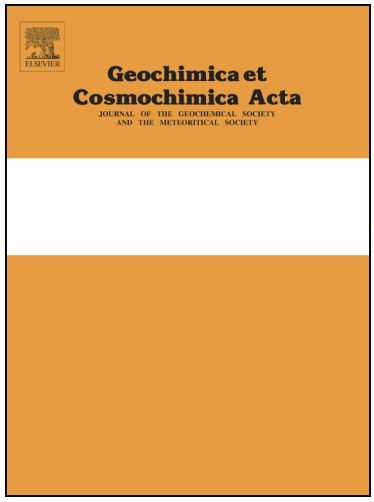


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# Petrography and geochemistry of distal spherules from the K-Pg boundary in the Umbria-Marche region (Italy) and their origin as fractional condensates and melts in the Chicxulub impact plume

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**Abstract**

The impact spherules from the distal K-Pg boundary sections are considered to represent silicate droplets condensed and solidified from a laterally expanding, cooling vapor plume formed upon hypervelocity impact. In the present-day Cretaceous-Paleogene boundary (K-Pg) spherule population of the Umbria-Marche region in Italy, three texturally and compositionally distinct types of impact spherules can be identified that are dominantly composed of (1) goethite, (2) K-feldspar or (3) glauconite. Although these phases represent the products of diagenetic alteration, the remnant textural characteristics of the spherules and the type of alteration product are indicative of the spherules' original compositions, which are important to constrain the physicochemical conditions prevalent throughout the impact vapor plume. The presence of relict ghost crystals and the identification of 'iddingsite' indicate that goethite likely represents pseudomorphic replacement after olivine. Goethite spherules contain numerous dendritic, euhedral and skeletal spinel crystals variably dispersed in the groundmass. In terms of textures, five types of goethite spherules can be distinguished, showing striking similarities to chondrules: (I) skeletal, (II) barred, (III) radial/barred, (IV) porphyritic and (V)e morphology of both spinel and olivine (pseudomorphs) is consistent with established formation conditions (peak temperature $T_{max}$, degree of supercooling $\Delta T$, cooling rate, presence of nucleation sites) for different chondrule textural types. As goethite spherules are anomalously enriched in moderately to highly refractory lithophile (Sc, V, Y, Zr, Nb, REE, Hf, Ta, Th) and siderophile (Cr, Co, Ni, W, Ir, Pt) elements, they are interpreted to represent (diagenetically altered) refractory (high-T) condensation products from a well-homogenized plume consisting of both vaporized target and projectile matter. Different from goethite spherules, K-feldspar spherules exhibit pseudomorphic textures after lower-liquidus silicates such as Ca-rich pyroxene and plagioclase. Furthermore, the K-feldspar spherules yield systematically lower abundances of the most