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Catalog of Antarctic Meteorites, 1977–1978

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and Brian Mason
EDITORS

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ABSTRACT

Marvin, Ursula B., and Brian Mason, editors. Catalog of Antarctic Meteorites, 1977–1978. *Smithsonian Contributions to the Earth Sciences*, number 23, 50 pages, 39 figures, 2 tables, 1980.—During two expeditions to Antarctica (1976–77 and 1977–78), more than 300 pieces of meteorites were collected from a small area adjacent to the Allan Hills (77°S, 159°E) in Victoria Land. The 1977–78 meteorites were collected with special care to avoid contamination, and were transported in frozen condition to the Johnson Space Center, Houston, where they were processed under similar conditions to those used for the lunar samples. Eighty-five specimens of the 1977–78 collection, including most of those weighing over 100 grams, have been characterized, and are described in this monograph. Appendices provide a listing of these in numerical sequence and with significant data, and a table of chemical analyses. A summary of the published data on the ten meteorites of the 1976–77 collection is also included.

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Catalog of Antarctic Meteorites, 1977–1978

Editors' Introduction

Ursula B. Marvin and Brian Mason

In December 1969, a Japanese expedition found nine meteorites on a bare-ice area about 5 × 10 km at the southeastern end of the Yamato Mountains in East Antarctica (near 72°S, 36°E). Subsequent collecting in this small area resulted in the recovery of almost 1000 meteorites. Since the collection included a variety of meteorite types, this occurrence could not be explained as the fragmentation of a single large meteorite. Clearly, some concentrating mechanism had been operative in the Antarctic, since similar meteorite concentrations have never been observed elsewhere. To test this hypothesis, in mid-1975 W. A. Cassidy of the University of Pittsburgh proposed to the National Science Foundation (NSF) a search for meteorites on the icecap in Victoria Land, which is accessible from the United States McMurdo Station. Edward Olsen of the Field Museum of Natural History in Chicago independently planned a similar proposal. As a result, in 1976–77 the NSF Division of Polar Programs supported a joint expedition by Cassidy and Olsen, which was joined by K. Yanai of the National Institute of Polar Research, Tokyo. During the period 15 December 1976 to 20 January 1977, this party collected 10 meteorites from the icecap on the inland side of the Transantarctic Mountains in Victoria Land.

The success of this expedition, which proved that the Yamato Mountains discovery was not unique but was likely to be repeated at other suitable areas on the Antarctic icecap, prompted extensive discussions among interested scientists as to the best procedures for exploiting this unexpected windfall of extraterrestrial material. Cassidy initiated these discussions at the annual meeting of the Meteoritical Society in Cambridge, England, in July 1977. In November 1977, the NSF convened an ad hoc committee of representatives from the NSF, the National Aeronautics and Space Administration (NASA), the Smithsonian Institution (SI), and the scientific community. As a result of this committee meeting, a plan was drawn up for the collection, processing, and distribution of Antarctic meteorites collected during the 1977–78 field season. This plan provided for the meteorites to be collected and returned to the United States, as far as possible in their pristine condition (in continuously below-freezing temperatures). They were to be initially stored and processed at the NASA Johnson Space Center under conditions similar

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to those used for lunar samples. After the committee meeting, the NSF set up two advisory groups, the Meteorite Working Group (MWG) and the Meteorite Steering Group (MSG). The MWG is composed of approximately ten members, representing the field collection teams, the curation groups, and members of the scientific community. Its primary responsibility is to consider requests for Antarctic meteorite samples for scientific research and to prepare an allocation plan for approval by MSG. The MWG may also discuss and make recommendations to MSG on any aspect of the Antarctic meteorite research program. The MSG is composed of three members, one each from NSF, NASA, and SI. Its function is to review the recommendations of the MWG, transmit them to the appropriate authorities, and to make recommendations on policy matters.

In order to inform the scientific community as quickly as possible of the number and character of the specimens, an Antarctic Meteorite Newsletter with preliminary descriptions of the hand specimens and thin sections is prepared during each episode of initial processing. The newsletter is mailed to interested scientists throughout the world.

Formal requests for Antarctic meteorite samples for scientific research should be submitted in writing to the Secretary, Meteorite Working Group, Lunar and Planetary Institute, 3303 Nasa Road 1, Houston, Texas 77058. Requests are welcome from all qualified U.S. and foreign scientists and are reviewed and considered two or three times each year by the Meteorite Working Group. In order for a request to be considered, it must arrive in the Secretary's office prior to a deadline published periodically in the newsletter. Consideration is given to sample requests independently of whether or not the requestor is presently funded for meteorite or lunar samples studies. It should be noted that sample allocation does not in any way commit funding agencies to financing of the proposed research on Antarctic meteorites. Requests for financial support for research, if required, must be submitted separately to the appropriate funding agencies.

Sample requests should provide detailed scientific justification of the proposed research. Requests for specific samples should include sample numbers, weight requirements, and special handling and shipping requirements. Consortium-type sample requests that are aimed at in-depth studies of specific samples by groups of scientists of different specialities are encouraged.

Investigators wishing to study polished thin sections of Antarctic meteorites in support of their sample requests can do so at the thin section libraries, which are established at the Johnson Space Center (contact Secretary, Meteorite Working Group), at the National Museum of Natural History, Smithsonian Institution, Washington, D.C. (contact Brian Mason, Curator), and at the National Institute of Polar Research, Ministry of Education, 1-9-10, Itabashi-ku, Tokyo, 173, Japan (contact T. Nagata, Director, and K. Yanai, Curator). These sections are for optical examination only and cannot be loaned out. When duplicate thin sections are available, loans will be considered.

Field Occurrences and Collecting Procedures

W. A. Cassidy

Historical Background

In 1969, a Japanese glaciological team was establishing a triangulation chain on an ice field adjacent to the Yamato Mountains in order to measure local flow in the Antarctic ice sheet. During this procedure, one of their number, Renji Naruse, picked up a meteorite. Visual searching in the area quickly produced eight more specimens, all lying on the ice (Yoshida, et al., 1971), which were returned to Japan for examination. In 1973, Makoto and Masako Shima described four of these specimens at the Meteoritical Society meeting in Davos, Switzerland (Shima and Shima, 1973). I attended the meeting out of a general curiosity about new meteorites and an interest in the exotic locale in which these had been discovered. During the oral presentation I suddenly realized Shima was describing four distinct subclasses of stony meteorites that had been found within the remarkably small area of 50 square kilometers. Normally, meteorite specimens encountered in such concentrations result from a shower of fragments from the same parent and, therefore, are all of one subclass; it was startling to find as many as four types of stony meteorite reported within such a restricted area.

It seemed necessary to postulate some mechanism of concentration to explain how this could have occurred. The obvious suggestion, made by Yoshida et al. (1971), was that the concentration mechanism has something to do with Antarctic ice: Meteorites falling in Antarctica fall onto a moving medium and there might be a potential in this for concentrating specimens from different falls. Whatever the mechanism, it did not seem likely that in a continent as large as Antarctica such an occurrence would be unique.

I discussed these matters with Professor Takesi Nagata, Director of the National Institute of Polar Research, Tokyo, during one of his stays as a visiting professor in our department at the University of Pittsburgh. As a result of these discussions, he directed the 1973–74 Japanese field party to make additional meteorite searches at the Yamato Mountains site. These produced twelve additional specimens (Shiraishi, et al., 1976). Thus encouraged, Japanese field parties found 663 during austral summer 1974–75 (Yanai, 1976), and 307 in 1975–76 (Matsumoto, 1978). The total Japanese collection as of this writing, midway through 1979, now numbers an almost incredible 991 meteorite specimens found within an area of 300–400 square kilometers at Yamato Mountains.

My initial proposal to the Division of Polar Programs, National Science Foundation, submitted in May 1974, was to search for meteorites during field season 1975–76 on ice patches accessible by helicopter from McMurdo Station. It was not funded, but I was encouraged to resubmit it for the following year. In the proposal, I pointed out the anomalously high concentration of meteorites found lying on the ice at the Yamato Mountains and suggested that other areas on the Antarctic ice sheet should bear similar numbers of meteorites. These locations would probably be

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ones where ablation, or wasting away of the ice surface, is occurring, while the ice being lost is constantly being replaced by newer ice arriving from the interior of the continent.

My proposal was funded for field season 1976–77. For several years, Japan had enjoyed cooperative research programs with the United States and New Zealand, working out of McMurdo Station and Scott Base, respectively, both bases being located on Ross Island. A joint U.S.–Japan field search for meteorites in areas accessible by helicopter from McMurdo Base was established. It was agreed that all specimens found would be cut in half and distributed equally between the United States and Japan. The first year's field party consisted of Keizo Yanai of the National Institute for Polar Research, Tokyo, Edward Olsen of the Field Museum of Natural History, Chicago, and myself.

Yanai had a valuable store of previous Antarctic experience and had been heavily involved in the Yamato Mountains meteorite recoveries. Olsen had earlier been in Greenland. Therefore, I was the only member of the group without previous experience of Arctic or Antarctic conditions. Our plan was to establish a series of field camps, beginning with one or two at low elevations under relatively mild climatic conditions, from which we could make forays on foot to search for meteorites. We planned to work up to more difficult sites gradually, mainly so that I could become accustomed to conditions of extreme cold. Our first campsite, therefore, was at the lower end of the Wright Upper Glacier, a valley glacier that carries ice directly off the Antarctic ice plateau. The glacier is fed principally by ice coming over the Airdevronsix Icefall, but it also receives a small increment from a minor ice mass between Mt. Fleming and Mt. Baldr. The latter site was our next objective; therefore, I asked the helicopter pilots to take us up there for a fast look around. As we disembarked on the ice, Yanai almost immediately found a meteorite (Figure 1). While we were examining it he was using his binoculars to good advantage and spotted another one about 700 m away. Olsen, Yanai, and

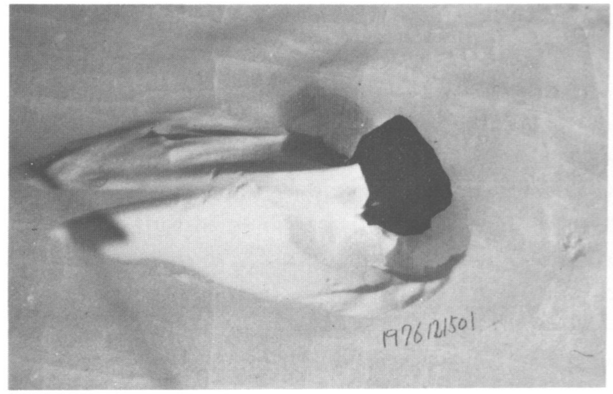

FIGURE 1.—Meteorite fragment found near Mt. Baldr. Eddy-current deposit of ice crystals has occurred downwind of the specimen; wind scooping has occurred at the sides.

I started across the ice toward it while the helicopter crew quickly returned to their machine to follow us aloft. An observer would have been drawn into the action irresistibly by the sight of three parka-clad pedestrians crossing the ice, followed by a helicopter, all obviously headed for the same place. We had found two meteorite specimens essentially in our first twenty minutes in the field.

We were elated by this initial success, but made no additional discoveries for about six weeks. We found no meteorites among the debris at the bottom end of the Wright Upper Glacier, and when we set up our next field camp at Mt. Baldr (Figure 2) we found no more meteorites. Subsequently we investigated a number of areas of bare ice located where the ice plateau meets the Transantarctic Range, but found nothing. During the closing days of the field season, acting at the suggestion of Ken Craper, one of the helicopter pilots, we investigated a large patch of ice adjacent to the Allan Hills. Almost immediately we found a stony meteorite; then an iron one only 70 meters away. During that visit and another, several days later, we recovered 45 specimens. Three were found close together on the ice and fitted together along fracture surfaces to form an almost complete fusion-crusted single specimen. Thirty-three fragments of varying sizes were found scattered within a radius of 50 meters.

These also appear to be fragments of a single individual; their masses summed to 407 kg. Accounts of these discoveries can also be found in Cassidy (1977), Cassidy, et al. (1977), Yanai (1978), and Yanai, et al. (1978).

All our discoveries at the Allan Hills site had been made using a helicopter as a movable, low-level observing platform, from which we could scan large areas in a short time. We found also that our helicopter pilots quickly gained proficiency not only in spotting rocks from about 10 meters above the ice surface but also in differentiating between rocks and meteorites. Thus we owe many of these finds and many subsequent discoveries to the excellent U.S. Navy flight personnel assigned to support the U.S. research effort.

The 1976–77 discoveries (Figure 3) demonstrated that the Yamato occurrence was not unique; it seemed likely, therefore, that many more meteorite concentration sites would be found on Antarctic ice. We suspected from the beginning that Antarctic meteorites in general might have unique characteristics not found in meteorites fallen in other regions. Among these were long preservation times and low levels of terrestrial contamination. Further, we felt there would be good chances of finding rare or previously undescribed meteorite types and also, possibly, lunar rocks that had reached the earth as products of impact on the moon's surface. Such musings prompted concerns over the adequacy of our collecting methods: it would be a shame to contaminate well-preserved specimens by collecting them in a careless fashion. This concern prompted me to mail a questionnaire to the membership of the Meteoritical Society, seeking an expression of opinion on how Antarctic meteorites should be handled. The response (Cassidy, 1979) included both specific and general suggestions which, in sum, outlined a careful curating process that begins at the moment of discovery and continues through the transport and later subdivision of the specimen for research. Based in large part on these recommendations, the National Science Foundation accepted an offer of help in the curating processing from the National Aeronautics and Space Administration (NASA). Currently, therefore, all the meteorite specimens are sent initially to the NASA/Johnson Space Center Lunar Curator's Divison for processing. The National Science Foundation also decided to eventually house the majority of the U.S. portions of the collection at the Smithsonian Institution.

FIGURE 2.—Field camp at the Mt. Baldr site. Extra food and some gear were stowed outside.

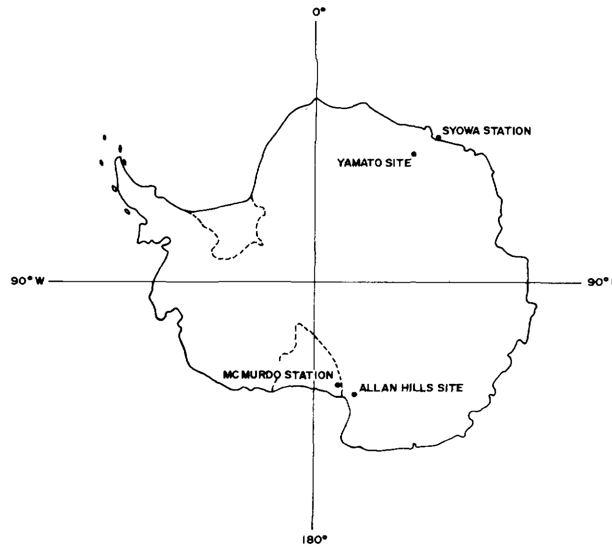

FIGURE 3.—Map of Antarctica, indicating the Yamato and the Allan Hills sites.

During the following field season (1977–78), our collecting, storage, and transport procedures became much more rigorous. Meteorites were never touched by hand or gloves, but were picked up and sealed in teflon bags and kept frozen throughout the journey from the ice cap to Houston. My co-investigator for the 1977–78 field season was Billy Glass of the Geology Department, University of Delaware. Keizo Yanai and Minoru Funaki of the National Institute of Polar Research comprised the rest of our four-man field party. We returned to Allan Hills and, collecting on foot, recovered 309 specimens.

Nature of the Field Occurrence

During field seasons 1976–77 and 1977–78, two meteorites were found that should be considered isolated occurrences. These are (1) the two Mt. Baldr chondrites, which, based on noble gas content, have now been paired (Weber and Schultz, 1978), and (2) an iron found by a member of a University of Maine field party, Steven Kite, in glacial moraine at the seaward end of Victoria Valley, near Purgatory Peak (Yanai, et al., 1978). A third, possibly isolated meteorite was found on bare ice near the upper (southern) end of Manhaul Glacier only a few kilometers from the main concentration site at Allan Hills. This specimen is included tentatively as an isolated occurrence because the site does not appear to be connected dynamically to the ice flow and ablation system that apparently produced the Allen Hills concentration. It was, however, found nearby.

A relatively high frequency of discovery for isolated meteorites should, I suppose, be expected in the Antarctic environment because some ice surfaces may have been in stagnant-flow conditions for very long periods of time and weathering of rocks proceeds very slowly, so that concentrations could build up over time. The Mt. Baldr (Cassidy, et al., 1977) and Manhaul Glacier (Yanai, et al., 1978) occurrences are therefore understandable as individuals whose survival was prolonged by fall onto a static surface and by retardation of the weathering process. The Purgatory Peak occurrence (Yanai, et al., 1978) was slightly different in that the iron probably was transported by ice and survived because of the slow rate of weathering in the Antarctic environment.

FIGURE 4.—Area around Allan Hills, Antarctica. Meteorite concentration was found on the patch of bare ice indicated by the arrow. (Landsat photograph, spectral band VII.)

The Allan Hills concentration is another matter (Figure 4). Through field season 1977–78 we had recovered about 350 specimens, representing perhaps 20 to 50 falls (Yanai, et al., 1978). There is evidence of ice flowing into the site and wasting by ablation, which suggests that meteorites found in the ablation zone could have been transported over great distances after fall.

