

CHEMISTRY AND MINERALOGY OF EARLY ARCHEAN IMPACT DEPOSITS,
FIG TREE GROUP, BARBERTON GREENSTONE BELT, SOUTH AFRICA

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Two well defined spherule-bearing impact deposits, S2 and S3, are key stratigraphic markers in the Fig Tree Group of the Barberton Greenstone Belt (1,2). In a companion paper at this meeting, we report that a distinct iridium anomaly is associated with both of these units (3). These units apparently formed after a large meteorite impact produced melting and probably volatilization of a large mass of terrestrial crust. Condensation of melt droplets and possibly high temperature silicates resulted in the widespread distribution of these units with little or no ballistically derived materials. In the present paper we present new data on the bulk rock compositions of the impact deposits, spherule compositions, and mineralogy.

At several localities these units consist of nearly pure spherules undiluted by local detritus, but in all samples significant alteration due to early diagenesis, hydrothermal metasomatism, or later low-grade metamorphism has modified the original spherule and rock compositions. Two different types of constant-volume compositional alteration are recognized, each preserving original textures. The more common involves replacement of all primary silicates by quartz, sericite, and rutile, with minor magnetite or pyrite, and barite. Less commonly, primary silicates are altered to chlorite, with minor Ca-poor carbonate and apatite. The quartz-sericite alteration that we have studied in associated igneous rocks typically preserves the original Al₂O₃, TiO₂, Cr, Zr, V, and REE values while K and Ba are enriched by several orders of magnitude over primary abundances. MgO, FeO, Ni, and Co have clearly been mobilized during either diagenesis or hydrothermal metasomatism.

Major and trace element analyses demonstrate that the spherule-bearing layers are not the volcanoclastic equivalents of any of the greenstone belt igneous rocks, even when the extreme effects of alteration are considered. The spherule-bearing samples have elevated values for U, Ta, and Hf, suggesting that they may include a dacitic component. LREE/HREE is also consistent with this interpretation, but the very low total REE content indicates little or no dacitic component. Co and Ni are highly variable and show no correlation with Ir or other immobile elements. Cr, TiO₂, and especially V require that the dominant target component was fractionated tholeiitic basalt.

Spherules were analyzed by microprobe for major elements and Cr₂O₃. The average composition of spherules showing well defined quench textures was Al₂O₃--17.4%, TiO₂--1.3%, and Cr--400ppm. When compared to bulk rock analyses corrected for about 50% original porosity and other diluents, the present Al₂O₃ and TiO₂ values appear to be good estimates for the average unaltered spherules, but primary Cr would seem to be closer to about 1000 ppm. Best estimates for the spherule compositions and some possible volcanic components known to occur in the Barberton greenstone belt are shown in the accompanying table. A highly fractionated tholeiitic basalt was chosen because no other common rock type known to us has the needed high values of TiO₂ and V. The komatiite chosen is a high MgO and Cr₂O₃ variety. C1 chondrite values are volatile-free (4). A least squares calculation yields a mixture of 76% fractionated tholeiitic basalt, 4% komatiite, and 20% C1 chondrite to explain the composition of the spherules. The calculated spherule composition is low in Al₂O₃ and V by about 50% and high in the REE by a factor of two. Other common greenstone belt or granitoid terrain lithologies modify the solution somewhat but do not remove the Al₂O₃, V, and REE residuals. The basaltic nature of the target material is clear.

Chrome-spinels in the spherule-bearing samples are unlike those found in basalts and komatiites of the greenstone belt. They have very low concentrations of Al, Mg, and Ti, typically below 1 wt. %; and very high concentrations of NiO (to 17 wt. %), ZnO (to 5 wt. %), and V₂O₃ (to 2 wt. %). Such spinels are generally regarded to be products of high temperature sulfide or metallic melts (5). These spinels are most common in the samples with highest iridium contents where they typically occur in small clusters within spherules. An immiscible sulfide or metal melt appears to have been a minor component of some of the spherules.

Our interpretation of the average composition of the spherules based on bulk rock analyses of entire spherule-bearing layers and microprobe analyses of quench-textured spherules seems to be internally consistent and reflect a predominantly basalt source. The non-quench-textured spherules, however, have extreme bimodal compositions. One group is now composed of fine-grained quartz. The second group is now nearly pure sericite or chlorite and has Al₂O₃ values between 35 and 45%. These spherules were also altered under constant volume conditions and therefore the Al₂O₃ contents should reflect primary compositions. Could these populations of Al₂O₃-rich and Al₂O₃-poor spherules reflect crystalline condensates from the impact-generated silicate-vapor at high and medium temperatures?

The two Fig Tree spherule beds are grossly similar in bulk composition, preserved textures, and exotic spinel content. The scenario for spherule genesis suggested by this compositional variation is as follows. Each impact involved target rocks composed primarily of fractionated tholeiitic basalt and minor komatiite. Significant dacitic components are unlikely. Perhaps as much as 20% of the vaporized material was derived from the impacting meteorite. After impact and condensation of melt droplets, some immiscibility developed between silicate and either sulfide or metal melts. Iridium was almost totally partitioned into the nonsilicate melt. In those areas where the spherule beds were deposited in shallow-marine environments and were subsequently current-worked (6), a minor, high-density phase with most of the Ir could have been easily reworked and lost, explaining the highly variable Ir content within and between units that otherwise contain similar proportions of spherules and similar bulk spherule-layer compositions.

	Al ₂ O ₃	TiO ₂	LREN	HREN	Zr	V	Cr	Ir	L.S. Mix
Dacite	16.0	0.5	200	8	230	50	20	0	0
Tholeiite	15.0	2.0	30	20	120	500	100	0	76%
Komatiite	4.0	0.4	6	4	25	150	2500	.001	4%
C1 Chondrite	2.4	0.1	1	1	6	85	3950	.710	20%
L.S. Spherule	13.0	1.6	24	16	94	404	972	.142	100%
Est. Spherule	17.4	1.3	10	3	80	600	1000	.100	

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References:

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