Impact spherules: Tiny peepholes to earth's geological past

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A class of tiny particles, whose presence in many sedimentary formations, were missed until now, are receiving increasing attention for their potential to provide useful information on earth's early history, its atmosphere, biosphere, climate and on some of the hazily known events in the planet's past. These particles are produced out of materials ejected when an extraterrestrial (ET) body impacts on the earth. Although earth was subjected to several ET impacts, particularly during the Precambrian and earlier periods, reports about discovery of such ejected particles in ancient formations have been very few. Possibly this may be due to a lack of expectation for their presence or to their misidentification as products of endogenic origin or as microfossils, which they resemble. The few studies on the reported Mesozoic and younger period occurrences of ET-collisions have dealt more on the catastrophic effects, particularly on the biosphere[1], but their application to interpret other aspects of geological past received little attention. A recent review[2] has outlined the existing state of our knowledge on these materials and highlighted the additional information one can gather from them in the hope that it may stimulate efforts to search for new sites of these materials.

When an ET object collides with earth at hypervelocity (~20–40 km/s), tremendous heat energy is liberated which melts and vapourises both the impacting object and the crustal rocks at the impact-site. The vaporized rocks and ET materials are ejected at immense force beyond earth's atmosphere where they get cooled and condense to droplets (splash forms). While some of the condensates fall back close to the impact site as proximal ejecta, the bulk of them are deposited thousands of kilometres away as distal ejecta. Their deposition may be as thin layers (~20–40 mm), or may be much thicker when the ejecta are produced by large kilometre-scale ET bodies. Apart from these, other types of ejected particles like unmelted, or shock metamorphosed or high-pressure polymorphs some of the target site minerals (quartz or zircon) may also be present.

Among the various types of ejecta deposited, there occur small spheroidal or near-spheroidal condensates called 'spherules' that are proving to be reliable peepholes to the past. Two kinds of spherules are recognized – microtektites, entirely glassy types of melted rock droplets, and microkrystites derived as condensates of vapourized material which are partly crystalline, which in some old occurrences are metamorphosed, deformed or replaced by other minerals. These impact spherules retain signatures of their impact derivation such as bubble cavities, quench devitrification textures, flow structures, streaks or schlieren of different composition caused by melting of quartz crystals from the impact site. Besides these, their unique chemistry also serves as hallmarks to their impact genesis. They show higher platinum group elements (PGE) and other siderophiles, in comparison to normal terrestrial rocks, which also serve to differentiate them from ovoids of sedimentary origin and 'lapilli' produced during terrestrial volcanism and from confusingly similar cosmic spherules which, however, are devoid of any terrestrial component[2–5].

Studies on the relatively few reported occurrences of spherule layers, have led to detection of several unrecorded impact events besides interpretations on post-impact regional and global changes in the environment, tracing secular changes in the nature of volcanism and earth's crustal make-up and variations in the incoming impactors. Several episodes of ET impacts during the Precambrian and Phanerozoic periods, that have escaped detection, due to the recycling of their mega-evidences like impact-craters have now come to light from countries like South Africa, Australia, North America, Greenland, Europe, Asia and Russia, besides on marine sediments in the Pacific, Atlantic and Indian oceans[2]. The accumulation of spherule layers between pre-impact and post-impact sediments has helped in dating of the impact events based on their position in the stratigraphic succession. Their role in explaining global extinction of the biota (e.g. K/T impact 65 m.y. ago) as well as their radiation (e.g. diversification following the Acraman bolide impact, South Australia, 600 m.y. ago) is too well known[1,6].

The 3.2–3.4 b.y. spherule beds in marine deposits in Barberton Greenstone belt (South Africa), incidentally the oldest recognized spherule beds, have enabled distinguishing impact-triggered tsunami sediments and also the mixing of globally stratified oceans[7]. Similarly, the observed disturbance and reworking of the Precambrian marine formations in Hammersley Basin (Western Australia), and of the Transvaal Group (South Africa), under high energy conditions, are now attributed to three to five oceanic impacts during 2.63–2.49 period[8]. The existence of two well-separated spherule beds in the Hammersley Basin succession indicates two separate impacts[9]; and similarly in Barberton Belt, South Africa, three separate impact events, at 20 million-year interval have been inferred from the carbonaceous chondritic and terrestrial compositions of well-separated spherule beds[10].

