to 15 2θ values established the unit cell dimensions as $a = 9.934(3)$, $b = 21.581(8)$, and $c = 8.674(2)$ Å. Integrated intensities were measured on an Enraf-Nonius CAD-4 diffractometer (Mo$K\alpha$ radiation, $\lambda = 0.71069$ Å; $2\theta_{max} = 54.90°$) for 2424 reflections, of which 1614 were significantly (2 standard deviations) above background. The structure was solved by a multisolution approach (*6*) and refined by least squares using a free-blocking approximation to the full matrix (*7*).

Initial atomic positions were found for all but one of the expected nonhydrogen atoms from an electron density map, with the remaining atom [the hydroxyl oxygen O(15)] being located from a difference electron density map. Refinement with anisotropic thermal parameters converged to an agreement residual $R = 0.149$. Two large peaks in the difference map corresponded to possible alternate positions for atoms C(22) and O(22) of the oxazolidine ring. A difference map, calculated under the assumption that these were correct, showed maxima at the original coordinates. Consequently, the four atoms were treated as half-occupied sites in subsequent refinement.

All but three of the hydrogen atoms were located from successive difference electron density maps; the missing atoms were expected to be disordered. Additional refinement converged at $R = 0.056$, with a weighted agreement residual $R_W = 0.066$ (*8*). In the last cycles, the site occupancy was allowed to vary for the disordered atoms and converged to values consistent with the predominance of one epimer by about a 60:40 ratio. This ratio is not only significantly different from random (50:50) disorder, based on the estimated standard deviations of the site occupancies, but also in agreement with the approximate 2:1 ratio found by integrating the doubled NMR peaks (*3, 5*). Although this work does not establish the absolute configuration of veatchine, the latter has been correlated with atisine (*9*), for which the absolute configuration has been established by x-rays (*10*). By analogy, the absolute configuration of veatchine is 4*S*, 5*S*, 8*R*, 10*R*, 13*R*, 15*R*, and 20*SR*, with the 20*S* epimer predominating.

Crystallization of two epimers in a disordered relationship is, as far as we can establish, a highly unusual observation (*11*). Such a manner of crystallization requires that both epimers exist in the solution and that their respective heats of crystallization be approximately the same. Furthermore, it seems unlikely that interconversion of the epimers occurs rapidly, since this would favor the growth of crystals which contain only a single epimer. In aprotic solvents, such interconversions may not occur at all. The only reasonable intermediate for such an epimerization is the normal form of the ternary iminium ion (II), the formation of which is favored in protic solvents. Kinetic studies of the isomerization of atisine clearly demonstrated the stability at room temperature of the iso- (III) over the normal-form of the iminium ion, but no information is available concerning the relationship of the rate constant for the ionization step (k_1) to that for the isomerization step (k_2). The fact that crystallization can occur more rapidly than epimerization suggests that in polar, aprotic solvents, the ionization step is sufficiently disfavored that it becomes rate-limiting. The reclosure of the oxazolidine ring (with the possibility of epimerization) thus becomes the preferred route to isomerization.

Even though veatchine (and, presumably, other similar diterpenoid alkaloids such as atisine, garryfoline, and cuachichicine) exists as a mixture of epimers, separation of the two molecules would be extremely difficult, if not impossible.

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Antarctica: A Deep-Freeze Storehouse for Meteorites

Abstract. *Meteorites that fall on the Antarctic ice cap are preserved for long periods of time under very clean conditions as they are carried toward the continental margin. If the host ice encounters a barrier it cannot flow over or around, it tends to dissipate by ablation, leaving an accumulation of meteorites on the surface.*

We have recovered 11 new meteorites in Antarctica during the period 15 December 1976 to 20 January 1977. At first glance, Antarctica would seem a poor place to search for meteorites. The vast, snow-covered Antarctic ice sheet moves radially outward, losing altitude and reaching zones having higher average temperatures as it approaches the edges of the continent. Cold, dense air spilling down over the surface also moves radially outward, creating winds that can attain hurricane force near the fringes of the ice sheet. Such winds can strip the ice bare of snow and promote local evaporation of the exposed ice surface. Blue ice patches appear and receive a rippled surface texture as evidence of working by the wind.

