# METEORITES, ICE, AND ANTARCTICA

## A personal account

WILLIAM A. CASSIDY

CAMBRIDGE

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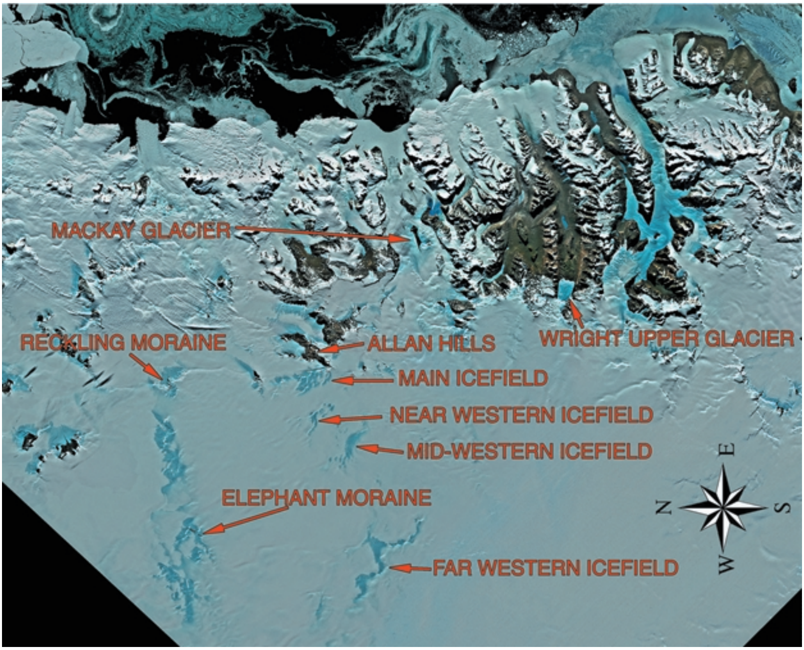
## Meteorites, Ice, and Antarctica

Bill Cassidy led meteorite recovery expeditions in the Antarctic for 15 years. His searches resulted in the collection of thousands of meteorite specimens from the ice. This fascinating story is a first hand account of his field experiences on the US Antarctic Search for Meteorites Project, which he carried out as part of an international team of scientists. Cassidy describes this hugely successful field program in Antarctica and its influence on our understanding of the moon, Mars and the asteroid belt. He describes the hardships and dangers of fieldwork in a hostile environment, as well as the appreciation he developed for the beauty of the place. In the final chapters he speculates on the results of the trips and the future research to which they might lead.

BILL CASSIDY was the founder of the US Antarctic Search for Meteorites project (ANSMET). He received the Antarctic Service Medal of the United States in 1979, in recognition of his successful field work on the continent. His name is found attached to a mineral (cassidyite), on the map of Antarctica (Cassidy Glacier) and in the Catalogue of Asteroids (3382 Cassidy). He is currently Emeritus Professor of Geology and Planetary Science at the University of Pittsburgh.




Frontispiece: The illustration shows a digitally enhanced, false-color mosaic of satellite photos of the Allan Hills – Elephant Moraine area. Blue areas are patches of exposed ice. Notice that the Allan Hills Main Icefield stands away from the roughly Y-shaped Allan Hills exposure, due to the presence of a low-lying structural barrier (a subice ridge). Ice flows over this barrier toward Allan Hills. Elephant Moraine is also indicated. The regional linear patches of blue ice, in one of which are found Elephant Moraine and Reckling Moraine, mark the presence of a subice ridge. Ice is spilling over this ridge on its journey northward. The irregular dark area at the top of the photo is open water of the Ross Sea, which is completely frozen during most of the year. Contorted patterns in the water are aggregates of floating ice chunks whose trends reflect eddy currents. Brownish patches in the upper right quadrant are Dry Valleys. (Courtesy of Baerbel Luchitta, USGS Image Processing Facility, Flagstaff, Arizona, USA)

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*I dedicate this book to my wife, Bev, who ran our home, and our family, for fifteen field seasons while I was in Antarctica, and never once complained.*

# Contents

# Foreword

This wonderful tale of physical and intellectual adventure details the development of the ANSMET (Antarctic Search for Meteorites) program of meteorite collection in Antarctica and its importance for planetary science. Starting from the chance discovery by Japanese glaciologists of several different *types* of meteorites in a limited field area of Antarctica, Cassidy describes the flash of insight that led to his conviction that Antarctica must be a place where many meteorites could be found. His basic idea was that it was wildly improbable to find different meteorites in a limited area *unless there was a concentration mechanism at work*. The subsequent discovery of several hundred meteorite samples by another Japanese team proved the point.

Alas, insights are not always easily shared. The initial rejection of his proposal to test his idea serves as a most useful lesson to young scientists everywhere – don't be discouraged by initial rejection of your new ideas, persist!

Initially undertaken as a joint Japanese–American effort, the national programs eventually diverged. The work directed by Cassidy matured into the highly successful ANSMET program that has become an integral part of the NSF's (National Science Foundation) polar research program.

