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Hot Idea posted March 9, 2004 [Additional references added to end of article]

Tiny Traces of a Big Asteroid Breakup

--- Fossil meteorites and chromite grains record a hundred-fold increase in the number of meteorites that fell 480 million years ago compared to the meteorite influx today.

Fossil Meteorite

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Ancient geologic conditions in southern Sweden were ideal to preserve meteorites that fell to Earth about half a billion years ago. Researcher Birger Schmitz (working as a visiting professor at Rice University and now at the University of Lund, Sweden) and his colleagues in Göteborg, Sweden have analyzed over 40 of these rare fossil meteorites along with relict chromite grains collected from sites in a 250,000-square-kilometer area of 480-million-year-old limestone. They attribute the abundance and wide distribution of this space debris to a meteorite influx at least one hundred times more intense than the influx today. Rather than a smorgasbord of different types, cosmochemical evidence shows that the fossil meteorites are L or LL chondrites leading the team to conclude that these meteorites and chromite grains derived from a major collision in the asteroid belt. The age of the limestone is very close to the impact age of many L chondrites suggesting that this major collision was the breakup of the L chondrite parent body, possibly the largest impact in the asteroid belt in the last few billion years.

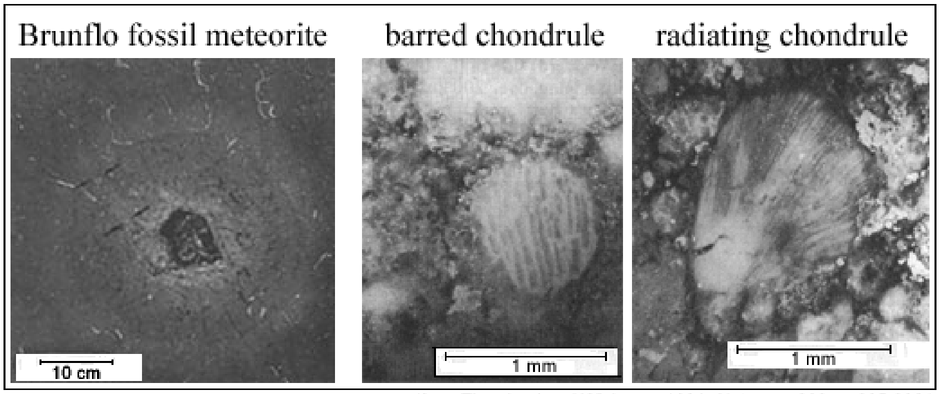
Reference:

Schmitz, B., Häggström, T., and Tassinari, M. (2003) Sediment-dispersed extraterrestrial chromite traces a major asteroid disruption event, *Science,* v. 300, p.961-964.

What Fell on the Seafloor

480 million years ago (during the Ordovician period), a large relatively shallow sea covered what are now southern Scandinavia and the Baltic region. Limestone beds formed in this tranquil environment at average sedimentation rates of one to a few millimeters per thousand years. Researchers know from studying the hardgrounds (cemented horizons) that the sedimentation rates varied from long periods of non-deposition to periods of more rapid sedimentation. This Ordovician limestone with beautifully preserved fossils is a popular decorative and building stone that has been quarried in Sweden since the 1100s. One inactive quarry in central Sweden, near Rättvik, is renowned for its rock...as well as jazz and opera since its transformation in 1991 into an open-air concert amphitheater called Dalhalla.

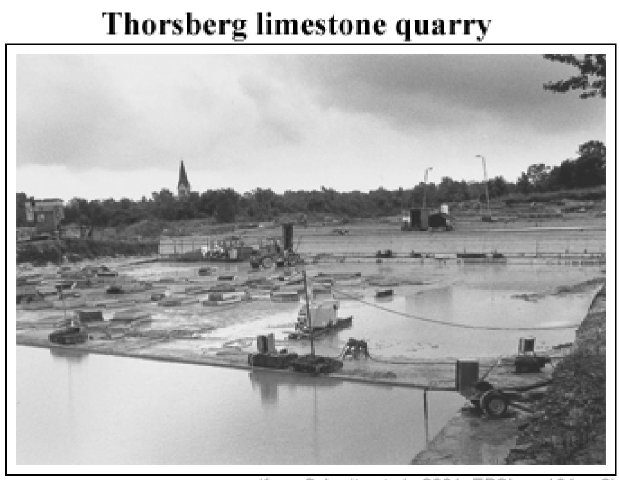
Aside from its obvious economic value, arguably the most extraordinary fact about the Ordovician limestone is fossil meteorites. Quarry workers originally considered them blemishes in the limestone and discarded the sawed plates that contained them. The first fossil meteorite (Brunflo) was discovered in 1952 when the rock plate was set aside as a curiosity. But it was not identified as a meteorite until 1979.



