PLANETARY SCIENCE RESEARCH
PSRD Discoveries

Hot Idea October 26, 2009

(Zolensky & Ivanov, 2003, Chem. Erde, 63, 185-246.)

Kaidun--A Meteorite with Everything but the Kitchen Sink

--- This unique breccia is called a single-stone meteorite collection.

Written by Linda M. V. Martel
Hawai'i Institute of Geophysics and Planetology

An unprecedented variety of chondritic and achondritic meteorite fragments make up the Kaidun meteorite. In a well-illustrated 2003 paper Michael Zolensky (NASA Johnson Space Center, Houston, Texas) and Andrei Ivanov (Vernadsky Institute, Moscow, Russia) summarize two decades of work on the complex, fragmental breccia, reviewing the types and origins of clasts present in Kaidun and theories for the origin of its parent body. Work on the stone continues and a recent report provides additional details of petrology, oxygen isotope chemistry, and trace element abundances by a group of Kaidun enthusiasts, including Glenn MacPherson (National Museum of Natural History, Smithsonian Institution) and colleagues from the Smithsonian, NASA Johnson Space Center, Purdue University, University of Chicago, and the Vernadsky Institute. Bulk Kaidun samples most closely resemble CR chondrites, but the matrix is more akin to CIs and the clast lithologies are of such disparate types that it is clear the fragments formed in many different bodies or conditions and assembled ultimately into the Kaidun parent body whose history cosmochemists are keen to unravel.

References:

- MacPherson, G. J., Mittlefehldt, D. W., Lipschutz, M. E., Clayton, R. N., Bullock E, S., Ivanov, A. V., Mayeda, T. K., and Wang, M.-S. (2009) The Kaidun Chondrite Breccia: Petrology, Oxygen Isotopes, and Trace Element Abundances. *Geochimica et Cosmochimica Acta,* v. 73, p. 5493-5511.

- Zolensky, M. and Ivanov, A. (2003) The Kaidun Microbreccia Meteorite: A Harvest from the Inner and Outer Asteroid Belt. *Chemie der Erde Geochemistry*, v. 63, p. 185-246.

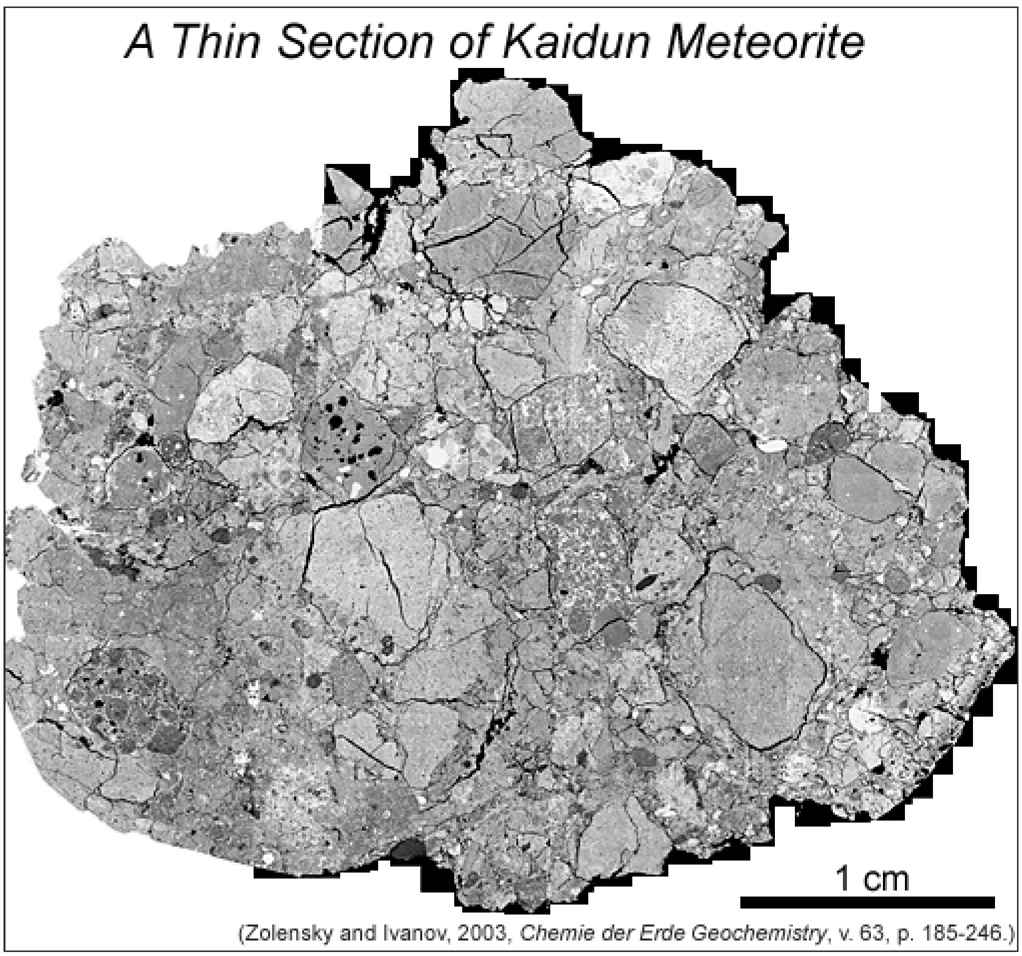
PSRDpresents: title--Short Slide Summary (with accompanying notes).

