THE KAIDUN METEORITE: WHERE DID IT COME FROM?

Andrei Ivanov[1] and Michael Zolensky[2]; [1]Vernadsky Institute, 119991 Moscow, Russia; [2]NASA Johnson Space Center, Houston, TX 77058, USA.

The Kaidun meteorite, which fell on 3.12.1980 at lat. 15° N, long. 48.3° E, holds a special place in the world meteorite collection. Kaidun is characterized by an unprecedentedly wide variety of meteorite material in its makeup. The high degree of variability in this meteorite's material is evidenced by the richness of its mineral composition – nearly 60 minerals and mineral phases have been identified in Kaidun, including several never before found in nature, such as florenskiite FeTiP, the first known phosphide of a lithophilic element [1].

<u>Lithologic Composition of the Meteorite</u>

Kaidun's matrix is made up of CR2 carbonaceous chondrite material, identified through mineralogical, petrographic, chemical and isotope studies. [2-4]. The matrix contains many inclusions of widely varying size, from microns to centimeters. So far, the following types of material have been identified in Kaidun:

- carbonaceous chondrite fragments of types C1, CM1 and C3 [2-6];
- enstatite chondrite fragments of various chemical groups [2, 7-9], including the first known unequilibrated EL3 chondrite and various EH chondrites, containing traces of nebular processes: nebular condensates (Na_2S_2 and other phases) and products of preaccretionary hydrous alteration;
- heterogeneous enstatite aggregates containing traces of nebular condensation [10, 11];
- many melted clasts [12, 13];
- differentiated material [14-16], including fragments enriched in alkaline elements.

Kaidun is the only known example of highly shocked carbonaceous chondrite.

The key to understanding the origin of Kaidun is the unusually varied components that make up the meteorite, starting with multiple traces of nebular processes and simultaneously the products of deep differentiation, such as alkaline-enriched rocks.

The alkaline-enriched rocks are represented by two different fragments. One is a fragment of a twinned albite crystal 1.2 x 0.7 mm in size, with inclusions of fluorapatite, aenigmatite, wilkinsonite and arfvedsonite [15]. Importantly arfvedsonite, aenigmatite and wilkinsonite are represented by their magnesium-rich forms, and the latter two minerals in this parameter and also in the relatively low content of manganese noticeably differ from terrestrial examples.

The second fragment is a melted clast ~3 mm in size [16]. The relationship of this clast to the rock which contains it indicates the clast was melted *in situ*. The matrix of the clast consists of tabletlike, skeletal and boxy plagioclase crystals (average composition $An_{22}Ab_{77}$) in a glassy mass. The rate of cooling, evaluated through the morphology of the plagioclase [17, 18] was approximately 5-10 C/h. The clast contains relict grains of fluorchlorapatite and two different pyroxenes – augite $En_{42}Fs_{21}Wo_{36}$ and pigeonite $En_{47}Fs_{43}Wo_{10}$. With a total silica content of 57.9 wt% in the sample and an alkaline sum of 7.76 wt %, the clast may be classified as an subalkaline intermediate rock. The clast's pyroxene compositions are similar to the pyroxene compositions of the basaltic shergottites.

The alkaline-rich clasts of Kaidun which have been studied have clear similarities in their mineralogical characteristics (acidic composition of plagioclase, presence of fluorapatite) and may be genetically related. On Earth, alkaline rocks are definitely not among the more common. Their formation is linked to processes of large-scale magmatic differentiation. The formation of the subalkaline and alkaline clasts of the Kaidun meteorite, apparently also requires deep differentiation of material in a fairly large parent body.

At the same time it is worth noting significant differences in the structure of these clasts. One clast, albite crystal #d4A, contains practically no traces of impact metamorphism. No doubt, the speed at which this clast encountered the parent body of the meteorite was very low, near zero. The second clast, made of partially melted rock, contains traces of *in situ* melting, i.e. it was melted upon impact with the parent body. Doubtless, the encounter speed of the fragment which formed the clast with the meteorite's parent body was fairly high, on the order of several kilometers per second.