Wherever the ice sheet becomes thin enough, or the rocky surface of the continent rises high enough, mountains protrude through the ice. The vast Transantarctic Mountain Range, for example, is prominent above the ice in many places. The interface between the ice mass, which is moving slowly but inexorably off the polar plateau, and these mountains is a region where the ice sheet splits into ice streams that drop sharply in elevation over highly crevassed icefalls, then funnel into valley glaciers and pass through the mountains. On the plateau side, mountain peaks and ridges extend outward into the approaching ice until they are engulfed by it. Such ridges, evidence of buried mountains, are called nunataks. It is in this interface zone of buried mountains, glaciers, icefalls, and high winds that bare blue ice patches occur. We found meteorites scattered about on some of these blue ice patches.

It is interesting that meteorites cannot be found on all areas of blue ice. Antarctic valley glaciers, for example, commonly consist of blue ice with no snow cover and we have not found meteorites on their surfaces. While this may be explained in some cases by the prevalence of terrestrial rocks, whose presence would make it difficult to visually identify the much rarer meteorites, it cannot be explained in other cases, where the glacier surface is practically devoid of rocks. We also searched many blue ice areas that could be thought of as "headwaters" of glaciers. These are accumulations of ice converging toward the head of a glacier before streaming down through the glacial valley. Such ice masses have a negligible burden of terrestrial rock on their surfaces and yet do not seem to bear meteorites.

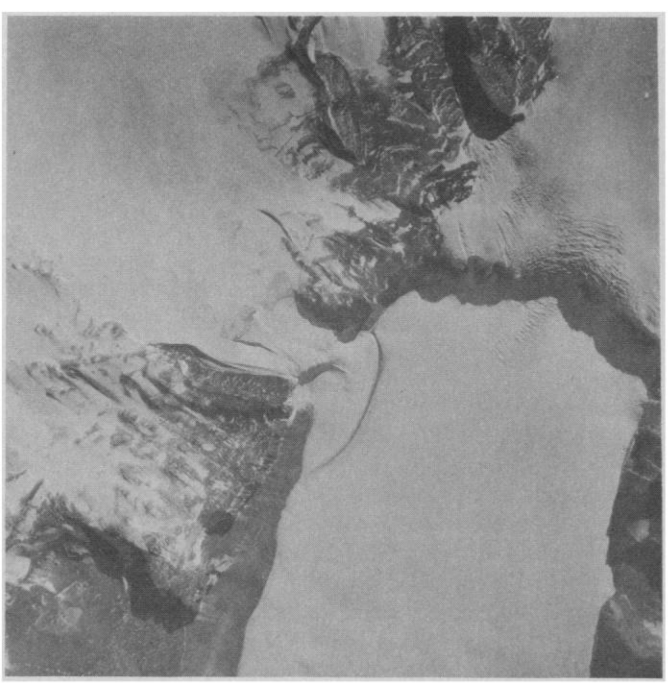
The two areas in which we did recover meteorites have somewhat the appearance of stagnant zones in an otherwise dynamic system. A 4 by 2 km patch of blue ice adjacent to Mount Baldr (Fig. 1), for example, had two chondrites lying on its surface about 700 m apart. This ice surface occupied a hanging valley above Wright Upper Glacier and fed down onto it over a rocky cliff by periodic icefalls. The main source of ice supplying Wright Upper Glacier, however, comes over the Airdevronsix Icefall nearby. That this is the main source is indicated by the shape of a medial moraine between ice streams from the two sources. This moraine actually truncates the ice stream originating on the Mount Baldr glacier. In relative terms, therefore, the Mount Baldr glacier is inactive, or stagnant.

