Rocks on the ice

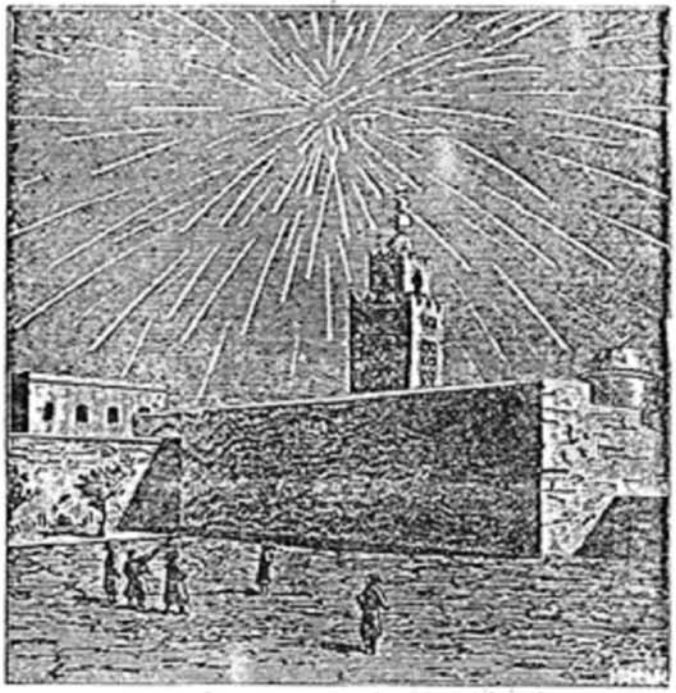
Meteorites recently discovered in Antarctica may date from the earliest days of the Solar System

Dr Derek Sears is a research fellow at the University of Birmingham

Scientists who work on meteorites have been amazed, over the past few years, by the number of meteorites being found in Antarctica—more than 1300 specimens have been discovered. Meteorite falls are very rare, and this figure may be compared with the 2000 or so pieces which the museums of the world can boast. The museum collections have been painstakingly assembled for over 200 years, incorporating meteorites from all four corners of the Earth. Why then, are there so many meteorites in Antarctica? How were they discovered, and what will be the consequences of this sudden growth in the size of our collections?

The first meteorite to be found in Antarctica was discovered by members of the Australasian Antarctic Expedition in 1912. In his book of the expedition, *The Home of the Blizzard*, Sir Douglas Mawson tells of how a black rock was found lying on the snow 30 km west of Cape Denison. Its dimensions were about 12·5×7·5×9 cm and it was immediately recognisable as a meteorite. It now resides in the South Australian Museum, Adelaide, under the name Adelie Land (meteorites are normally named after the location of their fall or find). For 50 years it remained the only known Antarctic meteorite. It seemed that the climate and low population of Antarctica meant it was the most unlikely place on Earth to expect to find them. We now know that quite the opposite is true.

By the early 1960s, the amount of research being carried out in Antarctica had considerably increased. As a result, three new meteorite finds were made; at Lazarev in 1961, Thiel Mountains in 1962 and Neptune Mountains in 1964 (Figure 1). However, it is the tenth Japanese Antarctic Research Expedition which can probably claim the major share of credit for our new attitude towards Antarctica as a source of meteorites. In 1969 a Japanese team was working 300 km south-west of the base at Syowa Station. At this location they discovered nine pieces of stony meteorite, all within 10 km of each other. It was four years before their next expedition to Antarctica, and on this they recovered a further 12 fragments.



