

ARE PRIBRAM, NEUSCHWANSTEIN AND BENEŠOV FRAGMENTS OF THE SAME NEAR-EARTH ASTEROID? A RE-EVALUATION IN THE LIGHT OF ALMAHATA SITTA

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Introduction: For about 40 meteorites, fireball observations allowed the determination of the orbit of their precursing meteoroid [1]. Among these, the orbits of Pribram (H5) and Neuschwanstein (EL6) are surprisingly similar (similarity criterion $D = 0.025$ [2]), although the meteorites fell 43 years apart. Spurný et al. [2] suggested that they might be members of a meteoroid stream derived from a near-Earth asteroid, but the different types and cosmic-ray exposure (CRE) ages (12 Ma [3] and 48 Ma [4], respectively) seem to suggest otherwise. A third meteorite, Benešov (a) and (b), potentially associated with the Benešov fireball in 1991 was found in 2011 [5] and has an orbit similar to the Pribram/Neuschwanstein pair ($D \sim 0.1$). Benešov (a) consists of two fragments: an LL3.5 type with a large achondritic clast (7.8 g) and an LL3.5 type (1.9 g). Benešov (b) consists of a single H5 type (1.5 g) [5]. If Pribram, Neuschwanstein and Benešov are indeed derived from a single near-Earth asteroid, this asteroid would thus contain H5, LL3.5, EL6, as well as achondritic clasts. This (hypothetical) suite is reminiscent of the one found in Almahata Sitta / 2008 TC₃, a polymict ureilite host containing multiple chondritic (H, L, LL, EL, CB, CI, R-like) and achondritic clasts (e.g., [6]). Here we re-evaluate the CRE ages and implied meteoroid sizes for Pribram and Neuschwanstein from literature data and contribute He and Ne data for Benešov (a). Elucidating the frequency of such “polymict” asteroids could have important consequences for our understanding of meteoroid transfer and regolith formation.

Methods: The Benešov samples were derived from Benešov (a). Eight samples were weighted (5-350 µg) on an experimental magnetic levitation balance at ETH Zurich, and He, Ne were measured on the compressor-source noble gas mass spectrometer at ETH Zurich according to established protocols [7]. Literature data for Pribram and Neuschwanstein were retrieved from [8] and [9]. Meteoroid sizes were determined with an established ab-initio physical production rate model [10].

Results: Pribram. The Pribram bolide data suggest a mass of 500-5000 kg [11], i.e., a radius of 0.3-0.7 m at 3.5 g/cm³. This is consistent with the ²⁶Al data (55±3 dpm/kg [9]) implying a radius of 0.2-1.0 m. The Pribram meteoroid was thus a sub-meter-sized body for at least the last few half-lives of ²⁶Al ($t_{1/2} = 0.7$ Ma). The ²²Ne_{cos}/²¹Ne_{cos} and ³He/²¹Ne_{cos} ratios are consistent with CRE in an $R = 1$ m sized object at ca. 20-30 cm depth, or in a larger object if some loss of cosmogenic ³He is allowed. In an $R = 1$ m object, the resulting CRE age is 17±2 Ma from cosmogenic ³He, ²¹Ne and ³⁸Ar (higher than the 12±2 Ma from [3]). A complex exposure, with a first stage in a larger object followed by a second stage in a $R < 1$ m object is permissible and favored by fireball and ²⁶Al data. In that scenario, the total CRE age is likely higher, with unconstrained upper end, as it depends on the radius of the first stage meteoroid.

Neuschwanstein. The Neuschwanstein bolide data suggest a mass of 200-400 kg [2] and a radius of 0.25-0.30 m at 3.5 g/cm³, consistent with the 1.2 dpm/kg of ⁶⁰Co measured [4]. Cosmogenic noble gases are consistent with that size at a depth of a few cm. The CRE age of 46±4 Ma determined here is consistent with previous estimates [4]. CRE ages vary with the system used (they increase He < Ar < Ne), hinting at the possibility of a complex exposure.

Benešov. The Benešov bolide data suggests a meteoroid mass of 4100 kg [12], i.e., a radius of 0.65 m at 3.5 g/cm³. No radionuclide data exist for Benešov (a) and (b). He and Ne analysis yields a cosmogenic ²²Ne/²¹Ne ratio of 1.18, requiring either a small radius ($R \sim 10$ cm) or a position within the top-most cm of a larger meteoroid, although that seems unlikely for a body that went from 4 tons to 2.7 kg terminal mass [12]. While the ³He/²¹Ne is consistent with a position deeper inside the meteoroid, this might also be due to loss of cosmogenic ³He or a complex exposure history. At this point, the association of Benešov (a) with the Benešov bolide remains unconfirmed and does not seem likely.

Discussion: Both Pribram and Neuschwanstein are, in principle, compatible with a complex CRE scenario in the regolith of a small rubble pile asteroid, in analogy to Almahata Sitta / 2008 TC₃. In Almahata Sitta, CRE ages between 7 and 24 Ma have been measured [13], defying the assumption that all fragments from an asteroid would have identical CRE ages and types. The noble gas data from Benešov (a) fragments do not support, but cannot exclude, an association of the meteorite with the Benešov bolide. Additional analyses, in particular the unsampled lithologies, are necessary.

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