The meteorites occur in a zone where ice moving off the Antarctic Plateau apparently passes over a rocky ridge, thinning appreciably in the process. The ice surface along this presumed ridge forms a monocline whose lower limb is on the downstream side (Figure 5). Several kilometers further downstream, the ice meets the absolute barrier of the Allan Hills. Meteorites were found on both the upper and lower limbs of the monocline within an area of about 100 square kilometers. They were relatively more abundant on

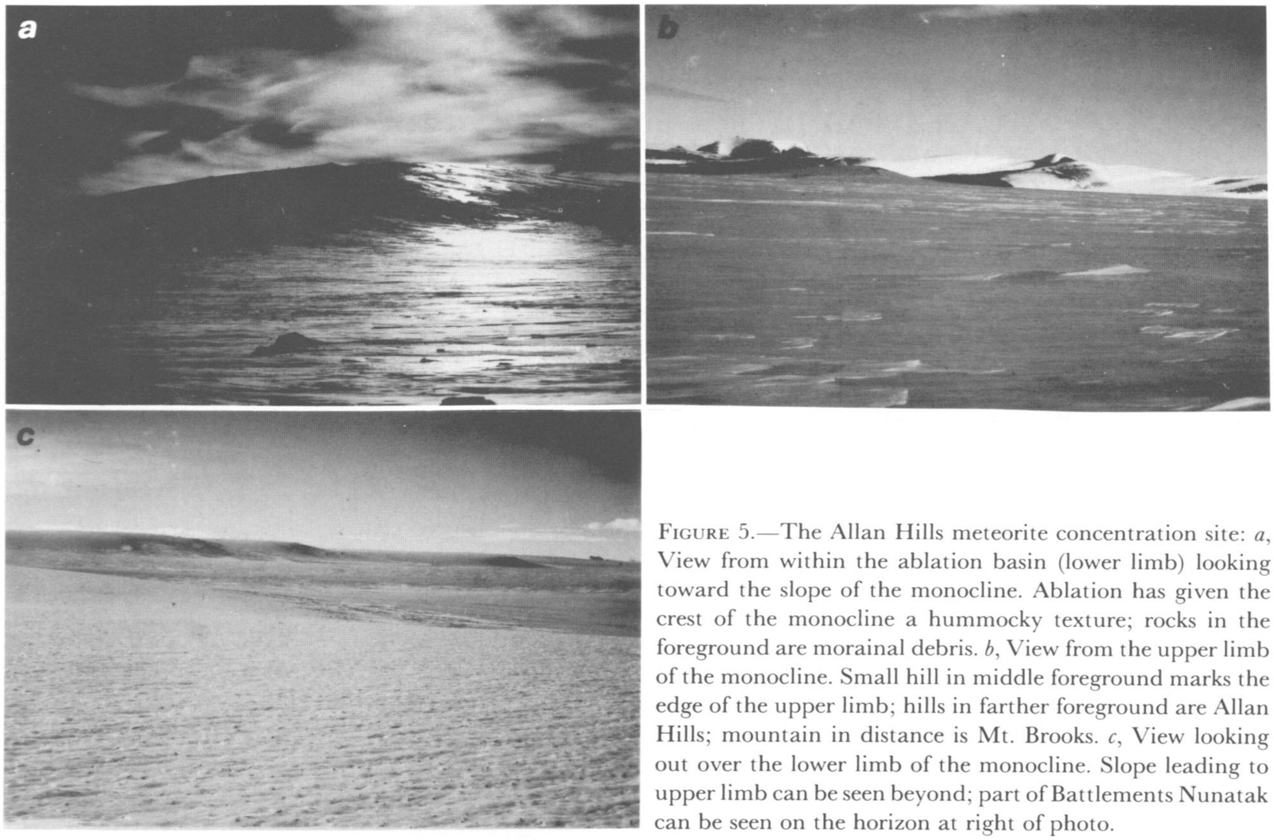

FIGURE 5.—The Allan Hills meteorite concentration site: *a*, View from within the ablation basin (lower limb) looking toward the slope of the monocline. Ablation has given the crest of the monocline a hummocky texture; rocks in the foreground are morainal debris. *b*, View from the upper limb of the monocline. Small hill in middle foreground marks the edge of the upper limb; hills in farther foreground are Allan Hills; mountain in distance is Mt. Brooks. *c*, View looking out over the lower limb of the monocline. Slope leading to upper limb can be seen beyond; part of Battlements Nunatak can be seen on the horizon at right of photo.

the lower limb. It seems likely that specimens first appear on the surface of the ice at the upper limb and then are carried down to the lower limb, where they are stored for great lengths of time. Smaller specimens were often found at the northern border of the ice patch on the lower limb, where a veneer of snow exists. It may be that these smaller specimens have been blown across the ice by the strong katabatic winds coming from the south and that once they reach snow their progress stops, so that they are concentrated along the snow boundary.

The lower limb of the monocline is also penetrated here and there by rocky outcrops. These produce much moraine debris, and meteorites can be found mixed with this morainal material. The ice at these points apparently has virtually zero thickness.

To summarize our field recoveries over two field seasons, it can be stated that three meteorites were found that were not parts of high residual concentrations, and 353 specimens, representing possibly 20–50 meteorites, were found in one residual concentration. The sporadic finds seem to occur in areas of active ablation having no source of new ice, while the high concentrations seem to require constant replacement of ablated ice, as well as active ablation.

Curation and Allocation Procedures

D. D. Bogard and J. O. Annexstad

Meteorites collected near Allan Hills, Antarctica, in the 1977–1978 field season were packaged in specially prepared containers and were returned to the Curatorial Facility of the NASA Johnson Space Center (JSC) at temperatures below 0°C (Figure 6*a*). The meteorites were unpacked, photographed, and processed at the Curatorial Facility by procedures that drew on experience gained from the processing of lunar samples. This section describes the return and initial curation of the 1977–1978 meteorite collection.

The JSC Curatorial Facility supplied the U.S.–Japanese field party, led by W. A. Cassidy, with four metal boxes (each about 60 × 60 × 90 cm) and an assortment of cleaned teflon bags, aluminum foil, numbered aluminum tags, and teflon tape. Two cleaned metal cans with air-tight seals were also supplied in case particularly rare or friable meteorites were found. The teflon bags, aluminum, and cans were cleaned to the same specifications used in processing lunar samples. All of these materials were tested in a cold room at −23°C before they were sent to McMurdo Station.

As the meteorites were discovered in the field they were wrapped in teflon bags, sealed with tape, and packed into padded metal boxes. Many of the smaller specimens were packaged several to a bag, but most of the larger ones were placed in individual bags. The two carbonaceous chondrites were sealed inside the two metal cans. Although an effort was made to keep the meteorites at temperatures below freezing, several specimens were known to have warmed up and to have contacted liquid water after they were collected. However, most of the meteorites did not thaw; snow was still present in fissures in several specimens. The meteorites were returned to Port Hueneme, California, in the refrigerated locker of a ship. Inside a cold room at Port Hueneme the meteorites were repacked into metal boxes and dry ice was added. These boxes were flown air freight to JSC, where the meteorites were unpacked and placed inside a cold storage room at −40°C. Ice placed in one of the boxes in Antarctica was unmelted, which indicates that the meteorites did not thaw after initial packing.

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Initial Processing and Description

Each individual bag, containing one or several meteorites, was transferred from the cold storage room to the processing laboratory in the JSC Curatorial Facility, was placed inside a chilled stainless steel can on a laminar flow bench, and was opened. A meteorite was withdrawn and compared to its field photograph to confirm its field identification. The meteorite was then placed inside a clean teflon bag inside a second chilled can, a processing identification number was assigned, and the meteorite was returned to the freezer. This process was repeated for all specimens. It was possible to identify many meteorites with their field photographs and to determine their orientation on the ice. Processing numbers initially assigned to the specimens were 30001 to 30307. These were later replaced by the permanent name/number combinations recommended by the Committee on Nomenclature of the Meteoritical Society. For all of the 1977–1978 collection, except one meteorite, these carry the information of locality, Allan Hills (ALH); field party (A); field season (77); followed by a three-digit number which identifies each individual specimen collected. The sequence in which these last three digits were assigned was based on the order of unpackaging in Houston, not on the order of recovery in Antarctica. Thus, when referred to in the catalog, the first specimen in the collection bears the identification: ALHA-77001, XX, where the digits following the comma refer to subsamples taken from this meteorite specimen.

The initial processing of meteorites in the Curatorial Facility provided a rapid characterization of each specimen that was reported to the meteoritical community via the Antarctic Meteorite Newsletter, which was created for this purpose.

FIGURE 6.—Processing Antarctic meteorites at Johnson Space Center, Houston: *a*, Arrival of the metal boxes containing the meteorites packed in dry ice. *b*, Inside the stainless steel, controlled-environment cabinets with a nitrogen atmosphere, the meteorites are weighed, photographed, dried, and chipped. *c*, Observation port of a processing cabinet, through which a meteorite is visible on the photo stage. *d*, Meteorite being chipped inside the processing cabinet; the chisel and bowl are of stainless steel.

Each meteorite was weighed, photographed, described, and a small chip was taken for a thin section (Figure 6). In most cases the chip was sent to the Division of Meteorites at the Smithsonian Institution (SI), where thin sections were made and the meteorites classified petrographically. The processing was done in a cleaned, stainless steel glove box with a controlled nitrogen atmosphere, using cleaned tools generally limited to stainless steel, aluminum, and teflon. The tools and techniques used were those routinely used for processing lunar samples, except that techniques were modified for greater efficiency wherever it was considered appropriate. The intent was to prevent any serious contamination or degradation of the specimens during initial processing. Attempts were made to keep many meteorites cold throughout these operations. For example, photographs were taken while the meteorite lay on a specially prepared stage, which was kept chilled by directing a small stream of liquid nitrogen onto its underside. The meteorite was always returned to this cold plate between operations, such as weighing and chipping. For many of the larger specimens, a chip was taken to be kept in long-term cold storage after the main mass of the specimen had been warmed. A summary of the initial processing steps in their approximate order is as follows:

With specimen kept cold, (1) each meteorite was quickly passed into the processing cabinet, removed from its bag and placed on a cold plate; (2) weighed; (3) photographed in color (orthogonals were taken of larger specimens); (4) a chip was taken for thin sections; (5) a second chip was taken (from the larger specimens only) for long-term cold storage; and (6) the specimen was dried (a few were freeze-dried but most meteorites were allowed to thaw in the nitrogen cabinet). After thawing, (7) each specimen was sawed in half and the cut surfaces photographed and described (Figure 7); (8) one-half of each meteorite was sent to Japan along with one of three thin sections made at the Smithsonian Institution. The two other thin sections were placed in libraries at the JSC Curatorial Facility in Houston and at the SI Division of Meteorites in Washington, where scientists may examine them.

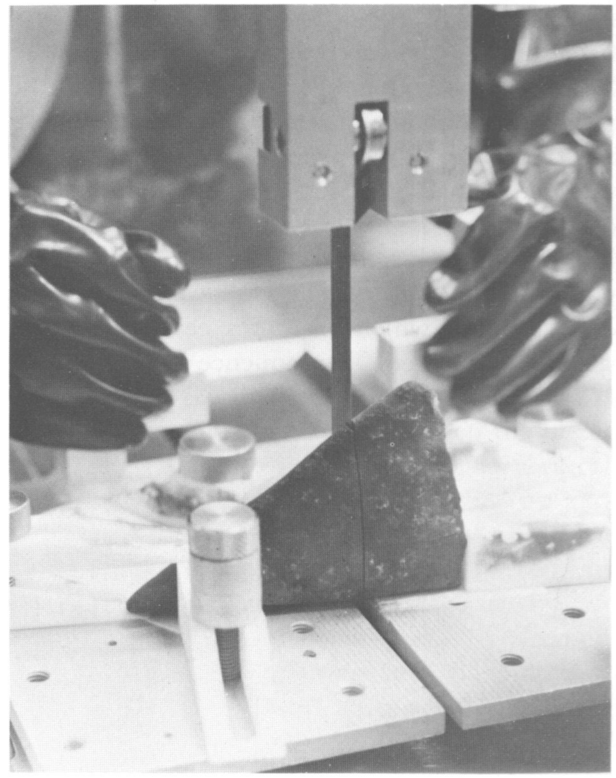

FIGURE 7.—An Antarctic meteorite being sawed with a band saw inside a stainless steel cabinet with a nitrogen atmosphere; no coolants are used.

Pebble-sized meteorites, which generally are those specimens weighing less than 100 grams and which were returned several to a collection bag, were initially processed in a different manner. These meteorites were allowed to thaw overnight in the processing cabinet, and all processing operations were done with the specimens at room temperature. Three specimens at a time from the same collection bag were processed together. Only three orthogonal photographs were made of all three specimens together. No chips for cold storage were taken from pebbles. Most of the pebbles were not sawed, but were subdivided by chipping.

The four iron meteorites in the collection were handled in yet another manner. The specimens were allowed to thaw and dry for 48 hours in a nitrogen cabinet. They were then placed on a laminar flow bench, weighed, photographed, and sealed in a teflon bag. The irons were sent to the Smithsonian Institution where they were sawed and subdivided, using the standard procedures of that institution.

All photography of meteorites was made with Kodak VPS color film in a large format camera, which produced 4 × 5 inch negatives. The six orthogonal views taken of the larger meteorites record many details of the surface features (ablation marks, fusion crust, coloration, etc.) as they appeared before the specimens were divided and distributed. Photographs also record features on sawed faces of the meteorites. Generally, the sizes and shapes of chondrules and clasts, the extent of internal fracturing, and the degree of oxidation of the interior metal can be readily discerned in these color photographs. The lettered cube shown in the photographs (T, N, E, etc.) indicates relative orientation of the specimens as assigned during processing and does not necessarily indicate the meteorite's orientation on the Antarctic ice cap.

Sawing of the stony meteorites in the Curatorial Facility was done with a cleaned band saw, which was contained in a nitrogen cabinet and which was furnished with a diamond-encrusted, stainless blade either 0.010 or 0.020 inch thick. Sawing was done dry; no lubricants were used. Between specimens, the blade and sample stage was cleaned and the entire saw cabinet was flushed with freon to remove meteorite dust. A portion of the meteorite dust produced during sawing was swept up, labeled as bandsaw fines, and retained. The fine dust that was washed from the saw cabinet was discarded with the freon washings.

Allocations to Scientific Investigators

The meteorites were subdivided according to guidelines prepared by the Meteorite Working Group. By prior agreement between the Division of Polar Programs of the National Science Foundation and the National Institute of Polar Research of Japan, each specimen collected by joint U.S.-Japanese field parties would be shared equally between the two nations. Thus, after the preliminary examinations and descriptions, each of the larger stones was either cleaved or sawed in half for division with the Japanese. The U.S. portion of the specimen was placed in a stainless steel chipping bowl in a nitrogen-processing cabinet. Allocations for requested material were filled by chipping off appropriate samples with a chisel.

Attempts were made to obtain samples according to specific requirements of investigators. Chipping rather than sawing was used as much as was practical, to minimize possible contamination. In the case of the achondrites, several grams of interior material were crushed to provide representative samples to investigators performing chemical analyses. In the case of allocations from carbonaceous chondrites, the final freon washings of cleaned processing tools were checked to determine levels of residual hydrocarbons. The relative positions of the samples were usually documented. In cases where several samples of documented subsurface depths were requested (e.g., for particle track studies), these depths were either measured when the samples were taken or a single piece of meteorite containing a wide range of depths was allocated so that the investigator could extract his own samples. Most polished thin sections allocated to investigators were made in the thin-section laboratory of the Curatorial Facility. Sections of a given meteorite were usually made from an interior chip, which was not the chip from which library thin sections were made as part of the initial survey.

Meteorite Descriptions

Trude V. V. King, Roberta Score,
Elizabeth M. Gabel, and Brian Mason

This section provides descriptions of the individual specimens, arranged by class: chondrites, achondrites, and irons. Within the chondrites, the specimens are grouped according to the Van Schmus-Wood (1967) classification, and the descriptions follow the order of increasing petrographic type. The descriptions are based largely on those published in the Antarctic Meteorite Newsletter, with additional information as available. The letter-number designation for each meteorite concurs with guidelines recommended by the Committee on Nomenclature of the Meteoritical Society; it carries the following information: ALH (Allan Hills); A77 (Expedition A, 1977); XXX (digits indicating the number of the specimen). The original weight of the specimen is given to the nearest gram (nearest 0.1 gram for specimens weighing less than 100 grams).

For completeness, the meteorites collected in the 1976–77 field season (ALHA76001–76009 and Mt. Baldr (MBRA 76001)), described in detail by Olsen, et al. (1978), and the Purgatory Peak iron (PGPA77006), collected by Steven Kite of a University of Maine field party in the 1977–78 field season, have been included.

As mentioned previously (p. 11), half of each specimen (except for the Purgatory Peak iron) is preserved at the National Institute of Polar Research, Tokyo, Japan. The remaining material is held and available for study partly at the Johnson Space Center Houston, Texas, and partly at the Smithsonian Institution, Washington, D. C. Each of these three institutions has a collection of polished thin sections of the stony meteorites, and these sections may be examined by interested scientists.

Preliminary examination of these meteorites has been based on small chips, usually from near-surface weathered material probably close to the fusion crust. In a few instances, more complete examination and consideration of possible pairings has resulted in a revision of the classification given in the Antarctic Newsletter. These revisions are (original classification in parentheses): ALHA77003, H3(L3); 77124, H5(H6); 77191, H4(H5); 77214, L3(LL3); 77219, mesosiderite (diogenite); 77224, H4(H5); 77252, L4 with L6 clasts (L5-6); 77278, LL3(L3).

The classification of the meteorites described here are summarized as follows: Chondrites.—*C2*: ALHA77306 (19.9 g). *C3*: ALHA77307 (181 g). *H3*: ALHA77003 (780 g), 77299 (261 g). *L3*: ALHA77015 (411 g), 77033 (9.3 g), 77140 (78.6 g), 77160 (70.4 g), 77164 (38.1 g), 77165 (30.5 g), 77167 (611 g), 77214 (2097 g), 77249 (504 g), 77260 (744 g). *LL3*: ALHA76004 (305 g), 77287 (313 g), 77304 (650 g). *H4*: ALHA77004 (2230 g), 77190 (387 g), 77191 (642 g), 77192 (845 g), 77208 (1733 g), 77224 (787 g), 77233 (4087 g), 77262 (862 g). *L4*: ALHA77215 (820 g), 77216 (1470 g), 77230 (2473 g), 77252 (343 g). *H5*: ALHA77014 (309 g), 77021 (16.7 g), 77025 (19.4 g), 77061 (12.6 g), 77062 (16.7 g), 77064 (6.5 g), 77071 (10.9 g), 77074 (12.1 g), 77086 (19.4 g),

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77088 (51.2 g), 77102 (12.3 g), 77118 (7.8 g), 77119 (6.4 g), 77124 (4.4 g), 77177 (368 g), 77182 (1109 g), 77264 (11.0 g), 77294 (1351 g), 77300 (235 g). *L5*: ALHA77002 (235 g), 77254 (246 g). *H6*: ALHA76006 (1137 g), 76008 (1150 g), 77144 (7.9 g), 77148 (13.1 g), 77258 (597 g), 77271 (610 g), 77285 (271 g), 77288 (1880 g), MBRA76001 (17881 g). *L6*: ALHA76001 (20151 g), 76003 (10495 g), 76007 (410 g), 76009 (407000 g), 77001 (252 g), 77150 (58.3 g), 77155 (305 g), 77231 (9270 g), 77261 (412 g), 77269 (1045 g), 77270 (589 g), 77272 (674 g), 77273 (492 g), 77277 (143 g), 77280 (3226 g), 77281 (1231 g), 77282 (4127 g), 77284 (376 g), 77296 (963 g), 77297 (952 g), 77305 (940 g). *H?*: ALHA77081 (8.6 g). ACHONDRITES.—*Eucrites*: ALHA76005 (1425 g), 77302 (236 g). *Diogenite*: ALHA77256 (676 g). *Ureilite*: ALHA77257 (1996 g). *Unique*: ALHA77005 (483 g). STONY-IRONS.—*Mesosiderite*: ALHA-77219 (637 g). IRONS.—ALHA76002 (1510 g), 77250 (10555 g), 77255 (765 g), 77263 (1669 g), 77283 (10510 g), 77289 (2186 g), 77290 (3784 g), PGPA77006 (19068 g).