The other site at which we found meteorites is a larger patch of blue ice located on the plateau side of Allan Hills (Fig. 2). This blue ice area has about 100 km² of surface exposure and can be considered part of the continental ice sheet proper. It appears to have encountered a barrier in Allan Hills and probably is also relatively stagnant.

A distinguishing feature of both these areas of blue ice is the complete absence over most of their surfaces of moraine deposits. This makes meteorites easy to find, and while at first we laboriously searched many blue ice areas on foot, we later found it was much more efficient to search by slowly taxiing over the ice in a helicopter at a height of 6 to 9 m. From this elevation even a meteorite only 8 cm long (Allan Hills No. 4) was easily seen on the ice. We also noted that in areas close to rock outcrops, where talus fragments had carried out onto the adjacent ice, we were able to see rock chips as small as 2 cm across while flying over them. We feel, therefore, that we are not missing the smaller meteorites by this search method.

The meteorites we recovered range in size from an individual weighing 305 g to a group of fragments totaling 408 kg; the latter is therefore the largest meteorite on record from Antarctica. These are not all fragments of a single shower: of the 11 individuals discovered, one is an iron (Fig. 3a), one is an achondrite (Fig. 3b), and the rest are chondrites. Nine appear to be discrete individuals, but one was found in three pieces that fit together along fracture surfaces without fusion crust (Fig. 3c), and the 408-kg specimen mentioned above apparently broke on impact or at some later time into at least 33 fragments ranging up to 114 kg in weight. These were found scattered over an area of approximately 4500 m². Table 1 gives preliminary data on the specimens recovered.

Earlier meteorite discoveries. Ours are not the first meteorites found in Antarctica, but before 1969 only four meteorites had been discovered on the entire continent (*1*); this seems to be an unusually small number when one considers the large area involved. Considering the almost 100 percent snow cover, difficulties



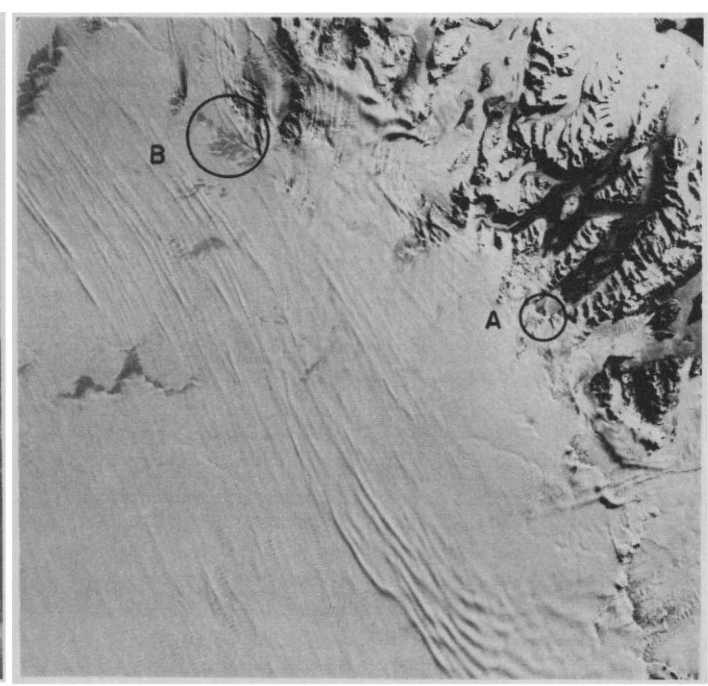


Fig. 1 (left). Patchy area of blue ice in the upper left corner was the site where two meteorites (Mount Baldr Nos. 1 and 2) were found. The ice appears darker gray than the snow. Note that the flow from this source onto Wright Upper Glacier at the lower right is completely truncated by a medial moraine. This occurs because a much higher volume of ice is moving down over the Airdevronsix Icefall at the upper right. The source at the upper left is therefore relatively stagnant. The bottom of the photograph spans 6.6 km. Fig. 2 (right). Satellite photograph showing the areas where we found meteorites. Except for the small triangular area at the upper right, which is water, the darkest areas are rock and soil. The snow appears light gray and the blue ice patches medium gray. This photograph was made in band VII (infrared). The circled area marked *A* includes Mount Baldr. Area *B* encloses the approximately 100-km² patch of blue ice at Allan Hills. The bottom of the photograph spans 120 km.

of access, and extremely low surface density of human observers, however, it might be argued that four was, in reality, a very large number.

