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Early Archean spherule beds: Chromium isotopes confirm origin through multiple impacts of projectiles of carbonaceous chondrite type: Comment and Reply

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Forum

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COMMENT

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Kyte et al. (2003) and Lowe et al. (2003) are to be congratulated on their study of Early to Middle Archean impact fallout units in the Barberton greenstone belt, South Africa, representing a major advance in the understanding of the nature of early Precambrian Earth. Here I point to some of the implications and outstanding questions arising from these studies.

Kyte et al. (2003) estimate asteroid diameters from mass balance calculations of Ir abundances and $^{53}Cr/^{52}Cr$ isotopes (Shukolyukov et al., 2000), consistent with Melosh and Vickery's (1991) calculations based on condensation spherule (microkrystite) maximum sizes, which suggest asteroids several tens of kilometers large. Applying projectile/crater scaling factors of 1/10 to 1/15, impact craters on a scale of several hundred kilometers in diameter are implied. The largely mafic (chlorite, Cr-sericite and stilpnomelane-dominated) composition of impact spherules and the absence of shocked quartz in the Archean impact fallout units suggest mafic/ultramafic crustal (simatic) loci of these craters, consistent with studies of impact fallout units in the Pilbara craton (Simonson et al., 1998; Vickers, 2003, personal commun.). The evidence for Archean analogues of lunar maria (Green, 1972; Glikson, 2001), on a similar scale as Crisium or Serenitatis, is inconsistent with uniformitarian models of the early crustal evolution.

Inferences from microkrystite spherule chemistry to projectile composition need to take into account vapor fractionation processes. Kyte et al. (2003) suggest the Barberton greenstone belt spherules display chondritic platinum group element distribution patterns, modified through hydrous alteration and consequent loss of the relatively mobile Pd and Au. However, similar depletion of low-condensation point platinum group elements (e.g., Pd at 3237 °C and Au at 3130 °C) as compared to the high-condensation point platinum group elements (e.g., Ir at 4701 °C and Pt at 4100 °C), reflected by $(Pd/Ir)_N$ ratios <1.0 (N is chondrite normalized), is also observed in 2.56 Ga (Simonson et al., 1998) and 2.47–2.50 Ga (Vickers, 2003, personal commun.) Hamersley Basin spherules, Western Australia. These patterns are contrasted with the relative enrichment of Pd relative to Ir in associated mafic and ultramafic volcanic rocks, which show $(Pd/Ir)_N$ ratios >1.0. The only other example for low Pd/Ir ratios of which I am aware is harzburgite depleted in low-melting point components. Since both the spherule beds and juxtaposed mafic/ultramafic greenstones were subjected to similar greenschist facies conditions, the depletion in volatile platinum group elements shown by the spherules may conceivably be related to original fractionation in the impact-released cloud from which the spherules condensed, with consequent loss in low-condensation temperature (volatile) components. Such fractionation is consistent with observed depletion in Cr (condensation temperature 2945 °C) relative to V (condensation temperature 3682 °C) in 2.47–2.50 Ga spherule-rich beds in the Hamersley Basin (Vickers, 2003, personal commun.).

The locally extreme enrichment in platinum group element levels in Barberton greenstone belt spherules, particularly the S3 and S4 units observed by Kyte et al. (1992), may be explained as a consequence of alteration of iridium nanonuggets reported in sulfides by these authors and also observed through laser inductively couple plasma–mass spectrometry analyses of nickel chromites from the Barberton greenstone belt S3 unit (W. Taylor and A.Y. Glikson, 2000, personal commun.). Extensive alteration of the chromites by chlorite is observed, with consequent heterogeneous secondary distribution patterns of the platinum group elements.

The depositional environment of the Barberton greenstone belt spherules interpreted in terms of a transition from shallow-water fan-delta environment in the southern Barberton greenstone belt to deep-water environments in the northern Barberton greenstone belt (Lowe et al., 2003; Kyte et al., 2003) requires consideration. As winnowing and reworking of spherule-bearing beds by shallow-water currents can be expected to result in destruction of the delicate, originally glassy spherule structures, unless protected by rapid burial and subsidence, preservation of spherules in shallow-water environments is less likely. In the Pilbara craton spherule-bearing units are invariably hosted by below–wave base siltstone, carbonate, chert, and banded ironstone, which show little or no shallow-water current reworking. Breccia and conglomerate-hosted spherules (in the ?2.56 Ga Carawine Dolomite and 3.47 Ga Apex Basalt) are interpreted in terms of large-amplitude tsunami disturbance of the deep (below normal wave base) sea bed (Vickers, 2003, personal commun.). Conspicuous features of these units are downward-injected sedimentary veins containing spherules, as below S3 in the Barberton greenstone belt (Lowe et al., 2003) and in the Carawine Dolomite spherule-bearing megabreccia. The almost invariably superior preservation of spherules within these veins has been attributed to extreme hydraulic pressures and consequent dilation affected by the tsunami (Vickers, 2003, personal commun.). Rapid subaqueous subsidence of host greenstone sequences, indicated by thick pillow lava sequences, suggests a high rate of subsidence of the depositional basin. It may be necessary to test whether current disturbances in the southern Barberton greenstone belt formed in a shallow fan-delta environment, or represent a deeper seafloor environment disturbed by deep-amplitude southwest- to northeast-directed tsunami waves.