Eye-Catching Breccia

A fascinating variety of space rocks land randomly on Earth each year, some of which are found and added to our scientific collections (for examples see **PSRD** articles: Meteorite Shower in Park Forest, Illinois and Meteorites on Ice). Each one, in turn, is analyzed, classified, and used to interpret the conditions and early history of our Solar System. Then along came Kaidun, a meteorite breccia containing such a remarkable array of materials that it is called, appropriately, a single-stone meteorite collection. Since its observed fall and recovery in South Yemen in December 1980 practically every new thin section made of Kaidun reveals something new and strange.

Researchers studied polished thin sections of clasts from the Kaidun meteorite by scanning electron microscopy followed by oxygen isotope analysis, instrumental neutron activation analysis (INAA), and radiochemical neutron activation analysis (RNAA). Since work began on this meteorite in 1980 researchers have identified numerous chondritic clasts including EH3, EH4, EH5, EL3, C1, C2, CM1, CM2, CV3, R3, and possibly O type. Achondrites include a high-calicum primitive achondrite, alkali-rich fractionated materials, and an aubrite-like clast. (The Meteoritical Bulletin Database [link opens in a new window] provides detailed descriptions of meteorite classes and groups.) MacPherson and coauthors report on 13 clasts; here we provide images and an overview of their descriptions.

The backscattered electron images shown here were acquired in the scanning electron microscope. The amount of scattering is proportional to the mean atomic number of the material under the electron beam. The higher the atomic number of the element, the greater the yield of backscattered electrons, and the brighter the intensity in the grayscale image. Cosmochemists use the information in backscattered electron images to determine elemental compositions.



This backscattered electron image of one thin section of the Kaidun breccia meteorite reveals the complex mixture of millimeter-sized clasts of diverse compositions and textures.

Analyses show Kaidun clasts are mixtures of meteorite types, dominated by carbonaceous chondrite lithologies, or as MacPherson and coauthors say, "the clasts blur the cosmochemical boundaries of CI-CM-CR chondrites." Classifying the materials based on bulk chemical and isotopic compositions does not work, so analyses are performed carefully clast by clast. MacPherson and coauthors compare the properties of the Kaidun clasts they studied to:

- Carbonaceous chondrite, CI group = chondrule-free, phyllosilicate- and magnetite-rich

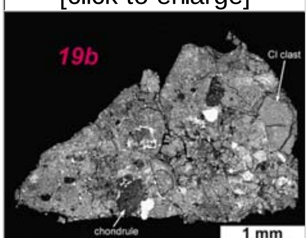
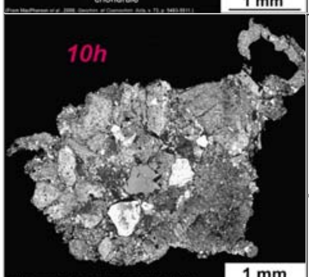
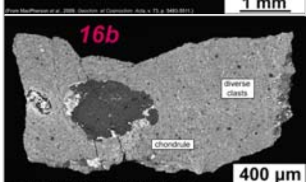
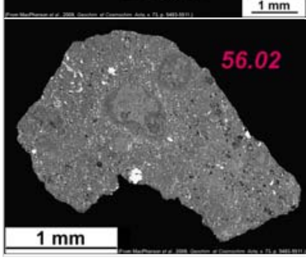
- Carbonaceous chondrite, CR group = with chondrules and a phyllosilicate- and magnetite-rich matrix
- Carbonaceous chondrite, CM group = with chondrules and a phyllosilicate-rich but magnetite-free matrix
- Enstatite chondrite, EL group = low-iron chemical group, with chondrules, abundant metal
- Aubrite, also known as enstatite achondrite = chondrule-free stony meteorite