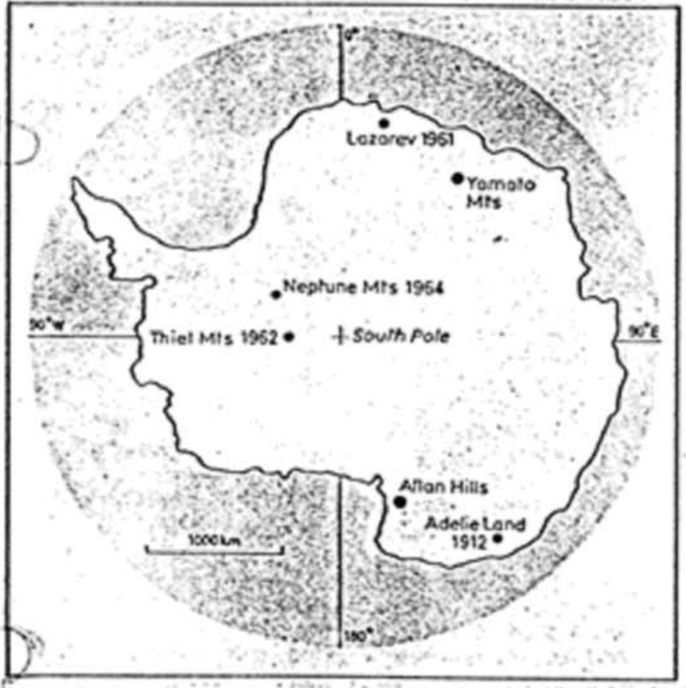


Figure 1 Locations of Antarctic meteorite finds

It clearly looked as if the Japanese had stumbled across a major source of meteorites. However, the next expedition caught everyone by surprise. The 1974-75 Antarctic season yielded 663 pieces of meteorite to the Japanese, and a further 307 the following year. As the meteorites were all found within a relatively small area, about 4000 sq.km, it seems most probable that the site of a major meteorite shower had been discovered. Meteorite showers, as opposed to falls of a single meteorite, are comparatively common. They occur when a meteorite breaks up during its passage through the atmosphere. This usually happens at high altitudes, so each fragment is worn away by friction as it continues through the atmosphere and looks like a complete individual when recovered, rather than an irregular fragment. The Japanese workers have suggested that the 991 fragments probably represent only 300 separate meteorites. Even so, this is 15 per cent of the world's known meteorites.

This high meteorite density is not unique to the Yamato Mountains. Prompted by the Japanese discoveries, a joint United States/Japanese expedition was despatched to the Allan Hills and Mount Baldr regions of the Trans-Antarctic Mountains for the 1976-77 season. It resulted in the recovery of 11 more meteorites, one of which was a massive 408 kg. The following year a joint expedition was again organised and more than 300 specimens were returned.

There are interesting differences between the collections at the two sites. The Yamato meteorites tend to be much smaller than the stones from Allan Hills and Mount Baldr. The total mass of the Yamato meteorites is 100 kg, which means that the average weight of each stone is about 100 g. Even ignoring the 408 kg sample, the average mass of the eleven meteorites collected from the Allan Hills site in the 1976-77 season is 5 kg. This is perhaps further evidence that among the Yamato stones there is a major shower, because stones from showers tend to be much smaller than stones from individual falls. However, this will have to be verified when a greater number of specimens from Allan Hills has been documented.

Even if we assume nine out of ten Yamato meteorites belong to a single shower, we are still faced with the fact that Antarctica is providing more meteorites per unit area than the rest of the world. The surface density of meteorites in Antarctica is something like one or two per 10 sq.km, compared with about one per 100 sq.km for the Prairie States in the US—the world's previous "best bet" for finding a meteorite. Meteorites are falling at the rate of one per million sq.km each year. This means that either the ice at the Yamato Mountains and Allan Hills sites is extremely old, in fact several hundred million years old, or that the meteorites are somehow being concentrated at preferred sites.

It is well known to glaciologists that the ice covering the Antarctic continent is, in geological terms, a highly mobile surface. The ice forms at the South Pole and moves toward the warmer continental edges where it evaporates or falls into the sea. The whole of Antarctica consists of about 10 major sheets of ice moving this way. Typically, a sheet may take one million years to move across the continent. Therefore the high densities of meteorites do not reflect a long accumulation time over a static area, but rather the work of a concentration mechanism.

The workers who discovered the first Yamato meteorites realised that their discoveries were always made on what they termed "blue ice". This refers to regions where snow has been swept from the ice sheet by fierce winds, and where evaporation is very efficient. They are regions where the ice sheet encounters a mountain range, such as the Yamato Mountains or the Trans-Antarctic Mountains, and rises, bringing any meteorites trapped in it to the surface. After a while the meteorites will be revealed, when evaporation and wind erosion have removed the overlying snow and ice (Figure 2).

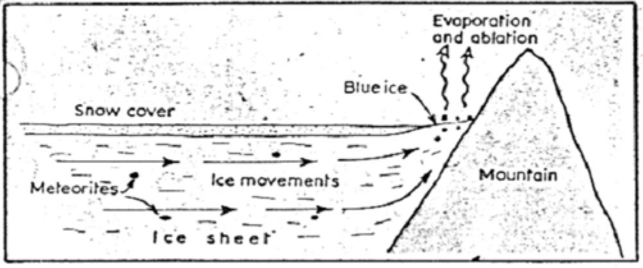


Figure 2 Concentration of meteorites at mountain ridges

So much for the way in which the Antarctic meteorites were discovered and the way we think the high surface densities of the finds came about. But what are the meteorites actually like?

