IDENTIFICATION AND EFFECTS OF LARGE, EARLY ARCHEAN, TERRESTRIAL METEORITE IMPACTS: A GEOLOGICAL PERSPECTIVE ON LATE ACCRETION.

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Planetary accretion is well documented on surfaces throughout the Solar System, but the terrestrial record of accretion has been largely obliterated by later geologic processes. Based on lunar data, the terminal stages of large-scale bombardment occurred 4.1 to 3.9 billion years ago (byr) [1, 2]. Rapidly declining impact rates resulted in values only 2 to 8 times present rates at about 3.5 byr [2, 3], the age of the oldest known, relatively unstrained sedimentary rocks on Earth in the Barberton Greenstone Belt, South Africa, and eastern Pilbara Block, Western Australia.

These Early Archean volcanic and sedimentary sequences have provided an important picture of early surficial processes and crustal evolution. Recent evidence indicates that they also contain a record of late accretion events [4]. At least three and perhaps four layers of sand-sized spherules representing quenched liquid silicate droplets thought to have been formed by large meteorite impacts have now been identified, three in Barberton and one in Western Australia. The droplets vary in composition and make-up from bed to bed, but most represent recrystallized and metasomatically altered silicate glass or glass containing skeletal quench crystals. The quench textures are confined to the spherules, even in layers reworked by currents where the spherules are mixed with other grains, and are unambiguously of primary, not metamorphic or metasomatic origin. Inferred primary spherule compositions vary from basaltic to nearly pure silica.

The origin of the spherules by impact melting and volatization of target and projectile rocks is indicated by their (1) formation as quenched liquid silicate droplets, (2) deposition by fall over a wide range of sedimentary environments, (3) non-magmatic compositions, commonly involving the mixing within single beds of spherules of greatly contrasting compositions [4], (4) regional distribution over large areas, including outcrops originally more than 100 km apart, and (5) high iridium contents [5]. The impact products were evidently distributed as clouds of rock vapor rather than ballistic droplets. Beds of ejecta around known impact craters contain relatively few spherules and large amounts of rock debris [6, 7]. The Archean units, which locally exceed 1 m thick, commonly consist almost entirely of spherules lacking admixed, hydraulically equivalent, impact-produced ejecta that might be expected if the spherules were of ballistic origin.

The composition and structuring of the spherule beds is related to the local depositional environments into which the spherules fell. In relatively deep- and some protected shallow-water settings, spherules accumulated directly as fall deposits. The beds consist almost entirely of spherules and lack admixed detrital material and evidence of current deposition. These beds are commonly graded, with the largest particles at the base and smaller ones toward the top. Ir abundances in such graded units also tend to vary systematically with vertical position in the beds. Associated sediments represent fine-grained carbonaceous oozes and airfall volcaniclastic deposits.

In most shallow water sections, the spherules are mixed with locally eroded, coarse- to very coarse-grained sandstone and conglomerate in current-deposited beds 0.5 m to 3 m thick. These coarse detrital layers are commonly single, unique beds deposited by high-energy events in sections otherwise representing low-enegry depositional environments. In such sections, the coarse, current-worked, spherule-bearing layers are overlain and underlain by fine-grained carbonaceous chert and airfall volcaniclastic sediments.

Spherules tend to occur mixed within the upper parts of these detrital layers. The uniqueness of these beds and their association with the spherules lead us to infer that they formed as a consequence of impact-produced waves or tsunamis. Tsunami formation by impacts has been discussed by Gault, Sonnett, and Wedekind [8], who concluded that large-body impacts would generate substantial waves throughout the world ocean. The widespread presence of spherules mixed near the tops of these detrital layers suggests that the initial waves passed locally prior to fall of the solidified droplets but that, during and following fall, residual currents and waves were still active in reworking the upper parts of the tsunami deposits.

Our results suggest that a record of late accretion is preserved in Early Archean sedimentary sequences. This record includes deposits reflecting both impact melting and volatilization of target and projectile rocks and the passage of catastrophic impact-generated water waves. Closer to impact sites, fringing carpets of impact ejecta might be expected to exist. If accretion through large-body impacts was still on-going 3.5 to 3.2 byr ago, it may have strongly influenced both greenstone belt development and early crustal evolution [e.g. 9]. The existence of flourishing, environmentally diverse organic communities before and after formation of the spherule layers argues that impact-produced rock vapor clouds, tsunamis, and dust clouds, while perhaps catastrophic in the short term, did not have long-term adverse affects on early life.

These layers also demonstrate unambiguously that chondrule-like objects can and did form in chondritic abundances during impacts on early planetary surfaces. Careful studies of their structuring and formation may provide an important new details on the mechanics of accretion.

Acknowledgements: This research has been supported by NASA grant NAG 9-136 from the Early Crustal Genesis Project and NSF grants EAR 82-06015 and EAR 84-06420.

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