I had the good fortune to participate in two ANSMET field seasons and believe that ANSMET is organized in just the right way. It need not have been thus. I suspect that most of us faced with the problem of collecting meteorites in the hostile Antarctic environment would have opted to send in teams of vigorous young male adventurers. And one would have been tempted to use the specimens so collected for one's personal research. But Cassidy had the wisdom to do things differently. The ANSMET field teams consist of a mixture of young and old, professors and students, male and female, Americans and citizens of other countries, with a sprinkling (mostly John Schutt) of experienced field people termed "crevasse experts". They share a common love for, and knowledge of, the scientific study of meteorites. The inclusion of lab scientists in the field teams has led to a much better understanding of the nature of the samples – it is impossible to speak of "pristine" samples when one has seen a black meteorite sitting in a puddle of melt water!

The meteorites are initially handled at NASA's Johnson Spacecraft Center in Houston, and scientists from all countries are invited to request samples. As with the lunar samples before them, the meteorites are considered as the heritage of the human race as a whole. This is as it should be.

The book shows why meteorites are scientifically interesting and the "intellectually curious general reader" addressed by Cassidy will learn much. A foreword is no place to delve into scientific particulars. Suffice to say that almost everything we *know* (as opposed to hypothesize) about the formation and early history of the Solar System is derived from studies of meteorites.

Most, but not all, meteorites are fragments of asteroids. Two important exceptions are those (rare) meteorites that come from the Moon and from the planet Mars. A major part of the NASA Planetary Science program is the continued exploration of Mars with the goal of one day returning samples of the planet to earth. The total cost will run into many billions of dollars. The continued collection of Martian meteorites from Antarctica, at a tiny fraction of the cost of a sample return mission, is clearly warranted. Cassidy also makes a convincing case of continuing the search for new lunar meteorites.

Museum collections have now been greatly surpassed by the thousands of Antarctic finds. A natural question is whether we really need more meteorites. Cassidy shows why the answer is a resounding yes! As luck would have it, the rate of return of interesting specimens just about matches the rate at which they can be properly studied.

There is thus every reason to continue the existing collection effort at about the same level.

Like most meteoriticists, Cassidy emphasizes the planetary insights gleaned from meteorites. He shows explicitly how the sampling of asteroidal fragments permits the study of the melting and differentiation of small planets leading to a better understanding of the processes that operated on the early earth.

Although not discussed by Cassidy, the reader might be interested to learn that meteorites also provide unique information about the larger universe beyond the planets. Relatively recently, researchers have shown that meteorites contain small grains of interstellar dust that formed around different stars at different times prior to the formation of our sun. The detailed study of these grains, some of which formed in the atmospheres of dying stars similar to our own, and others in supernova explosions, provide new insights into stellar evolution and the processes of element formation. Meteorites also provide unique information about the nature and history of galactic cosmic rays.

Cassidy's discussion of the meteorite concentration mechanism and its possible implications for future studies of past and present Antarctic ice movements is both original and important. In collaboration with the late glaciologist, Ian Whillans, he developed a basic model for "meteorite stranding surfaces." These are envisioned as backwaters of ice flows around natural barriers where wind ablation (wind is a near constant presence in Antarctica) serves to build up the surface concentration of meteorites originally trapped in the volume of the incoming ice. He surmises that measurements of the distribution of terrestrial ages of meteorites on different stranding surfaces, coupled with careful glaciological measurements of current ice flow patterns and sub-surface topography, could give new information on the history of the ice flows. He also signals the potential importance of dust bands in the ice for providing "horizontal ice cores" which, if they could be properly dated, would add to our overall understanding. His ideas deserve to be further exploited.

The book treats grandiose phenomena such as the nature of the Antarctic ice sheet and the march of the ice from the polar plateau to the sea. But it is also a highly personal and intimate account. The reader will see clearly the thought patterns and passions that characterize the natural scientist.

I also trust that the reader will understand why other ANSMET veterans and I find Cassidy to be such a splendid expedition companion. His wonderful sense of humor breaks out repeatedly (and mostly unexpectedly) throughout the narrative. I cite just one example. In trying to understand why the meteorite concentrations were not discovered earlier he realizes the dog teams do very poorly on ice fields and such places were thus avoided. This leads him to speculate on equipping dogs with crampons – a thought quickly dismissed as he imagines the consequences of a crampon-equipped dog scratching its ear! I invite the reader to find and enjoy the many other examples sprinkled throughout the text.

Robert M. Walker
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Washington University
January 2003

# Acknowledgments

I hope, and intend, that this book will appeal to the intellectually curious general reader, as well as those who do research on meteorites and field work in Antarctica. In seeking to write such a book, I have prevailed upon the good natures of a number of friends and colleagues to read early drafts, criticize, and suggest. The following persons have done much to influence the final form of the book. I thank them all, very sincerely.

Bev Cassidy, for reading several chapters and making suggestions.
John Schutt, for reading several chapters for accuracy and detail.
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Leon Gleser, for critical reading of Chapter 9.
Lou Rancitelli, for critical reading and style suggestions on Chapter 9.
Kunihiko Nishiizumi, for age determinations, before publication.