Chondrites

CLASS C2

FIGURE 8

ALHA77306 (19.9 g).—A fusion crust 0.5–1.0 mm thick is present on approximately 50% of the specimen. The crust is cracked, broken, and furrowed. Some areas are glassy and vesicular; the remainder of the crust has a dull matte finish. The specimen is remarkably free of limonite stain. A light gray weathering rind 2–4 mm deep has formed on portions of the stone lacking fusion crust. On freshly broken surfaces the interior appears charcoal-gray with a slight olive-green cast. The matrix is fine-grained with 2% to 3% of light-colored, irregularly shaped inclusions scattered throughout. No obvious chondrules are visible in the hand specimen, but there are a few light-colored, 0.1–0.2 mm spherical masses. No white veins were observed. Several vugs, ~1 mm across, were noted when the meteorite was chipped in half.

Thin sections reveal a few sparse, poorly defined chondrules up to 0.5 mm in diameter; most consist largely of granular olivine and some contain small globular grains of nickel-iron. The bulk of the meteorite (80% to 90%) consists of opaque to translucent olive-brown matrix, the translucent material showing weak birefringence; an X-ray powder photograph shows that the matrix consists largely of a layer-lattice silicate, which by analogy with other C2 meteorites can be tentatively identified as as ferruginous chlorite. Scattered through the matrix are colorless birefringent grains, mostly olivine, up to 0.3 mm but usually

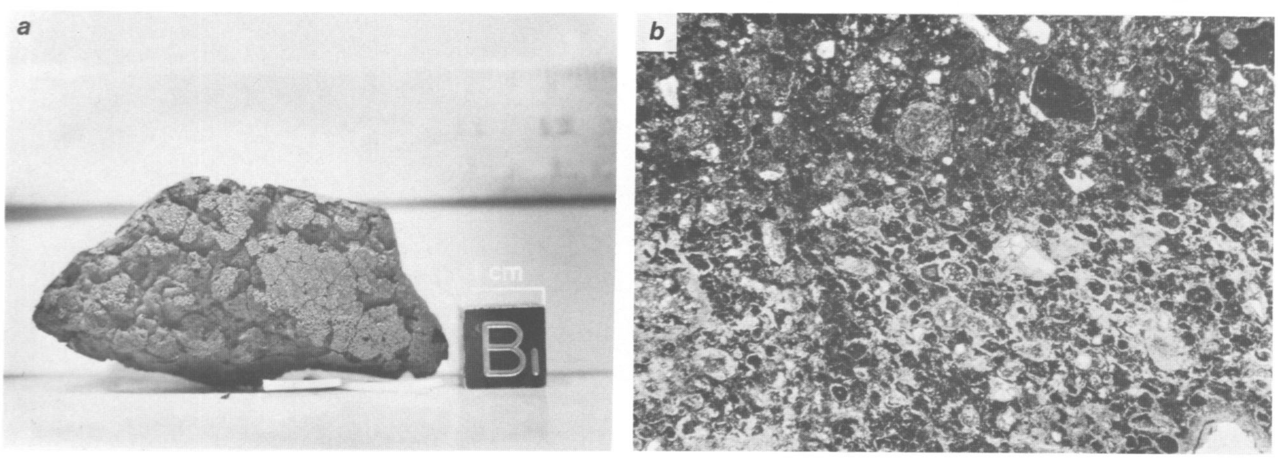


FIGURE 8.—ALHA 77306, C2 chondrite: *a*, A partial coating of fusion crust (lighter gray) is present. *b*, Photomicrograph of thin section (width of field is 2.0 mm); irregular grains and rare chondrules, mainly of olivine (white to light gray) in opaque to translucent matrix (dark gray to black).

less than 0.1 mm across. Rare grains of chromite are present in the matrix. A notable feature is the apparent absence of metallic sulfides. The meteorite is moderately porous, containing irregular voids up to 0.3 mm across; the specific gravity, 2.58, measured on a small fragment, is therefore probably somewhat lower than the true value. No evidence of weathering was seen in the section, which suggests that the meteorite may be a recent fall.

Class C3

Figure 9

ALHA77307 (181 g).—The rounded specimen (4.5 × 4.0 × 5.0 cm) is covered with a dull black fusion crust ~1–2 mm thick, except for a fracture surface at one end (Figure 9*a*) about ~1/8 of the total surface area. The fusion crust is characterized by delicate polygonal fractures. In a few places the crust has broken away, revealing a black fine-grained matrix. The specimen is cut by several large fracture planes. On the surface near one of these fractures there is a white material, which may be an evaporite deposit. The side of the specimen that was in contact with the ice at the time of recovery is slightly reddish. Small, irregular white inclusions and several chondrules are apparent on some freshly broken surfaces.

The thin section (Figure 9*b*) shows a closely packed aggregate of mineral grains (up to 0.2 mm), mineral aggregates (up to 0.8 mm), and rather sparse small (0.1–0.5 mm) chondrules, set in a dark brown to black opaque matrix; the matrix makes up to 40% to 50% of the section. The mineral grains, aggregates, and chondrules consist of olivine and polysynthetically twinned clinopyroxene in approximately equal amounts. Microprobe analyses show that most of the olivine has forsterite composition, $Fa_{\sim 1}$, with a few grains ranging up to Fa_{30}; the average for 30 grains is Fa_5. The pyroxene is mostly clinoenstatite, $Fs_{\sim 1}$, but with a few more iron-rich grains. A little (1% to 2%) nickel-iron is present in the matrix as scattered grains, many partly altered to brown limonite. Fine-grained sulfide (~5%) is dispersed throughout the matrix. Fusion crust, 0.5 mm thick, is present along one edge of the thin section. The meteorite is a carbonaceous chondrite; an X-ray powder photograph shows that the matrix consists largely of olivine and pyroxene with some magnetite, which indicates a C3 classification.

Class H3

Figure 10

ALHA77003 (780 g).—The specimen (Figure 10*a*) is very well-rounded and no surface fissures

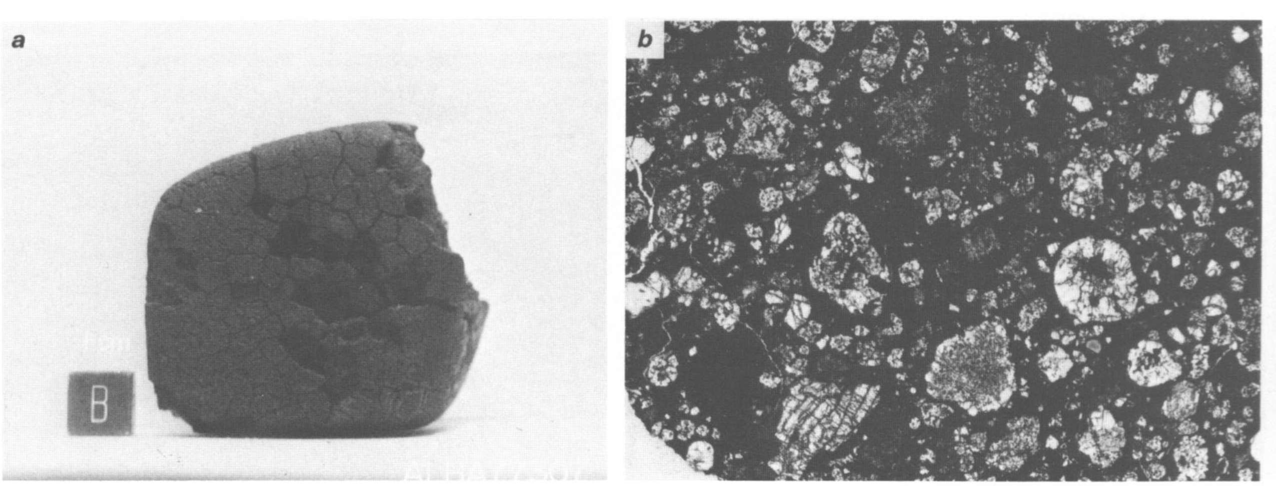


Figure 9.—ALHA77307, C3 chondrite: *a*, Fusion crust is crazed and broken away in places. *b*, Photomicrograph of thin section (width of field is 2.0 mm); irregular grains, aggregates, and rare chondrules of olivine and pyroxene (white or light gray) in dark brown to opaque matrix (black).

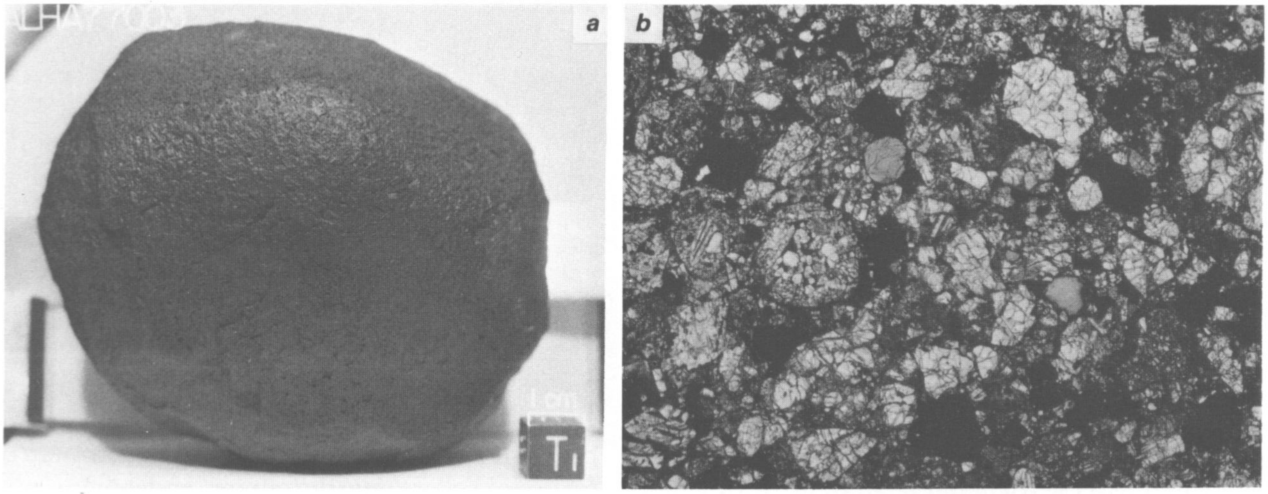


FIGURE 10.—H3 chondrites: *a*, ALHA77003, upper surface, showing fusion crust. *b*, ALHA 77299, photomicrograph of thin section (width of field is 2.0 mm); a closely packed mass of chondrules and irregular aggregates mainly of olivine and pyroxene set in a minor amount of dark matrix.

are present. A medium black, slightly glassy fusion crust, 1–3 mm thick, covers approximately 35% of the meteorite on the surfaces that were up at the time of discovery. The remaining surface of the meteorite is smooth, brownish black, and has a polished appearance, which may be due to wind action or to the presence of the lower portion of an abraded fusion crust. There is very little iron-oxide staining, except on one area of approximately 1 × 2 cm where the interior is exposed. Abundant small (~1 mm) metallic flecks, chondrules, and lithic clasts were observed after the meteorite was cut in half. These inclusions, with the exception of the metallic material, for the most part ranged in color from white to tan. The overall dimensions of the stone are 10.3 × 8.7 × 9.2 cm.

The polished thin section shows numerous and well-defined chondrules, 0.1–0.6 mm in diameter, together with mineral clasts, in a fine-grained groundmass, which is stained brown with hydrous iron oxides. The chondrules exhibit a variety of form and structure, the most common consisting of granular aggregates of olivine and polysynthetically twinned clinopyroxene; some chondrules have pale brown transparent glass interstitial to the olivine and pyroxene grains. Microprobe analyses show that both olivine and pyroxene have a wide range of composition. Olivine ranges from Fa_4 to Fa_{48}, with a mean of Fa_{22}; pyroxene ranges from Fs_2 to Fs_{25} with a mean of Fs_{14}, and its calcium content averages 1% CaO. The wide range of composition of olivine and pyroxene indicates a type 3 chondrite, and the chemical analysis (Appendix 2) shows that it belongs to the H group (this meteorite was tentatively classified L3 in the preliminary examination).

ALHA77299 (261 g).—The specimen (9.5 × 5.5 × 3.5 cm) is roughly tabular. A thin patchy fusion crust covers approximately 10% to 15% of the surface. The remaining surface areas are smooth, medium brown, and partially coated with glass, which probably is the inner portion of an abraded fusion crust. Fresh metal, chondrules, and lithic clasts are visible in hand specimen. A weathering rind, 1 mm thick, is present on all sides of the specimen.

The thin section (Figure 10*b*) shows a closely packed mass of chondrules (0.15–1.5 mm diameter) and irregular crystalline aggregates with interstitial nickel-iron and troilite and a small amount of matrix. A considerable variety of chondrules is present: many are granular or porphyritic olivine with transparent to turbid interstitial glass; other types consist of fine-grained pyroxene, medium-grained olivine and polysynthetically twinned clinopyroxene, or barred olivine. The section is stained yellow-brown with limonitic material, with small areas (as much as 0.4 mm across) of reddish brown limonite along one edge (near-surface?). Microprobe analyses show olivine ranging in composition from Fa_{11} to Fa_{21}, with a mean of Fa_{16}; the pyroxene is low-calcium (CaO = 0.4% to 1.2%), with a range in composition from Fs_{15} to Fs_{20} and a mean of Fs_{18}. The mean composition of the olivine and the amount of nickel-iron suggest H group, so the meteorite is classified as H3. A chemical analysis of this meteorite is given in Appendix 2.

Class L3

Figures 11–15

ALHA77015 (411 g).—The specimen (Figure 11*a*) is angular, 9.0 × 5.5 × 5.0 cm, and charcoal-brown fusion crust with vitreous luster covers approximately 50% of the surface. Fusion crust is present on the S surface, and is partially preserved on the B surface. The remainder of the sample is devoid of fusion crust; however, it is nearly the same color as the portion with fusion crust. Both angular lithic fragments and chondrules are observed on the B surface. These range in color from light brown to dark gray and are as large as 0.5 cm in maximum length. Many fractures are present. When the meteorite was cleaved it broke along fractures, thus producing only one chip with unweathered material exposed. This chip revealed dark matrix with small, unweathered metallic grains.

The polished thin section shows a closely packed aggregate of chondrules, 0.2–1.8 mm in diameter, with only minor fine-grained matrix. Chondrules are mostly olivine and olivine plus polysynthetically twinned clinopyroxene; transparent pale brown glass is interstitial to olivine and pyroxene grains in some chondrules. Minor subequal amounts of nickel-iron and troilite are present, concentrated in the matrix and at chondrule margins; the nickel-iron grains are corroded extensively and altered to limonite, and thin veins of limonite occur throughout the section. Microprobe analyses show a wide range in the composition of olivine (Fa_1–Fa_{21}) and pyroxene (Fs_4–Fs_{24}); the pyroxene is a low-calcium clinopyroxene (CaO = 0.2% to 0.5%). This range of com-

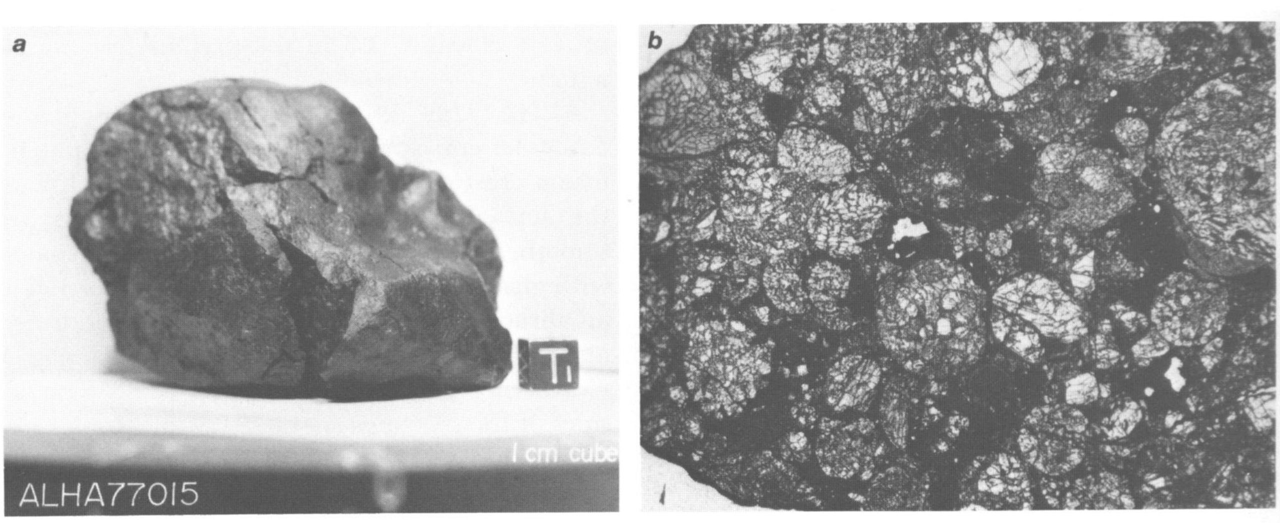


Figure 11.—L3 chondrites: *a*, ALHA77015, part on the right is coated with fusion crust; the part on the left is a fracture surface. *b*, ALHA77033, photomicrograph of thin section (width of field is 2.0 mm); a close-packed aggregate of chondrules characteristic of type 3 chondrites.