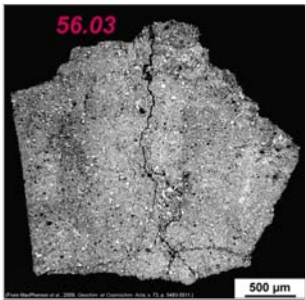
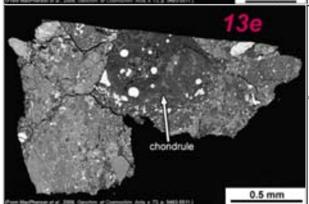
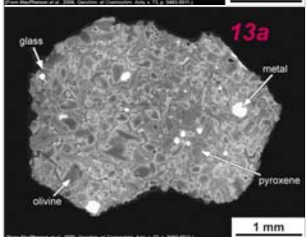
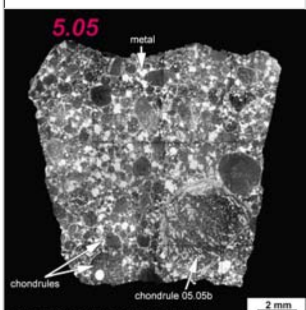
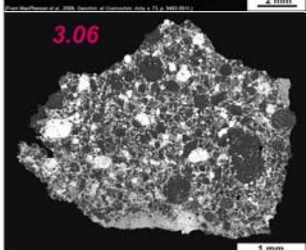
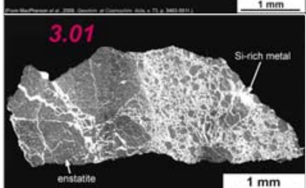
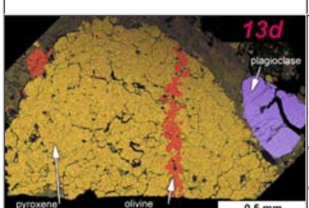
---

Pretty Much Everything

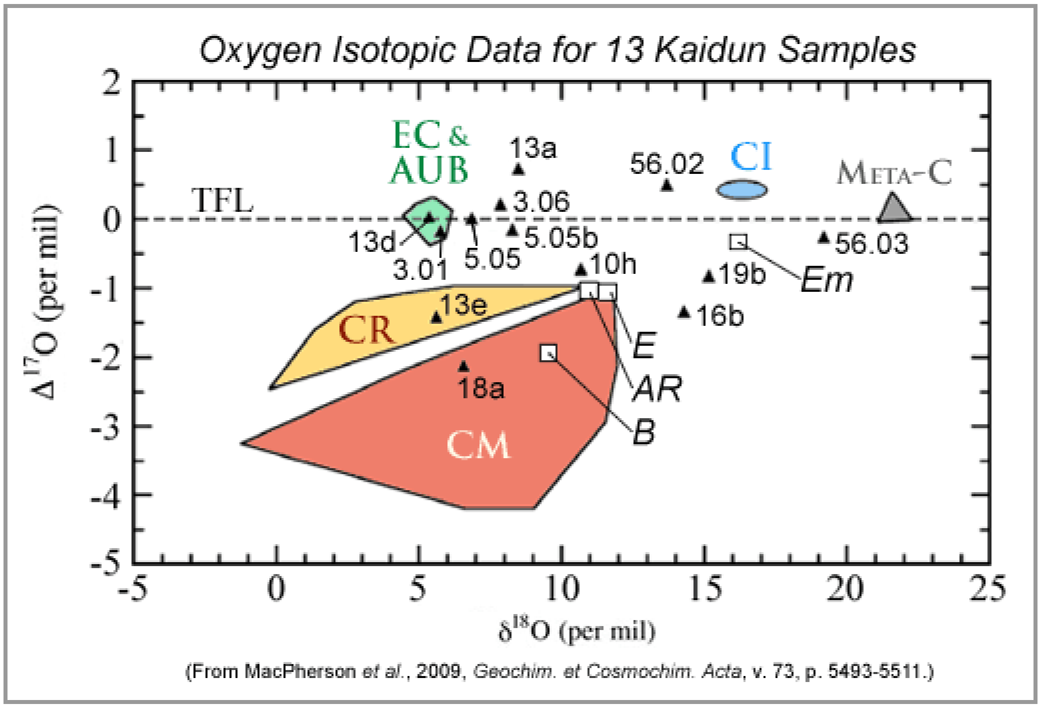
Cosmochemists are finding that every Kaidun clast they analyze has obvious affinities with known meteorite types yet in most cases there are no perfect matches. Thus, the ongoing studies of Kaidun are helping to extend the petrologic, isotopic, and trace element characteristics of meteorite groups.