Parts I and II of this book were reviewed by Roger Hewins and Part III was reviewed by Phil Bland. These were very constructive reviews, containing excellent suggestions. I followed many suggestions but declined others, for one reason or another. If the book is less than it could be because I have not accepted all these suggestions I accept full responsibility.

# Introduction

The Yamato Mountain Range wraps the ice sheet around its shoulders like an old man with a shawl. Ice coming from high off the ice plateau of East Antarctica, arriving from as far away as a subice ridge 600 km to the south, finds this mountain range is the first barrier to its flow. The ice has piled its substance up against the mountains in a titanic contest that pits billions of tons of advancing ice against immovable rock, whose roots extend at least to a depth of 30 km. The ice is moving because billions of tons of ice are behind it, pushing it off the continent and into the sea. Ultimately it yields, diverging to flow around the mountains. On the upstream side the rocks have been almost completely overwhelmed – only pink granite peaks protrude above the ice, which spills down between and around them in tremendous frozen streams and eddies, lobes, and deeply crevassed icefalls. The change in elevation of some 1100 m between the high plateau upstream of the mountains and the lower ice flowing away from the downstream slopes creates a spectacular view of this giant downward step in the ice surface. Almost constant howling winds from the interior blow streamers of ice crystals off the mountain peaks and "snow snakes" dance down the slopes in sinuous trains, as if somehow connected to each other. The scale of the scene is such that people become mere specks in an awesome, frigid emptiness.

In 1969, a group of Japanese glaciologists were specks in this scene. With all their supplies and equipment, they had traveled inland 400 km from Syowa Base, on the coast, to reach the Yamato Mountains (called the Queen Fabiola Mts. on most maps) and carry out measurements on the velocity of ice flow, rate of ablation and ice crystallography. Their safety depended on the reliable operation of two tracked vehicles in which they ate, slept and waited out the storms. These scientists were physically hardy and highly motivated. Because the Japanese supply ship could reach Syowa base only in the middle of summer, when parties had already left for the field, they had already wintered over at Syowa Base and would spend another winter there before being able to return to their families, just so they could spend the four months of antarctic summer at this desolate place, gathering fundamental data along the margin of a continental ice sheet. One of them, Renji Naruse, picked up a lone rock that was lying on the vast bare ice surface and recognized it as a meteorite.

In the preceding 200 years only about 2000 different meteorites had been recovered over the entire land surface of the earth, and finding a meteorite by chance must be counted as extremely improbable. It's lucky, therefore, that this initial discovery at the Yamato Mountains was made by a glaciologist, who would not be expected to have a quantitative understanding of exactly how rare meteorites really are, and of what a lucky find this should have been; Naruse and his companions proceeded to search for more. By day's end they had found eight more specimens in a $5 \times 10$ km area of ice – a tiny, tiny fraction of the earth's land surface.

Until that time, such a concentration always represented a meteorite that had broken apart while falling through the earth's atmosphere, scattering its fragments over a small area called a strewnfield. In such a case, all the fragments are identifiable as being of the same type. In this instance, however, all nine meteorites were identifiably different, and so were from different falls. A meteoriticist would strike his forehead with the palm of his hand, in disbelief.

Naruse and his companions undoubtedly were pleased with this unexpected addition to their field studies but there is no record that they immediately attached great significance to the find. They bundled up the specimens carefully, for return to Japan, and then resumed the ice studies that had drawn them to this spot. The ice at the Yamato Mountains, however, was destined for great fame, not for its glaciology but for the thousands of meteorites that would later be found on its surface. One might say that the Yamato Mountains icefields were *infested* with meteorites.

This book is about what some of us did about that discovery, how we did it, what we thought while we were doing it, and what the effects have been on planetary research.

# Part I **Setting the Stage**

Antarctica is the best place in the world to find meteorites, but it is also a singular place in many other ways. In Part I, while I outline the manner in which the Antarctic Search for Meteorites (ANSMET) project came into being, I also describe our field experiences as untested beginners, discovering the hardships and dangers of this special place in the world, as well as our slowly growing awareness and appreciation of its alien beauty. Antarctica is a *presence* in any scientific research conducted there, imposing its own rules upon what can and cannot be done, how things can be done, and what the cost is for doing those things. At the same time, it rewards the dedicated field person, not only in yielding scientific results not available anywhere else in the world, but with a headful of wonderful memories, startling in their clarity, of snow plumes swept horizontally off rocky peaks like chimney smoke in a strong wind; of poking a hole through a snowbridge and marveling at the clusters of platy six-sided ice crystals that have grown in the special environment of a crevasse below the fragile protection of a few centimeters of snow; of emerging from one's tent after a six-day storm to find the delicate snow structures randomly sculpted by a wind which, while it was churning furiously through camp, seemed to have no shred of decency about it, much less any hint of an artistic impulse; of returning late one evening after a 12-hour traverse to a campsite occupied earlier in the season, when the sun makes a low angle to the horizon and we camp beneath a tremendous tidal wave of ice with its downsun side in shadow and displaying every imaginable shade of blue, and, having been there before, learning again the pleasant feeling of having come home.