Generally speaking, meteorites are either stony—superficially resembling terrestrial rocks—or they are almost pure iron-nickel alloys. There are also a few which consist of roughly equal amounts of metal and stony material. Most stony meteorites, called chondrites, also contain metal in millimetre grains. This is one of the properties by which they may readily be distinguished from terrestrial rocks. Achondrites are metal-free stony meteorites, particularly valuable because of their rarity. Chondrites and achondrites owe their curious names to Gustav Rose, who observed that the former generally contained "chondrules", or stony globules, while achondrites did not. All these meteorite types are represented in the Antarctic collections, but their relative proportions are significantly different from those being found over the rest of the world.

Meteorites actually observed when they fall are usually stones, whereas iron meteorites, which are more readily distinguishable from normal terrestrial rocks, tend to dominate finds. This selection effect does not apply in the Antarctic collections, because a black stone stands out against the ice as readily as a black iron. As a consequence, the relative proportion of meteorite types in Antarctica is much the same as it is for observed falls (Figure 3).

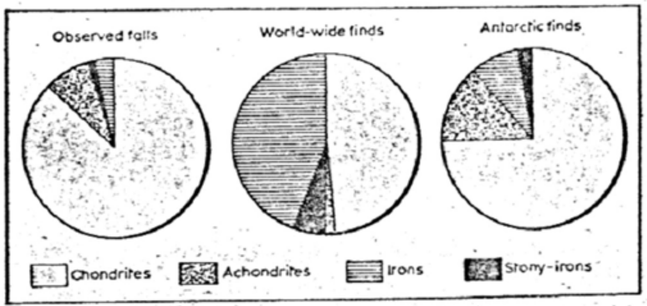
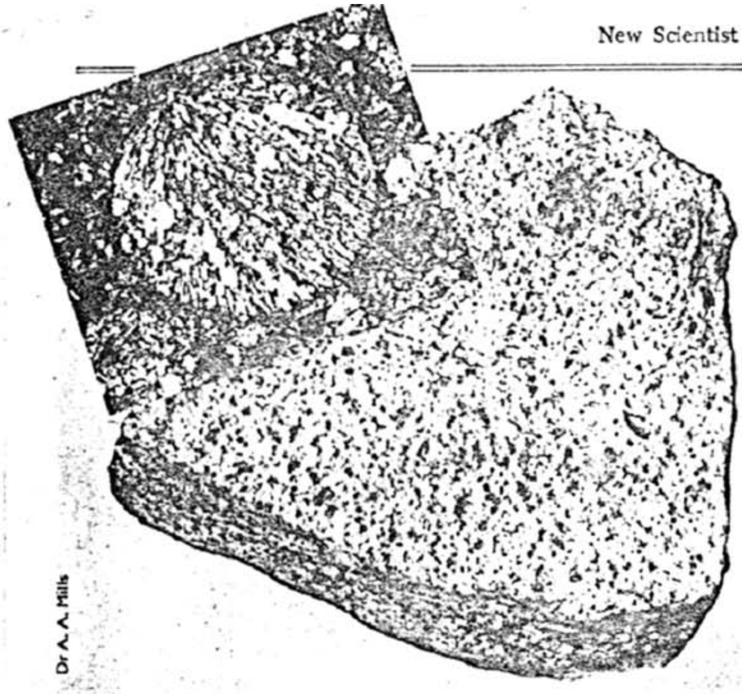


