Meteorite concentration mechanisms in Antarctica

Literature Review

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Contents:

1. Abstract

Meteorites are an obscure and finite (within any reasonably time period) land-based resource in Antarctica that are of significant interest to planetary science. They can hold clues to the early formation of the solar system, the formation of the moon and the earth, and even evidence of life on Mars. Meteorites found in Antarctica are extremely well preserved because they have been buried in the ice for up to several hundred thousand years.

Following impact, the meteorites are thought to move with the ice and are typically released into the sea and become unrecoverable. However some ice movement does not end in the sea, instead the ice raises against a mountain barrier and is removed by ablation (sublimation, melting and abrasion). The meteorites held within such ablating ice can remain on the surface for extended periods of time, where they have been found in large numbers.

This review examines the concentration mechanisms of meteorites in Antarctica, and considers the implications for future rates of meteorite discovery and removal.

2. The importance of Antarctic meteorites

Meteorites are of significant interest to planetary science as they can hold clues to the early formation of the solar system, the moon and the earth, and even evidence of life on Mars. Meteorites found in Antarctica are extremely well preserved because they have been buried in the ice for up to several hundred thousand years.

According to the Antarctic Meteorite Location And Mapping Project (AMLAMP), about 35,000 meteorite specimens have been recovered, from 59 locations (8). This is an extraordinary number, making up over 80% of all meteorites ever collected.

3. The history of Meteorite Discovery in Antarctica

The first Antarctic meteorite was discovered during the Australian Antarctic expedition, on an exploratory traverse on the Adelie Coast in 1912 (1). Similarly, three meteorites were discovered serendipitously while undertaking geological surveys during the 1957 International Geophysical Year, including the first meteorite to be found on hard glacier ice.

The potential of Antarctica to yield large numbers of meteorites was only realised when the 1969 Japanese Antarctic Research Expedition, embedding a network of survey stations on glacial ice, found a total of nine meteorites (2). These discoveries lead to the creation of the first model of the concentration mechanism of meteorites by the up-thrust of glaciers moving over mountain barriers, and by the sublimation of the surface ice.

Currently Japan and the USA have the largest meteorite recovery programs. This season (2010/2011) the US program has a systematic survey party of eight people and a reconnaissance team of four. Japanese search teams tend to be larger, but occur less frequently (13). There have also been meteorite recovery expeditions by German, Chinese, Korean and Italian teams, and a European consortium (EUROMET), and possibly others. As well as national programs, there have been a number of private expedition to recover meteorites (e.g. the Planetary Studies Foundation).

4. Global distribution of meteorites

Meteorites originate from asteroid and comet material in orbit about the sun. As the Earth sweeps through its orbit it could be expected that there would be fewer meteorite impacts per unit area at the poles due to the glancing angle of incidence. However, the majority of interplanetary objects orbit close to the plane of the ecliptic (the plane in which the planets are found), changing their velocity relative to the earth. Further, the gravity of the earth will redirect the path of any objects in its vicinity to “fall in” toward the earth from every direction. This results in a near-uniform distribution of meteorite impacts on the earth’s surface (14).

The rate of meteoric influx to Earth is examined in (14), based on observations from a network of cameras which recorded fireballs and correlated them to observed meteorite falls. It was shown that there are around

4500 events per year that result in over 1kg of meteorite fragments reaching earth. This equates to one large (1kg or more) meteorite fall per square kilometre approximately every 110,000 years.

As an example of the concentration of Antarctic meteorites, the Lewis Cliff Ice Tongue, only 3 × 8 km in size, has yielded more than 1300 meteorites to date (13), giving a density of 54 meteorites per square kilometre. If we assume that each meteorite was part of a combined meteorite fall mass of over 1kg, then without a concentrating mechanism it would take six million years for this number of meteorites to fall in such an area. The ANSMET average is about 10 meteorites per square kilometer (9), which still equates to a non-concentrating accumulation time of over a million years.

5. Distribution of Antarctic meteorite fields

In most areas on the earth, relatively high meteorite abundance results from two specific conditions: the recognition of meteorites must be easy and the preservation of meteorites must be guaranteed over relatively long time periods (6). These conditions are found in desert environments, and indeed meteorites have been collected from several deserts around the world. Antarctic meteorite recovery sites have the additional advantage of accumulation of meteorites by the movement of ice, however meteorite accumulation will only occur in regions that are characterized by a stable, old surface with slow or negative rates of terrestrial accumulation (13). Each individual meteorite field exhibits distinct and often unique characteristics, with different combinations of the concentrating mechanisms.