Our work was initiated as a result of the accidental discovery in 1969 of a dense concentration of meteorites on blue ice adjacent to the Yamato Mountains (*2*) by the Enderby Land traverse team of the tenth Japanese Antarctic Research Expedition (JARE), whose work changed the statistics on meteorite recoveries in Antarctica. The JARE group was approaching the Yamato Mountains, about 300 km southwest of Syowa station (Fig. 4), and were extending a triangulation chain when they found a meteorite lying on the ice. Examining the immediate area for additional specimens, they found eight more. During succeeding field seasons, they have collected meteorites in the vicinity of the Yamato Mountains as part of the overall field program of the Japan National Institute of Polar Research, finding 12 in field season 1973 to 1974 (*3*), 663 in 1974 to 1975 (*4*), and 307 in 1975 to 1976 (*5*). Yamato Mountains is the place name used to designate this collection.

The total area of blue ice exposed at the Yamato Mountains is of the order of 4000 km^2, and much of it remains to be searched. The current total number of meteorites found there is 991 and is believed to represent about 300 individual meteorites—about a 3 : 1 ratio of fragments to individual meteorites. Of these, only two are irons and one is a pallasite, quite a different proportion from that determined in observed meteorite falls—8 percent irons and pallasites to 92 percent stones (*6*).

The largest Yamato meteorite weighs 11.3 kg and the total weight of meteorites recovered there is nearly 100 kg. These figures reflect a real difference between Yamato Mountains and the sites at which we have collected: meteorite specimens appear to be much more abundant at Yamato Mountains but much smaller. The average mass of the Yamato meteorites is 100 g; the average mass of our finds, excluding the extraordinary 408-kg meteorite, is 5000 g.

It is possible that many of the Yamato Mountains specimens represent individuals from one or more showers. A shower is generated when a meteorite enters the upper atmosphere and breaks into fragments, each of which usually develops a fusion crust over its entire surface. These pieces then shower down within a relatively limited area. A significant number of shower meteorites are known—examples of which are Pultusk (Poland), Nakhla (Egypt), and Forest City (Iowa) (*7*). In Antarctica a shower raining down onto the ice cap, moved by the ice, and later mixed with other meteorites and perhaps with other showers would not be easily recognized as a single shower (that is, as having a single parent meteorite) and an individual could easily be thought to represent a separate fall. Individuals from known showers sometimes suffer further breakage into fragments on impact with the ground. This is easily recognized, however, because the new breaks will have no fusion crust on the fractured surfaces (for example, Allan Hills Nos. 3 and 9).

