

Ironstone pods in the Archean Barberton greenstone belt, South Africa: Earth's oldest seafloor hydrothermal vents reinterpreted as Quaternary subaerial springs: Comment and Reply

COMMENT

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Lowe and Byerly's (2003) description of iron-oxide-depositing spring terraces in the Barberton greenstone belt and how they relate to the ironstone pods we studied is misleading and inaccurate. Here we demonstrate that the Archean iron deposits we studied have no relationship to the iron deposits studied by Lowe and Byerly. Thus, the ironstone pods we studied are relevant to understanding seawater compositions in the Archean.

1. All our studies on postulated Archean seafloor hydrothermal vents pertain only to the ironstone pods on Mendon farm. This locality excepted, those mentioned by Lowe and Byerly are from small outcrops up to ~20 km away associated with Quaternary landslide deposits and/or they occupy small topographic saddles.

2. Field relations show the Mendon farm ironstone pods are clearly part of the local Archean stratigraphy and are considerably larger than at other localities described by Lowe and Byerly. These ironstone pods have strike lengths up to 120 m, original thicknesses of 25 m, and downdip extensions ≥ 5 m (de Ronde et al., 1994) and thus are certainly *not* "slope parallel" in nature. They host large (~1 m), rounded boulders of silicified volcanic rocks (see Figure 3b of de Ronde et al., 1994), similar to those outcropping immediately below the ironstone pods, which could not have been transported to the surface by the springs postulated by Lowe and Byerly, nor is there evidence for eruption breccias. Rather, they are constructional hydrothermal mounds formed on the original Archean seafloor that have incorporated talus from nearby fault scarps. The ironstone pods are massive and are not likely to record deformational features as they occur in an area where the strain is heterogeneous and typically partitioned into zones of bounding, ultramafic-hosted (serpentinite-rich) shear zones. Our 1:5000 scale map over ~9 km² shows the ironstone pods unit grades into Archean oxide-facies banded iron formation along-strike and is cut by a 3230 Ma porphyry (de Ronde et al., 1994). Clasts of banded iron formation and ironstone pods are found in coarse clastic units stratigraphically overlying the ironstone pods unit. The assertion by Lowe and Byerly (2003, p. 911) that they observed "no stockwork vein complex systematically related to the ironstone pods" is clearly inconsistent with the obvious quartz-hematite-goethite stockwork veins mapped by us (cf. Figures 4a, 4b of de Ronde et al., 1994).

3. The ironstone pods are dominated by specular hematite. Primary goethite is also present within ironstone pods, although it is of lesser importance and has been remobilized in places where it "appears to be late-stage" (de Ronde et al., 1994). Goethite is not a "thermally unstable...mineral" (Lowe and Byerly) but is stable to ~130 °C at 1 bar and ~175 °C at 1 kbar (Garrels and Christ, 1967). Fluid inclusion studies on Philippines geothermal systems indicate formation temperatures for goethite from ambient to 250 °C (Reyes et al., 2003), in contrast to Lowe and Byerly's assertion that goethite

would not be recorded in Archean rocks exposed to overprinting temperatures of ~200 °C. Hematite, seen dominating subsurface exposures of ironstone pods (in adits) but not seen at any other Barberton locality described by Lowe and Byerly, occurs at temperatures >240 °C in the Philippines (Reyes et al., 2003) and other geothermal systems. Together, these results are incompatible with ironstone pod formation by surface discharge of thermal waters.

4. Lowe and Byerly's suggestion that quartz veins in the ironstone pods are Archean yet the pods themselves are Quaternary is untenable. The quartz stockwork veins have a close paragenetic relationship with hematite and goethite, as is clearly shown in Figure 5 of de Ronde et al. (1994). They are intact veins that do not occur as introduced angular fragments. Vug-filled quartz is commonly intergrown with hematite while needles of hematite are prevalent within individual quartz crystals (de Ronde et al., 1994). It is difficult to reconcile the survival of delicate networks of quartz microveinlets (cf. 3d of de Ronde et al., 1994) if ironstone pods were formed by "iron oxide replacement of microquartz in the silicified Archean rocks that were its original hosts" (Lowe and Byerly, 2003, p. 910). The "coarse [Archean] quartz" of ironstone pods is highly unlikely to be spared this replacement. Lowe and Byerly state that all their study areas are "related to young iron-oxide-depositing springs," implying recent constructional features, but this is contradictory to a replacement origin. Detailed fluid inclusion and stable isotope studies on ironstone pods quartz veins show they have precipitated from modified seawater solutions ≤ 220 °C, with hydrothermal end-member compositions similar to modern vent fluids (de Ronde et al., 1994).

