A BRIEF REVIEW OF (MOSTLY) DISTAL IMPACT EJECTA ON EARTH.

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Introduction: Impact cratering on Earth results in an unusual group of melted, shocked, and brecciated rocks, some of which fill the resulting crater, and others which are transported, in some cases to considerable distances from the source crater. The latter are called "distal impact ejecta" and can have different forms and textures. Their study is often essential, as only the presence of diagnostic shock-metamorphic effects and, in some cases, the discovery of meteorites, or traces thereof, are generally accepted as unambiguous evidence for an impact origin, and distal ejecta are commonly a rich source of such evidence. In this brief review, I discuss three different types of distal ejecta: 1) altered deposits of ejecta that form ejecta layers (such as from the K-Pg event), 2) a special form of glassy ejecta called "tektites" and some of their "relatives", and 3) enigmatic spherule layers of mostly Early Archean age, which are probably (but not certainly) distal ejecta. About 90% of all ejecta are generally deposited within five crater radii from the crater rim; these are called proximal ejecta. Ejecta deposited farther away are called distal ejecta. A comprehensive description of such ejecta can be found in Glass and Simonson [1,2].

Distal Ejecta Layers: The impact ejecta at the Cretaceous-Tertiary boundary, now called the Cretaceous-Paleogene (K-Pg) boundary, were not the first distal ejecta layer to be described, as microtektite-bearing layers were already discovered in the late 1960s. However, the study of the K-Pg boundary ejecta provided the most influence for the discussion about the importance of impact events, following the discovery of extraterrestrial platinum group element (PGE) enrichments in the K-Pg boundary by Alvarez and colleagues in the late 1970s, later augmented by the discovery shocked minerals in these ejecta (see reviews by [2] and [3]). It is easy to detect the K-Pg boundary layer in the field, where is appears as a distinct break in lithology, with a thin (usually up to 1 or 2 cm thick) layer commonly composed of clay or claystone at distal marine sections (but also in terrestrial deposits). The case of the K-Pg layer is important as at the time when it was identified as an impact deposit (due to the presence of a meteoritic component and of shocked minerals), no source crater was known; the Chicxulub impact structure was identified only later (and confirmed as linked to these deposits). Several other distal ejecta layers are known by now as well, with some of them linked to the categories described in the next two paragraphs, but for others either just the impact nature was confirmed, and others again are linked to specific craters (e.g., Popigai, Vredefort, Sudbury).

Tektites: Tektites are a specific group of natural glasses on Earth of up to a few cm in size that occur mostly in four geographically extended (but well-defined) strewn fields: the North American strewn field of 35.5 Ma age (associated with the Chesapeake Bay impact structure; the Central European strewn field of ca. 14.8 Ma age (associated with the Ries crater in southern Germany); the Ivory Coast tektite strewn field of 1.1 Ma (derived from the Bosumtwi impact structure in Ghana); and the 0.79 Ma Australasian strewn field (for which no undisputed source crater has been identified so far) (see reviews in, e.g., [2, 3]). It is well established that the chemical and the isotopic composition of tektites in general are identical to those of the upper terrestrial continental crust. A detailed discussion of tektite characteristics is given by Koeberl [3], but, in brief, important characteristics are: found only distal to a crater, are glassy, rather homogeneous, poor in water, contain lechatelierite, occur in geographically extended strewn fields, and are interpreted to have formed from the uppermost layer of the target surface, all of which require specific impact conditions. It is recommended that the term "tektite" only be used for glasses that have (most) of the above characteristics; if not, or if data are still ambiguous, the more general term "impact glass" is more appropriate.

Proterozoic and Archean Spherule Layers: Found mainly in South Africa and Australia, with ages from about 2.4 to 3.4 Ga, these are often thick deposits of about millimeter-sized spherules from quenched melt droplets that supposedly formed by condensation from vapor clouds. The spherule layers are coarse-grained and have been interpreted to reflect high-energy depositional events in otherwise low-energy, quiet water environments. The original mineralogical and chemical composition of the spherules has been almost completely changed by alteration. The stratigraphic positions of these layers at different geographic locations are difficult to correlate and the possibility exists that some of the layers represent duplication. These spherule layers show extreme enrichments in the PGEs (in some cases exceeding the PGE abundances found in chondritic meteorites), unlike modern impact ejecta deposits, which have much lower meteoritic components [2, 3]. Their origin, distance to (now eroded or not yet identified) source crater, and mechanism of enrichment of the meteoritic component, are not yet well understood.

References: [1] Glass B.P. and Simonson B.M. (2012) *Elements* 8:43-48. [2] Glass B.P. and Simonson B.M. (2013) Distal Impact Ejecta Layers, Springer, Heidelberg, 716 pp. [3] Koeberl C. (2014) The Geochemistry and Cosmochemistry of Impacts. In: Holland H.D. and Turekian K.K. (eds.) Treatise on Geochemistry, Second Edition, vol. 2 (Planets, Asteroids, Comets and The Solar System), pp. 73-118. Oxford, Elsevier.