While impacts are random, the meteorites move with the ice becoming buried in areas of surface accumulation and subsequently becoming exposed in areas of surface loss. While most of the ice in Antarctica, and thus most of the meteorites, is lost into the sea, there are some areas where ablation is the major ice loss mechanism. Ablation is the combined ice loss processes of sublimation, melting and abrasion (13), all of which are enhanced in areas of strong wind and northerly aspect occurring on side of nunataks or mountains and surrounding large ice scarps. The effect is strengthened where the ice raises against a mountain barrier and is effectively brought to a halt.

Surface areas of ice that experience relatively low accumulation and high sublimation rates will be snow free, and will expose the deeper glacial ice. These so-called “Blue ice” areas, covering only 1% of the area of the continent, are where almost all Antarctic meteorites are found. While these areas show up readily in satellite and aerial imagery, the vast majority harbor no concentrations of meteorites at all (13). Many sites are located form such imagery, however it still requires a physical visit to establish whether or not meteorites are present (15). While most areas of blue ice are less than 100 km^2, the Yamato Mountains site is the largest icefield, covering 4000 km^2 (4).

The location of some meteorite fields on the down-hill slopes of mountain ranges has led to a realization that some areas of ice are stationary and disconnected from the general movement of the glaciers. In these area, where ablation is dominant, the ice have been shrinkage since the previous glacial maximum (13). This causes any meteorites entrained in the ice to become stranded on the surface, thus constituting a slow but highly effecting concentration mechanism. Interestingly this leads to the conclusion that the meteorite concentration mechanisms may be dynamic, though on very long timescales.

In East Antarctica, most blue ice areas occur at the periphery of the ice sheet, very close to the coast and near the end of glaciers, and no meteorite concentrations have been found in such areas. Similarly, a search of the Partiot Hills area found no meteorites, dispite searching an area of area of approximately 60 km^2 (11 and 12). It was speculated that the altitude at this site (800-1100m) was too low for meteorites, allowing the meteorites to warm sufficiently in summer for the creation of cryoconites. Cryoconites result from rocks being warmed by radiation from the sun until they can melt the ice through conduction of heat and sink into the melted ice which then freezes over (7 and 10). Meteorites deposited in such regions are likely melted under the ice, and subsequently could not be located by a visual search. At the Patriot Hills site in particular it was noted that there were many cryoconite holes, melt ponds and refrozen ice are, attesting to the significance of this effect (12).

Sinking is dependant on rock size and mass, as larger rocks will sink deeper before reduced solar illumination and increased thermal contact with deeper, colder ice create a new equilibrium. Most meteorite

stranding surfaces lie above 2000 m and rarely show any evidence for melting, while there is significant evidence of melting at sites below 1500 m altitude (13).
Complicating the collection process, it is important to note that terrestrial rocks can also become entrained in the ice movements, such as moraine features. Of the 5900 specimens recovered from meteorite stranding surfaces in the Walcott Névé region, all but a few hundred were recovered from regions rich in terrestrial rock (13).

6. Discussion

The major concentration mechanisms for Antarctic meteorites are:

- Glacial movement over bedrock barriers
- Ablation (sublimation, melting and abrasion)
- Low accumulation, often assisted by high wind
- Shrinkage of the ice cap since the previous glacial maximum

Confounding factors that can prevent the concentration of meteorites, or make their identification difficult include:

- Weathering, particularly the presence of any amounts of liquid water
- Sinking, through the formation of cryoconites at low altitude
- Mechanical abrasion by airborne ice particles
- Wind redistribution
- Search resolution and meteorite size

Interestingly, the emphasis of searches to date has been on easily accessible targets, which is not unreasonable. At present the collection rate is limited by resources; namely the number of people that can be put into the field, and it is unlikely that there will be a shortage of productive sites in the coming decade. Beyond that, however, the availability of new meteorite sites is likely to become limited, leading to increased competition and greater innovation. This will no doubt increase out understanding of the cryosphere as well.

A prime target for long term meteorite searches is the potential for meteorites buried in cryoconites. While not of interest to the current search teams, it is recommended that some early research be done in areas of cryoconite sinking to understand their potential.

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