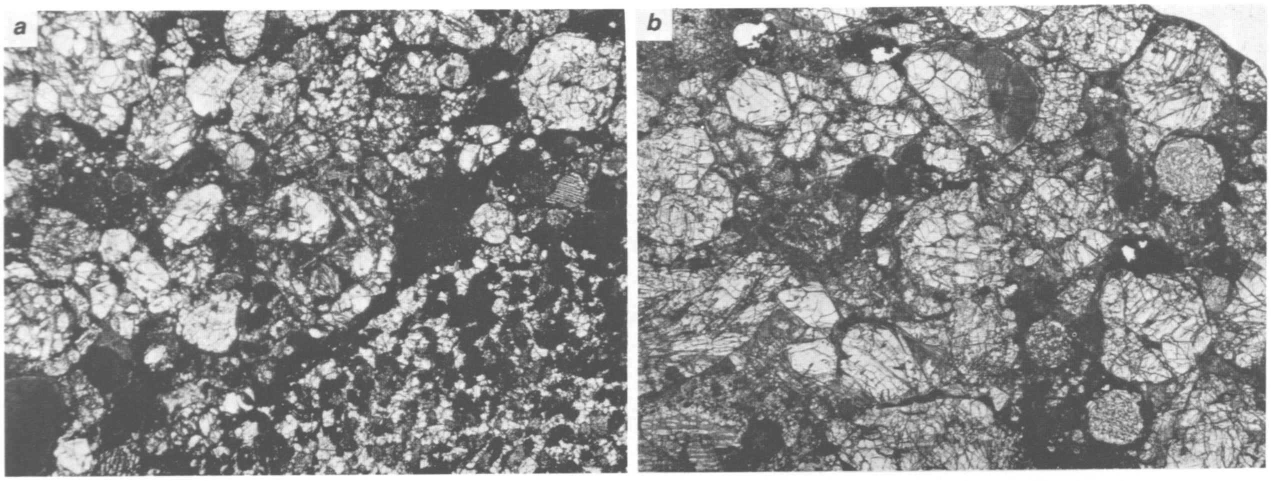


FIGURE 12.—L3 chondrites: *a*, ALHA77140, photomicrograph of thin section (width of field is 2.0 mm); chondritic material encloses a granular nonchondritic enclave. *b*, ALHA77160, photomicrograph of thin section (width of field is 2.0 mm); a close-packed aggregate of chondrules characteristic of type 3 chondrites.

position, together with the presence of glass and twinned clinopyroxene, indicates type 3, and the small amount of nickel-iron suggests L group; the meteorite is therefore tentatively classed as an L3 chondrite.

ALHA77033 (9.3 g).—The specimen is angular, rough and dark brown. Exterior surfaces are highly weathered and do not appear to have fusion crust. The stone chipped easily, revealing a highly oxidized broken face.

The polished thin section (Figure 11*b*) shows a closely packed mass of chondrules (0.3–1.1 mm diameter) and irregular crystalline aggregates, with a small amount of interstitial nickel-iron and troilite (1% to 2% of each) and a relatively small amount of fine-grained matrix. A considerable variety of chondrules is present, the most common being granular olivine and olivine plus polysynthetically twinned clinopyroxene, porphyritic olivine, and fine-grained pyroxene. Some chondrules have intergranular transparent pale brown glass. In others the glass is turbid and partly devitrified. Yellowish brown limonitic staining pervades the section, and patches and veinlets of reddish brown limonite are common. Microprobe analyses show olivine ranging in composition from Fa_8 to Fa_{38}, with a mean of Fa_{18}; the pyroxene is relatively uniform in iron content (Fs_{8-9}) but shows a considerable range in calcium ($Wo_{0.3-8.5}$). The low content of nickel-iron and troilite suggest L group, and the meteorite is classified L3.

ALHA77140 (78.6 g).—The specimen is roughly conical. The basal portion is irregular and appears to be broken surface. The remainder of the surface is extensively weathered, making it difficult to tell how much fusion crust remains. The entire meteorite (4.6 × 3.3 × 3.0 cm) is a dark reddish brown with considerable iron-oxide staining. Small (~1 mm) metallic and many light colored inclusions, chondrules and lithic fragments (?) are visible in the gray matrix material on the sawed surface of the stone. However, some areas of the stone are iron oxide-stained. A small, thin, white, presumably evaporite, deposit is present on this stone.

The polished thin section (Figure 12*a*) shows an elliptical nonchondritic enclave (8 × 5 mm), completely enclosed in chondritic material. The enclave consists of polysynthetically twinned clinoenstatite (with a range of composition, averaging $Wo_{0.2}Fs_7En_{93}$) poikilitically enclosing irregular to globular isotropic or weakly anisotropic masses. These masses range in composition (SiO_2

59% to 83%, FeO 15% to 31%, MgO 5% to 9%, K_2O 2.7% to 4.3%, Na_2O 0.6% to 2.5%, Al_2O_3 ~0.3%, CaO, TiO_2, <0.1%); they appear to be devitrified glass, and some analyses are close to that of merrihueite. The chondritic portion consists of a close-packed mass of chondrules, with a relatively small amount of fine-grained matrix. Chondrules range in diameter from 0.2 to 2 mm, and exhibit a variety of form and structure; the most common type consists of granular aggregates of olivine and polysynthetically twinned clinopyroxene, commonly with a little interstitial glass. Both olivine and clinopyroxene have a wide range of composition. Olivine ranges from Fa_8 to Fa_{44}, with an average of Fa_{25}; pyroxene ranges from Fs_2 to Fs_{17}, with an average of Fs_7 and a low calcium content, averaging 0.2% CaO. Troilite and nickel-iron are interstitial to the chondrules, and part of the nickel-iron has weathered to limonitic material. The highly variable composition of olivine and pyroxene indicates a type 3 chondrite, and the mean composition of the olivine and the amount of nickel-iron suggest L group, so the meteorite is tentatively classified L3.

ALHA77160 (70.4 g), 77164 (38.1 g), 77165 (30.5 g).—These three pebble-sized meteorites are so similar in physical appearance and petrography that they are described together; they may be different pieces of the same meteorite. Although some fusion crust is still present, most of the surface of these stones is dark brown and has a patina that probably resulted from chemical weathering and wind polishing. All three specimens have broken surfaces and are not, therefore, complete.

Thin sections (Figure 12*b*) show abundant chondrules, 0.2–2.5 mm diameter, in a minimal amount of dark fine-grained matrix; some chondrules are spherical, but many are elliptical to irregular in form. The chondrules are composed mainly of barred or porphyritic olivine, some with polysynthetically twinned clinopyroxene. Interstitial glass in chondrules is pale gray, transparent to turbid. Minor subequal amounts of troilite and nickel-iron are present, the nickel-iron is extensively altered to red-brown limonitic material, which pervades the section along chondrule boundaries. Microprobe analyses show a wide range of olivine composition, Fa_3–Fa_{46}, and a similar range in pyroxene composition. This range in composition, together with the presence of glass and twinned clinopyroxene, indicates type 3, and the small amount of nickel-iron suggests L group; these meteorites, therefore, are classified L3 chondrites.

ALHA77167 (611 g).—This is an angular specimen (Figure 13), approximately 12.5 × 8.0 × 6.0 cm, and is weathered very dark reddish brown. The S surface has small remnants of fusion crust, but the other surfaces are broken. Fractures are present on the N, S, and B surfaces. Some light-colored angular clasts and chondrules, as much as 0.5 cm in diameter, are apparent through the weathering rind. Many small holes are distributed randomly over the exterior of the stone, presumably due to the weathering out of lithic clasts and chondrules. When the sample was cleaved it broke into many pieces, none of which exposed fresh unweathered material.

The polished thin section shows a closely packed aggregate of chondrules and chondrule fragments, with a minimal amount of dark fine-grained matrix. The chondrules range from 0.2

FIGURE 13.—ALHA77167, L3 chondrite; a deeply fractured stone with a pitted surface, probably produced by the weathering out of lithic clasts and chondrules.

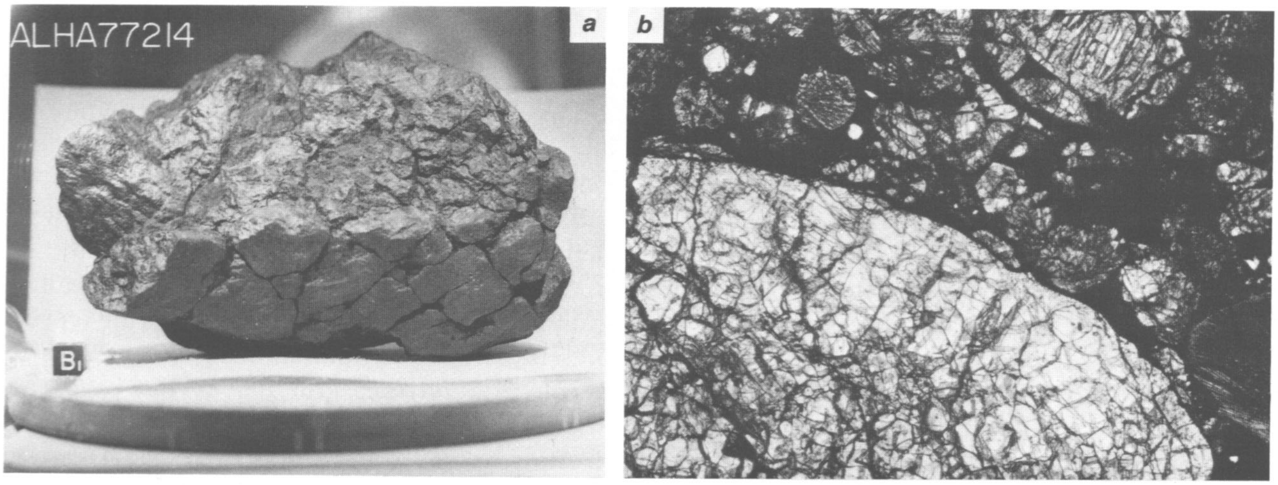


FIGURE 14.—ALHA77214, L3 chondrite: *a*, Note well-developed fissuring and remnants of original surface on lower part. *b*, Photomicrograph of thin section (width of field is 2.0 mm), showing part of elliptical granular inclusion (p. 20).

mm to 1.5 mm in diameter, and show a variety of types, the most common being granular olivine, olivine-pyroxene, and fine-grained pyroxene (commonly radiating). The pyroxene is polysynthetically twinned clinopyroxene. The granular chondrules contain intergranular glass, mostly turbid and partly devitrified, but rarely transparent and pale violet in color. Minor amounts of nickel-iron and troilite are present, commonly concentrated on the surface of chondrules. The meteorite is weathered extensively, with brown limonitic staining pervading the section and numerous veins and small patches of limonite throughout. Microprobe analyses show a wide range in the composition of olivine (Fa_2–Fa_{41}) and pyroxene (Fs_3–Fs_{17}); the pyroxene is low-calcium (CaO = 0.2% to 0.5%). This range of composition, together with the presence of glass and twinned clinopyroxene, indicates type 3, and the small amount of nickel-iron suggests L group; the meteorite is therefore tentatively classed as an L3 chondrite.

ALHA77214 (2097 g).—The specimen (Figure 14*a*) is angular (approximately 16 × 7 × 14 cm), with remnants of fusion crust on 30% of the surface. Another 30% of the surface may have been covered with fusion crust that has been abraded away. The remaining surface is a fracture plane. The stone contains many fissures. The material near these is severely weathered and friable. Snow was observed in several of the fissures when the meteorite was removed from cold storage. A weathering patina, ranging from brown through brownish black, covers the total specimen with the exception of the fracture surface. Some oxidized-iron staining is apparent on the exterior surface; however, the most severe staining occurs on the material adjacent to the fissures and on the fracture surface. A number of chondrules are visible in the hand specimen.

The polished thin section shows considerable weathering, with much of the metal oxidized to limonite. However, the narrow end of the section shows much more weathering than the wider end, giving some hope that the deep interior of the stone may be much fresher. Troilite is abundant and outlines the margins of many chondrules. Chondrule margins are sharply distinguishable from the fine-grained matrix. At least two chondrules contain fresh pinkish brown glass that shows strain isogyres in crossed polarizers. Most chondrules appear to be fluid-drop chondrules, and some are broken or are only small portions of their original volumes, as judged from their radii of curvature. Some chondrules, ranging in size to more than 4 mm in maximum diameter, contain large euhedral olivine crystals, and some large euhedral olivine and pyroxene grains occur as individual crystals. A number of the fluid-drop and lithic chondrules appear to be surrounded by fine-grained troilite-rich dark rims or rinds, but the exact nature of the rims is difficult to distinguish because of the weathering. Microprobe analyses show a wide range in olivine composition, Fa_1–Fa_{49}. The section contains an elliptical body 3 mm across (a chondrule or a lithic fragment) with a poikilitic texture of orthopyroxene ($Wo_1Fs_{13}En_{86}$) enclosing smaller round grains of olivine Fa_{17-20}, averaging Fa_{18} and another pyroxene (?) (Figure 14*b*). Other lithic fragments are present. A chemical analysis of this meteorite is given in Appendix 2.

ALHA77249 (504 g).—The sample has broken surfaces and is only partially covered with fusion crust (Figure 15*a*). The S and T surfaces have very thin, dull black patches of fusion crust. The B surface has thin, shiny black fusion crust, portions of which have weathered to reddish brown. There are numerous inclusions, both lithic clasts and chondrules, visible through the reddish brown oxidation rind. The largest chondrule is approximately 0.5 cm in diameter and is lighter colored than the surrounding matrix. A few inclusions that are darker than the matrix also are observed; however, they are not as numerous or as large. The sample is angular, 11.0 × 6.5 × 5.0 cm, and has many obvious fractures on the exterior surface.

The thin section shows an aggregate of well-defined chondrules, 0.3–2.1 mm in diameter, set in a relatively small amount of fine-grained groundmass. A wide variety of chondrule types is present, the most common being barred olivine, porphyritic olivine, granular olivine-pyroxene, and fine-grained pyroxene. The olivine chondrules commonly have interstitial glass, mostly turbid and partly devitrified, but rarely transparent and pale brown. Pyroxene grains show polysynthetic twinning. Sparse nickel-iron and troilite are concentrated on the surfaces of chondrules. Limonitic staining pervades the section, and scattered grains of reddish brown limonite are present. Microprobe analyses show a wide range in the composition of olivine (Fa_7–Fa_{35}, average Fa_{17}) and pyroxene (Fs_2–Fs_{25}, average Fs_{11}). This range of composition, together with the presence of glass and twinned clinopyroxene, indicates type 3, and the small amount of nickel-iron suggests L group; the meteorite, therefore, is tentatively classified as an L3 chondrite.

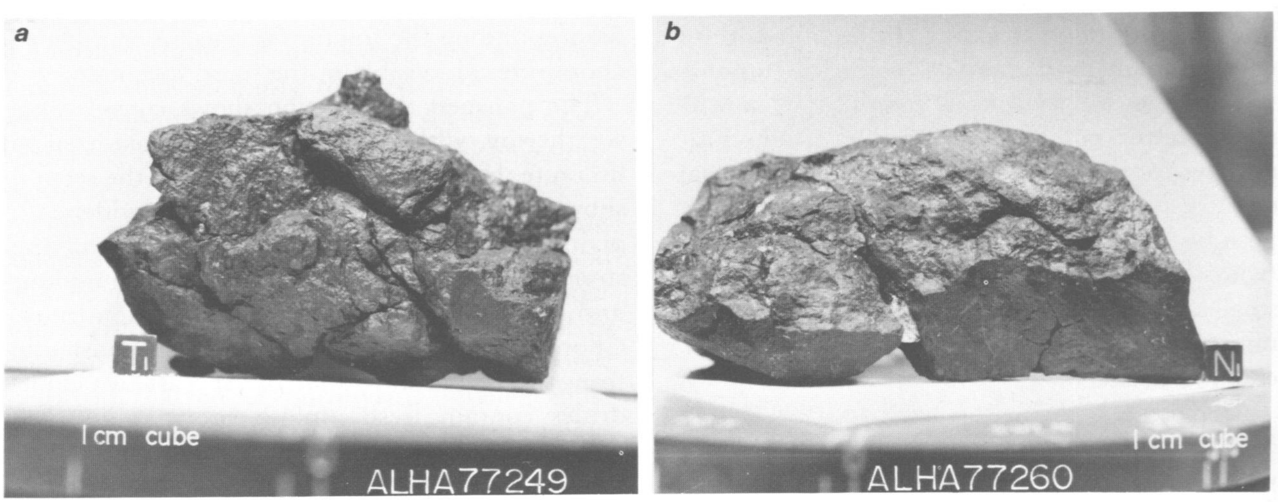


FIGURE 15.—L3 chondrites: *a*, ALHA77249, deeply fractured stone with remnants of fusion crust (lower right). *b*, ALHA77260, a fractured stone with fusion crust on the lower part.

ALHA77260 (744 g).—The specimen is oblong (Figure 15*b*), 14.0 × 5.5 × 6.5 cm. A thin fusion crust, approximately 0.5 mm, covers 50% of the specimen. There are several fractures that penetrate the stone, and snow was preserved in these when it was removed from cold-storage. Light colored, lithic clasts and chondrules, as much as 0.5 cm in maximum length, were observed on the fractured surfaces. Apparently, the reddish brown color of the weathering rind masks out the darker inclusions on the exterior surface. The meteorite appears to be weathered throughout.

The polished thin section shows well-developed chondritic structure. The chondrules range from 0.2–1.5 mm in diameter, and some of the chondrules are irregular or broken. A variety of chondrule types is present, the most common being barred olivine, granular olivine-pyroxene, and fine-grained radiating pyroxene. The barred and granular chondrules have interstitial glass, mostly turbid and partly devitrified, but occasionally transparent and pale brown. Much of the pyroxene is polysynthetically twinned clinopyroxene. The groundmass is fine-grained olivine and pyroxene, with minor subequal amounts of nickel-iron and troilite. Limonitic staining and rare patches of limonite are present throughout the section. Microprobe analyses show a wide range of composition for both olivine (Fa_{7-23}, average Fa_{16}) and pyroxene (Fs_{1-28}, average Fs_{11}). The wide range of composition of olivine and pyroxene indicates a type 3 chondrite, and the small amount of nickel-iron suggests L group, thus the meteorite tentatively is classified L3.

Class LL3

FIGURES 16, 17

ALHA76004 (305 g).—This meteorite was collected by the 1976–77 party. Olsen, et al. (1978: 214–216) described it (as Allan Hills #4) as follows:

> [It] is a very heterogeneous breccia consisting of chondrules and chondrule fragments, clasts of several different crystalline rocks, clasts of glass, and quenched glasses that are interstitial to the clasts .... Thin-section examination shows a low metal/sulfide ratio, which is appropriate for an LL-group chondrite. Four thin sections showed metal present between 1 and 4% .... A random survey of olivine and pyroxene compositions in a thin section yield ranges from Fa_0 to Fa_{34}, and Fs_0 to Fs_{53}. When plotted on a histogram there are no peak compositions evident for either mineral. Minor phases include plagioclase, nepheline, fassaite, chromite, and other spinel-group phases.

