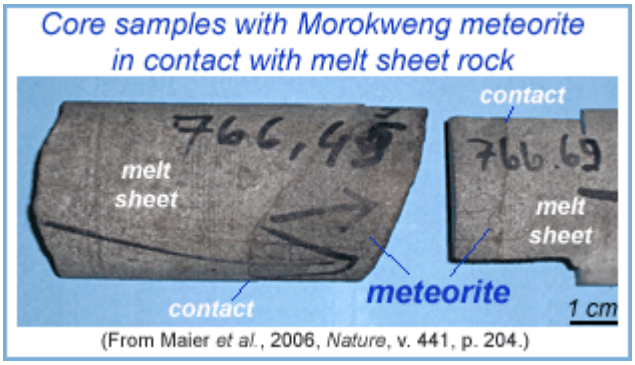
PLANETARY SCIENCE RESEARCH PSRD Discoveries

Hot Idea posted June 14, 2006

Fossil Meteorite Unearthed From Crater



(From Maier *et al.*, 2006, *Nature*, v. 441, p. 204.)

--- A meteorite of unusual chondritic composition was found in a highly unlikely place, challenging how we think about colossal impact events on Earth.

Written by Linda M. V. Martel
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A team of scientists lead by Wolf Maier (University of Quebec, Canada and University of Pretoria, South Africa and soon at University of Western Australia, Perth) and Marco Andreoli (University of the Witwatersrand and South African Nuclear Energy Corp.) and colleagues who also hail from Canada, South Africa, the United Kingdom, and the United States, have announced the discovery of a 25-centimeter-wide chondritic meteorite unearthed from the 145-million-year-old Morokweng impact crater in South Africa. Found within the crater's impact melt sheet about 770 meters (half a mile) down a drilling borehole, the hefty meteorite's existence would seem improbable given its low chance of surviving the high shock pressures and temperatures normally associated with large impact events. Its unusual composition could mean it is a sample from a previously unknown part of the LL chondrite parent body or maybe it is from an entirely different asteroid population than other known meteorites.

Reference:

- Maier, W. D., M. A. G. Andreoli, I. McDonald, M. D. Higgins, A. J. Boyce, A. Shukolyukov, G. W. Lugmair, L. D. Ashwal, Pl. Gräser, E. M. Riples, and R. J. Hart (2006) Discovery of a 25-cm Asteroid Clast in the Giant Morokweng Impact Crater, South Africa. *Nature*, v. 441, p. 203-206.

One of Earth's Largest Impact Craters

The Morokweng crater, centered at 26°32' S and 23°32' E, is at the edge of the Kalahari Desert in northern South Africa. It has a diameter of at least 70 kilometers and is one of the largest terrestrial impact craters known today. Worn by erosion and obscured by sediments and Kalahari sands, the crater is unrecognizable on the surface but was discovered by Marco Andreoli as a circular pattern of magnetic anomalies during early-1990s mining explorations (as documented in the book A Century of Geological Endeavour in Southern Africa 1895-1995.)

ESA Envisat MERIS mosaic of Africa

This satellite view shows the location of the Morokweng impact crater in South Africa.

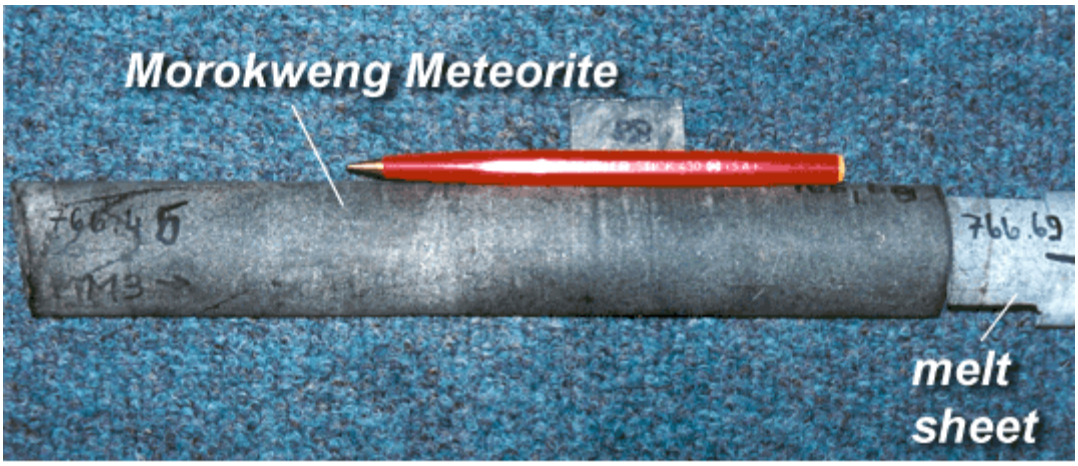
In 1997 researchers from University of the Witwatersrand and their colleagues reported that boreholes drilled into the center of the crater hit an impact melt sheet at least 870 meters thick. The melt sheet is rock at the base of the crater that was liquified by heat of the impact. This melt sheet has high abundances of chromium, nickel, cobalt, and the platinum-group elements.