It is conceivable that the high surface

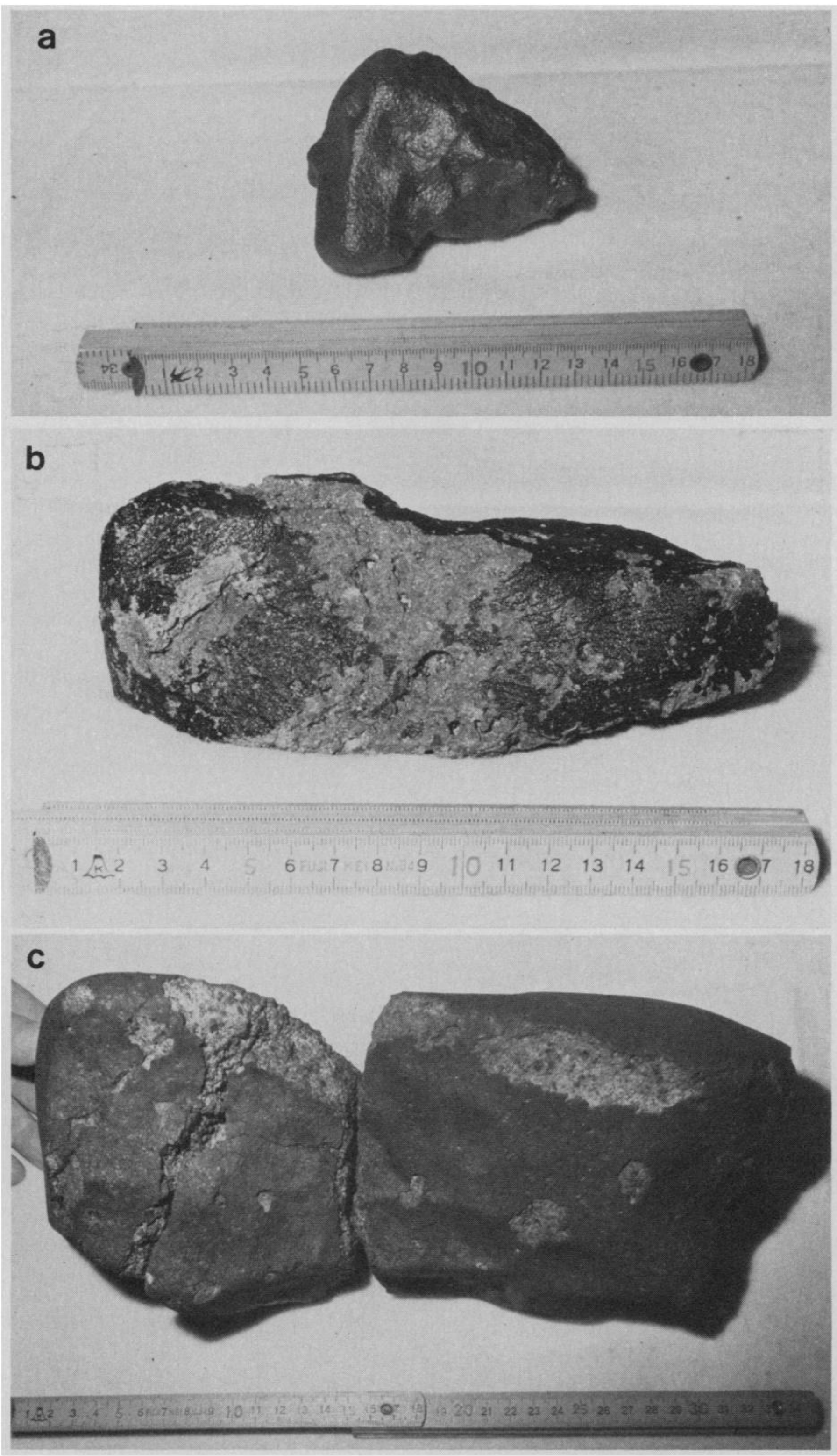


Fig. 3. Antarctic meteorites: (a) iron (Allan Hills No. 2), (b) achondrite (Allan Hills No. 5), and (c) chondrite (Allan Hills No. 3), which was found in three pieces at about 10-m intervals along a straight line. The scales are in centimeters.

Table 1. Initial data on meteorites found during the 1976–1977 field season.

Field collection number	Type	Weight (g)	Latitude	Longitude
Mount Baldr No. 1	Chondrite	4,108	77°35′2″S	160°19′35″E
Mount Baldr No. 2	Chondrite	13,782	77°35′2″S	160°22′25″E
Allan Hills No. 1	Chondrite	20,151	76°39′27″S*	159°33′16″E*
Allan Hills No. 2	Iron	1,510	76°39′27″S*	159°33′16″E*
Allan Hills No. 3	Chondrite	10,495	76°47′29″S	159°26′44″E
Allan Hills No. 4	Chondrite	305	76°45′16″S	159°20′12″E
Allan Hills No. 5	Achondrite	1,425	76°37′2″S	159°21′46″E
Allan Hills No. 6	Chondrite	1,137	76°38′47″S	159°22′57″E
Allan Hills No. 7	Chondrite	410	76°40′8″S	159°21′46″E
Allan Hills No. 8	Chondrite	1,150	76°39′27″S	159°18′14″E
Allan Hills No. 9	Chondrite	407,041	76°43′14″S	159°17′39″E