# 1 Antarctica and the National Science Foundation

## THE CONTINENT

Antarctica occupies about 9% of the earth's total land surface. For this to be true, of course, you must accept snow and ice as "land surface," because this is what mainly constitutes that part of the continent that lies above sea level. Think of the antarctic continent as a vast convex lens of ice with a thin veneer of snow. In contrast to the region around the north pole, which is just floating ice at the surface of the ocean, the antarctic ice lens rests on solid rock. In most places the ice is so thick, and weighs so much, that it has depressed the underlying rock to about sea level. If the ice melted completely, the surface of the continent would rebound over a long period of time until its average elevation would be higher than any other continent. As it is, the ice surface itself gives Antarctica a higher average elevation than any other continent.

It is only in a very few places, where mountains defy the ice cover, that we can directly sample the underlying rocks. Most of these places are near the coast, where the ice sheet thins. At the center of the continent the elevation is about 4000 m. At the south geographic pole, which is not at the center of the continent, the elevation is 3000 m.

This ice ocean is both vast and deep. Except near the coast, total precipitation averages less than 15 cm of water-equivalent per year, so Antarctica is by definition a desert. It has accumulated such a great thickness of ice by virtue of the fact that whatever snow does fall, doesn't melt. Antarctic ice comprises about 80% of all the fresh water on the earth's surface. This great mass of ice is not contained at its margins, so as it presses downward it ponderously moves outward, creeping away from its central heights toward the edges, thinning and losing altitude as it spreads out, but partly replenished along its way by sparse precipitation.

We have marked the southernmost point on earth with a pole surmounted by a silvered sphere, of the type sometimes seen on well kept lawns or in formal gardens. But ice is moving past the geographic south pole at a rate of 10 m per year, so every few years we must get the pole and bring it back to its proper location. The problem is less tractable for South Pole Station itself. It slowly drifts away with the ice and at the same time sinks ever deeper as the yearly snowfalls impose their will. As a result, we have a string of several buried former South Pole Stations marking the particular flow line that passes through the south pole. They are accessible for a while, but as they go deeper below the surface they are ultimately crushed flat, or invaded and filled by ice.

Field conditions in Antarctica are extreme; more so the closer one approaches the south pole. The areas where we work are typically at 2000 m elevation. In these areas and at the times of year during which we are in the field we expect temperatures ranging between −10 and −25 °C. In still air, with proper clothing and a high-calorie diet, these temperatures are quite tolerable. In moving air they are less so.

We are in Antarctica during the relatively more balmy months of the austral summer: November, December, and January. This is also a time of continuous daylight: suppose when you emerge from your tent in the morning, the sun is shining directly on the entrance. It will be at an elevation in the sky that I would read as around 10 a.m., if I were home in Pennsylvania. During the following 24 hours, due to the rotation of the earth, the sun will appear to make a complete circle of the tent, but will always give the impression that the time of day is around 10 a.m. Actually, at "night" it will appear to be around 9 a.m., changing its angle of elevation a little because we are not exactly at the south pole. But it never sets during the summer season. Knowing this does not mean that we immediately adjust to this new set of conditions. Many times we leave our camp when the atmosphere is hazy, and I find myself thinking, "Well, this fog will burn off as soon as the sun comes up." And the sun has been up for two months!

In the past, territorial claims have been made in Antarctica by Argentina, Australia, Chile, France, New Zealand, Norway and the United Kingdom. Because of sometimes overlapping claims, about 110% of Antarctica was divided up, in pie-shaped areas that converged to points at the south pole. The exception to this was Norway, whose claim stopped at 85° S and looked like a piece of pie that someone had begun to eat. Of the seven countries claiming territory, only Norway stopped short of the south pole, and she seemingly had more right than anyone else to claim it because the Norwegian explorer Roald Amundsen had been the first to reach the south pole.

In an effort to reduce tensions over the expressions of nationalism represented by territorial claims, the claiming nations were persuaded to set aside their aspirations temporarily and, with six other nations, to sign an international accord: the Antarctic Treaty. This treaty has by now been acceded to by 45 nations, and 27 of these are conducting active research programs there. The treaty provides for unhindered access to any part of Antarctica by any signatory nation for scientific purposes. The United States (US) is a signatory nation but makes no territorial claim. We have a large and continuing scientific effort in Antarctica that is supervised by the National Science Foundation (NSF).

## MCMURDO STATION

The US has permanent year-round research bases on Ross Island (*McMurdo Station*), at the South Pole (*Amundsen–Scott South Pole Station*), and on the Antarctic Peninsula (*Palmer Station*) (see map, Fig. 1.1). By far the largest of these is McMurdo. At 77° 30′ S, it is admirably sited for scientific work, being as far south as is practical for late-summer access by small ocean-going vessels aided by an ice-breaker, so that yearly resupply missions can be relied upon. It is at the land–sea interface, where the specialized fauna of Antarctica are concentrated and are most accessible for study. It is on a volcanic

