LIGHTNING STRIKE SAMPLES FROM THE PILBARA, AUSTRALIA: CRITERIA FOR IDENTIFYING LIGHTNINGOGENIC SPHERULES.

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Introduction: Within the geologic record, sub-millimetre microspherules may be found in trace amounts, most likely formed by high-temperature processes. Lightning strikes discharge an average of 4 x 10^8 J per strike [1], creating temperatures in excess of 2,500 K [2]. This process may form molten droplets from the target rock that are rapidly quenched, resulting in microspherules. Given that ~44 lightning flashes occur per second globally [3], with the majority occurring over landmasses and over 25% reaching the ground [2], the abundance of lightningogenic spherules throughout the geologic record is likely to be non-trivial.

Other microspherules on the Earth's surface may be formed by the atmospheric entry of cosmic dust, impact events, volcanic activity and anthropogenic activities. They are likely to have different mineralogical, textural and compositional features allowing them to be distinguished. Characterising the nature of lightningogenic microspherules would allow them to be identified in the rock record, which may have implications for palaeoenvironment and palaeoclimate models.

Methods: Fine-grained sediment was collected from pan holes on a 30 m high exposure of granite gneiss in the Pilbara region of Western Australia. Spherical particles were picked from the sediment under a binocular microscope, mounted in an epoxy stub and analysed using a Hitachi TM4000Plus scanning electron microscope (SEM) at Imperial College London. Textural features were identified using backscattered electron imaging and compositional data were obtained using energy-dispersive spectroscopy (EDS) via point analyses and maps.

Results: The particles have a size range of 20-60 µm, with near-perfect spherical morphologies. Textures are diverse and include glassy, microcrystalline, vesicular and coarse-grained. Where present, vesicles are spherical, off-centre and typically < 10 µm in diameter. Two over-all categories of particle were identified: (1) silicate dominated particles, primarily composed of K, Ca, Al-silicate glass and containing irregular, relict crystals of quartz and orthoclase, and (2) oxide dominated particles, usually with dendritic oxide crystals. The spherules show significant compositional variation. Some are Ti-rich (< 25 wt%), resembling mineralogies such as rutile, anatase or ilmenite. Others have high Fe, Al and O abundances, indicating spinel or magnetite, where Al content is low. Silicate particles contain high Al (< 21 wt%) and appreciable K (< 8 wt%) or Ca (< 6 wt%), which may be derived from orthoclase or plagioclase feldspars, respectively. While Mg abundances are low (< 6 wt%), Fe is found in most spherules (< 45 wt%).

Discussion: A lightningogenic origin of the Pilbara spherules is suggested by their mineralogies, textures and compositions. The silicate spherules are non-chondritic and oxides contain Ti indicating they are not cosmic spherules [4, 5]. The compositional variability contrasts with distal impact microspherules [4], and no local impact craters are present to suggest they are proximal ejecta. A volcanic origin can be discounted owing to the large abundance of spherules and absence of recent volcanism in the Pilbara. The remote location and absence of industry suggest they are not anthropogenic in origin. Finally, the compositions of spherules and their inventory of relict minerals corresponds closely to the underlying granite gneiss, suggesting generation by localised energetic events capable of melting or vaporising the substrate bedrock. Lightning strikes are thus the most likely mechanism.

The compositional variability of the spherules suggests direct melting of individual minerals rather than gas phase condensation owing to the minimal mixing observed. The presence of Ti-rich spherules, formed by melting of ilmenite and rutile, suggest a minimum temperature of 2,130 K [6]. Vesicles imply an indigenous volatile content, since exogenic diffusion of volatiles is unlikely during the short time these small spherules spent above the liquidus. Localised weathering of the exposure surface is likely to be a source of water and iron in the particles. The unexpected high abundance of spherules may relate to the elevation of the exposure compared to the local topography making it more susceptible to lightning strikes.

Implications: The absence of micrometeorites in the Pilbara collection may give clues as to the frequency of cloud-to-ground lightning strikes, given a steady background flux of cosmic dust [5]. The textural and compositional features described here – particularly variable, mineral-derived compositions – may form the basis for identifying lightningogenic microspherules in the geologic record.

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