The age of the crater was determined by isotopic age dating of zircons plucked from the impact melt rock. Ion microprobe analyses (see **PSRD** article: Ion Microprobe) for uranium-thorium-lead isotopic compositions place the age of the crater at 146.2 ± 1.5 million years--the same age as a major geological boundary, the Jurassic-Cretaceous.

A Cosmochemical Record Breaker

The Morokweng melt sheet is out of the ordinary for a few reasons. First, it contains more meteorite fragments than melt sheets of most other impact craters--fragments thought to be relicts of the impactor that created the crater. In Morokweng the fragments are pebble-sized (<1 centimeter) and represent 5-6% chondritic contamination of the melt sheet--a percentage so high that only one other crater's melt sheet (Clearwater East crater in Quebec, Canada) has come close to that figure. Second, the impact melt is unusually rich in nickel (up to 0.25% NiO in pyroxene) and chromium (up to 0.35% Cr_2O_3 in the orthopyroxene, and 0.69% in clinopyroxene).

Third, and unique to Morokweng's melt sheet is the new discovery reported by Wolf Maier and colleagues of a large (25-cm) fossil meteorite. Never before has such a boulder-sized chuck of the impactor been found within a large crater. Previously, researchers have found fossil meteorites in crater ejecta deposits (for an example, see **PSRD** article: Tiny Traces of a Big Asteroid Breakup), but finding a large fragment inside a huge crater has been deemed nearly impossible. We explore the ideas of why the survival of this meteorite fragment is so extraordinary in the next section, after we examine the meteorite itself in more detail.



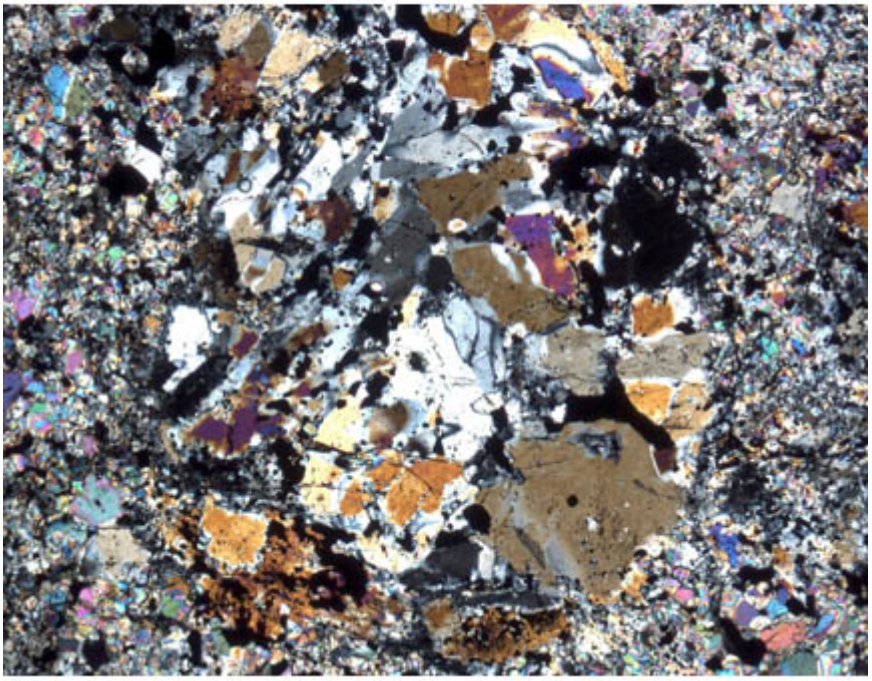
(Courtesy of Wolfgang Maier, Univeristy of Quebec, Chicoutimi.)