Another promising application the spherules offer is in the monitoring of different kinds of secular variations in earth's geological evolution, though some of these conclusions will remain hypothetical unless corroborated by future studies[2]. For example, temporal variations in sizes of the impacting bodies have been inferred from the thickness of the spherule layers in global formations of different ages. Most of these layers are much thicker in the Archaean–Paleoproterozoic sedimentary beds, a feature ascribed to high impactor-flux expected from the larger ET bodies known to have impacted frequently in those periods. In contrast, these layers are found to be thinner in the younger periods, implying incidence of smaller-sized bodies producing low impactor flux[2,3,7,11]. Based on the composition of spherules, which reflect the nature of the crustal rocks vapourized from the impact site, temporal shifts in the character of earth's crust could be tracked. For example, spherules are found to be predominantly ultramafic (komatiitic) during 3.3–3.2 b.y period and essentially mafic (basaltic) nature around 2.6–2.5 b.y. period[7,3,11], a finding which has implications also on nature of volcanism and its source region.

Similarly, shifts in the nature of incoming ET impactors could be monitored from the siderophiles, PGE and Cr-isotopes in the spherule layers. PGE and other siderophiles in Precambrian spherules are found to be more chondritic than those of later periods[4,5,7]. Moreover, meteoritic materials have been found to have excess ^{53}Cr relative to terrestrial materials; and carbonaceous chondrites excess ^{54}Cr relative to terrestrial and ET materials. These variations, reflected in the spherules, have been used for interpreting secular variations in the impactors even within short periods. In the Australian beds, spherules of the older Archaean layers happen to be products of carbonaceous chondrites while spherules of younger Archaean beds appear to be generated by ordinary chondrites, indicating impacts from heterogeneous bodies[2,12].

In keeping with the greater ocean-coverage of earth's surface in the early earth, compared to later geological times, there is a predominance of spherules of oceanic crust derivation (basaltic spherules) in early Precambrian beds. This has led to the inference that during this period oceans were shallow for the impactors to excavate oceanic crust, whereas in younger geological periods the oceans were deeper, and hence could cushion the force of the ET-impact from reaching the ocean crust[2,11]. Results from studies on Archaean age impact spinels in South Africa and Australia have strengthened existing views about an oxygenless Archaean atmosphere. These spinels show richer Fe, Ni, Cr, V, Ni/Fe values relative to Cenozoic impact spinels, which is explained as the result of the less oxidizing Archaean atmosphere experienced by the molten ejecta during their re-entry[13]. Investigations are also currently in progress if spherule layers could be used to determine the size and distance of the source impact site (crater) through studies on variations in the thickness of spherule layers, and from the ratio of melted to unmelted particles[2].

Notwithstanding impediments to preservation of spherules in normal sedimentary environments, like extreme dilution from fresh sediments or dissolution, in the light of several useful applications highlighted in recent studies, renewed searches for new occurrences are worth undertaking in different continents. In this context, the Indian subcontinent provides several promising areas stretching over a vast time period from early Archaean to the Cenozoic. Though a few spherule layers have already been reported from the Lonar Crater (Maharashtra), from the early Cambrian Vindhyan formations, from the distal ejecta of the K/T Deccan volcanic-clay horizon in Western India and in the P/T beds in Northeast India, their studies were more for confirming bolide impacts or for correlation purposes[14,15]. Systematic quest for new spherule occurrences not only lead to detection of impact events unrecorded in India but also comment about suspected impact craters such as the crescent shaped Cuddapah sedimentary formations[16] and the controversial undersea Shiva Crater off the west coast of India[17]. The fact that India's cratonic blocks were co-existing with similar blocks of Africa, Australia wherefrom most of the presently known spherule layers are reported should also rejuvenate renewed searches for similar occurrences in Indian rocks of that age.

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