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REPLY

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We appreciate Glikson's congratulations on our study of Early Archean spherule beds and we note that he accepts the central point of our paper—that the Cr isotopic data provide unequivocal evidence of extraterrestrial matter in three Barberton greenstone belt spherule beds. He also does not dispute our inference that these represent the distal ejecta of major large-body impacts. We agree that the simplest interpretation of the data for beds S3 and S4 is that these were basin-forming events, comparable to impacts during the Late Heavy Bombardment at 3.9 Ga that formed the lunar maria. In various papers (Lowe et al., 1989, 2003; Byerly and Lowe, 1994) we have suggested that the target was pre-existing mafic-ultramafic volcanics and that impacts might have triggered volcanism and reorganized tectonic regimes on a regional if not global scale. But this is a very different argument from the Green (1972) models for a fundamentally different tectonic style based on impacts for the Early to Middle Archean. We do not believe there are sufficient data to support such models.

While vapor fractionation may affect the chemistry of Archean spherule beds, we doubt that there is evidence that it is responsible for the platinum group element abundances in our samples. Our discussion of the Kyte et al. (1992) study of platinum group elements in bed S4 was meant to point out that the fractionated platinum group element pattern observed in these rocks was opposite to the effect expected by Au mineralization. Kyte et al. (1992) discuss in detail the relative partitioning of platinum group elements by magmatic and hydrothermal processes and by impact vapor fractionation, when considering the origin of the platinum group element abundances in bed S4. In rocks such as S4, where all the original minerals have been replaced, secondary processes such as diagenesis, hydrothermal activity, and metasomatism are likely to have affected the platinum group element pattern much more than vapor fractionation. The small differences in condensation temperature between Pd and Au are unlikely to explain Pd/Au ratios in S4 that are 20 times CI chondrites. This is easily explained by mobilization of Au. We consider it likely that virtually all of the projectile will condense with the silicate fraction, resulting in very little platinum group element fractionation in the final ejecta deposit. Further, we find no evidence in Glikson's comment to support vapor fractionation. We note that the Pd/Ir ratios of published data on 2.56 Ga Hamersley Basin spherules are all greater than in chondrites, contrary to the assertion by Glikson. This is consistent with relatively high Pd concentrations (and Pd/Ir ratios) in crustal rocks. We cannot evaluate unpublished data on other deposits by Glikson and his colleagues.

We cannot agree with the assertion that extreme platinum group element enrichment is related to alteration of ''iridium nanonuggets.'' Kyte et al. (1992) reported that three micron-sized platinum group element (not just Ir) nuggets were found in a single pyrite grain in bed S4. They stated that such nuggets could not be the primary host of platinum group elements in that rock or others would have been found. There are no other published data on platinum group elements in any mineral phase in any spherule beds. Glikson implies that he has data on platinum group elements from minerals in S3, and we encourage him to publish these so that they can be properly evaluated.

Glikson suggests that because ''winnowing and reworking of spherule-bearing beds by shallow-water currents can be expected to result in destruction of the delicate, originally glassy spherule structures, unless protected by rapid burial and subsidence, preservation of spherules in shallow-water environments is less likely.'' It is noteworthy that a wide variety of seemingly fragile particles, including accretionary lapilli, pumice grains, and fluffy carbonaceous particles, were widely preserved in Barberton greenstone belt sediments deposited in environmental settings showing evidence of long-term wave and current activity. Rapid deposition, early silicification, and particles more robust than expectations have all played roles in the preservation of these materials. One might ''expect'' spherule destruction mainly if the ''winnowing and reworking'' involved prolonged exposure to currents and extended abrasion. However, fan deltas on a vegetation-free world would probably have been dominated by flashy events, like those in modern arid environments, and could have provided an excellent setting locally for the rapid burial and preservation of fall-deposited spherules. The sedimentology of clastic sediments associated with S3 and S4 in the Barberton greenstone belt has been extensively discussed (e.g., Nocita and Lowe, 1990; Lowe and Nocita, 1999) and a fan-delta setting for Jay's Chert is reasonably well established. If Glikson has new sedimentological data from this unit that would support reinterpretation, he should present it. It seems unwarranted to question interpretations derived from extensive sedimentological data based on an untested model as to how someone thinks impacting should work. Perhaps it is the model and the associated expectations that should be reconsidered. These greenstone sequences also show dikes at virtually all levels containing a wide variety of debris derived from surface layers, including volcanic ash, carbonaceous matter, and impact debris. They do not bear on arguments for shallow- versus deep-water spherule deposition.

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