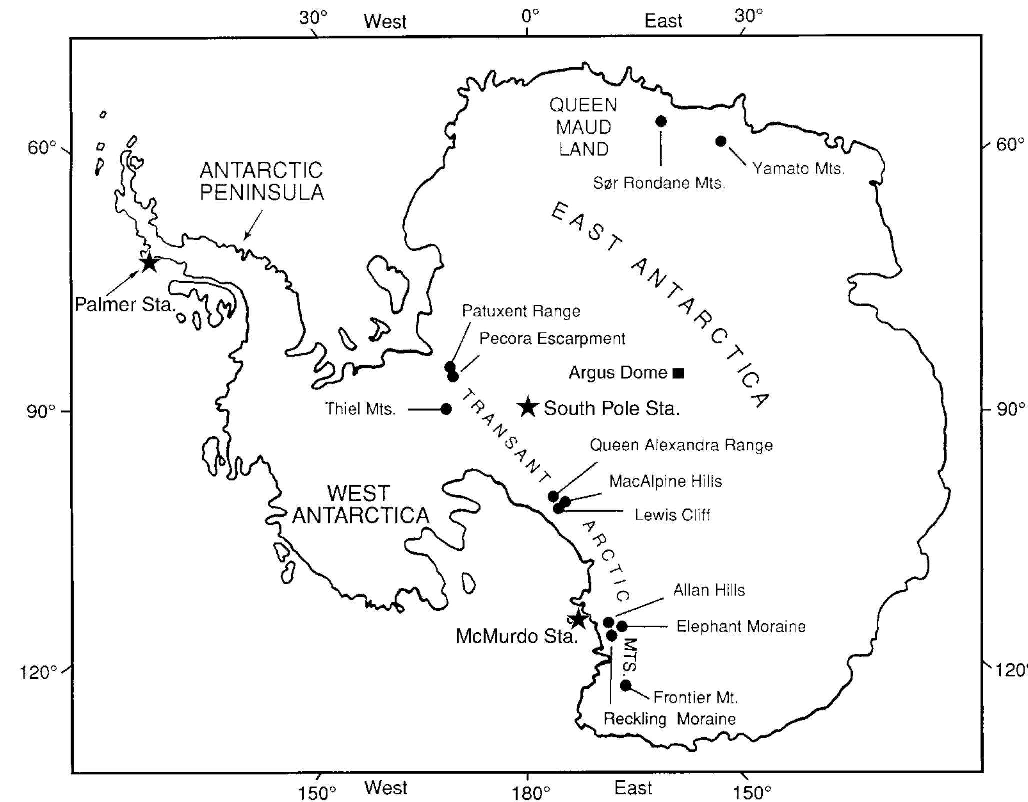


FIGURE 1.1 Map of Antarctica, showing the United States research stations (indicated by stars), the Transantarctic Mountains and some of the major meteorite concentration sites (indicated by filled circles).

island, with an active volcano whose lava lake and associated igneous rocks are of great interest to volcanologists. It is close to that part of the Transantarctic Mountain Range where the Dry Valleys are located. McMurdo has commodious laboratory facilities, extensive computer capability, and good communications with the outside world.

Many scientists operate out of McMurdo directly to nearby research locations. Cold adaptations and the metabolic effects of low temperatures on a wide variety of organisms, from penguins and seals, to fish, krill and bottom-dwellers that will not freeze when their body temperatures reach 0 °C, to the plankton on which they all depend, can be studied from nearby sea ice or with short trips along the shore. The Dry Valleys, only 60 km away, have a poorly understood microclimate that keeps them snow-free all year. The biology and geochemistry of meltwater lakes in the Dry Valleys also are not completely understood. Rocks are exposed in the Dry Valleys, and the geologist can study them there, unhindered by mantling ice. Fascinating adaptive responses to extreme conditions are displayed by endolithic organisms found along the very edges of the ice sheet. These are algae and fungi, living in symbiosis below the rock surfaces in a very special microenvironment beneath transparent minerals. They are able to spring to life almost instantaneously when the greenhouse effect of the overlying transparent mineral grains enhances the heat of a low, weak sun and when, simultaneously, liquid water becomes available. They can sink into dormancy just as rapidly when conditions change.

McMurdo-centered science also includes satellite-coupled meteorology, upper-atmosphere research and ozone-hole observations.

For those scientists needing access to more distant research sites, McMurdo has the capability to construct and support temporary remote stations for periods of years at sites where there is common interest from groups of scientists who wish to carry out a variety of research projects with greater than a one-year duration. For smaller operations, individual field parties can be put in to deep-field camps for periods of weeks, over a large part of the continent. McMurdo

Station is only three hours flying time away from the south pole, so it can support that very remote facility by air.

### AMUNDSEN–SCOTT SOUTH POLE STATION

Research carried out at the geographic south pole, at an elevation of 3000 m in an exceptionally dry atmosphere includes meteorology, seismology as part of a global network of seismological stations, climatology with studies of snowmass accumulation trends and atmospheric trace constituents and aerosols, upper atmosphere studies, magnetosphere observations, cosmic-ray studies and, during the darkness of the austral winter, astronomical observations over significant fractions of the electromagnetic spectrum. A recent development is the use of the 3-km thick ice sheet as a highly transparent medium within which to observe, count and categorize the tiny flashes of Cherenkov radiation produced by neutrinos that have *passed through the earth*.

On a more mundane level, but more closely related to my interests, South Pole Station has become a collecting site for ancient cosmic dust particles.