Figure 3 Relative proportions of meteorite types

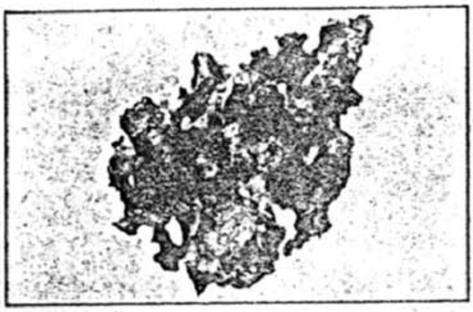
The small and rare classes of meteorites are well represented in the Antarctic collections. For instance, only 16 members of the C2 class of chondrites are currently known, but one has already been found among the Antarctic meteorites so far examined. They are particularly interesting because of the large quantity of carbon they contain (hence the C in their class designation)—typically 2 to 3 per cent. The carbon exists in a variety of forms, sometimes being present in organic compounds such as amino acids of the kind found in proteins. The study of these organic compounds has a bearing on many questions outside meteoritics, such as the formation of the precursor molecules to life on Earth and the origin of interstellar molecules. Much of the carbon also exists in complex polymers with atomic weights of many thousands. This class of meteorite also contains abundant water and other volatile compounds. The Antarctic probably provides an ideal collecting surface for C chondrites because the volatile compounds would be readily lost in any other kind of environment. The snow and ice encapsulates the meteorite at sub-zero temperatures, freezing in the volatile compounds. Meteorite recovery in the Antarctic is now being handled with the same care as is given to lunar samples. Indeed, the laboratory processing is being carried out in the Lunar Receiving Laboratory of the Johnson Space Center, Houston.

Because of their volatile-rich composition, the C chondrites are commonly regarded as the least altered material we have which dates from the formation of the solar system. Some of the C2 chondrites also contain white aggregates of minerals that are thought to have been the very first solids to have formed—they may even contain interstellar grains brought into the Solar System from outside. The chondrite classes as a whole formed at the same time as the planets, by condensation and accretion in the primordial solar nebula, some 4600 million years ago. The achondrites, stony-irons and irons, which are also abundant in the Antarctic collections, seem to have formed by a number of processes involving partial or complete melting of material similar to the chondrites. There also seems to have been a certain amount of mixing of materials originally formed in different ways.

After the meteorites were formed into solid objects, perhaps tens or hundreds of kilometres in size, some event caused them to take up an orbit which intercepted that


Dr A. A. Mills


Professor Ed Olsen


Dr A. A. Mills

Far left Chondritic meteorite. Insert shows photomicrograph of a chondrule 1 mm diameter *Left (above)* Meteorite found blue ice near Mount Baldr *Left (below)* Stony-iron meteorite with silicates removed by terrestrial corrosion

of the Earth. The event was probably a collision between two of the bodies. Some chondrites, including at least one from the Antarctic, were blackened by the force of such an event. What orbit they were on previously is the subject of some debate. It seems probable that most were on the inner fringes of the Asteroid Belt, but that the minor classes, especially the irons, were spread throughout the Solar System. Once on Earth-crossing orbits, it seems they were broken down into smaller objects by several less violent fragmentation events. By the time they encountered Earth they had reached metre-sized dimensions. With several Antarctic meteorites these small scale fragmentation events have been dated at between 1 million and 20 million years, consistent with existing data. How long had they lain undiscovered in Antarctica? From the amount of radioactivity induced in the meteorites by cosmic rays, which decays away once on Earth, it seems that at least one fell over a million years ago, several fell 100 000 years ago, while three I have examined seem to have fallen much more recently, only a few thousand years ago.

It is probably the abundance of the minor classes, such as C2 chondrites and achondrites, that is going to cause a major impact on current meteorite studies. Until now we have found such meteorites only in observed falls, and as their abundance in space seems to be low, the number of specimens in our collection is small. Because they weather very rapidly and are difficult to distinguish from terrestrial rocks, they have never been discovered as finds. This has all changed with the Antarctic discoveries.

Dating meteorite finds

Several specimens of Antarctic meteorites are being studied at the University of Birmingham, where we are estimating how long ago they fell to Earth, using the phenomenon of thermoluminescence (TL). Similar methods have already proved to be particularly valuable in dating pottery of archaeological interest, but the techniques used with meteorites are quite different.

TL is essentially the light emitted by a sample when it is heated, before it starts to glow with red heat. It is caused by radiation from two sources: from radioactive elements within the meteorite, and from cosmic rays, which deposit energy as they pass through the meteorite. When the specimen is heated it releases some of this energy in the form of light. But the energy storage is not perfect and some escapes slowly, so that the level of TL is governed by an equilibrium between the rate of irradiation and the rate at which the stored energy decays.

Because large doses of cosmic rays are received in space, a meteorite is exposed to higher levels of radiation before it falls to Earth, and after falling the level of TL slowly decays. By comparing the level of TL in meteorite finds, such as one from Antarctica, with that in meteorites which were observed to fall very recently, it is possible to calculate the "terrestrial age" of the find. The major difficulty is that some estimate has to be made of TL decay on Earth, and these studies are as yet at an early stage. *D.S.*