(from Thorslund and Wickman, 1981, *Nature*, v. 289, p. 285-286.)

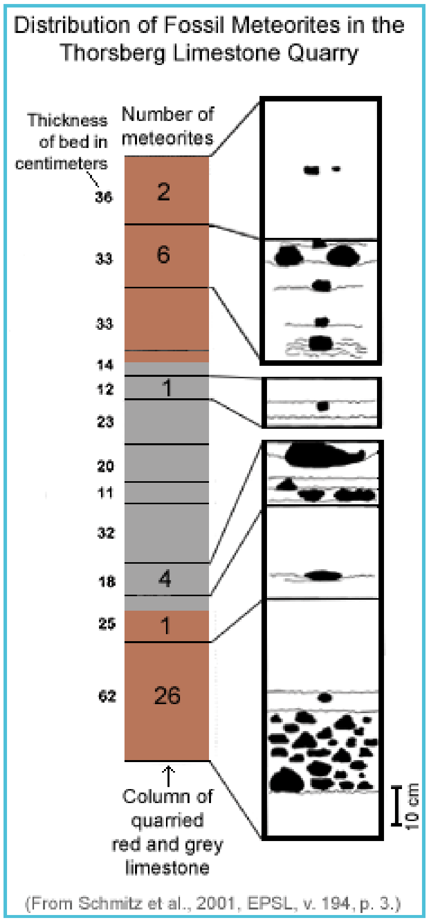
Brunflo fossil meteorite in limestone (left) with close-up views of relic chondrules, both barred (center) and radiating (right).

The second fossil meteorite (Österplana) found in a discarded plate was announced in 1988. Professor Schmitz's group has now analyzed more than 40 additional fossil meteorites collected at the Thorsberg quarry at Kinnekulle since systematic searching began there in the early 1990s. Their collection of space debris from Thorsberg quarry also includes sand-sized grains of chromite, dropped from disintegrated meteorites. As we'll see in a following section, the preserved structure of the meteorites and the chemical composition of the relict chromite grains are critical in proving these "blemishes" are genuine meteorites.



(from Schmitz et al., 2001, EPSL, v. 194, p.2)

This 1999 photo shows the basins where the ground water is pumped out to remove the rock.