ALHA77278 (313 g).—This is a moderately rounded conical specimen (Figure 16), approximately 8.0 × 5.5 × 4.5 cm, and appears to be a

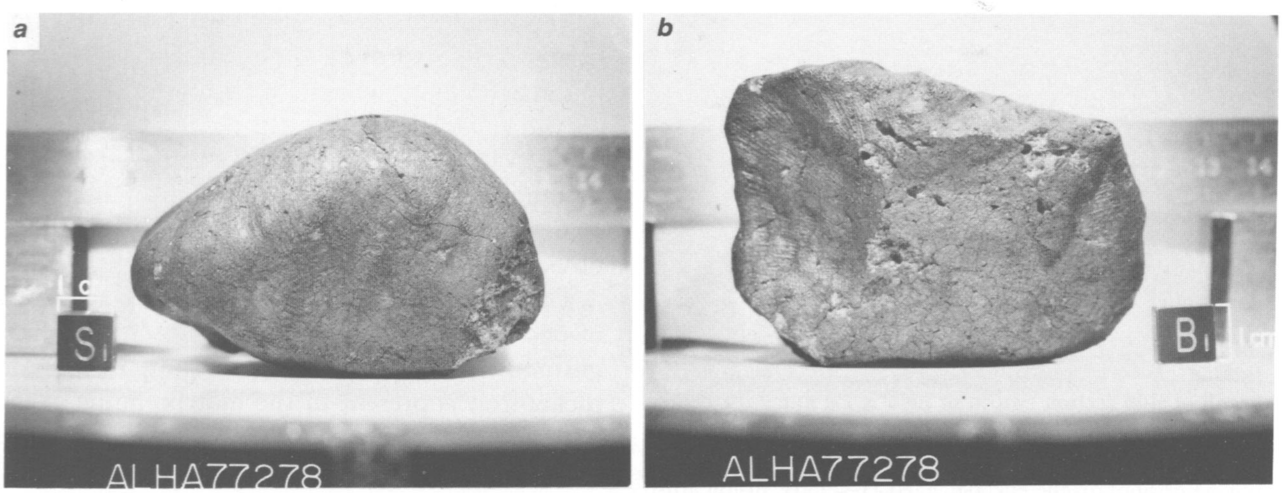


FIGURE 16.—ALHA77278, LL3 chondrite: *a*, Note conical form. *b*, Posterior surface showing radial flow lines in fusion crust.

complete stone (except the B surface). Approximately 95% of the surface area is covered by dull black fusion crust that is ~1–2 mm thick. The fusion crust on the B (posterior) surface is reddish, shows well-developed radial flow lines, and is more oxidized than the other surfaces. Several spots (~1 cm diameter), where the fusion crust has been plucked, reveal interior material that is dark gray and moderately stained by oxidized iron. No weathering rind is present; however, some of the near-surface clasts are highly weathered, but the matrix is not.

The polished thin section (Figure 17*a*) shows a closely-packed aggregate of spherical to ellipsoidal chondrules (0.3–1.8 mm diameter) with interstitial nickel-iron and troilite (concentrated as rims to chondrules) and relatively little matrix. Most chondrules consist of granular or porphyritic olivine, commonly accompanied by polysynthetically twinned clinopyroxene, and with partially devitrified glass between the mineral grains. Microprobe analyses show that both olivine and pyroxene have a range of composition; olivine ranges from Fa_{11} to Fa_{29}, with a mean of Fa_{24}, and pyroxene is low-calcium (Ca = 0.1% to 0.4%) ranging from Fs_9 to Fs_{21}, with a mean of Fs_{12}. Some unusual enclaves were noted in the section. One, 1.5 mm across, consists of numerous small (maximum 0.2 mm) grains of olivine and pyroxene in a brown-black semitranslucent, possibly carbonaceous matrix. Another, 3 mm long, consists of an aggregate of olivine (composition Fa_{13}-Fa_{26}) and orthopyroxene ($Fs_{16\text{-}17}$) grains with a little interstitial turbid glass. The section shows a slight amount of yellow-brown limonitic staining, concentrated near the fusion crust. A chemical analysis of this meteorite is given in Appendix 2.

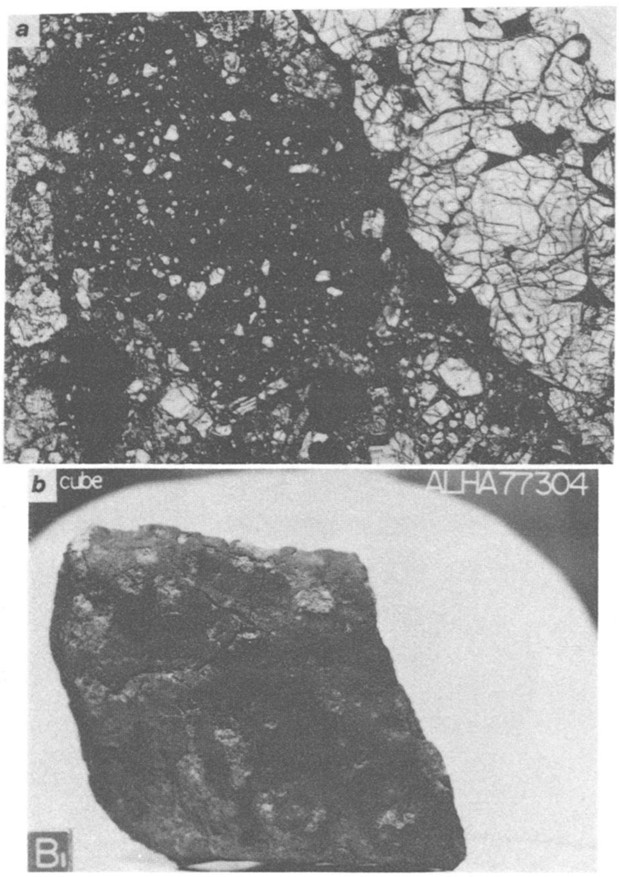


FIGURE 17.—LL3 chondrites: *a*, ALHA77278, photomicrograph of thin section (width of field is 2.0 mm); the center of the photograph is occupied by the carbonaceous(?) enclave described on p. 22, and also shows part of the granular olivine-orthopyroxene enclave. *b*, ALHA77304, fusion crust covers most of the surface, but has spalled off in small areas, revealing matrix material with numerous chondrules and lithic clasts.

ALHA77304 (650 g).—Dull, brownish black, fusion crust, approximately 0.5 to 1 mm thick, covers all but the W surface of this angular, 9.5 × 8.0 × 6.5 cm, sample (Figure 17*b*). On the W surface and small areas where the fusion crust has been plucked away, greenish matrix material with numerous chondrules and irregular lithic clasts, ranging from light to dark gray, and as much as 1 cm in diameter are exposed. A fracture on the B surface appears to penetrate the entire stone. When the meteorite was cleaved in half, haloing effects were observed around some inclusions in the interior of the stone. There is no obvious weathering rind.

The section shows a closely packed aggregate of chondrules with a minimum amount of fine-grained matrix; a small amount of troilite and nickel-iron is present in the matrix. Some of the chondrules are unusually large, ranging up to as much as 3 mm in diameter. The most common types are barred and porphyritic olivine chondrules with interstitial glass; some of the glass is isotropic and transparent, but most is turbid and partially devitrified. Polysynthetically twinned clinopyroxene occurs with the olivine in some chondrules. A 6 × 3 mm enclave, consisting of closely packed idiomorphic olivine crystals with interstitial turbid brown glass, is present at one edge of the section. Brown limonitic staining pervades the section. Microprobe analyses show olivine (Fa_{18-27}, average Fa_{24}) and pyroxene (Fs_{13-19}, average Fs_{15}) have a wide range of composition; the olivine in the enclave has uniform composition, Fa_{25}. A few grains of calcic plagioclase, averaging An_{77}, were noted. The low content of nickel-iron and troilite suggest LL group, and the wide range of olivine and pyroxene compositions type 3; thus the meteorite tentatively is classified LL3.

Class H4

Figures 18, 19

ALHA77004 (2230 g).—The angular specimen, 7.0 × 5.5 × 2.0 cm (Figure 18*a*), has many parallel fractures. Only the B surface has dull brownish black fusion crust. The other surfaces are weath-

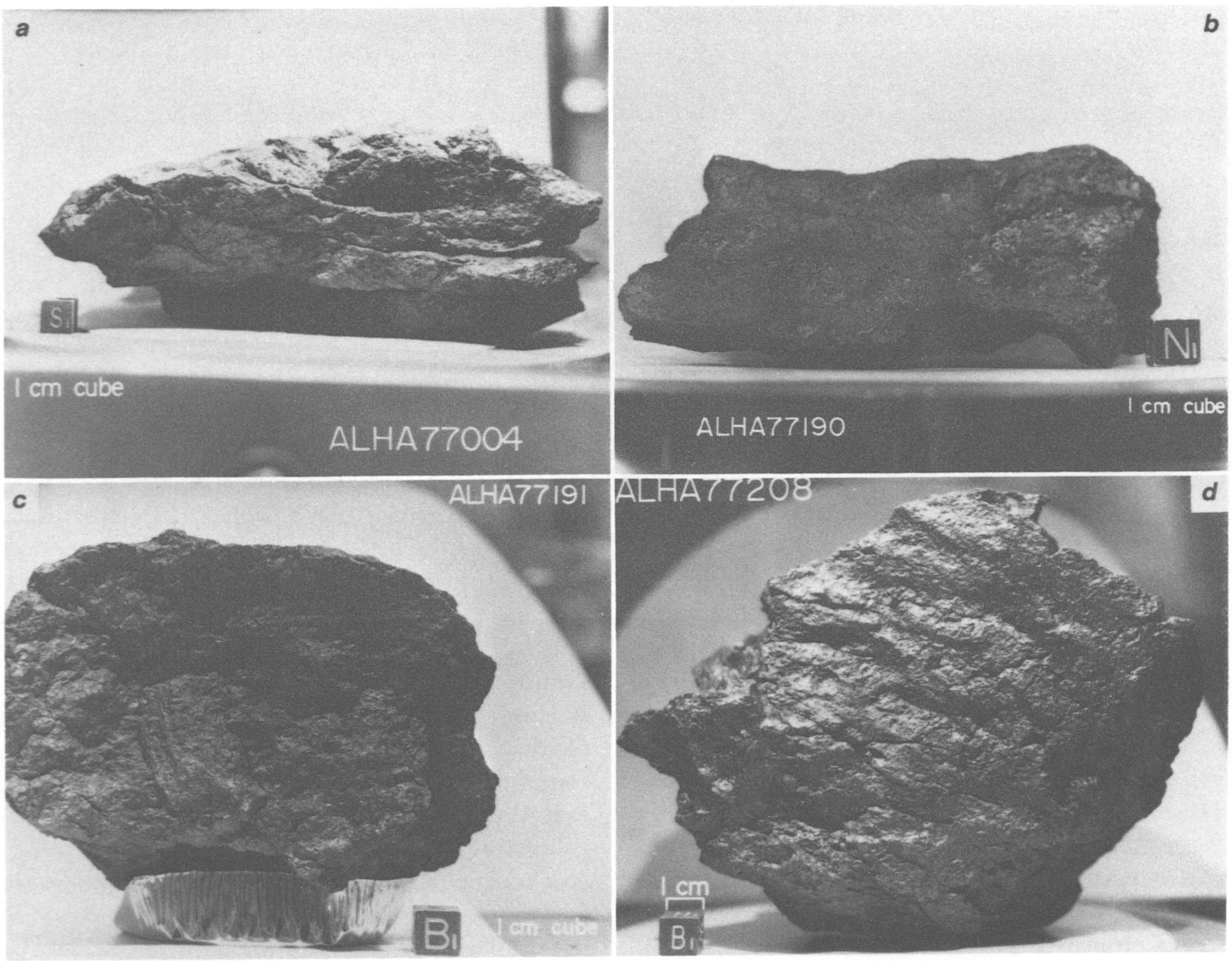


Figure 18.—H4 chondrites: *a*, ALHA77004, severely weathered stone with deep parallel fractures. *b*, ALHA77190, a tabular specimen with patchy remnants of dull black fusion crust. *c*, ALHA77191, the area photographed is a concave fracture surface, stained red-brown with iron oxides produced by weathering. *d*, ALHA77208, a severely weathered and deeply fractured stone, without fusion crust.

ered orangish brown. Because of the severity of the weathering, it is impossible to define the shape, size, and color of the inclusions, which are distinguished by textural changes on the exterior of the stone. When attempting to obtain a thin section sample, the stone broke into six pieces, none of which exposed unweathered material.

ALHA77190 (387 g).—The specimen is approximately 11.0 × 6.0 × 3.4 cm and is tabular (Figure 18*b*). The N, T, and S surfaces have remnants of a thin, dull black fusion crust. The E surface is highly oxidized, reddish brown and a fracture surface. No unweathered material was exposed in the meteorite when it was cleaved in half. The sample is a uniform reddish brown throughout. After drying in the nitrogen cabinet for 48 hours (after cleaving), a small spot area of white material, presumably evaporites, developed on the freshly exposed interior surface.

ALHA77191 (642 g).—This 11.0 × 7.0 × 5.0 cm specimen is semi-rounded (Figure 18*c*); however, the B surface is concave. This stone is extremely weathered, making it difficult to determine the amount of fusion crust present. The oxidation staining is semiglossy and reddish brown. Parallel fractures, in the north-south direction, penetrate the stone. No unweathered material was exposed by cleaving the stone in half; the same reddish brown oxidation staining that is present on the exterior of the stone penetrates throughout the specimen with the exception of a few areas, approximately 0.5 cm in diameter, which are slightly lighter. According to field notes, this is believed to be one of a group of 19 samples that are likely to be a single fall.

ALHA77192 (845 g).—The angular specimen (~9.0 × 8.0 × 15.0 cm) is void of fusion crust. The entire stone is weathered reddish brown, with the exception of a few small areas of gray matrix material that was exposed when the stone was cleaved in half. The severity of the weathering masks any textural characteristics. This is one of the 19 specimens that W.A. Cassidy believes to be related. The meteorites that have been initially processed and comprise this group are: ALHA77004, 77190, 77191, 77192, and 77233.

ALHA77208 (1733 g).—The specimen is angular, highly fractured, and severely weathered (Figure 18*d*). No fusion crust remains on the specimen. The fractures appear to penetrate throughout the 13.75 × 10.0 × 9.0 cm stone. Numerous chondrules and irregularly shaped fragments, as much as 1.0 cm in diameter, are apparent. When the stone was cleaved, only a few areas, ~2 mm in diameter, appeared unweathered and grayish. Approximately 95% to 97% of the interior surface was the same reddish brown color as the exterior of the stone.

ALHA77224 (787 g).—This is an angular specimen, approximately 13 × 14 cm, extremely weathered and friable, with many fissures that appear to penetrate throughout the meteorite. One surface shows patches of fusion crust (very thin) and remnants of regmaglypts. Small inclusions were observed on the weathered surfaces.

ALHA77233 (4087 g).—This stone is 15.0 × 14.0 × 10.5 cm (Figure 19*a*). Thin (<1 mm), dull black, patchy fusion crust is present on the S and E surfaces. The remainder of the stone is shiny reddish brown. White deposits, presumably evaporites, are present in minor cracks on all exterior surfaces. Chipping and cleaving of the specimen did not expose any unweathered material.

ALHA77262 (862 g).—The specimen is covered by dull, brownish black, polygonally fractured, fusion crust on all surfaces with the exception of the B surface, which is only partially covered. The angular stone (Figure 19*c*) is approximately 9.5 × 7.5 × 6.5 cm. Snow/ice was present on the sample when it was removed from cold storage. Areas of the sample are covered with a thin white coating, presumably evaporites. After drying the sample in the nitrogen cabinet, additional white material, which was not present during initial processing, was noted around many of the surface cracks. Small, irregular, and round inclusions are apparent on the sawed surface. Metallic particles present in the light gray matrix material of the sawed surface have oxidation halos. A weathering rind, as much as 0.8 cm thick, is present on the stone.

The thin sections (Figure 19*b, d*) of the H4

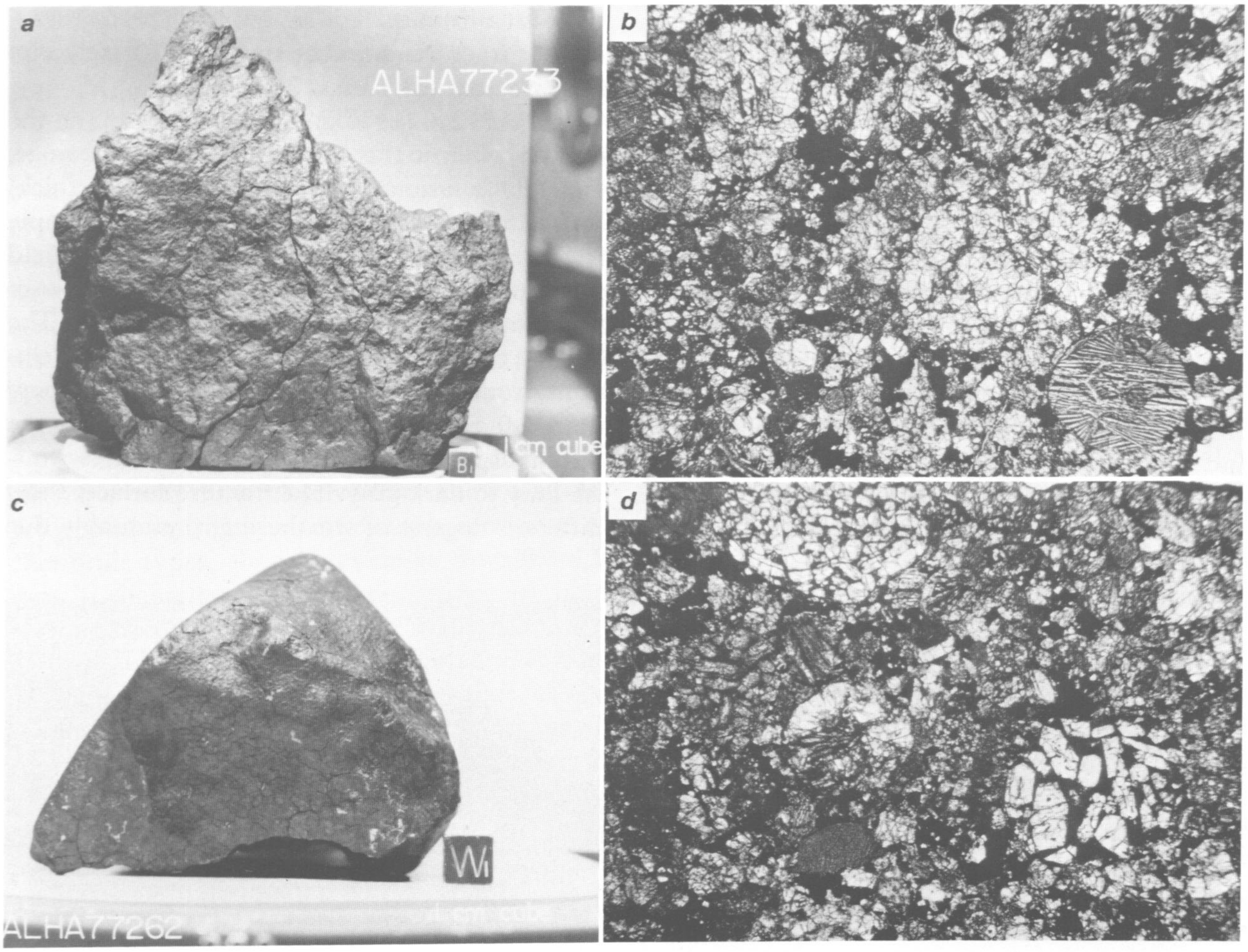


FIGURE 19.—H4 chondrites: *a*, ALHA77233, severely weathered and moderately fractured stone; *b*, photomicrograph of thin section (width of field is 2.0 mm), showing well-developed chondrules in a granular matrix. *c*, ALHA77262, angular, roughly conical stone covered with fusion crust except on the base; *d*, photomicrograph of thin section (width of field is 2.0 mm), showing large porphyritic and granular olivine chondrules.

chondrites resemble each other closely. They all show well-developed chondritic structure, chondrules averaging 0.5–1.0 mm in diameter. (ALHA77233 has some unusually large chondrules, ranging up to 2.8 mm in diameter.) A variety of chondrule types is present, the commonest being porphyritic to granular olivine, barred olivine, fine-grained pyroxene, and granular olivine-pyroxene. The chondrules are set in a fine-grained granular matrix consisting largely of olivine and pyroxene, with minor amounts of nickel-iron and troilite (nickel-iron in greater amount than troilite). Some of the pyroxene in the chondrules and in the matrix is polysynthetically twinned clinobronzite. All these meteorites are extensively weathered with brown limonitic staining throughout the sections, and veins and patches of limonite often associated with the nickel-iron grains. The section of 77190 is distinguished from the other H4 chondrites by the partial fragmentation of many of the chondrules, possibly shocked-induced. Microprobe analyses (Appendix 1) show variable olivine and pyroxene compositions (except in 77208 and 77224). Average composition of olivine ranges from Fa_{16} to Fa_{19}, of pyroxene from Fs_{14} to Fs_{17}.