Imagine the surprise when the drill sliced through an obviously different kind of rock 770 meters down. This is a photograph of the core with the dark-colored fossil meteorite before it was cut for analysis. The melt sheet is also shown for comparison. Pen is shown for scale.

Maier and his colleagues report that the Morokweng meteorite is chemically unaltered except for a thin (1 millimeter) coating of brown alteration minerals. Their laboratory analyses show that the meteorite has chondritic chromium isotope ratios and identical platinum-group element ratios to the bulk impact melt.

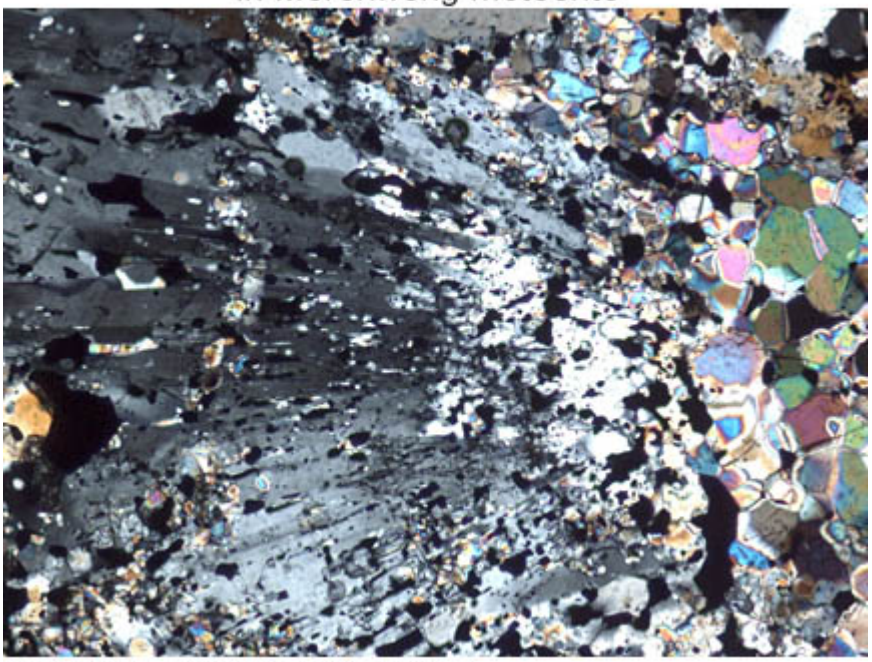
The research team found diagnostic features of a highly equilibrated chondrite breccia, including well-preserved chondrules of various textures: porphyritic, excentroradial (see images below), and barred. These textures are produced by different degrees of melting and are typical of chondrules in chondrites. Olivines with 120^{o} triple junctions indicate that recrystalization occurred in the parent asteroid as the result of thermal metamorphism.

Porphyritic orthopyroxene chondrule in Morokweng meteorite



(Courtesy of Wolfgang Maier, University of Quebec.)