*Allan Hills Nos. 1 and 2 were found 80 m apart and were therefore assigned the same geographic coordinates.

density of meteorites in the 100-g range at Yamato Mountains is due to the presence in that accumulation of individuals from one or more showers. To test this, we weighed 496 fully fusion-crusted individuals from the Forest City chondrite shower. The total weight was more than 82 kg, and the average was only 166 g. This lends credence to the idea that individuals from showers were mixed into the Yamato Mountains recoveries and suggests that there were fewer than the 300 individual meteorite falls estimated by Japanese workers. While this would explain the abundance of small meteorites at the Yamato Mountains site, we have as yet no way to explain the absence there of large meteorites such as the ones we found.

Before the Yamato Mountains discovery there were only about 2000 other known meteorite falls and finds in the rest of the world; dozens or hundreds added to this number are a significant increment. The significance of our discoveries, 3200 km across the continent from the Yamato Mountains, is that concentrations of meteorites on blue ice surfaces can now be considered a general phenomenon in Antarctica. Thus, it is becoming clear that the Antarctic ice cap is a vast, dynamic system that collects and preserves meteorites.

Preservation and concentration. Meteorites found on patches of Antarctic blue ice seem to occur in numbers that indicate a much greater surface density than is normal for the rest of the earth. At Allan Hills, for example, we find one meteorite per 10 km^2. At the Yamato Mountains a 9 by 9 km area searched in great detail yielded 192 individual meteorites. If 10 percent of these represented separate falls, the surface density would be 2.4 per 10 km^2. Brown (*8*) has estimated the rate of fall onto the earth's surface to be one meteorite per 10^6 km^2 per year at the latitude of Calcutta. Halliday (*9*), however, finds that the rates of fall in polar regions are 50 or 60 percent of the equatorial values for meteorites with average or above average velocities; if this is true the high local concentrations of meteorites found in Antarctica are even more remarkable. If we assume that Brown's estimate is correct and that no concentration mechanism is operating other than the passage of time, we calculate that the blue ice surface at Allan Hills is 100,000 years old and that at Yamato Mountains may be 240,000 years old.

These seem rather long periods for even isolated "backwaters" in a dynamic system such as a continental ice sheet to remain stagnant, and the Japanese investigators have, in fact, demonstrated that the ice in the 9 by 9 km area where they recovered 192 specimens is not quite stagnant (*3*). Its horizontal flow rate of about 1.8 m/year diminishes progressively toward the Yamato Mountains, until in the area of their detailed search it averages somewhat over 1 m/year, with a minimum measured rate near an outlying nunatak of 0.5 m/year. A new upward vector averaging 5 cm/year appears, however, and this is balanced by a measured ablation rate almost exactly equal to the upward vector. The conclusion from these measurements is that the ice being ablated at the Yamato Mountains is continually being replaced by ice flowing into the area from farther inland and from below. Meteorites that have fallen over quite a large area are eventually carried by moving ice into the Yamato Mountains zone of ablation, where they join other meteorites left behind by vaporizing and eroding ice, while the ice mass that carried them is ablated in turn. It seems reasonable to assume the same interpretation for the sites at Mount Baldr and Allan Hills.