Class L4

Figures 20–22

ALHA77215 (820 g).—The S surface of this specimen mostly is weathered reddish brown; however, a small remnant of fusion crust remains (Figure 20*a*). The E, W, and N surfaces are fractures that show numerous chondrules and lithic clasts. The largest chondrule is approximately 0.5 cm in diameter. Both the chondrules and lithic clasts commonly are lighter in color than the surrounding gray matrix. The surfaces not covered with weathering rind range from greenish brown to reddish brown. There are numerous fractures over the surface. The meteorite is approximately 13.0 × 7.0 × 7.0 cm.

ALHA77216 (1470 g).—Ice was present on the sample when it was removed from cold storage. Dull black fusion crust (as much 0.5 mm thick) covers half of the surface (Figure 20*b*). The sample is approximately 15.0 × 9.0 × 8.0 cm. Field photographs show that the T and N surfaces were in contact with the ice at time of recovery. The overall color is greenish gray. Numerous inclusions (rounded and irregular), ranging to more than 2.0 cm in diameter, are apparent on the fracture surfaces; these range from white to whitish gray to dark gray. The fracture surfaces show different degrees of weathering, presumably due

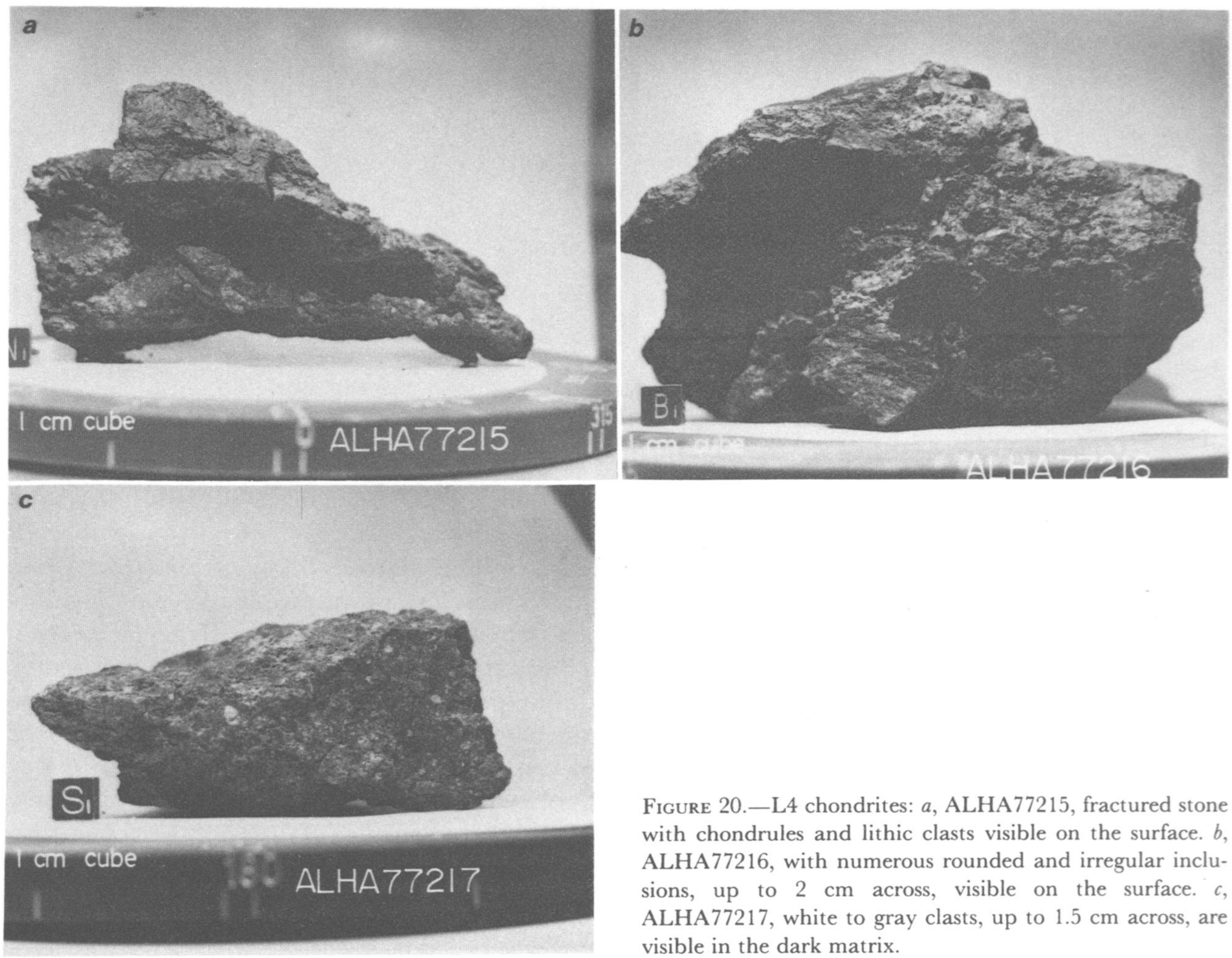


Figure 20.—L4 chondrites: *a*, ALHA77215, fractured stone with chondrules and lithic clasts visible on the surface. *b*, ALHA77216, with numerous rounded and irregular inclusions, up to 2 cm across, visible on the surface. *c*, ALHA77217, white to gray clasts, up to 1.5 cm across, are visible in the dark matrix.

to different lengths of surface exposure time. This meteorite is very heterogeneous on a centimeter scale. Many fractures penetrate the meteorite.

ALHA77217 (413 g).—This stone is approximately 9.5 × 7.0 × 4.5 cm (Figure 20*c*). Fusion crust (~1 mm thick) covers approximately 20% of the surface. The remaining surfaces are stained with hydrous iron oxides. The S surface is only lightly stained; presumably this is the most recently exposed surface. The broken surface show distinct clasts ranging from white to dark gray, as much as 1.5 cm in length. The stone is extremely heterogeneous on a centimeter scale.

The thin sections of 77215, 77216, and 77217 resemble each other closely. They show well-developed chondritic structure, with a variety of chondrule types; chondrules range from 0.3–1.8 mm in diameter. The chondrules are set in a granular groundmass consisting largely of olivine and pyroxene, with minor nickel-iron and troilite in approximately equal amounts. Much of the pyroxene, especially in the chondrules, is polysynthetically twinned clinopyroxene. Weathering is slight, being confined to a small amount of limonitic staining around the nickel-iron grains. Microprobe analyses show variability in olivine and pyroxene compositions; olivine; Fa_{17-26}, average Fa_{23}; pyroxene, Fs_{9-26}, average Fs_{17}. The thin section of 77216 contains three enclaves; two consist of granular olivine and pyroxene, and measure at least 3 mm across; the third is an irregular object 2 mm in maximum dimension, and consists of small grains of olivine and pyroxene in a translucent brown groundmass. Olivine and pyroxene in the two granular enclaves have essentially identical and uniform composition, Fa_{24} and Fs_{19}. Olivine in the brown enclave has uniform composition, Fa_{24}, but the pyroxene is somewhat variable, Fs_{13-21}, average Fs_{17}.

ALHA77215, 77216, and 77217 were collected in the same restricted area and are very similar in macroscopic and microscopic appearance. It is therefore possible that these pieces are related, probably pieces of the same fall.

ALHA77230 (2473 g).—This is a subrounded to angular specimen that is a nearly complete stone (Figure 21*a*). It is covered with a brownish black fusion crust, approximately 0.5–1.0 mm thick, except for some small broken surfaces. The portion of the fusion crust that was in contact with the ice at time of recovery has an iridescent sheen and is more severely weathered than the upper portion. The specimen has several surface fissures, along which weathering has penetrated to a depth of nearly 0.5 mm.

A polished thin section (Figure 21*b*) shows a

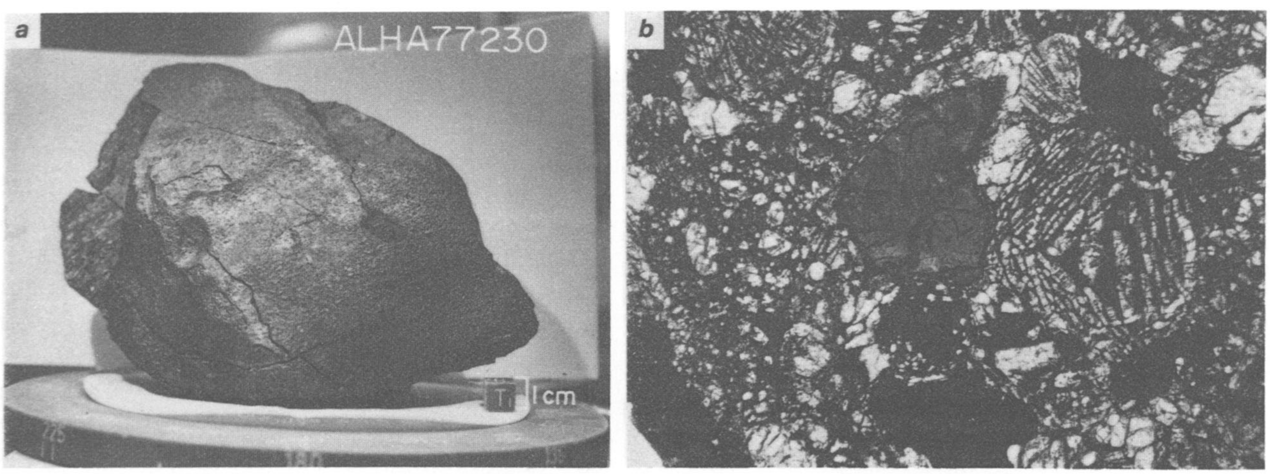


FIGURE 21.—ALHA77230, L4 chondrite: *a*, Stone with well-preserved fusion crust. *b*, Photomicrograph of thin section (width of field is 2.0 mm), showing large barred olivine chondrule and dark gray angular grain, possibly devitrified glass.

closely packed aggregate of chondrules (0.3–1.0 mm diameter): Some are spherical, but many appear fragmented and broken. A variety of chondrule types is present: barred olivine, porphyritic olivine, and pyroxene that is either fine-grained or polysynthetically twinned. Some chondrules have interstitial turbid devitrified glass. Minor subequal amounts of troilite and nickel-iron are present. A moderate amount of limonitic staining pervades the section. Fusion crust is present on one edge of the section. Microprobe analyses show olivine (Fa_{22-25}, average Fa_{23}) and pyroxene (Fs_{18-29}, averaging Fs_{21}) of fairly uniform composition.

ALHA77252 (343 g).—This specimen suffered considerable damage during transport from the Antarctic and was noted as consisting of chips and fines on its arrival in California (Figure 22). One piece has dull black fusion crust. The matrix of all pieces is greenish gray and contains many inclusions ranging to more than 1 cm across. Many surfaces have an orangish brown weathering rind. This specimen looks very similar in macroscopic appearance to ALHA77215, 77216, and 77217.

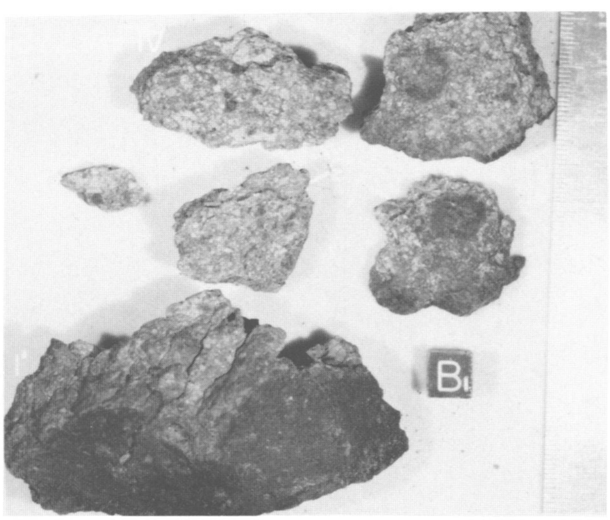


FIGURE 22.—ALHA77252, L4 chondrite; the stone broke into numerous fragments during transport from Antarctica, and light gray chondrules and lithic clasts are visible in the darker gray matrix; the largest fragment is partly covered with fusion crust.

The chip from which the thin section was made showed a marked division into two parts, the larger dark gray and chondritic, the smaller (probably a lithic clast) pale gray and granular. This division is also prominent in the thin section. The granular part appears to contain some poorly defined chondrules; in the chondritic part chondrules are numerous and well defined, sometimes broken and fragmentary. Minor subequal amounts of nickel-iron and troilite are present in both parts. A small amount of limonitic staining is present, concentrated around the metal grains. Microprobe analyses show olivine and pyroxene in the granular part to have uniform compositions: olivine, Fa_{25}; pyroxene, Fs_{20}. Minor plagioclase (An_{12}) was detected in the granular part. The chondritic part has variable composition in the olivine (Fa_{22-28}, average Fa_{24}) and pyroxene (Fs_{2-22}, average Fs_{15}). The meteorite is classified as an L4 chondrite with lithic clasts.

CLASS H5

FIGURES 23–25

The following chondrites are pebble-sized specimens (Figure 23*a*) and are very similar in macroscopic and microscopic appearances and in degrees of weathering: ALHA77014 (309 g), 77021 (16.7 g), 77025 (19.4 g), 77061 (12.6 g), 77062 (16.7 g), 77064 (6.5 g), 77071 (10.9 g), 77074 (12.1 g), 77086 (19.4 g), 77088 (51.2 g), 77102 (12.3 g), 77118 (7.8 g), 77119 (6.4 g), 77124 (4.4 g), and 77264 (11.0 g). Of these samples only ALHA77025, 77119, and 77264 are complete specimens covered with fusion crust; the others have suffered various degrees of fracturing.

ALHA77177 (368 g).—The sample is angular and is approximately 7.0 × 6.5 × 5.5 cm (Figure 23*b*). This appears to be a complete specimen, with the exception of a 3.0 × 4.0 cm area, which has been chipped away. Dull black fusion crust covers approximately 30 to 40 percent of the sample. The portion of the sample not covered with fusion crust is weathered reddish brown. A yellow-brown clast, ~0.5 cm in diameter, was observed on the W surface.

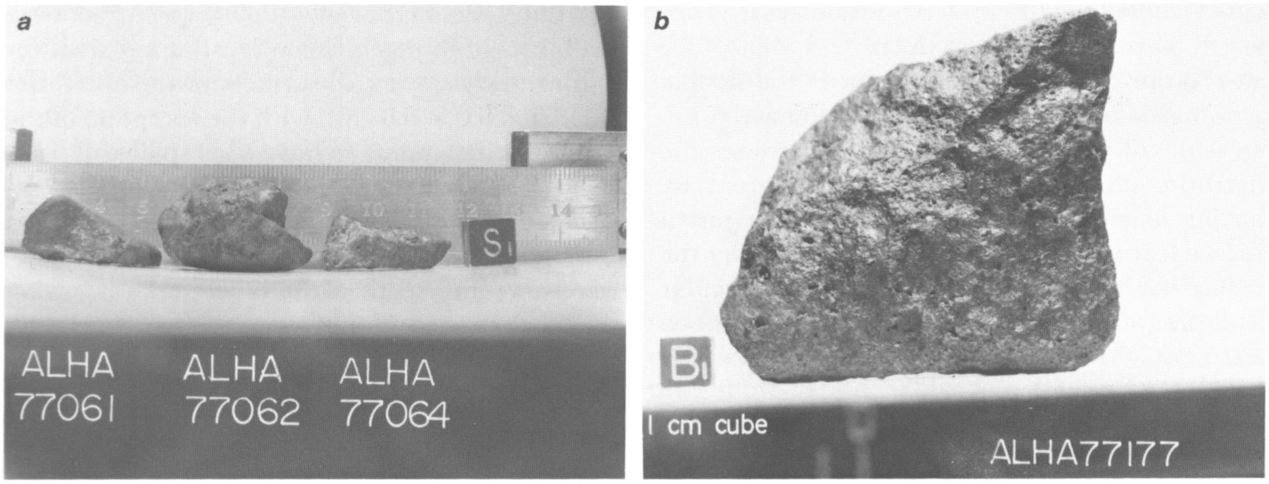


FIGURE 23.—H5 chondrites: *a*, ALHA77061, 77062, 77064; pebble-sized chondrites. *b*, ALHA77177, an angular stone with a pitted surface, probably produced by the weathering out of chondrules and lithic clasts.