None of the active warm springs in South Africa ($n = 90$; $T = 25$ – 64 °C; Fe concentrations <3.2 mg/L) appear to form deposits of the size or extent of the ironstone pods (Hoffmann, 1979). Such springs are situated along regional escarpments where meteoric water recharge is obtained from the highveld (plateaus), with gravity-driven discharge focused at the base of the escarpments (e.g., Badplaas hot springs ~45 km W of the Mendon ironstone pods). Formation of the largest ironstone pods (120 × 25 × 5 m, 85 wt% Fe₂O₃, 15% SiO₂; de Ronde et al., 1994) from a Badplaas source (Fe 0.05 mg/L, flow rate 9.5 L/s; Hoffmann, 1979) would require 1165 km³ of focused discharge over ~4 m.y. to form this single pod. These *minimum* values require 100% Fe extraction efficiency from constantly flowing spring waters, which together with the ironstone pods location along a topographic high (1530 m above sea level), makes the Lowe and Byerly model of subaerial iron-depositing hot springs implausible.

We believe the small, goethite-rich 'springs' described by Lowe and Byerly, but not the Archean age ironstone pods, form via normal precipitation of Fe³⁺ from laterally moving groundwater (Thomas, 1994) and are typical of modern ferricrete deposition in tropical climates (Barberton is at ~26°S). Alternating wet and dry seasons, as seen in Barberton, and a fluctuating water table promote the formation of ferricrete, with various manifestations, such as the dripstones and terraces described by Lowe and Byerly, commonly formed (Thomas, 1994). Abundant Fe²⁺ in the Barberton greenstone belt provides an iron source for remobilization and deposition as ferricrete. Ferricrete is a standard response to surficial weathering and not a result of hydrothermal activity.

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REPLY

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We respond to de Ronde et al. as per their numbered comments.

1. de Ronde et al. suggest that there are two populations of ironstone pods in the Barberton greenstone belt: those on Farm Mendon that are Archean in age and composed primarily of hematite and all other ironstone pods, which are young and composed of goethite. We disagree and regard all of the ironstone pods as related to young spring activity, but will restrict our discussion here to the Mendon ironstone pods. We did not mention pods occurring in “small topographic saddles.”

2. Our observations on the stratigraphic setting of the Mendon ironstone pods are at odds with those of de Ronde et al.: the Mendon ironstone pods are clearly not “part of the local Archean stratigraphy.” The dimensions provided by de Ronde et al. are those of the present outcrops and provide no information on whether the pods mantle the present surface or are part of Archean stratigraphy.

There are blocks of silicified sediment (chert) and silicified volcanic rock in the Mendon ironstone pods in the old mine and on the surface. In all cases that we have seen, bedding in these blocks is parallel or subparallel to that in surrounding Archean units. These “blocks” have not fallen from cliffs, but are masses of local Archean bedrock remaining after ironstone replacement or protruding through the surface-mantling ironstone veneer.

The Mendon ironstone pods are neither in contact nor interfinger with banded iron formation, as shown by de Ronde's map (de Ronde et al., 1994, their Fig. 2). Although this map shows them surrounded mainly by shale, our mapping (Lowe and Byerly's [2003] Fig. 1) shows them to be developed on a substrate of vertically dipping Archean ultramafic rock and carbonaceous and banded cherts. While strain has been preferentially partitioned into serpentinized ultramafic rocks, cherts and silicified volcanic rocks are strongly fractured, veined, and disrupted. No Archean rocks have escaped strain as suggested by de Ronde et al. for the Mendon ironstone pods. The hematitic portion of the largest Mendon ironstone pods contains open, unfilled cavities up to 70 cm across lined with fresh botryoidal hematite, features unlikely to survive 3.2 billion years of deformation and metamorphism.