Theoretically, such a concentration system is ideal in two ways: (i) it transports everything that falls within the collecting area into the area of residual con-

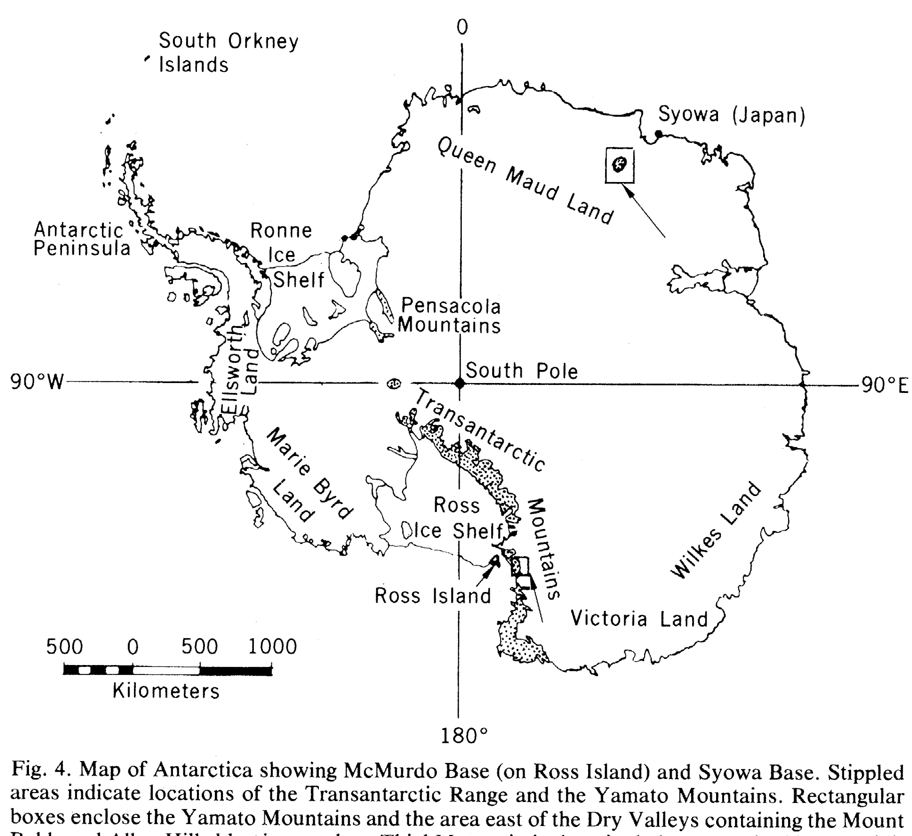


Fig. 4. Map of Antarctica showing McMurdo Base (on Ross Island) and Syowa Base. Stippled areas indicate locations of the Transantarctic Range and the Yamato Mountains. Rectangular boxes enclose the Yamato Mountains and the area east of the Dry Valleys containing the Mount Baldr and Allan Hills blue ice patches. Thiel Mountain is the stippled area on the 90°W meridian.

centration, and (ii) it carries everything that is embedded even in the most ancient ice to the surface as the ice sheet rides up the side of the barrier. Thus, in theory, the concentration occurs across an area and also back through time.

Other factors unique to the Antarctic environment undoubtedly act to favor preservation of friable and chemically less stable meteorites once they have fallen. Initial impacts may often occur in deep snow, favoring retention of meteorites as larger individuals. Chemical weathering is greatly retarded by low temperatures, low humidity, and the absence of plant-produced organic acids or inorganic soil acids. The low rates of chemical reaction and high degree of cleanliness on the Antarctic ice plateau would be particularly important in maintaining carbonaceous chondrites in their pristine states. Because of these factors the distribution of meteorite types in Antarctica may be different from that in other climatic zones and may more accurately reflect the original distribution in space.

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10. The work reported here resulted from a joint U.S.-Japan field project. The U.S. members were supported by NSF grant DPP76-10800. In addition, E.O. received partial support from the Field Museum of Natural History. K.Y. was supported by the Japan National Institute of Polar Research. We received very valuable preliminary advice on the field operations from W. MacDonald, D. Elliott, and C. Bull. Fruitful discussions on sections in the report were had with L. Rancitelli and P. M. Millman. We owe a special debt of gratitude to the pilots and aircrew members who helped ensure our success in the field by willing and intelligent application of their special skills. We thank all the institutions and individuals mentioned above.