### PALMER STATION

Palmer Station is located on the Antarctic Peninsula, just north of the antarctic circle, and has subantarctic floral and faunal assemblages. Like McMurdo, it is located at the land–sea interface and much of the research carried out there involves marine ecosystems. This can be done in combination with research vessels, which find it much easier to visit Palmer than McMurdo. Tourist vessels also can reach Palmer, however, and there are ongoing programs to assess ecological damage due to tourism. Palmer has a seismic station as part of the global network, there is air sampling for trace gases and aerosols, and a range of upper atmosphere studies, including ozone-hole measurements linked to effects on marine microorganisms.

Palmer Station is run in complete separation from the much larger McMurdo–South Pole complex. Visitors to Antarctica via

McMurdo and South Pole Stations arrive mainly by air from New Zealand, while those arriving at Palmer have come by ship from South America.

## LOGISTICS

In most NSF-supported, *non-polar* research, grants are made to the home institution of the grantee and, if logistics arrangements are necessary, funds are included in the grant for field vehicles and field equipment. For *non-polar* research, the grantee typically makes all his or her own arrangements. Because antarctic research can be quite dangerous, and because just getting to many remote sites is very expensive, the NSF's Office of Polar Programs is intimately involved in every aspect of the field work carried out on the continent, and runs an extensive operation that involves air transportation within Antarctica, the operation of research vessels around the coast, support of major research stations, supplying equipment, food, and clothing to scientific investigators and support of smaller-scale logistics needs such as snowmobiles and sledges for moving remote field camps. In 1976, which was the first year of my experience in Antarctica, US Navy personnel had a prominent role in the logistics operations, piloting and maintaining a fleet of six ski-equipped LC-130 Lockheed Hercules cargo planes and six Vietnam-era UH1N "Huey" helicopters. These helicopters ("helos") have an effective operating range of 185 km and the LC-130s can reach any point on the continent, if need be. Ski-equipped Twin Otters have been phased in in recent years to help bridge the gap between cargo-carrying capacities and ranges of the helos and LC-130s. Twin Otters are operated by Canadian bush pilots.

With shrinking military budgets, the Navy has been phasing out its participation in the antarctic enterprise. The 1995–96 austral summer saw the last of the Navy helos – they have been replaced by civilian contractor helos and pilots. Since the 1996–97 season, the Navy LC-130s and their pilots have been replaced by LC-130s and pilots of the New York State National Guard. At the same time, a civilian contractor ran many functions of the permanent US bases, and the Division of Polar Programs[1] oversaw the entire operation, with offices at McMurdo Station. So being funded for antarctic field work is not like any other geological field work, where you are on your own. In McMurdo, you become part of a rigid structure with a complicated hierarchy of procedures, requirements and rules. In this system you may not know immediately the best direction from which to approach a problem. It is always a great relief to escape this atmosphere to a deep-field camp on the ice plateau of East Antarctica, where survival may be more difficult but life is simpler.

A US-run deep-field camp in Antarctica is an interesting mixture of modern technology and a retreat to the past. We live in Scott tents, so named because they are designed after the tents that Robert Falcon Scott used in his polar expeditions early in the twentieth century. We do travel by snowmobile, which is more convenient than man-hauling sledges, as Scott did disastrously, or using dog teams as Amundsen did very successfully. We tow all our equipment, tents, food and fuel on Nansen sledges, designed in the nineteenth century after sledges used by eskimos. Modern touches, however, are appearing. A great convenience for mapping has been the introduction of Global Positioning System (GPS) instruments that can tell you where you are within a few meters on the earth's surface by triangulation, using signals generated by satellites. Lap-top computers are appearing in tents, and batteries are maintained in a fully charged condition by solar panels.

## IF YOU WANT TO GO THERE

According to the Antarctic Treaty, the continent is reserved for scientific research, so to go there you should be a scientist or a science support person. Minor exceptions can be Members of Congress, selected

[1] The Division of Polar Programs, in 1994 became the administratively more important OPP, or Office of Polar Programs, in recognition of the increasing importance of Antarctica as a research site.

persons in the arts, selected newspersons, the occasional boy scout or girl scout and, on certain anniversary celebrations, OAEs (Old Antarctic Explorers). There are a lot of OAEs around. For the most part, they seem to cling to life with tenacity and zest.

Suppose you plan to go to Antarctica, as I did. At least six months before departure I had to have a complete medical and dental checkup. The NSF does not want personnel going to very remote sites, or even to McMurdo Station, with medical or dental problems that might require an emergency evacuation. The dental examination also has a grimmer aspect that is discussed among the grantees but very seldom by the grantor – dental records are a last resort for identification of very badly damaged corpses.

All personnel who expect to winter over also must have a psychiatric examination. This is supposed to screen out all those who are certifiably insane, but sometimes does not. There are those, of course, who claim that you have to be insane anyway to want to winter over. Now that I think of it, there are those who claim you have to be insane to want to go to Antarctica at all. Actually, the great majority of people can be divided into two groups of unequal size – a large group who would rather die than go to Antarctica, and a smaller cohort who would kill to get there.