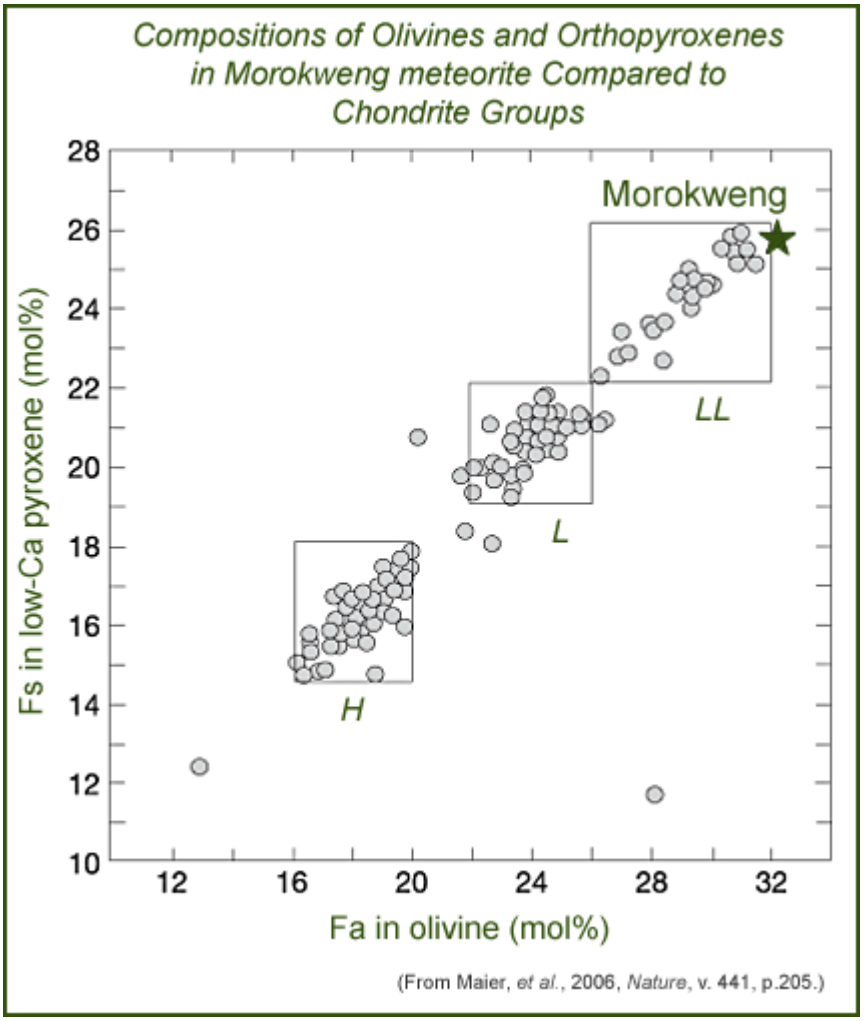
Excentroradial orthopyroxene chondrule in Morokweng meteorite



(Courtesy of Wolfgang Maier, University of Quebec.)

These are photomicrographs taken in polarized transmitted light of chondrules in the Morokweng meteorite. On the top is porphyritic orthopyroxene. On the bottom is excentroradial orthopyroxene.

Maier and coauthors report that the fossil meteorite resembles an LL6 chondrite breccia, yet its atypical composition and texture do not fit exactly into any of the known chondrite groups. The platinum-group element contents of the Morokweng meteorite are lower than in normal LL chondrites. It contains unusually iron-rich silicates and iron-nickel sulfide, but does not have troilite (an iron sulfide) and there is no metal, which would be expected in this type of meteorite. It seems they have found some thing a little different.



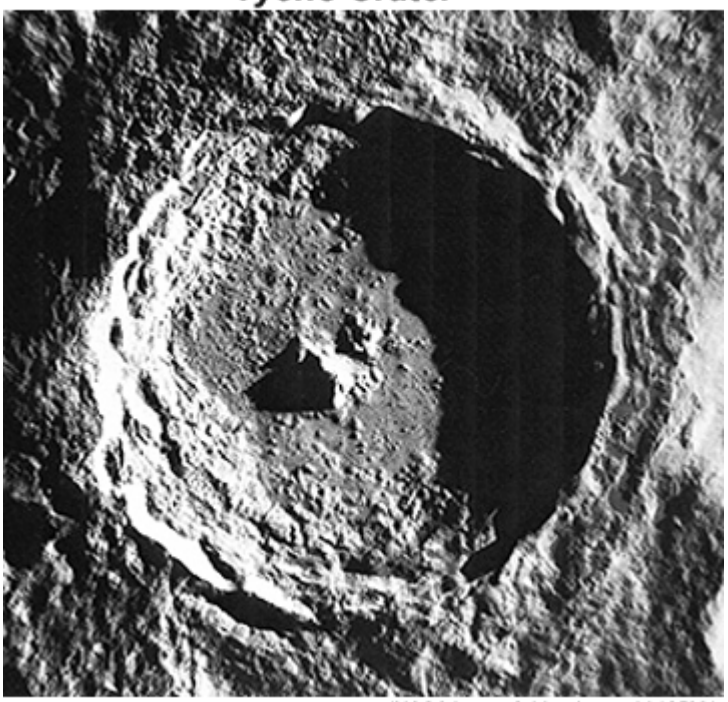
The olivines and orthopyroxenes in the Morokweng meteorite (plotted as the star symbol) have higher iron contents than most other LL, L, and H chondrites. Axes are labeled Fs and Fa. Fs (ferrosilite, FeSiO3) is the iron-rich end-member of the enstatite-ferrosilite solid-solution series. Fa (fayalite, Fe2SiO4) is the iron-rich end-member of the olivine solid-solution series.)