The so-called ironstone pods porphyry is irrelevant to establishing the age of the Mendon ironstone pods. de Ronde's map (de Ronde et al., 1994, their Fig. 2) shows that it nowhere cuts or is in contact with the ironstone pods. Their line of reasoning is apparently that the ironstone pods porphyry is related to another small felsic intrusion, the mudpools porphyry, some 10 km away. This second intrusion cuts Fig Tree banded iron formation containing so-called mudpool structures that supposedly reflect hydrothermal activity that might be related to the hydrothermal vents that formed the ironstone pods.

No coarse Archean clastic units are in contact with or directly overlie Mendon ironstone pods. The second largest Mendon ironstone pod, exposed in low cuts along Powerline Road, overlies and is in turn overlain by modern regolith in a number of places. Chunks of ironstone from the pods have been incorporated into the regolith, which de Ronde et al. may have mistaken for Archean clastic material. While clasts of jasper and banded iron formation are common in coarse Fig Tree clastic units, no fragments of ironstone pods have been identified in any Archean sediments.

3. The pods are *not* composed largely of specular hematite. The eastern half of the largest Mendon ironstone pod is composed largely of hematite, but the western half, including an old mine face some 5 m high (de Ronde et al., 1994, their Fig. 3c), is made up entirely of well-layered goethite containing large open cavities, many with dripstone fill. The other large Mendon ironstone pods (de Ronde et al., 1994, their Figure 2; Lowe and Byerly's [2003] Fig. 1) are composed of 10%–30% hematite and >70% goethite. The vertical open fluid-flow conduit illustrated by Lowe and Byerly (their Fig. 4) from the Mendon ironstone pod along Powerline Road is composed entirely of goethite.

Goethite described by Reyes et al. (2003) occurs from surface temperatures to 290 °C. These authors note that goethite commonly forms at <150 °C and their data clearly indicate that this is a nonequilibrium mineral assemblage. Even if goethite is stable up to ~175 °C at 1 kbar, as stressed by de Ronde et al., rocks of the Barberton greenstone belt, including those around the Mendon ironstone pods, have been altered at sustained temperatures >300 °C (Tice et al., 2004) and goethite is still essentially unknown in the geologic record before the Ordovician.

4. Virtually all quartz veins occur around the margins of the Mendon ironstone pods where iron oxides are replacing chert and other country rocks. Within the main parts of Mendon ironstone pods, quartz occurs mainly as irregular, disrupted masses being replaced by iron oxides, as confirmed by de Ronde et al. Many if not most hydrothermal fluids are brines and represent “modified seawater,” but most do not provide useful data on the specific composition of the ocean or atmosphere because of extensive subsurface modification and exchange. The same is true of the fluids in the quartz masses in the Mendon ironstone pods.

5. The composition of thermal waters in other parts of South Africa is irrelevant to springs discussed by us (Lowe and Byerly, 2003). Badplaas springs issue from an extensive plutonic terrane and represent waters that have flowed through platform sedimentary sequences, tonalites, and granites. The waters that we suggested to have formed the ironstone pods flowed through thick, vertical sections of sideritic cherts and mafic and ultramafic volcanic rocks. The goethite terrace on Farm Avontuur (Lowe and Byerly, 2003) was clearly formed by surface outflow rather than as ferricrete, as de Ronde et al. suggest, and unambiguously indicates that iron-depositing springs have existed in the Barberton greenstone belt region in the very recent past.

While it is difficult for the reader to evaluate the conflicting interpretations of local Barberton greenstone belt geology, at issue is whether large bodies of finely structured hematite and thermally unstable goethite containing large open cavities and complex organic compounds have survived intact and undeformed since the Archean through multiple episodes of intense deformation and metamorphism at temperatures >300 °C. Alternatively, the Mendon ironstone pods are part of a recognized set of goethite and hematite ironstone pods in the Barberton greenstone belt that show essentially the same characteristics and were deposited by relatively recent springs. Our observations support the latter interpretation and imply that these deposits are irrelevant to understanding Archean Earth.

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