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EVIDENCE IN METEORITES FOR AN ACTIVE EARLY SUN:

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Was the sun once brighter than it is today? Recent meteorite studies suggest that the sun may have gone through a period of intense solar flare activity as a young star 4.5 billion years ago. Astronomical observations of a class of stars called T-Tauri stars, stars that are similar in size to our sun but in a much younger stage of evolution (several million years old or less), show that this class of stars can be very active. Scientists have suspected that our sun also went through a period of increased activity, but it's difficult to find direct evidence for an event that happened so long ago.

However, in the same way that spacecraft are sent to other planets to gather new information, meteorites can serve as probes into our solar system's early activity. Most meteorites formed about 4.5 billion years ago, and have been altered little since then. Some of these meteorites contain grains that were individually exposed to energetic particles before formation of the meteorite. These grains have preserved a record of the early solar activity that can be studied. We have found that these grains have surprisingly large abundances of a rare isotope of neon, which can only be produced by energetic particles. These particles can come from only two sources: galactic cosmic rays or solar flares. Unless the grains were exposed to galactic cosmic rays for a much longer period than is predicted by current theories, this excess neon must have been produced by solar flares at least 100 times more intense than those of our present sun.

A simple history for this type of meteorite includes three stages. In the first stage, which occurred at least 3.5 billion years ago (more likely 4.5 billion years ago), some mineral grains were exposed to the sun, while others, deeper in clumps or within the rubbled surface of a small asteroid-like body, were not. In the next stage, many grains, only a few of which had been exposed to the sun, were compacted together in a solid object, shielded from further bombardment by energetic particles. This stage constitutes the major period of a meteorite's history. Finally, sometime within the last 30 million years or so, this larger body broke apart, probably the result of collisions that also placed the meteorite on a collision course with the earth.

EVIDENCE IN METEORITES

Caffee, M. W. et al.

We can learn about these three stages of exposure from the records the grains have retained. For example, if we treat the grains with acid and look at individual grains under a microscope, we find that some grains (5 to 10 percent of the grains in the meteorites we've studied) show evidence of exposure to solar flares. During a solar flare, the sun ejects particles at a high enough energy that they will penetrate the first 10-20 microns (millionths of a meter) of a rock, leaving a scar in the rock that the acid attacks and enlarges to make a visible "track." Since these solar flares are stopped in such a short distance, grains with solar flare tracks must have been exposed directly to the sun. Furthermore, those grains must have been exposed to the sun in the first stage of their history, since they were recovered from inside the meteorite.

Meteorites are also bombarded by galactic cosmic rays. The galactic cosmic rays, which do not come from our solar system, are mostly protons that are moving at nearly the speed of light. They have energies comparable to those produced by the most powerful particle accelerators on earth. These cosmic rays can penetrate only a few meters of soil or rock, so grains in meteorites can be exposed to them during the early and recent stages of their history, but not during the long intermediate stage of deep burial. When a cosmic ray proton collides with an atomic nucleus within a rock, it can break off ("spall") part of the nucleus, converting it into a different element. We study neon, which can be produced from common elements like magnesium or silicon in this type of reaction. One particular isotope of neon, neon-21, is rare in meteorites unless such spallation reactions have occurred. Solar flare particles can also produce spallation reactions, but in the modern solar system, the number and intensity of solar flares are low enough that the products of such reactions are rare and difficult to detect. However, this might not have been true of the early solar system.

In our experiment, we compared the amounts of neon-21 produced by spallation reactions in grains that had been exposed to the sun (in other words, grains that had solar flare tracks) and grains that had not. Since all the grains had the same exposure in all but the earliest stage of the history of the meteorite, we hoped to find out something about that earliest stage. In three different meteorites, grains that had been exposed to solar flares had much more neon-21 (by factors as large as 50) than those that had not. If the neon-21 were produced by galactic cosmic rays, these grains must have had early exposures of up to several hundred million years, much longer than models of meteorite evolution predict. On the other hand, if solar flares were much more numerous and much more energetic when the sun was young, those flares could have produced the effects we see in a much shorter time span. For instance, solar activity 100 times greater than current solar activity would require pre-compaction exposure times of only a few million years. These times would then agree with most models for meteorite formation.

There are questions remaining to be answered before accepting this evidence as proof that the early sun was more active. For example, we need to know precisely when the early production of neon-21 took place. This is important since the period of enhanced solar flare activity would not be expected to last more than several million years. Therefore, if any of the grains containing the excess neon-21 are much younger than 4.5 billion years old (for example, if they are only 3.5 billion years old), a different explanation would have to be found. There are currently experiments under way that we hope will answer these questions.