The table below shows pictures and descriptive summaries of clasts reported by MacPherson and coauthors. Ignoring the scale bars, each picture resembles one entire meteorite instead of only one small bit, and this is by no means a complete list of all the clasts in Kaidun! To take a closer look, click on each picture to see a 4x enlargement. Clicking on the enlarged image will minimize it. Fair warning, the table is long but a true illustration of this meteorite's diverse makeup.

<table>
<tr><th colspan="2">Characteristics of Selected Clasts in the Kaidun Meteorite</th></tr>
<tr><th>Sample Clast Photo
[click to enlarge]</th><th>Meteorite Classifications</th></tr>
<tr><td>
</td><td>Mineralogy and Texture: CR-like breccia with chondrules, crystal fragments, and abundant CI-like clasts
Oxygen Isotopes: CR chondrite; it plots along an extension of the CR field toward CI.
Trace Elements: Chondritic, closest to CM but enriched in alkalis.</td></tr>
<tr><td>
</td><td>Mineralogy and Texture: CR-like breccia with chondrules, crystal fragments, and abundant CI-like clasts
Oxygen Isotopes: CR chondrite; it plots at the ^{18}O-rich end of the field defined by CR chondrites.
Trace Elements: Chondritic, closest to CM but enriched in alkalis.</td></tr>
<tr><td>
</td><td>Mineralogy and Texture: CR-like chondrite
Oxygen Isotopes: Similar to 19b, but closer to CM chondrite; it plots along an extension toward CI.
Trace Elements: Scattered patterns, but broadly CI-like.</td></tr>
<tr><td>
</td><td>Mineralogy and Texture: CR or CM chondrite
Oxygen Isotopes: CM chondrite
Trace Elements: Scattered data, but closest to CM and CR.</td></tr>
<tr><td>
</td><td>Mineralogy and Texture: CR-chondrite like
Oxygen Isotopes: CR chondrite; it plots at the ^{18}O-rich end of the fields defined by CR and CM chondrites.
Trace Elements: no data</td></tr>
</table>

	**Mineralogy and Texture:** CI-like chondrite **Oxygen Isotopes:** Plots slightly below the terrestrial fractionation line at more extreme ^{18}O-rich values than CI meteorites, and near Meta-C chondrites. **Trace Elements:** no data
	**Mineralogy and Texture:** CR chondrite **Oxygen Isotopes:** CR chondrite **Trace Elements:** no data
	**Mineralogy and Texture:** Unique igneous clast or CR chondrule **Oxygen Isotopes:** Unusual composition. It plots above the terrestrial fractionation line. It is richer in ^{18}O than ordinary chondrites, but ^{18}O-poor relative to CI chondrites. **Trace Elements:** Flat abundance pattern. Yet clast is depleted in all siderophiles relative to CI or any chondrite type. This clast is probably a chondrule despite its large size.
	**Mineralogy and Texture:** EL3 chondrite **Oxygen Isotopes:** 5.05 and 5.05b plot on terrestrial fractionation line but are slightly more ^{18}O-rich than field defined by enstatite chondrites. **Trace Elements:** 5.05 is closest to EL chondrites. 5.05b refractory lithophile elements show a flat pattern enriched relative to the host clast, CI chondrites, and EL chondrites.
	**Mineralogy and Texture:** EH3-4 chondrite **Oxygen Isotopes:** Plots on terrestrial fractionation line near sample 5.05, slightly more ^{18}O-rich than field defined by enstatite chondrites. **Trace Elements:** Closest to EL chondrites.
	**Mineralogy and Texture:** Metal-rich, Aubrite-like impact melt **Oxygen Isotopes:** Enstatite chondrite/Aubrite **Trace Elements:** Very irregular, non-chondritic pattern; authors could not define a particular meteorite type for this clast based on trace element patterns.
	**Mineralogy and Texture:** Layered enstatite-olivine igneous clast **Oxygen Isotopes:** Plots in the middle of the enstatite chondrite/aubrite field. **Trace Elements:** Scattered patterns, but broadly CI-like. **This is a false-color, composite Ca-Mg-Si X-ray map, which clearly shows the olivine layer.**