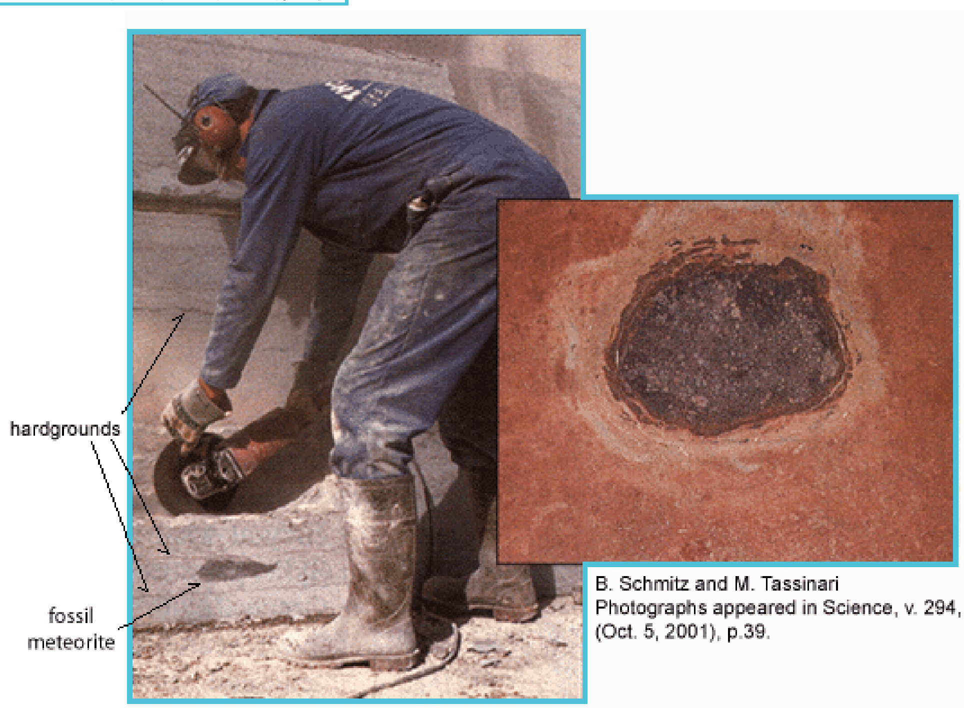


Fossil Meteorites from Thorsberg Quarry

The active part of the Thorsberg quarry spans a 3.2-meter vertical sequence of rock showing 12 prominent beds that range in thickness from 11-62 centimeters. Based on fossil assemblages and sedimentation rates, the researchers estimate that the sequence represents 1 to 2 million years of sedimentation. Fossil meteorites have been recovered from half of the beds in the sequence. So far, the most meteorite-rich bed has produced 26 specimens found over a seafloor area of 2,700 square meters.

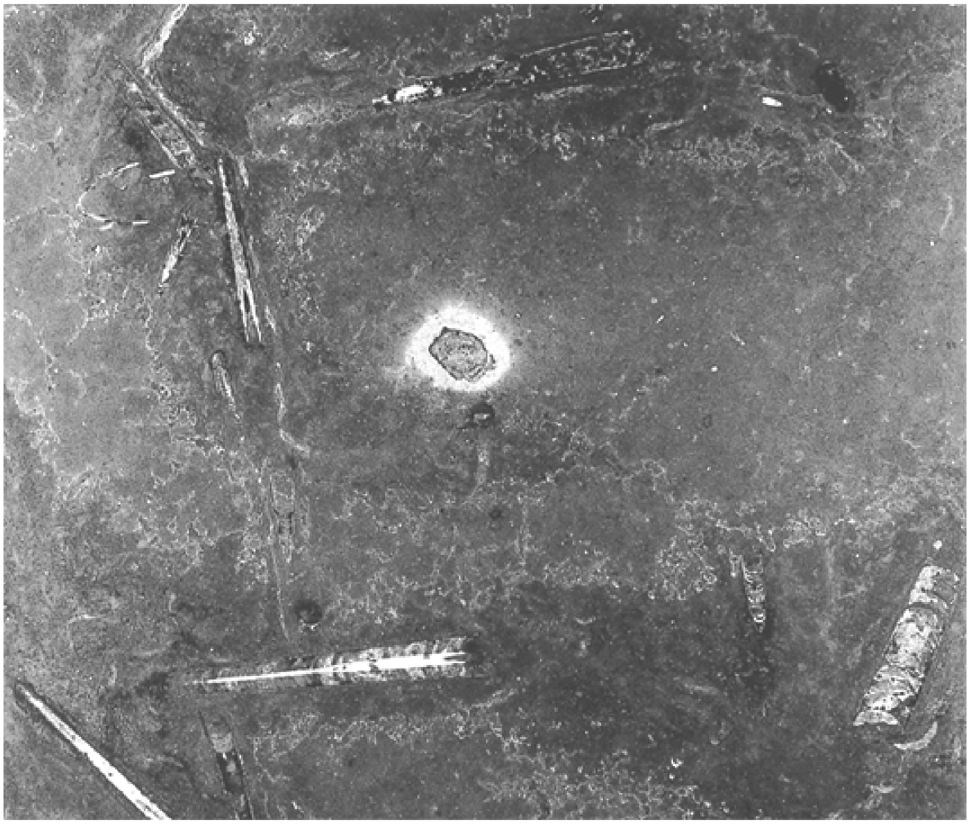
The fossil meteorites range in length from about 1 to 20 centimeters and typically occur on hardgrounds where they accumulated with nautiloid shells. In work reported in 2001, Schmitz and colleagues observed that the delicate shells show no preferred orientation and are usually well preserved and concluded that the meteorites and shells were concentrated due to sediment winnowing by bottom currents. They ruled out that the meteorites were simply transported into position by strong bottom currents. In other words, the meteorites settled where they fell.

The left-hand column represents the 12 limestone beds being quarried at Thorsberg. Numbers inside this column show how many meteorites were found in a bed. The right-hand column shows the distribution of meteorites.



Quarry worker saws a plate of limestone. Below the blade is a meteorite. The photograph on the right shows a typical fossil meteorite with alteration halo in the red limestone.