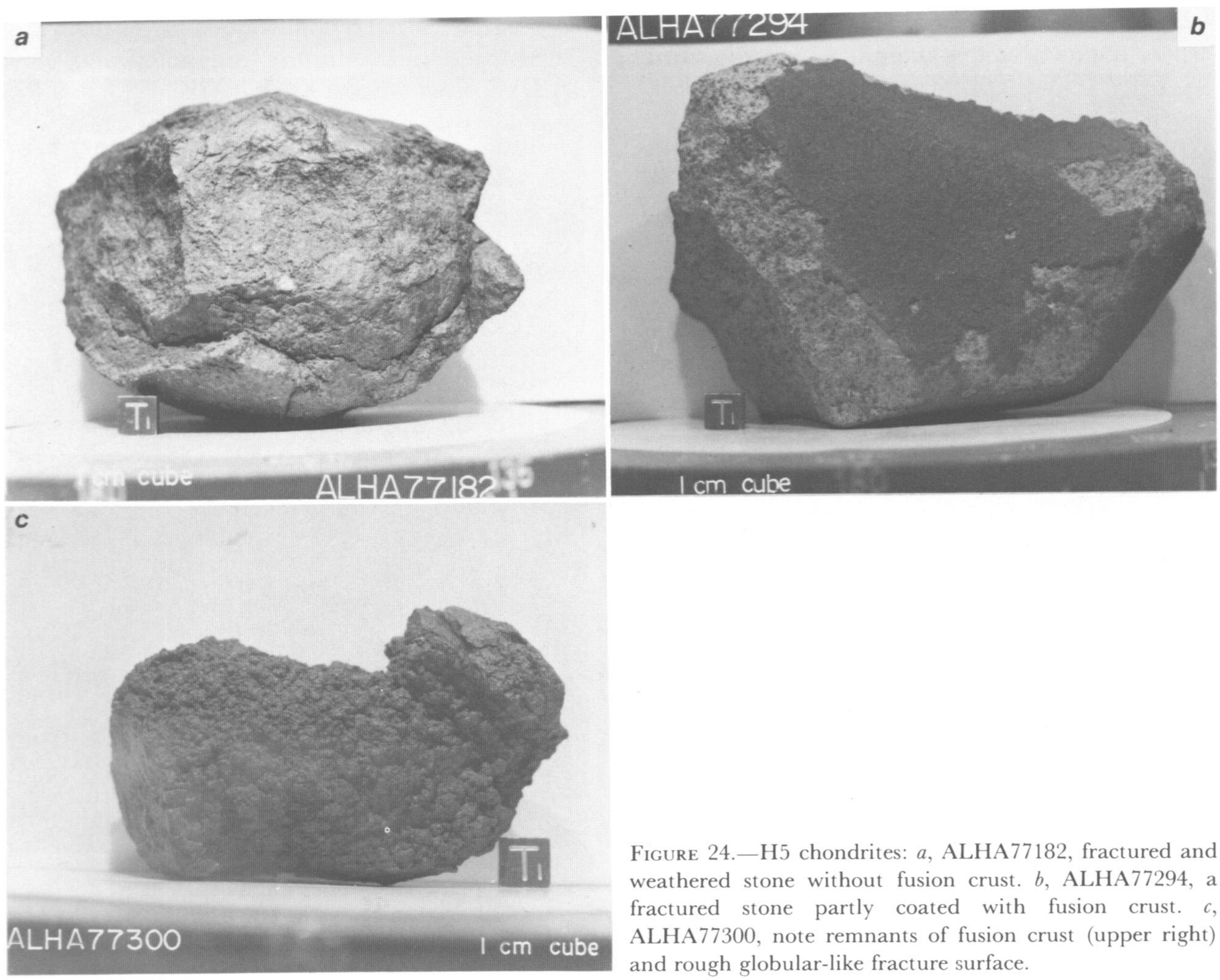


FIGURE 24.—H5 chondrites: *a*, ALHA77182, fractured and weathered stone without fusion crust. *b*, ALHA77294, a fractured stone partly coated with fusion crust. *c*, ALHA77300, note remnants of fusion crust (upper right) and rough globular-like fracture surface.

ALHA77182 (1109 g).—No fusion crust is apparent on this angular specimen, 12.5 × 8.0 × 7.0 cm (Figure 24*a*). The overall color of the sample is orangish brown. A band, approximately 1–5 cm wide, of yellowish green material crosses the meteorite on the E-W axis. It is apparent by looking at the T surface that this is not just a surface feature. Many random fractures cover the surface of the meteorite. Numerous irregular lithic fragments and chondrules, up to as much as 0.5 cm in diameter, are apparent. This sample appears to be exfoliated.

Surfaces revealed by sawing the meteorite in half exhibit metallic particles, approximately 1–2 mm in diameter. Three fractures, ~3 cm in length, are apparent on the cut face. The meteorite has no weathering rind and no weathering is apparent along fractures.

ALHA77294 (1351 g).—Polygonally fractured, dull, brownish black fusion crust, approximately 1 mm thick, covers all surfaces of this meteorite (~13.5 × 9.0 × 6.0 cm), with the exception of the edges, which appear to have been spalled (Figure 24*b*). White material, presumably evaporite deposits, fills the grooves in the polygonal fractures on the B surface. This surface appears more severely weathered than the other surfaces, owing to the presence of rounded areas of oxidation staining. The matrix of the stone is whitish gray with areas of orangish brown oxidation stain. Chondrules and irregular inclusions (lithic fragments?), as much as ~2 mm in diameter and both lighter and darker than the matrix, are apparent throughout the sample. After 60 hours of drying in the nitrogen cabinet, a heavy crystalline deposit was noted on the corner of the W, B, and S

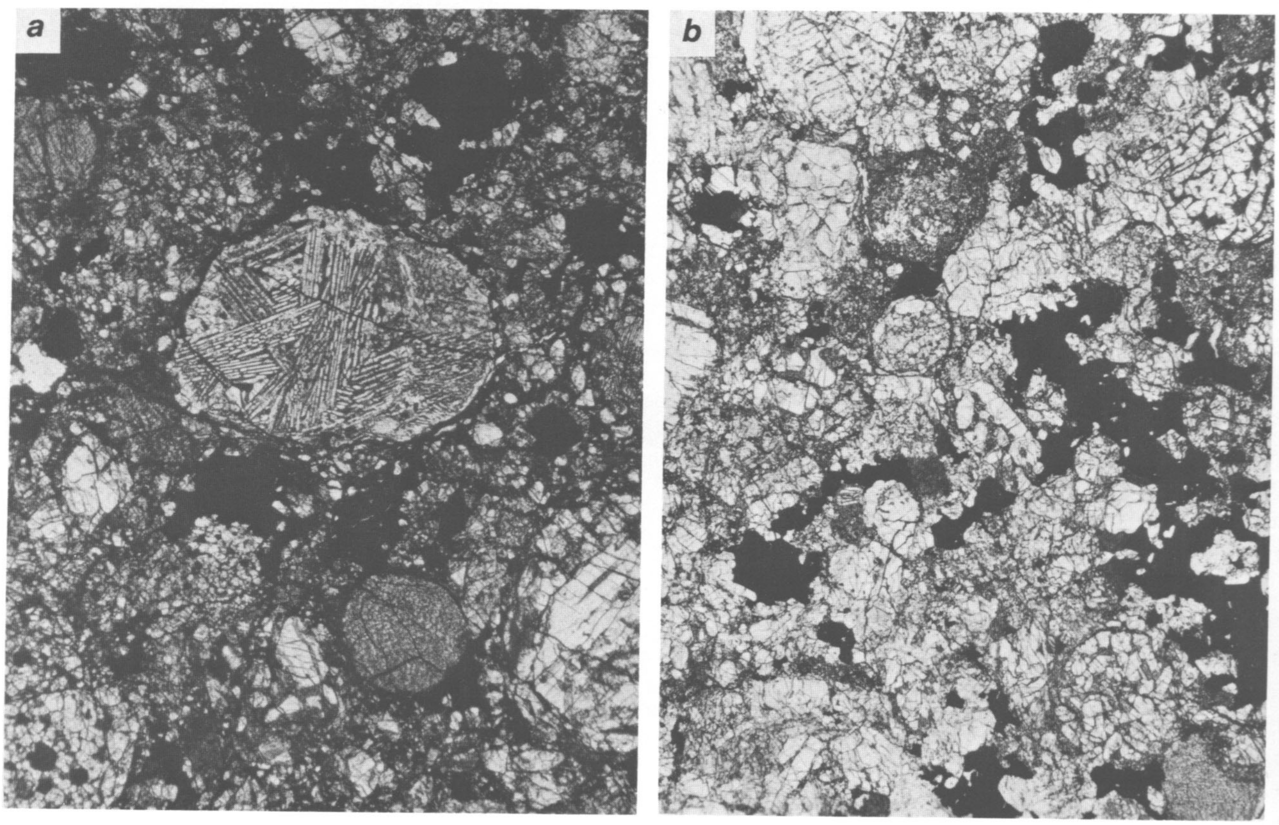


FIGURE 25.—H5 chondrites: *a*, ALHA77102, photomicrograph of thin section (width of field is 2.0 mm); note two juxtaposed barred olivine chondrules apparently fused together. *b*, ALHA77264, photomicrograph of thin section (width of field is 2.0 mm).

surfaces. When the stone was cut in half, no weathering rind was visible. Approximately 15% to 20% of the sawed surface appears to be metallic particles.

ALHA77300 (235 g).—This stone is 9.0 × 5.0 × 4.5 cm and oblong (Figure 24*c*). Half the surface appears to have had fusion crust that has been almost completely abraded, leaving only small particles of dull, brown fusion crust. Half the specimen has a rough, globular-like fracture surface. The exterior is weathered uniformly to dark orangish brown.

When the sample was cleaved in half, no unweathered material was exposed. The severity of the weathering caused the sample to crumble into many pieces during handling for photography.

In thin sections (Figure 25) all the H5 chondrites show a well-developed chondritic structure, with a variety of chondrule types, the commonest being barred olivine, granular and porphyritic olivine, and fine-grained pyroxene. The matrix is fine- to medium-grained, and consists largely of olivine and pyroxene, with minor amounts of nickel-iron, troilite, and small grains of sodic plagioclase. The compositions of the olivine (Fa_{18-19}) and orthopyroxene (Fs_{15-17}) are essentially uniform within the individual specimens.

The following specimens are possible pieces of a single meteorite: ALHA77021, 77025, 77061, 77062, 77064, 77071, 77074, 77086, 77088. Confirmation of these and possible additional groupings requires additional research.

Class L5

Figures 26, 27

ALHA 77002 (235 g).—The meteorite, approximately 6.5 × 4.5 × 5.0 cm (Figure 26*a*), is covered completely with brownish black thin fusion crust that shows appreciable weathering. One large fracture is present. When this stone was cut, fresh metal and rounded inclusions were apparent in the medium gray matrix. Some of the clasts are severely weathered, making the sawed surface appear orangish brown.

In thin section (Figure 26*b*) chondrules are prominent and well-defined. The matrix is dominantly olivine, in angular grains as much as 1.0 mm in maximum dimensions, with lesser amounts of orthopyroxene. Minor minerals in the matrix are nickel-iron, troilite, and chromite; plagioclase is present as very small grains that are difficult to recognize. The section is stained brown with limonitic materials, and the metal grains are corroded, evidently by terrestrial weathering; troilite is unaffected. Microprobe analyses show

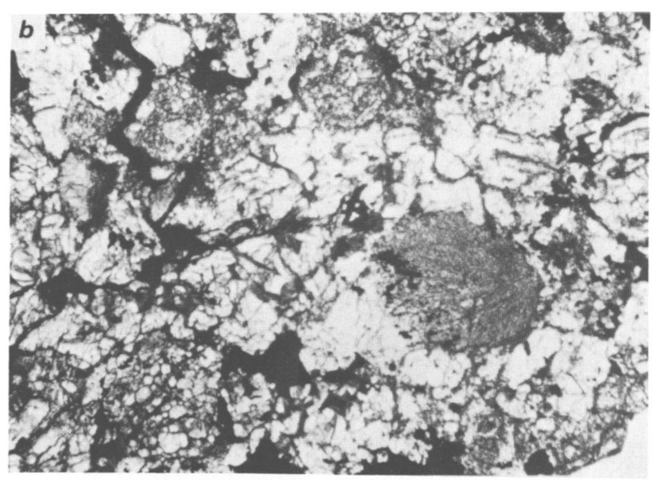


FIGURE 26.—L5 chondrites: *a*, ALHA77002, angular stone completely covered with fusion crust. *b*, ALHA77002, photomicrograph of thin section (width of field is 2.0 mm); prominent chondrules in a granular matrix.

uniform composition of the olivine (Fa_{25}) and orthopyroxene ($Wo_{1.2}$ En_{77} Fs_{22}); plagioclase averages Ab_{84} An_{10} Or_6, but has a slightly wider range of composition.

ALHA77254 (246 g).—Very thin dull black fusion crust is present on two surfaces (T and N) of the meteorite (Figure 27). The surfaces free of fusion crust have a dull orangish brown weathering patina, with the exception of the B surface, which is shiny or orangish brown. From field photographs it was determined that this angular specimen had its B surface in contact with the ice at the time of recovery. The B surface has slickensides. The specimen is 10.5 × 5.0 × 4.0 cm. Many inclusions ranging to as much as 1 cm in maximum length are visible on the sawed surface of the meteorite. Discoloration due to weathering of the outermost material was observed to a depth of approximately 1.5 cm along the surface.

The section shows well-developed chondritic structure, the chondrules ranging from 0.3 to 2.1 mm in diameter; a variety of types is present, the most common being barred olivine, granular olivine and olivine-pyroxene, and radiating pyroxene. The chondrules are set in a granular matrix of olivine and orthopyroxene, with minor subequal amounts of nickel-iron and troilite. Limonitic staining and a few patches of reddish brown limonite are associated with the metal grains. Fusion crust is present along one edge of the section. Microprobe analyses show olivine (Fa_{23}) and orthopyroxene (Fs_{20}) of essentially uniform composition.

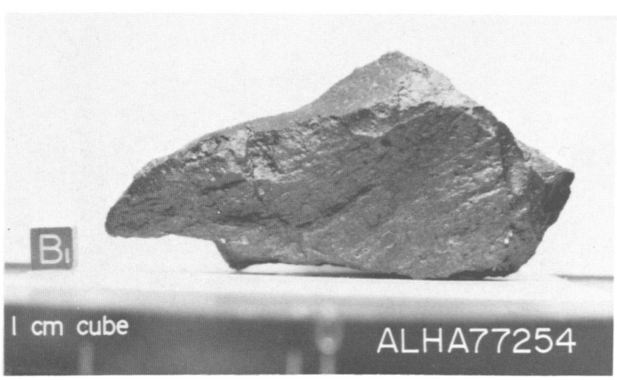


FIGURE 27.—ALHA77254, L5 chondrite; the B surface is a slickensided fracture surface.

CLASS H6

FIGURE 28

ALHA76006 (1137 g) and 76008 (1150 g).—These specimens were collected by the 1976–77 party and have been described by Olsen, et al. (1978). They report very similar compositions for the principal minerals: olivine, $Fa_{18.3}$ (76006), $Fa_{19.2}$ (76008); pyroxene, $Fs_{16.1}$ (76006), $Fs_{16.5}$ (76008); plagioclase, $An_{13.6}$ (76006), $An_{13.6}$ (76008). However, 76006 and 76008 appear to be different meteorites. Olsen, et al. (1978: 211–212) state:

> L. Rancitelli (personal communication) has measured terrestrial ages on several of these Antarctic chondrites. All the ages are on the order of 10^5 years, however, Allan Hills #8 [i.e., 76008] has a terrestrial age of 1.7×10^6 years, making it one of the oldest falls known. Because of this venerable terrestrial age it was thought worthwhile to perform a bulk analysis.... The analysis is that of a normal H-group chondrite that has been very weathered. The H_2O+ value, 2.20%, is far above the average for this group, and the carbon content, 0.20%, is twice the average for the group. The bound water content suggests the presence of relatively stable secondary hydrated minerals that were formed during the almost two million year long weathering period....The higher than normal carbon content suggests carbonate contamination during the long weathering history.

Examination of a specimen and thin section of ALHA76008 in the Smithsonian Institution (Mason, pers. comm.) shows that this meteorite is heavily veined with limonite near the surface, but the interior is relatively unweathered; there is less limonite in association with interior metal grains in 76008 than in 76006. Planimetric analysis of the thin section of 76008 gives 17.7 weight percent of metal; this is not much less than the average for unweathered H-group chondrites (18.6%) and is considerably greater than given by the chemical analysis (8.5%), which suggests that the sample for chemical analysis was taken from near-surface weathered material. Many of the chondrites collected by the 1977–78 party are far more weathered than76008, and might therefore be expected to give very old terrestrial ages. However, weathering is a function not only of time but also of composition and structure of the meteorite; some newly fallen chondrites show a rapid development of rusting, whereas others remain unaffected. Caution should therefore be used in correlating degree of weathering with terrestrial age.

Kirsten, Ries, and Fireman (1978) have calculated a cosmic-ray exposure age of 20 ± 2 my for 76006 and 1.5 ± 0.2 my for ALHA76008.

ALHA77144 (7.9 g) and 77148 (13.1 g).—Of the H6 chondrites collected by the 1977–78 party, 77144 and 77148 are small pebbles partially or wholly coated with fusion crust. Both are considerably weathered; yellow-brown limonitic staining pervades the thin sections.

ALHA77258 (597 g).—This five-sided specimen is completely covered with fusion crust, with the exception of one small area. The matrix material is yellowish brown with small metallic particles.

ALHA77271 (610 g).—This completely rounded stone, 8.0 × 7.5 × 5.0 cm has about 25% of the surface covered with small patches of dull black fusion crust. Where the fusion crust is missing, the surface is weathered dark brown; small inclusions are visible on this surface.

ALHA77285 (271 g).—This semi-rounded specimen, 5.0 × 6.0 × 6.5 cm, is comprised of three individual pieces that fit together. The meteorite has a reddish brown weathering patina. Only one small patch of weathered fusion crust is present on the B surface. No unweathered material was exposed during attempts to obtain material suitable for thin sections.

