

Giant iron-ore deposits of the Hamersley province related to the breakup of Paleoproterozoic Australia: New insights from in situ SHRIMP dating of baddeleyite from mafic intrusions: Comment and reply

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Müller et al. (2005) have presented important new age data for mafic intrusions in the Hamersley province of Western Australia, which they use to constrain the ages of the Ophthalmian orogeny and giant iron-ore deposits. Their 2208 ± 10 Ma age for dolerite sills intruded into the Turee Creek Group is within analytical error of the 2209 ± 15 Ma maximum age determined by Martin et al. (1998) for the Cheela Springs Basalt near the base of the unconformably overlying Wyloo Group. Interpretation of these statistically indistinguishable and apparently contradictory ages is dependent on critical field relationships that the authors have not presented or do not appear to have considered.

The assumption that ca. 2208 Ma dolerite sills were intruded at approximately the same stratigraphic level throughout the region would imply a facies change from glaciogenic diamictites in the Hardey syncline (Martin, 1999) to deltaic and marine quartzites in the Turee Creek syncline (Thorne and Seymour, 1991; Martin et al., 2000). This implied facies change, and resultant differences in lithology, grain size, and paleocurrent directions, is not accounted for. Such a correlation also does not consider that dolerite-hosting quartzites in the Turee Creek syncline are conformably overlain by vesicular basalts of the Cheela Springs Basalt (Thorne et al., 1991), a stratigraphic relationship consistent with their correlation with the Beasley River Quartzite as exposed throughout the Hamersley province. Undated dolerite sills intrude the Beasley River Quartzite at the eastern end of the Hardey syncline and along the northern flank of the Wyloo Dome (Seymour et al., 1988; Thorne and Tyler, 1996), as well as in the Duck Creek syncline. Undated dolerite sills also intrude the overlying Cheela Springs Basalt (Trendall, 1979; Thorne and Seymour, 1991; Martin et al., 2000).

An important field relationship for the interpretation of dolerite sills that have intruded into the Turee Creek Group is the presence of a highly discordant sill at the eastern end of the Wyloo Dome. This sill cuts across stratigraphy from within the Turee Creek Group up to the unconformity at the base of the Beasley River Quartzite (Seymour et al., 1988; Trendall, 1979). My own unpublished mapping shows that the sill locally intrudes ~50 m above the unconformity, separating the basal Three Corner Conglomerate Member from the remainder of the formation. Interestingly, the youngest detrital zircon in the Beasley River Quartzite is 2420 ± 18 Ma (Geological Survey of Western Australia, 2005; sample number 169084), which does not appear to support erosion of ca. 2208 Ma dolerites on a ~180 m.y. unconformity (Müller et al., 2005).

Regional field relationships of both dated and undated dolerite sills in the southern Hamersley province indicate that they are unreliable for stratigraphic correlation. An alternative interpretation of the ca. 2208 Ma dolerites is that they are sub-volcanic mafic intrusions genetically related to the Cheela Springs Basalt (Krapež, 1999). This interpretation provides a source for the ca. 2209 Ma detrital zircons from near the top of the Cheela Springs Basalt and accounts for the absence of detrital zircons of this age in the Beasley River Quartzite. Furthermore, the Beasley River Quartzite and basal Cheela Springs Basalt were folded along the same east-west axes as the Turee Creek Group (Martin et al., 2000). These multiple lines of evidence imply that the Beasley River Quartzite is older than ca. 2208 Ma and was deformed during the Ophthalmian orogeny (Powell et al., 1999; Martin et al., 2000). Also, the Panhandle folding event, assigned

an age of ca. 2031–2008 Ma by Müller et al. (2005), cannot be related to the much younger 1830–1780 Ma Capricorn orogeny (Cawood and Tyler, 2004). Clearly further dating, particularly of mafic intrusions and detrital zircons, is required in order to resolve the timing and significance of the Ophthalmian orogeny.

The ca. 2008 Ma age proposed for the giant iron-ore deposits of the Hamersley province is a reliable maximum age for mineralization at the Paraburdoo mine, but may not necessarily apply to all deposits. Small ore clasts are present in the basal Cheela Springs Basalt and Beasley River Quartzite, suggesting that some iron enrichment occurred prior to ca. 2209 Ma (Martin et al., 1998). This observation is supported by recent studies of the timing of regional-scale metamorphic fluid flow (Rasmussen et al., 2005) and the formation of hematite veins associated with the Mount Whaleback deposit (Brown et al., 2004).

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Paleoproterozoic basins are notoriously difficult to date if they are poor in zircon-rich felsic-volcanic rocks. The detail with which basins are mapped often resolves the problem, as many contain thin zircon-rich ash beds. Dating detrital zircon is useful, but there are always questions of the ultimate source of zircon and the origin of the host rocks. If source rocks are older than the basin, detrital zircon dating aids provenance analysis more than basin chronostratigraphy. While there is the question of which rocks provided detrital zircon, mafic rocks are an unlikely source of zircon in zircon-rich heavy-mineral assemblages. One technique that can help basin analysis is dating baddeleyite in mafic intrusions, but correct observation and interpretation of field relationships between intrusions and basin strata are required. Sequence stratigraphy is also the best way to document basin chronostratigraphy when options for precise dating are limited. We applied all those techniques to understanding the tectonic context of the giant iron-ore bodies of the Hamersley province. In contrast, the comment on our paper focuses on parochial aspects of field geology that are either easily resolved or irrelevant. Our responses are given below.