In 1976, when I first started going to Antarctica, the results of the physical exams were forwarded to the ranking US Navy doctor who was to be in charge of the medical service at McMurdo Station. He had the right of final approval of your visit. When the Navy doctor found me to be fit, I knew I had an excellent chance of actually making the trip.

# 2 How the project began

## ANTARCTICA AS A PLACE TO SEARCH FOR METEORITES? YOU MUST BE KIDDING!

The concept followed no evolutionary path. It was suddenly there, as bright as the comic-strip light bulb that signifies a new idea: *meteorites are concentrated on the ice in Antarctica!* The occasion was the thirty-sixth annual meeting of the Meteoritical Society, which took place during the last week of August 1973 in Davos, Switzerland. I was listening to a paper by Makoto and Masako Shima, a Japanese husband and wife team who are both chemists. He was describing their analyses of some stony meteorites. These specimens were interesting to me because they had been recovered in Antarctica. The pre-meeting abstract of the paper mentioned four meteorites that had been found within a 5 × 10 km area, lying on the ice at the Yamato Mountains (see Figure 1.1). I was quite aware of how rare meteorites really are, and as far as I knew, when meteorites are found near each other, as these had been, they are invariably fragments of a single fall. This was my assumption in the present case, and I had attended this presentation because of a long-standing, general interest in Antarctica, rather than a specific interest in the meteorites to be described. Actually, the abstract made it clear that these specimens were of distinctly different types, but I had been skimming and had not read that far. The key word, so far as I was concerned, had been *Antarctica*.

It took some time to get used to Dr. Shima's accent, and it was about halfway into the talk before I suddenly realized that he was describing meteorites of four different types, and these could not have come from anything but four separate falls. That is when the light bulb went on over my head, and I thought, "Meteorites are concentrated on the ice in Antarctica!" I suddenly started paying very close attention. Repeating it over and over to myself, however, was not encouraging because I could think of no mechanism that would concentrate meteorites, much less one that would be unique to Antarctica. These insights would come only slowly, and much later. Clearly, also, I cannot claim to be the first to realize that meteorites must be concentrated somehow on the ice. Yoshida and colleagues in a 1971 paper that included as a coauthor Renji Naruse, the discoverer of the first Yamato Mountains meteorite, had already recognized the fact and they were wrestling with possible causes of the concentration process. Their general suggestion was that the meteorite concentration was related somehow to the movement and structure of the ice, and also that other such concentrations might be found. But I had not yet seen this paper.

After his talk at Davos, I spoke to Dr. Shima and he mentioned that the glaciologists had actually found *nine* meteorites in this small area, and superficial examination suggested that they were all different. So there *must* be some kind of concentration mechanism. Half an hour later, I started mentally writing a research proposal to visit Antarctica and search for concentrations of meteorites. The hypothesis was that the site where the Japanese scientists had found a concentration – the Yamato Mountains – could not be unique in a continent that occupied 9% of the total land surface of the earth. Others, however, were not so sure, and the eventual proposal, when submitted to the National Science Foundation's (NSF) Division of Polar Programs, was politely declined. It is easy to see why the reviewers were unimpressed, because aside from the apparently anomalous concentration of nine meteorites at the Yamato Mountains, only four other specimens had ever been found in all of Antarctica.

## SOME HISTORY

The first antarctic meteorite ever found was a 1 kg L5 chondrite discovered during Douglas Mawson's Australian Antarctic Expedition in 1911–14. The distinction of finding this specimen belongs to an unnamed member of an exploration party led by Mr. F.H. Bickerton, whose mission was to explore and map westward from Mawson's base at Cape Denison, in Commonwealth Bay on the Adelie Land coast. On their fourth day out, and only 43 km into their traverse, the three-man party found a meteorite, which they assumed was a fresh fall. The Adelie Land meteorite can be seen today at the South Australian Museum, in Adelaide.

Meteorites 2–4 were found subsequently at widely separated points in Antarctica: the second one, an iron meteorite, was found almost 50 years after Adelie Land in 1961 on a southern spur of the Humboldt Mountains by Russian geologists mapping near their base, Novolazarevskaya; Antarctica's third, a pallasitic stony iron in two pieces, was picked up in 1961 on ice in a moraine below Mt. Wrather in the Thiel Mountains by geologists of the United States (US) Geological Survey; and the fourth, an iron, was discovered in 1964 in the Neptune Mountains by geologists of the U.S. Geological Survey. At first glance, there was nothing to recommend the antarctic continent as a place where one could find great numbers of meteorites, since so few had been found.

With hindsight, of course, the following hints suggested the great potential of Antarctica as a meteorite recovery ground: (1) only a very small number of people had ever visited Antarctica, yet four of these had found meteorites; (2) only a very small total of the surface area of Antarctica had been examined on foot, yet this area contained four meteorites; and (3) one of the four meteorites, the pallasite, was of an extremely rare type, suggesting that many more, of the more common classes, should be recoverable. Singly, these hints are straws in the wind, but taken together they are somewhat suggestive. This perception is quite clear only now, but it received thunderous confirmation in events beginning in 1969 with the Japanese discovery of nine meteorites at the Yamato Mountains, and these events continue today. During only 20 years, the meteorites collected from perhaps 4000 km$^2$ of ice in Antarctica have doubled or tripled the number of individual specimens that had been accumulated in the world's museums over the preceding 200 years, collected from over 90% of the earth's land surface. Nonetheless, in 1974 we did not foresee what a magnificent place to collect meteorites the antarctic ice sheet really was, and the evolution of this idea and its implementation took a tortuous path.