The table shows that the data collected for a particular clast are not necessarily in accord. For example, clast 18a has a magnetite-rich matrix and relatively large chondrules that place it in the CR group, yet its oxygen isotopic and trace element compositions are closest to CM. Nevertheless, MacPherson and colleagues found that every Kaidun clast they analyzed has similarities, if not exact matches, with known meteorite groups. The diagram below helps to illustrate this point showing many Kaidun data points outside or intermediate between the established isotopic classifications (colored fields). The data do not suggest a paradigm shift or the need to create entirely new chemical groups, yet the Kaidun clasts clearly expand current meteorite definitions and support the idea of a chemical-continuum of carbonaceous chondrite material.



Kaidun samples are plotted as black triangles and labeled with sample numbers from the study by MacPherson and coauthors. Shown as a dashed line labeled TFL is the terrestrial fractionation line, which is simply the way the oxygen isotopes vary with melting and crystallization on Earth. Fields where certain meteorites plot are shown in color. Green is the EC & AUB, enstatite chondrite and aubrite field. Yellow is the CR chemical group of carbonaceous chondrites. Orange is CM carbonaceous chondrites. Blue is the CI carbonaceous chondrites. Grey is Meta-C, metamorphosed carbonaceous chondrites. A few individual meteorites Essebi (E), Al Rais (AR), Bells (B), and Essebi matrix (Em) are also plotted by the authors to show comparisons.

Some materials in the Kaidun meteorite are anhydrous, meaning no water in their chemical structure. Moreover, the enstatite chondrites and achondrites show virtually no evidence of aqueous alteration. Yet many clasts do show evidence of different degrees of alteration by water. Most notably, the CI, CR, and CM carbonaceous chondrite clasts all contain carbonates derived from aqueous alteration. Matrix materials in CMs and CIs were changed into an array of hydrated minerals with layered structures called phyllosilicates. MacPherson and coauthors found that the phyllosilicates in Kaidun span a very wide range in composition and vary from clast to clast, suggesting that the aqueous alteration in the clasts predated assembly of the Kaidun parent body. This is such an interesting idea because it suggests aqueous processing started very early in Solar System history, which is another hot topic in cosmochemistry research circles.

Identifying Kaidun's Parent Body

Though not discussed explicitly in the 2009 paper, how the Kaidun meteorite came to be is an intriguing question because of its notable variety of materials. Many cosmochemists suggest that the carbonaceous chondrite make up of Kaidun points to a carbonaceous or at least a C-type asteroid. That asteroid either had plenty of time to wander the Solar System gathering diverse materials or it was in just the right location to receive debris blasted off assorted asteroids to create this remarkable single-stone meteorite collection.

Additional Resources

LINKS OPEN IN A NEW WINDOW.

- **PSRDpresents:** Kaidun--A Meteorite with Everything but the Kitchen Sink -- Short Slide Summary (with accompanying notes).

- MacPherson, G. J., Mittlefehldt, D. W., Lipschutz, M. E., Clayton, R. N., Bullock E, S., Ivanov, A. V., Mayeda, T. K., and Wang, M.-S. (2009) The Kaidun Chondrite Breccia: Petrology, Oxygen Isotopes, and Trace Element Abundances. *Geochimica et Cosmochimica Acta*, v. 73, p. 5493-5511, doi:10.1016/j.gca.2009.06.012.
- Martel, L. M. V. (2001) Meteorites on Ice. *Planetary Science Research Discoveries.* http://www.psrd.hawaii.edu/Nov01/metsOnIce.html
- McSween Jr., H. Y., 2000, *Meteorites and Their Parent Planets*, Cambridge University Press, 310 p.
- Petitat, M., Gounelle, M., McKeegan, K., Mostefaoui, S., Marrocchi, Y., Meibom, A., and Zolensky, M. E. (2009) Kaidun Carbonates: Re-examing the 53Mn-53Cr Systematics. *XV Lunar and Planetary Science Conf*. abstract 1666.
- Zolensky, M. and Ivanov, A. (2003) The Kaidun Microbreccia Meteorite: A Harvest from the Inner and Outer Asteroid Belt. *Chemie der Erde Geochemistry*, v. 63, p. 185-246, doi:10.1078/0009-2819-00038.

2009
psrd@higp.hawaii.edu
main URL is http://www.psrd.hawaii.edu/