Fossil meteorite and nautiloid shells in Ordovician limestone

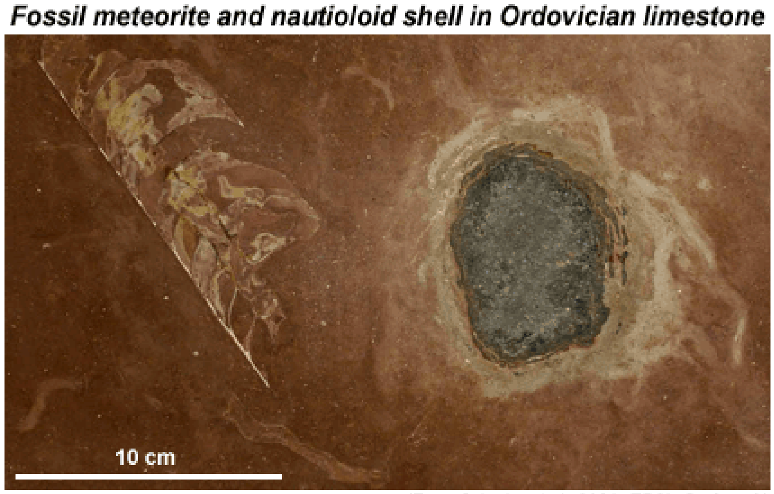


10 cm

(From Schmitz *et al.*, 2001, *EPSL*, fig. 5, p.6.)

This plate of limestone was cut parallel to the seafloor surface. Nautiloid shells accumulated near the 4.5-cm-wide meteorite seen in the center of the scene. Iron in the red limestone around the meteorite was reduced resulting in the halo of lighter gray limestone.

Fossil meteorite and nautioloid shell in Ordovician limestone



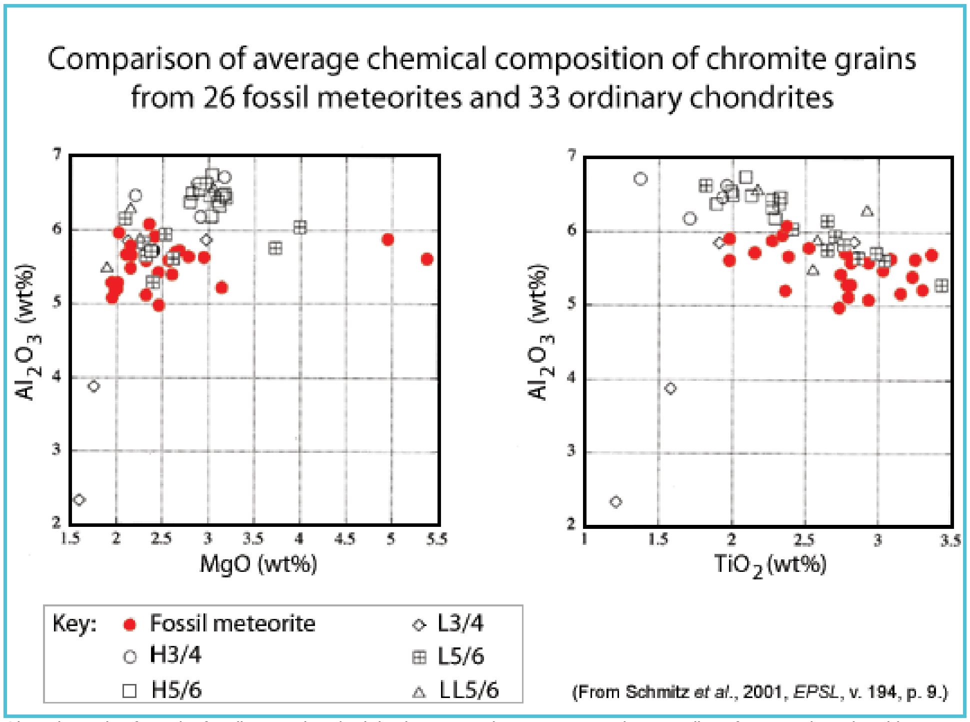
(From Schmitz *et al.*, 2001, *EPSL*, fig. 3, p.4.)

This plate of limestone was also cut parallel to the seafloor surface. A nautiloid shell is seen to the left of the 6 cm x 8 cm meteorite. Tiny white spots in the meteorite are relict chondrules. The ragged edge of the meteorite shows where the fusion crust was partly peeled off.

Summary of Chromite Chemistry

The fossil meteorites contain only two relict mineral phases: chromite and chromian spinel. All other minerals were altered during fossilization. Elemental analyses of the relict chromite as well as bulk-meteorite platinum group element or osmium isotope analyses allowed Schmitz and his colleagues to identify the type of meteorite. We'll focus on their chromite analyses.

They found that the majority of the chromites from fossil meteorites plot in the low MgO and Al_2O_3 and high TiO_2 fields characteristic of L and LL chondrites.