## THE JAPANESE CONNECTION

In 1973, Professor Takesi Nagata had been since 1961 a Visiting Professor at the University of Pittsburgh in our Department of Geology and Planetary Science. Typically, he would be present once or twice a year for periods of two to four weeks at a time, doing collaborative research with Mike Fuller and Vic Schmidt, who were professors in our department. Nagata was also the director of the Japanese National Institute for Polar Research. He always claimed that his time in Japan was completely occupied in administration, and the only times in which he could do any research were those short periods that he could spend with us, in the relaxed atmosphere of our department. In Japan, Dr. Nagata was always addressed in terms of the deepest respect, as Nagata-*san*. He encouraged us, however, to call him "Tak," more in line, I guess, with the American style.

During the fall of 1973, Tak came for a visit and I took advantage of the occasion to mention the remarkable meteorite concentration his people had found on the ice in Antarctica. Apparently nobody had told him about it. Here was a scientist who had been designated by the Emperor as a National Living Intellectual Treasure (this is no joke). I told him what I knew, and a little light immediately came on over his head, except that his was more appropriately a Japanese lantern (this is a joke). His thought was, "Meteorites must be concentrated on the ice in Antarctica!" My thought exactly, and arrived at with about the same speed – we had had a meeting of minds. We agreed on the fundamental importance of this concept, and I drew strength from the fact that one of us was a National Living Intellectual Treasure and also one of the few non-US members of the US National Academy of Sciences. He turned away to send a few quick telegrams back home asking for full details on the discovery and, after a few replies, sent a telegram to his field team in Antarctica, which was even then preparing for another visit to the Yamato Mountains, instructing them to search for meteorites. I returned to writing the unsuccessful proposal I mentioned above, to search for meteorites out of McMurdo Station, on the other side of the continent from Syowa Base.

We agreed to keep in touch on the matter, and so I learned eventually that his field team, pretty much in their spare time, had collected 12 more specimens during the December 1973 to January 1974 field season and, remarkably, these were all recovered at about the same place as the 1969 finds. Encouraged by this, I resubmitted my proposal with this new information. That season, during December 1974 and January 1975, the Japanese field team made an all-out effort and recovered a stunning 663 meteorite specimens at the Yamato Mountains!

At that time, Dr. Mort Turner was Program Manager for Geology at the former Division of Polar Programs (now known as Office of Polar Programs), and I had gotten to know him in the course of events involved in my unsuccessful research proposal. In an agony of frustration, I called him up and gave him the latest news. After only a moment, he said in a thoughtful tone of voice, "Well, the panel has just declined your proposal again, but they did not have this information. I urge you to resubmit it immediately, and I think it will be funded." And that is the way it turned out: we were funded for the 1976–77 summer field season, on the third try. The project would become known as the Antarctic Search for Meteorites, or ANSMET. The Japanese, meanwhile, recovered 307 more specimens during the 1975–76 austral summer.

When Tak next came to visit, I hastened to tell him that my proposal had finally been accepted, and that I expected to go to the ice in the 1976–77 season. He congratulated me, and then shocked me with, "Bill, I am planning to send a man to McMurdo that season also, to search for meteorites." I learned then that the Japanese Antarctic Research Expedition (JARE) apparently had had a cooperative arrangement with the US program for a number of years, and that Tak was sending his man as part of that agreement. I didn't know how to deal with this news, because my supposition had been that the Japanese would continue their very successful meteorite-collecting activities at Yamato Mountains, where they had searched only a small fraction of the icefields. Instead, they planned to suspend that operation for a while. Suddenly, I had a disturbing mental picture of field teams from two different countries competing for logistics support, competing to be the first to find meteorites in this place across the continent from the Japanese site, and competing to collect more meteorites than the other group. I waited to see if Tak would suggest some kind of arrangement to mitigate the seemingly destructive aspects of what he was planning, but he did not. I was too stunned to think creatively, so in deep confusion I let the moment pass. As succeeding months became busier, I was able partially to ignore this situation.

### STARTING FROM SCRATCH

When I was planning our first field season, I had no clue about how the system operated, and I badly needed expert advice. I knew there was a dynamic group of polar scientists at The Ohio State University in Columbus, and I got the name of David Elliot, who was part of that group and at the time was also Chairman of the Department of Geological Sciences. I cold-called him, introduced myself, explained my situation, and he invited me over for a chat. David is a remarkably gracious person, and gave no hint of how I must have been disrupting his busy schedule. During the major part of one day, he explained exactly how the system works, what clothing and equipment I might wish to take along to supplement what would be issued, what materials I would not need to take, what the danger signs were in the field in a changeable weather situation, and something of the geology along the Transantarctic Mountains. This was my first introduction to anyone involved in polar research, and it was a very happy one. I later learned that these characteristics of friendliness and helpfulness are almost universal among principal investigators