Does This Challenge Our Ideas of Impact Cratering?

The Morokweng fossil meteorite is a rare find. It is a surviving remnant of a much larger projectile that blasted out the crater. Its existence challenges the accepted idea that large bodies hit with such energy that they are melted or vaporized within seconds of impact. Laboratory modeling experiments and numerical simulations of the cratering process support this idea. For example, at high impact angles (close to vertical), the predicted peak shock pressures are 200-500 GPa. Predicted temperatures exceed 2,000K (1,700 ^{o}C). If any bits survived, they would be melted and chemically altered.

Until now craters larger than four kilometers in diameter have not yielded any large remnant meteorites. In these cases, the composition of the original impacting body is usually determined indirectly by analyzing chemical tracers of metals, such as nickel, cobalt, and the platinum-group elements. What were the special conditions that made it possible to preserve this unaltered meteorite in the Morokweng melt sheet? Was it slower than the normal 15-20 kilometers/second (say Earth's escape velocity of 11 kilometers/second)? Was it an asteroid rubble pile, hence weak? (For example, see **PSRD** article: Honeycombed Asteroids.) Running more cratering experiments and finding similar fossil meteorites on Earth in large impact craters, particularly those with melt sheets that contain an elevated dissolved platinum-group element component, would help to answer such questions. Perhaps future explorers will find projectile pieces in the impact melts of large lunar craters, such as Tycho pictured below.

Tycho Crater



(NASA Lunar Orbiter image V-125M.)

Tycho Crater on the Moon is about 85 kilometers across and is visible in the southern highlands. This orbital image shows the floor's central peak and smooth impact melt sheet.

The Low-Down on This Crater

The discovery of the Morokweng fossil meteorite is a new piece of information that may help us better understand the bombardment history in the inner solar system. The unusual composition of Morokweng might suggest that the nature of meteorites may have changed through time --types of impactors hitting Earth 145 million years ago were not the same as bodies hitting more recently. Morokweng may represent a sample of a different asteroid population from any other meteorite collected so far.

Maier and colleagues state that they found no evidence to suggest that the absence of metal and abundance of sulfide are the result of contamination from interaction with the impact melt. They attribute the mineralogy to metamorphism in the parent body. If the mineralogy reflects metamorphism in the parent body, then the Morokweng fossil meteorite could have come from a previously unknown interior portion of the LL chondrite parent body.

Additional Resources

LINKS OPEN IN A NEW WINDOW.

- Andreoli, M. A. G., L. D. Ashwal, R. J. Hart, C. B. Smith, S. J. Webb, M. Tredoux, F. Gabrielli, R. Cox, and B. B. Hambleton-Jones (1995) The Impact Origin of the Morokweng Ring Structure, Southern Kalahari, South Africa. *Geol. Soc. South Africa Centennial Geocongress, Johannesburg, Extended Abstr.* Vol. 1, p. 541-544.
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- Maier, W. D., M. A. G. Andreoli, I. McDonald, M. D. Higgins, A. J. Boyce, A. Shukolyukov, G. W. Lugmair, L. D. Ashwal, Pl. Gräser, E. M. Riples, and R. J. Hart (2006) Discovery of a 25-cm Asteroid Clast in the Giant Morokweng Impact Crater, South Africa. *Nature*, v. 441, p. 203-206.
- Martel, L. (2004) Tiny Traces of a Big Asteroid Breakup. *Planetary Science Research Discoveries.* http://www.psrd.hawaii.edu/Mar04/fossilMeteorites.html
- Martel, L. and G. J. Taylor (2006) Ion Microprobe. *Planetary Science Research Discoveries.* http://www.psrd.hawaii.edu/Feb06/PSRD-ion_microprobe.html
- "Shock Discovery of Ancient Space Invader" Antenna: science news by the Science Museum, London.
- Taylor, G. J. (1999) Honeycombed Asteroids. *Planetary Science Research Discoveries.* http://www.psrd.hawaii.edu/Aug99/asteroidDensity.html
- University of Quebec news item with photograph.

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