We did not accept the 2209 ± 15 Ma age of the Cheela Springs Basalt of Martin et al. (1998) because we could not replicate the field sample from the published field coordinates. We considered their sample suspect, because the only petrographically similar rock we found was a surficial breccia. We have since identified the ca. 2210 Ma age from detrital zircon in quartz-bearing sandstones at several horizons in the Cheela Springs Basalt, and it records the age of unknown felsic source rocks, not the eruption age of the Cheela Springs Basalt.

We did not assume that ca. 2208 Ma dolerite sills were intruded at approximately the same stratigraphic level, so perceived facies changes in the Turee Creek Group are irrelevant.

The Cheela Springs Basalt is not present in the Turee Creek syncline. Traverses across it revealed no exposures of basalt and only float of dolerite. It is our contention that dolerite float has been mistaken for the Cheela Springs Basalt because orthoquartzites were misinterpreted to be the Beasley River Quartzite.

Dolerite sills and dikes intrude the Beasley River Quartzite, but one previously mapped dolerite is amygdaloidal basalt (Krapež, 1999). We did not find baddeleyite in any of those dolerites, distinguishing them from the ca. 2208 Ma dolerites in the Turee Creek Group. Dolerite dikes that cut the Beasley River Quartzite also cut the Turee Creek Group and ca. 2208 Ma dolerites. The challenge is to distinguish ca. 2208 Ma dolerites from younger intrusions, with one distinction being that the latter are highly discordant to the Turee Creek Group, which is the field description given for the eastern end of the Wyloo Dome. Our critical field observations establish the dolerite sill at the eastern end of the Wyloo Dome is cut by an erosion surface below the Beasley River Quartzite. We have dated baddeleyite from that sill and although giving a ca. 2210 Ma age, analyses are too few for statistical certainty. We assert that any highly discordant dolerite that cuts into the Beasley River Quartzite is not a ca. 2208 Ma intrusion. It is illogical to believe that a dolerite sill below an erosion surface can elsewhere become an intrusion above that surface. It is obvious there are different-aged intrusions.

The assertion that 2420 ± 18 Ma detrital zircon in the Beasley River Quartzite does not support erosion of ca. 2208 Ma dolerites on an ~180 m.y. unconformity is erroneous, particularly as the ca. 2208 Ma dolerites do not contain zircon.

We do not use dolerite sills for stratigraphic correlation. We obtained identical ages for sills that intruded the Turee Creek Group prior to the Ophthalmian orogeny, and so determined the maximum age of orogeny from them. The age is considerably older than the depositional age of the Woolly Dolomite and, by inference, the age of the Cheela Springs Basalt. The assertion that ca. 2208 Ma dolerite sills are sub-volcanic to the Cheela Springs Basalt is not consistent with the field relationships. Krapež (1999) did not consider that the sills were subvolcanic to the Cheela Springs Basalt. He stated that the dolerite sills are the only rock record of an extensional event that occurred prior to the Ophthalmian orogeny and long before the Beasley River Quartzite was deposited.

The premise that the Beasley River Quartzite and Cheela Springs Basalt are deformed by the same folds as the Turee Creek Group is a persisting myth. Orthoquartzites in the Turee Creek syncline are folded concordantly with strata that are Turee Creek Group, but we contend that those orthoquartzites are part of the Turee Creek Group and not the Beasley River Quartzite. Poor documentation of the Turee Creek Group is responsible for the belief that the same cleavage is present in the Beasley River Quartzite and Turee Creek Group. Krapež (1996), following fieldwork with A.B. Goddard in 1992, documented the sequence stratigraphy of the Turee Creek Group in the Hardey syncline. Martin et al. (2000) admitted that the unconformity-bound unit they initially believed was basal Beasley River Quartzite was actually part of the Turee Creek Group, but they did not correct their earlier structural interpretation, continuing the belief that the cleavage they identified in the unit that they incorrectly assigned to the Beasley River Quartzite records common folding between the Beasley River Quartzite and the Turee Creek Group. Although critical field relationships were eventually accepted, there is reluctance to give up the structural misinterpretation.

We did not assign the Panhandle event to the 1780 Ma Capricorn orogeny. Krapež (1999) recognized it as a ca. 2000 Ma syn-rift deformation, and Taylor et al. (2001) reached a similar conclusion.

Fieldwork during 2006 will include a search for iron-ore clasts in the Beasley River Quartzite and Cheela Springs Basalt, and if found, we will publish field coordinates of localities. It is unlikely all iron-ore deposits are the same age, but no structural, ore-deposit, or geochronologic studies have reasonably established that iron ores are linked to compressional tectonics. Rather, iron ores formed during extension or transtension, most likely subsequent to the Ophthalmian orogeny, the age of which is <2208 Ma (the age of prefolding dolerites) and >2030 Ma (the age of the Woolly Dolomite). The significance of the ca. 2030 Ma Woolly Dolomite to the age of the Beasley River Quartzite and Cheela Springs Basalt appears to have been ignored by Martin. This is surprising, because it is difficult, if not impossible, to believe that the syn-rift Beasley River Quartzite and Cheela Springs Basalt spanned the period 2208 Ma to 2030 Ma.

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