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Did a Comet Deliver the Chelyabinsk Meteorite?

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Abstract

An explosion of a celestial body occurred on the fifteenth of February, 2013, near Chelyabinsk (Russia). The explosive energy was determined as ~500 kt of TNT, on the basis of which the mass of the bolide was estimated at ~10^7 kg, and its diameter at ~19 m [1]. Fragments of the meteorite, such as LL5/S4-WO type ordinary chondrite [2] with a total mass only of ~$2 \cdot 10^3$ kg, fell to the earth's surface [3]. Here, we will demonstrate that the deficit of the celestial body's mass can be explained by the arrival of the Chelyabinsk chondrite on Earth by a significantly more massive but fragile ice-bearing celestial body.

During the interaction of large (>10 cm) meteorites with the earth's atmosphere, 1–25% of the original body mass is usually retained [4], whereas the Chelyabinsk bolide retained only ≤0.02% of its initial mass. It is assumed that all other matter evaporated. During the course of several days, the Suomi satellite registered the aerosol trail of the Chelyabinsk body [5].

It is natural to suppose that after ablation and explosive fragmentation, fragments of deep inner layers should fall to Earth. However, this proved not to be the case. Tracking [6] and isotope [7, 8] research showed that a significant portion of the Chelyabinsk meteorite fragments belonged to the surface layers of a celestial body before its entry into the earth's atmosphere. It is widely known that while a meteorite is in outer space, it is bombarded by currents of charged energetic particles, i.e. galactic (GCR) and solar (SCR) cosmic rays. Cosmic rays may form tracks (particle traces) in minerals of target, as well as cascades of secondary particles, terminating in the formation of radioactive or stable isotopes at different depths from the surface.

The study of 450 phosphate and olivine microcrystals of the Chelyabinsk meteorite showed that ~5% of the examined matter was directly exposed to SCR radiation, and in several granules a track density gradient was discovered from the surface to deep within the microcrystal. It is determined that the source of the appearance of such a gradient can be only the direct bombardment of the crystal by SCR iron nuclei with energy of 1-100 MeV [6].

Interacting with the surface of the meteorite, protons and helium GCR nuclei form isotopes, some radioactive, which are allocated to a specific location by depth in the body of the meteorite. A measurement of the composition of radionuclides ^{22}Na, ^{26}Al, ^{54}Mn and ^{60}Co in 12 fragments of the Chelyabinsk meteorite, and a comparison of the results with model calculations of the formation of these isotopes in meteorites according to depth, showed that 4 fragments of the meteorite were located in a layer 30 cm deep, 3 fragments at a depth of 70-90 cm, two more at a depth of <180 cm and the remaining 3 fragments at a depth of ≤250 cm from the surface of the meteorite [7]. Analysis of the composition of the cosmogenous isotopes ^{10}Be, ^{26}Al and ^{3}He in 10 samples of the Chelyabinsk meteorite and comparison of the results with the model calculations led to the conclusion that the radius of the Chelyabinsk meteorite was 3-4 meters [8].

In addition, the Fe^{3+} ion was discovered in the meteorite, indicating that conditions were more oxidised than those characteristic of the Chelyabinsk meteorite matter [9]. One of the possible reasons for the formation of Fe^{3+}-containing oxides and hydroxides would be the meteorite's introduction to a humid or even aquatic environment. Fe^{3+} hydroxides were found around troilite granules in so-called "rusty halo" zones, where water could penetrate from surface layers through microfractures. The authors arrived at the conclusion that the Fe^{3+} hydroxides could also form during the meteorite's collision with an object containing ice. And the most important, that the Chinese meteorological satellite Feng-Yun 2D registered water as ice debris in the bolide trail [10].

Study of the destruction process of the Chelyabinsk body led to the conclusion that a large part of the object was not durable (~1 MPa), while the durability of a stone meteorite >15 MPa corresponded to only <1% of the initial mass [11]. We can assume that a celestial body with a durability of ~1 MPa delivered the durable stone Chelyabinsk meteorite to Earth,

having become “tied” to it during a space incident, traces of which were found in the form of shock melting of the meteorite matter [2, 6].
The dispersion ellipse of the Chelyabinsk meteorite matter is close to the classic representation of the destruction of meteorites, though it shows a certain displacement relative to the flight trajectory, likely linked to wind transfer (fig.). According to the location of small pieces of the meteorite, it may be concluded (fig.) that the Chelyabinsk bodye began to disintegrate into fragments at altitudes of 30–35 km under dynamic pressure of <5 MPa, which would not so much disturb a durable meteorite. However, a series of explosions occurred at these heights, registered by sound data [11]. As a result of these explosions, the fragments that reached earth may have been knocked out of the surface layers of the meteorite. The location of the meteorite in the zone of explosions explains the trajectory deviation of the largest fragment by 1.3^{o} from the initial flight direction [11] and crust melting on all, even small fragments of the meteorite [3, 7].

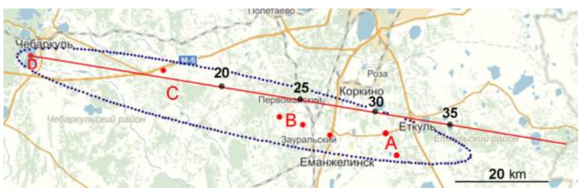

Figure: The impact site of the meteorite.
Note: A straight line: body trajectory. Figures above the line: the height of the trajectory points according to Borovička [11]. Line of points: the dispersion ellipse of meteorite matter. A: location of found fragments in the form of dust or millimeter-long splinters, B: centimeter-long fragments, C: decimeter-long fragments, D: meter-long fragments. Points indicate localities near found meteorite fragments, as well as Chebarkul Lake.

Therefore, the mass deficit of the meteorite, the significant differentiation of the bolide substance in durability and the initial location of the meteorite fragments in the surface layers of the celestial body indicates that the meteorite could form only ~ 1% of the bolide mass. The remaining less durable but more massive part, according to the combustion of matter along the trajectory [12] and the intermittent process of cloud ascent in the trail, contained water. It could be a short-period comet.

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