. 2018) to together define a best-fit array (slope 0.01) corresponding to source Lu/Hf = 0.019 (fig. 2). Moreover, the $^{176}Hf/^{177}Hf^{initial}$ value of the 4015 Ma spot (0.28002) is nearly identical to the average $^{176}Hf/^{177}Hf^{initial}$ value (0.28003) of 4031 Ma ($^{176}Hf/^{177}Hf^{initial}$ =

0.28005) and 4036 Ma ($^{176}Hf/^{177}Hf^{initial}$ = 0.28001) grains reported by Chaudhuri et al. (2018), indicating that they were derived from a similar (if not the same) source reservoir. However, it is unknown whether mafic or felsic rock(s) hosted these Hadean zircons, but their source Lu/Hf ratio (0.019) suggests that these rock(s) were produced from a reworked mafic- to intermediate-composition crust existing during Hadean time, which is in contrast with the conclusion of "felsic crust formation before 4015 Ma" drawn by the authors (Miller et al. 2018, p. 549). Rare earth element compositions and the Ti content of these Hadean zircons may provide significant clues in elucidating the nature of source rock (Belousova et al. 2002).

The existence of a depleted mantle reservoir during the Hadean–Early Archean is highly speculative (see Hawkesworth et al. 2010; Kemp et al. 2010). Hence, the model age (4.29 Ga) of a 4.03 Ga age spot with respect to depleted mantle (DM) calculated by Miller et al. (2018) represents only one among many possibilities. Once the Lu/Hf ratio of the source is estimated, the separation age of the source reservoir can be estimated by calculation of a two-stage model age of zircons (Nebel et al. 2007). We refine this age of separation from DM by calculating a two-stage model age considering crustal Lu/Hf = 0.02 as recommended for mafic crust (Kemp et al. 2010) in combination with DM parameters of Blichert-Toft and Puchtel (2010). We additionally calculated chondrite uniform reservoir model ages (T_{CHUR} model ages) for this zircon, considering the possibility of source separation from chondritic mantle, using the CHUR parameters of Bouvier et al. (2008) in combination with $^{176}Lu/^{177}Hf = 0.02$ for mafic crust. These calculations yield T_{DM} and T_{CHUR} ages of 4521 and 4507 Ma, respectively, with a difference of only 14 Ma between them.

To conclude, the geochronological data presented by Miller et al. (2018) are very important, but necessary alternative explanations/interpretations are lacking. More intensive scrutiny, along with additional CL images of the zircons, is essential for proper interpretation of their valuable data.

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