These differences in structure of two genetically linked clasts, due to the different encounter speeds of the clasts with the parent body of Kaidun, obviously indicate that these two events were separated in time.

Origin of The Meteorite

Alkaline-rich fragments are extremely rare in meteorites. They have been found only in two of the more than 20,000 currently known meteorites: Adzhi-Bogdo [19] and Kaidun. Kaidun contains two different clasts of this type, which entered the parent body at different times as a result of two separate events. It seems unlikely that such a situation could be coincidence. It is more likely to expect that a source of alkaline-rich rock – products of deep differentiation – may have been near the Kaidun parent body; though naturally still within the bounds of the Solar System.

The currently available data on the lithologic composition of the Kaidun meteorite – primarily the composition of the main portion of the meteorite, corresponding to CR2 carbonaceous chondrites and the presence of clasts of deeply differentiated rock – provide weighty support for considering the meteorite's parent body to be a carbonaceous chondrite satellite of a large differentiated planet. The only possible candidates in the modern solar system are Phobos and Deimos, the moons of Mars. However, the orbit of Deimos is located farther from Mars, and the probability of capture of Mars fragments by Deimos is considerably lesser. Phobos undoubtedly is the main candidate.

Previously, a model for the parent body of Kaidun was suggested to be an orbiting body with carbonaceous chondrite composition, whose motion within the Solar System occurred along a greatly elongated orbit [20]. It was supposed that such a body could pass through various regions of the Solar System, gathering samples of material along its way much as a trawl would. Another model of the Kaidun parent body advances a very large carbonaceous asteroid like Ceres [21] Note, that the model of a space trawl coincides in the first approximation with the most popular of the current models of Phobos' origin – the nebular capture model [22].

Acknowledgments: This work was supported by RFBR grant 01-05-64239 to AVI and the NASA Cosmochemistry Program to MEZ.

References: [1] Ivanov A.V. et al. (2000) *Amer. Min.* **85**, 1082-1086; [2] Ivanov A.V. (1989) *Geochim. Intern.* **26**, no.9, 84-91; [3] Ivanov A.V. et al. (1987) *LPS XVII*, 453-454; [4] Clayton R.N. et al. (1994) *LPS XXV*, 269-270; [5] Zolensky M.E. et al. (1986) *MAPS* **31**, 484-493; [6] Ulyanov A.A. et al. (1994) *Meteoritics* **29**, 542-543; [7] Ivanov A.V. et al. (1993) *Geochim. Intern.* **30** no.3, 11-19; [8] Ivanov A.V. et al. (1996) *MAPS* **31**, 131-136; [9] Ivanov A.V. et al. (1998) *Geochim. Intern.* **36**, no.2, 101-106; [10] Kurat G. et al. (1997) *MAPS* **32**, A76-A77; [11] Ivanov A.V. et al. (1998) *MAPS* **33**, A75-A76; [12] Ivanov A.V. et al. (1996) *LPS XXVII*, 585-586; [13] Ivanov A.V. et al. (2000) *MAPS* **35**, A82-A83; [14] Migdisova L.F. et al. (2000) *Geochim. Intern.*, 38, Suppl. 3, S369-S374; [15] Ivanov A.V. et al. (2002) *Geochem. Intern.* **40**, no.7, 694-697.; [16] Ivanov A.V. et al. (2001) *MAPS* **36**, A87; [17] Lofgren G. (1974) *Amer. Jour. Sci.* 274, 243-273; [18] Lofgren G. (1980) In: "Physics of magmatic processes" (R.B.Hargraves, ed.), Princeton University Press, Princeton, New Jersey, 487-551; [19] Bischoff A. et al. (1993) *Meteoritics* **28**, 570-578; [20] Ivanov A.V. (1997) *MAPS* **32**, A65-A66; [21] Zolensky M. and Ivanov A. (2001) *MAPS* **36**, A233; [22] Burns J.A. (1992) In: "Mars", eds. Kieffer H.H. et al. Tuscon, Univ. Arisona Press, p.1283-1301.