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Planetary Radiation Balance as a Function of Atmospheric Dust: Climatological Consequences

Abstract. *An analysis of several atmospheric dust-loading events at Phoenix, Arizona, under background cloudless sky conditions, allowed determination of dust-induced changes in both the net solar and net thermal radiation received at the earth's surface. The resultant climatological forcing function for surface temperature change was plotted against the ratio of diffuse to normal-incidence solar radiation. It was found that initial increases in atmospheric dust concentration tend to warm the planet's surface. After a certain critical concentration has been reached, continued dust buildup reduces this warming effect until at a second critical dust concentration a cooling trend begins. This second critical dust concentration is so great, however, that any particulate pollution of the lower atmosphere by man will have a tendency to increase surface temperatures. Thus, anthropogenically produced tropospheric aerosols cannot be looked on as offsetting the warming tendency of increased carbon dioxide: their concurrent buildups must inexorably tend to warm the planet's surface.*

The climatological effects of atmospheric dust on the earth's radiation balance have been of great concern to scientists for many years. Interest centers chiefly on the question: Would an increase in the dust content of the atmosphere tend to warm or cool the earth?

Most research on this subject has concentrated on effects of airborne particulates on solar radiation. These studies, practically all theoretical, have dealt with absorption and forward- and back-scattering characteristics of different aerosol types with different numbers and size distributions over different surfaces, such as forest, farmland, desert, snow, and water. A sampling of results is highly ambivalent; many studies have predicted cooling trends for increases in atmospheric dust concentrations, while many others have predicted warming trends.

A second research effort, somewhat more experimental, has concentrated on effects of airborne particulates on atmospheric thermal radiation. These studies have not been as equivocal as the solar radiation studies, as almost all of them have predicted a warming trend with increasing atmospheric dust concentration. However, they have not been completely unambiguous either, yielding somewhat different heating rates for different experimental conditions. Thus, we felt that a more unified and systematic approach to the problem was needed, consisting of an experimental study of both solar and thermal radiation interactions with atmospheric dust as a function of dust loading of the atmosphere.

Our primary data were obtained from two intensive, long-term radiation balance studies conducted at Tempe and Phoenix, Arizona, over the period December 1976 to May 1977. The Tempe study involved a characterization of incoming solar radiation. Normal-incidence and diffuse solar radiation were measured every 20 minutes with an Eppley normal-incidence pyrheliometer on a motorized equatorial mount and an Eppley precision 180° hemispherical radiometer equipped with a shadow band appropriate for our latitude, respectively; both were atop a 9.2-m tower at the Laboratory of Climatology on the Arizona State University campus. Altitude and azimuth angles of the normal-incidence pyrheliometer and the position of the shadow band about the hemispherical radiometer were checked every other day.

The Phoenix study, carried out 4 km southwest of the Tempe study site at the U.S. Water Conservation Laboratory, included a characterization of incoming and reflected solar radiation and net all-wave radiation over a wheat crop. Three hemispherical solarimeters (Eppley, Spectran, and Lambda Instruments) recorded incoming global (direct plus diffuse) solar radiation, 24 inverted Spectran solarimeters recorded reflected solar radiation, and 24 Fritschen-type net radiometers recorded net all-wave radiation—all on an every-20-minute basis. These instruments were checked daily.

With this large data base available, we decided to search the records of the nearby Phoenix National Weather Service Office for days that had blowing dust events under cloudless skies. Out of the entire 6-month study, only 3 days met these two criteria: 11 January, 22 February, and 15 April 1977. For these 3 days, the results from the 24 inverted solarimeters were averaged and subtracted from the average incoming solar radiation determined from the three upright solarimeters at the U.S. Water Conservation Laboratory to yield the net solar radiation over the wheat plot (Fig. 1A). This result was then subtracted from the aver-