Chromite grains from the fossil meteorites (red dots) compared to a representative sampling of H, L, and LL chondrites.

Schmitz and his team analyzed chromites from the fossil meteorites and chromite grains found separately in the limestone. They searched for chromite grains at other localities where they could sample the same sequence of Ordovician limestone beds as in the Thorsberg quarry. The limestone was crushed to 0.5-centimeter fragments and then dissolved in acid. The bits left behind, in the size range from 63 to 355 microns, were searched for chromite grains. At the nearby Hällekis locality, they examined 150 kilograms of limestone from the bed below the meteorite-rich base at Thorsberg but found no chromite grains or fossil meteorites. [See PSRD supplementary map showing collection sites.]

The dispersed chromite grains collected over the 250,000 square-kilometer area have similar chemistry to the chromite found in the fossil meteorites. The researchers conclude that these dispersed grains are remnants of some, perhaps most, of the meteorites that fell 480 million years ago and disintegrated over time. The chemical data support the interpretation that the fossil meteorites are L chondrites.

Meteorite Influx Rate

Schmitz and colleagues determined an Ordovician meteorite flux rate based on the abundance and distribution of the fossil meteorites and dispersed chromite grains. These samples were collected in limestone beds representing 1 to 2 million years of deposition. They've ruled out longer time spans because the evolutionary changes they see in the trilobite and conodont fossils through the section are quite small.

The fossil meteorites are too altered to be paired with any certainty, so the researchers used total meteorite mass rather than number of falls to estimate the influx rate. They report, for example, that the 26 fossil meteorites found over the 2,700 square meter area in the basal bed in Thorsberg quarry represent a total original mass of 2.2 kilograms. This same bed contains on average 2.5 chromite grains per kilogram of limestone. They calculate that these dispersed chromite grains represent 15 kilograms of original meteoritic mass. On the basis of the total original mass of recovered fossil meteorites as well as dispersed chromite grains, Schmitz and coauthors estimate that the flux of meteorites in the mass range from 10 to 1,000 grams was enhanced at least by a factor of 120±50 in the Ordovician period compared to today. This enhanced flux applied to the entire 250,000 square kilometer search area.

Where did the Fossil Meteorites Come From?

Gaspra, irregular in shape, measures 19x12x11 kilometers and is littered with impact craters.

Professor Schmitz and his colleagues suggest that when the fossil meteorites arrived on Earth 480 million years ago they were an early surge of debris from a massive collision in the asteroid belt. The field data support the idea that the surge, 100 times higher than today's influx, continued throughout the 1 to 2 million years of limestone deposition. About half the meteorites that fall today are L chondrites and many of them were shocked 465±15 million years ago. Meteoriticists simply call the disrupted asteroid that produced these meteorites the L chondrite parent body. Some astronomers have suggested that remnants of the L chondrite parent body are the Flora family of S-type asteroids. The Flora family, one of the largest asteroid families with more than 800 members, is thought to have formed by the destruction of a 200-kilometer-sized asteroid sometime during the last billion years. So the fossil meteorites may come from an asteroid like Gaspra, a member of the Flora family that was photographed by the Galileo spacecraft on its way to Jupiter.

The terrestrial age of the fossil meteorites is consistent with theoretically modeled lag times between the breakup of the asteroid and when the early surge of meteorites would rain down on Earth. Schmitz and colleagues from Zurich, Switzerland report in an abstract to the 2004 Lunar and Planetary Science Conference that the fossil meteorites they've collected in southern Sweden had very short cosmic ray exposure ages, ranging from a few 100,000 years to about one million years, and that the meteorites found in the upper, younger limestone beds have the higher exposure ages.

The Challenge to Find More

By looking in Earth's own ancient rock record, researchers in Sweden are collecting fossil meteorites to understand the bombardment history of the inner solar system. More samples would help support the idea that these meteorites are evidence of a global hundred-fold increase in the bombardment rate following the breakup of the L chondrite parent body. Since shallow seas were spread over many areas of Earth during the Ordovician period, Professor Schmitz and his colleagues think that similar concentrations of fossil meteorites and chromite grains should be present worldwide in Ordovician limestone. Future work will take these fossil meteorite hunters to China. They say there are promising sites in South America as well. In North America, the best place to search might be in New York state. Look around, if you live near Ordovician limestone you might find a fossil meteorite.

Additional Resources

Dalhalla. Enjoy a fresh air concert at the dramatic festival stage Dalhalla built in a former Swedish limestone quarry.

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