The Angrite Meteorite Mystery

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The angrites are an important and unusual group of basaltic igneous meteorites that are like no other rocks anywhere. Their ages are ancient, and their mineralogies are strange. The deciphering of this meteorite group is an interesting story in which Astromaterials Research and Exploration Science (ARES) is prominently involved. The angrite story also emphasizes a truism of scientific research: that many different bits and pieces have to fit together, like a jigsaw puzzle, and this fitting often takes time.

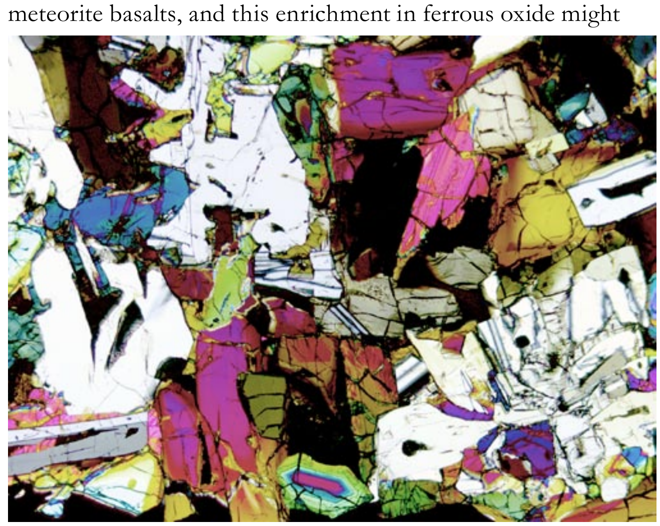
The importance of angrites stems from their ancient origins, approximately 4,556 million years ago. These are some of the oldest rocks and, therefore, they record the presence of short-lived radioactive isotopes that only existed during the first few million years of the early solar system. The angrites are also used to define the initial lead isotopic composition of our solar system—a quantity that is necessary in order to do uranium-lead dating. Therefore, understanding the origins of these strange basalts has far-reaching implications.

The angrites are so strange that, for decades, their origins were obscure. This was not helped by the fact that the first known angrite, Angra dos Reis, is unusual even for an angrite. Angra dos Reis, which fell in Brazil in 1869, consists almost entirely of fassaitic pyroxene, a type of clinopyroxene that is rich in aluminum and titanium—elements that normally do not readily enter pyroxene. The rareness of angrites is underscored by the fact that the next angrite, LEW86010, was not found until 1986 in the Lewis Cliff region of Antarctica.

Even "normal" angrites, such as LEW86010, have weird mineralogy for basalts. The olivine in angrites is very calcium rich, and the plagioclase feldspar has almost no sodium because the rock has almost no sodium. Angrites are also rich in ferrous oxide and critically undersaturated with silica. Thus, in addition to studying angrites because of their ancient ages, we also study them because they are weird. Scientists do that sometimes.

Many people initially reached the wrong conclusion concerning how angrites are made, so it is hard to point a finger at any one person. The only other meteorite samples commonly known to contain fassaitic pyroxene were the calcium-aluminum-rich inclusions (CAI) of the Allende chondrite. Many people thus felt that Angra dos Reis came from a planet that was unusually enriched in CAI material. Moreover, recall that, until 1986, the only angrite that people had seen was Angra dos Reis, which is weird even by angrite standards.

The first person to reach the correct conclusion regarding the origins of angrites was ARES scientist David Mittlefehldt in 1990. After the finding of LEW86010 and LEW87051, Mittlefehldt reasoned from his petrologic studies of these meteorites that many of the strange properties of angrites could be understood if they formed under more oxidizing conditions. This could make them more ferrous-oxide-rich than "normal" meteorite basalts, and this enrichment in ferrous oxide might

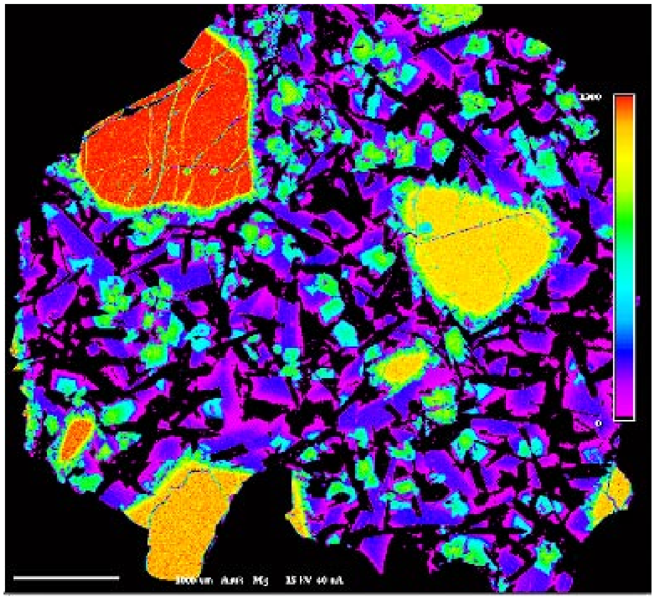


Polarized light photomicrograph of D'Orbigny.

cause angrites to be silica undersaturated. Mittlefehldt, in turn, persuaded fellow scientists Amy Jurewicz and John Jones to do partial melting experiments on chondrites under oxidizing conditions (> iron-ferrous oxide buffer) to see whether they could make angrites that way. The answer was yes and no. Partial melts of Murchison at 1180°–1200°C under oxidizing conditions looked a bit like the Antarctic angrites. Jurewicz and Jones's partial melts of Allende were even closer in composition, but nothing matched exactly. Nevertheless, the notion that the angrites came from an oxidized source region was reinforced by the experiments and analyses of Gordon McKay and Ghislaine Crozaz, who inferred that LEW86010 formed just above the iron-ferrous oxide buffer. This was the situation as of 1994.

In the meantime, more angrites—the Asuka881371, Sahara99555, and D'Orbigny—were found. Mittlefehldt performed a petrologic study of D'Orbigny; and Takashi Mikouchi, Gordon McKay, and Loan Le did the same for Asuka881 371 and Sahara99555. What Mikouchi and McKay found, using their and Mittlefehldt's data, was that the angrites other than Angra dos Reis (which was known to be weird) formed a trend of olivine addition. This was not surprising because some angrites were known to contain foreign ("xenocrystic") olivines.

This year, Mikouchi and McKay also noticed that the apparent amount of olivine contamination did not exactly match the amount of olivine contamination observed. The inferred amount was usually greater, suggesting that, in addition to just suspending this contaminating olivine in the angrite magmas, some of the olivine had actually dissolved. Their observation also implied that some angrites should be more primitive than others; the samples with the least contamination (D'Orbigny and Sahara99555) were probably closest. At about the same time, Jurewicz and Jones noticed that the compositions of their Allende partial melting experiments looked remarkably like D'Orbigny, an angrite unknown at the time of their experiments.



Magnesium map of Asuka 881371. Warmer colors indicate higher magnesium concentrations. Large red, orange, and green crystals are olivine. It is unusual that different olivine crystals have different magnesium contents.

After 13 years, the genesis of angrites seems pretty well understood. Chondritic materials are partially melted under redox conditions where iron metal is unstable. Primitive angrites and experimental melts are remarkably similar in composition. However, most angrites have experienced contamination by foreign materials and these only vaguely resemble the experimental melts. New samples and persistence by the ARES team have combined to make a compelling angrite story. Other issues, though, such as the source of the contaminating xenocrysts, remain to be solved.