ALHA77288 (1880 g).—This is an angular stone, 12 × 10 × 8 cm. Four surfaces are rounded and smooth with brown weathering rind and patches of dull black fusion crust ~1–2 mm thick. The other surfaces represent fracture planes and

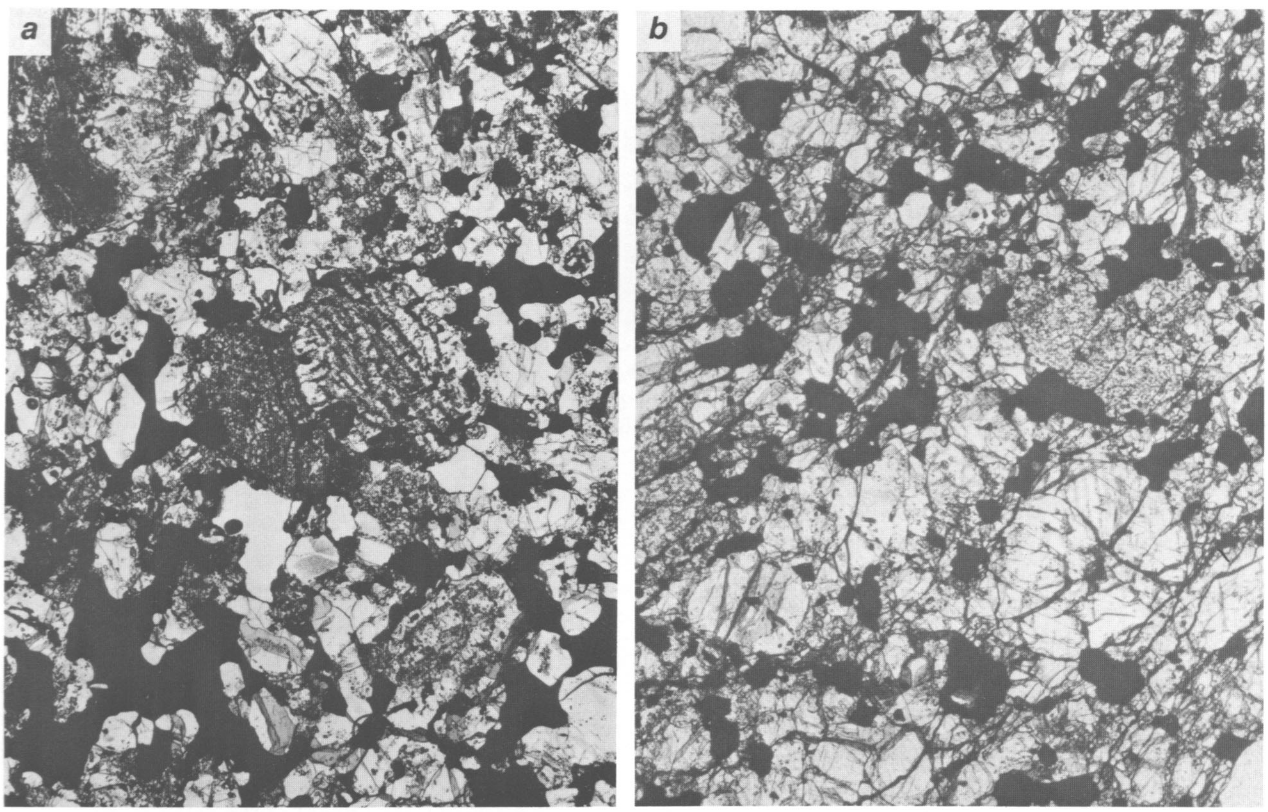


FIGURE 28.—H6 chondrites: *a*, ALHA77271, photomicrograph of thin section (width of field is 2.0 mm); chondrules are sparse and tend to merge with the granular matrix. *b*, ALHA77288, photomicrograph of thin section (width of field is 2.0 mm); chondrites are scarcely discernible from the granular matrix.

also are covered with brown weathering rind; inclusions are apparent on the severely weathered surfaces. Numerous fractures penetrate the stone.

Petrographically, all the H6 chondrites are very similar (Figure 28). Chondrules are sparse and poorly defined, tending to merge with the granular groundmass, which consists mainly of olivine and pyroxene, with minor amounts of nickel-iron, sodic plagioclase, and troilite, and accessory chromite. Microprobe analyses show olivine (Fa_{19}) and orthopyroxene (Fs_{17}) of essentially uniform composition.

MBRA76001 (17881 g).—These two stones, originally called "Mt. Baldr a and b," were collected by the 1976–77 party about 100 kilometers south of the Allan Hills. Olsen, et al. (1978: 210) comment:

> The close similarity between Mt. Baldr a and Mt. Baldr b lead us to believe they are paired finds. They were found less than a kilometer apart, and no other meteorites were present in the area. ...Thus, the two Mt. Baldr specimens could be simply a single fall in that area, with some subsequent movement by the glacial tongue that ultimately avalanches into the upper end of the Wright Valley. Whether these constitute a single meteorite, or two meteorites cannot be decided absolutely until rare-gas data are obtained.

Olsen et al., classify these chondrites as H6, but Yanai, Miyamoto, and Takeda (1978) classify Mt. Baldr a as H4-5 and Mt. Baldr b as H5-6. Weber and Schultz (1978) have shown from rare-gas data that Mt. Baldr a and b belong to the same fall.

Class L6

Figures 29, 30

The following chondrites are classified as L6: ALHA76001 (20151 g), 76003 (10495 g), 76007 (410 g), 76009 (407000 g); ALHA77001 (252 g), 77150 (58.3 g), 77155 (305 g), 77231 (9270 g), 77261 (412 g), 77269 (1045 g), 77270 (589 g), 77272 (674 g), 77273 (492 g), 77277 (143 g), 77280 (3226 g), 77281 (1231 g), 77282 (4127 g), 77284 (376 g), 77296 (963 g), 77297 (952 g), 77305 (940 g).

Table 1.—Composition of four 1976–77 L6 chondrites (after Olsen, et al., 1978)

ALHA	*Olivine* (Fa)	*Pyroxene* (Fs)	*Plagioclase* (An)
76001	24.5	20.9	10.8
76003	24.6	21.0	10.8
76007	24.4	21.2	10.8
76009	23.1	20.7	10.8

Of the four L6 chondrites collected by the 1976–77 party, ALHA76009 was notable as being the largest meteorite yet discovered in Antarctica; it was found as a group of 33 fragments, the three largest weighing respectively 114, 102, and 58 kg. (In December 1978, a 138 kg iron and several smaller masses of the same meteorite were found on the slopes of Derrick Peak, near the Darwin glacier (80°S 158°E).) These four chondrites are very similar in megascopic appearance, degree of weathering (minor, confined to limonitic staining around metal grains), and composition of principal minerals (Table 1). Weber and Schultz (1978) have published He, Ne, and Ar data on these meteorites, and for 76007, Kirsten, Ries, and Fireman (1978) have calculated an exposure age of 22 ± 2 my.

The L6 chondrites collected by the 1977–78 party are partially coated with fusion crust (Figure 29), except for 77305, on which only traces remain. Weathering is slight to moderate in most specimens, being confined to limonitic staining on the surface and around metal grains in the interior; in 77150, 77269, and 77273 weathering is more extensive, with limonitic staining throughout the polished sections.

Polished thin sections show sparse, poorly defined chondrules, which tend to merge with the granular groundmass (Figure 30). Principal minerals are olivine and orthopyroxene in subequal amounts, together with minor amounts of plagioclase, nickel-iron, troilite, diopside, and accessory chromite and merillite. Microprobe analyses (Appendix 1) show essentially uniform compositions for the principal minerals: olivine, Fa_{24-25}; orthopyroxene, Fs_{20-22}; plagioclase, An_{11}.

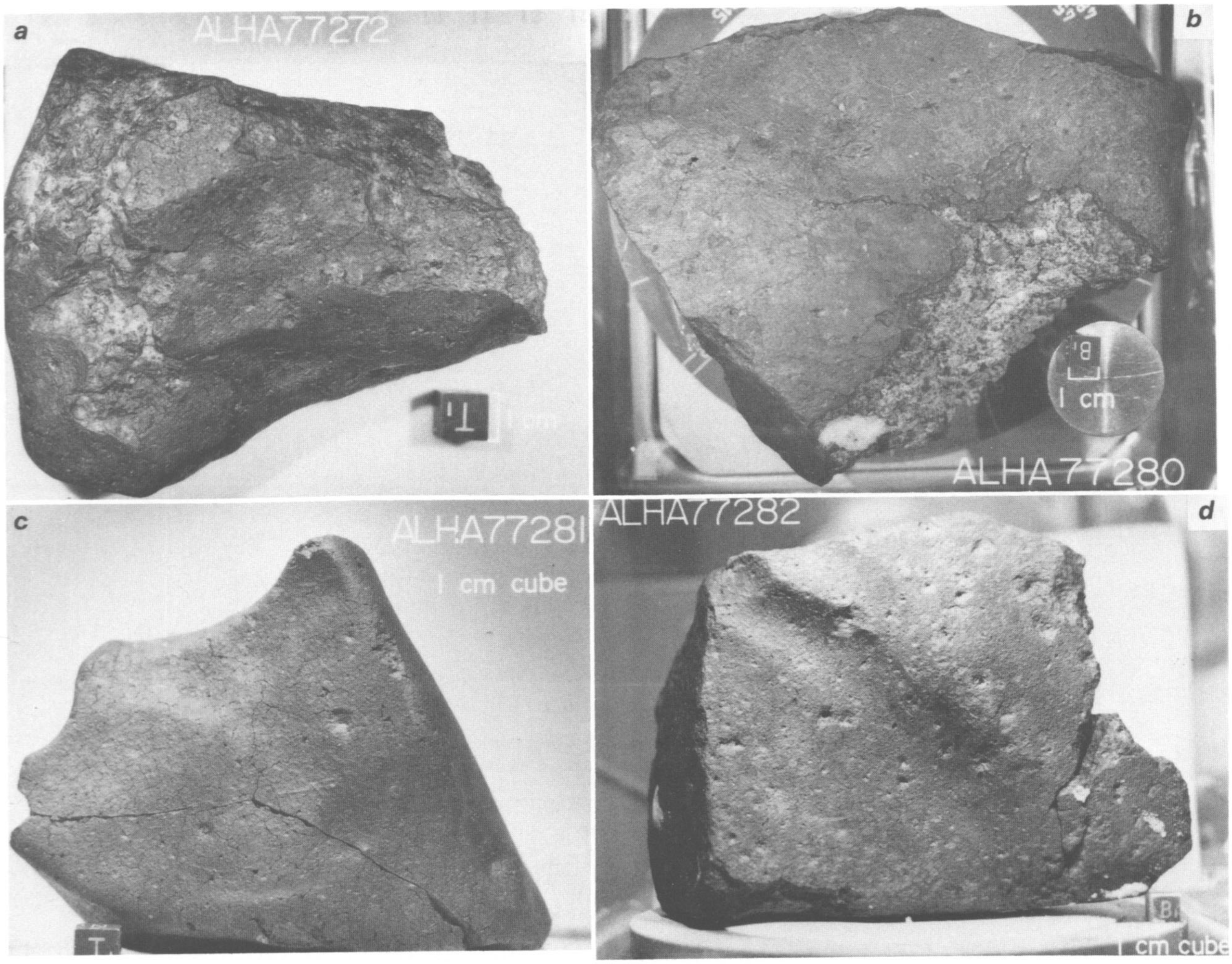


FIGURE 29.—L6 chondrites: *a*, ALHA77272, angular stone, partly coated with fusion crust. *b*, ALHA77280, stone with fusion crust partly spalled away. *c*, ALHA77281, a completely crusted stone showing some fracturing. *d*, ALHA77282, an incompletely crusted stone.

CLASS H?

FIGURE 31

ALHA77081 (8.6 g).—The stone (1.5 × 20 × 1.5 cm) is angular to subrounded. Approximately 60% of the surface is covered by a highly weathered, brownish black to reddish brown fusion crust and remnants of fusion crust. One broken surface shows a granular texture and iron-oxide staining. Several rounded and irregular inclusions and small metallic particles were apparent in the whitish gray matrix.

A thin section (Figure 31) shows that this meteorite is an equigranular (grains 0.1–0.3 cm in diameter) aggregate of approximately equal amounts of olivine and orthopyroxene, with minor amounts of diopside, plagioclase, nickel-iron, and troilite, and accessory chromite. Fusion crust is present along one edge of the section. A moderate amount of yellowish brown limonitic stain is present, concentrated around nickel-iron grains. Microprobe analyses show the minerals are uniform in composition: olivine, Fa_{11}; orthopyroxene, $Wo_{1.7}$ Fs_{11} En_{87}; diopside, Wo_{45} Fs_5 En_{50}; plagioclase, An_{15} Or_4.

The classification of this meteorite presents dif-

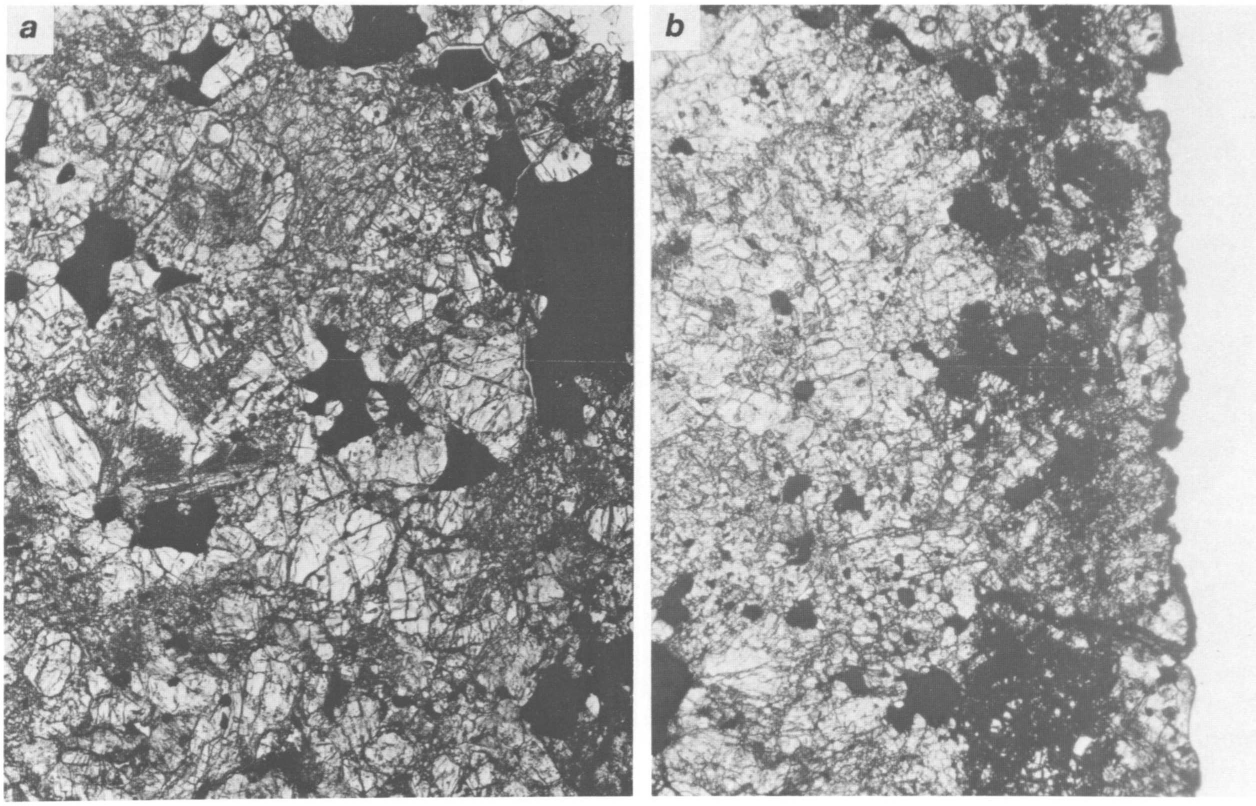


FIGURE 30.—L6 chondrites: *a*, ALHA77277, photomicrograph of thin section (width of field is 2.0 mm); chondrules are sparse and tend to merge with the granular matrix. *b*, ALHA77281, photomicrograph of thin section (width of field is 1.7 mm); note fusion crust on one edge, and almost total absence of chondritic structure.

ficulties. The texture is achondritic, but the mineralogical composition is similar to that of the H-group chondrites, which suggests that this meteorite may be a completely recrystallized chondrite. However, the composition of the olivine and orthopyroxene is more magnesian than for the H-group chondrites. The meteorite resembles some silicate inclusions in iron meteorites. This meteorite is identical in mineral composition and structure to Acapulco, a recent Mexican fall, described by Christophe Michel-Levy and Lorin (1978).

Achondrites

EUCRITE

FIGURE 32

ALHA76005 (1425 g).—This eucrite was collected by the 1976–77 field party and has been described in detail by Olsen, et al. (1978:217–223):

> It is pale gray in color and consists of finely divided macrocrystalline pyroxene-rich matrix that contains abundant clastic fragments: (1) Clasts of white, plagioclase-rich rocks. (2) Medium-gray, partly devitrified, cryptocrystalline. (3) Monomineralic fragments and grains of pyroxene, plagioclases, oxide minerals, sulfides, and metal. In overall appearance it is very similar to some lunar breccias.

They also report (1978:220–221) pyroxene compositions ranging from pigeonite (Wo_9 Fs_{39} En_{52}) to ferroaugite (Wo_{32} Fs_{37} En_{31}); plagioclase ranges from An_{83} to An_{91}. Weber and Schultz (1978) have reported He, Ne, and Ar contents in this meteorite.

ALHA77302 (235 g).—The meteorite is angular to subrounded with the approximate dimensions 9.25 × 5.5 × 4.0 cm; it appears to be a complete stone (Figure 32*a*). A thin, black, glassy

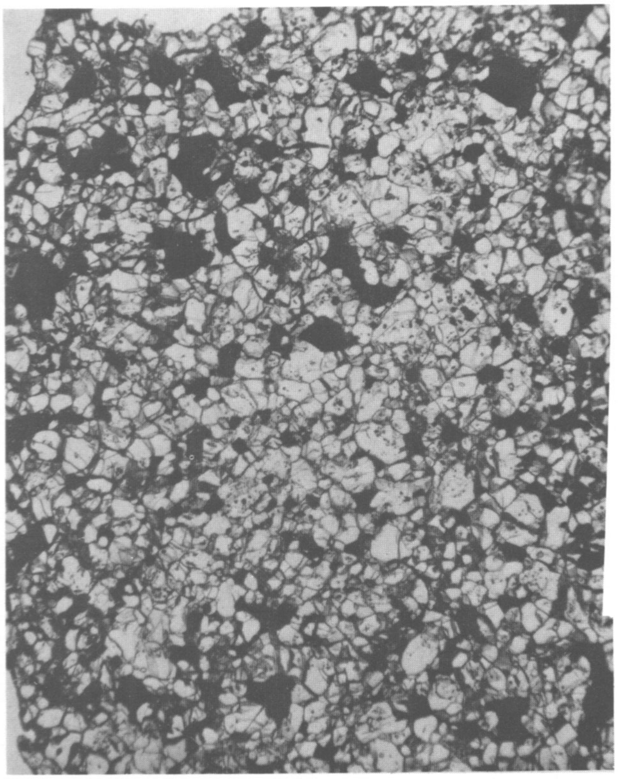


FIGURE 31.—ALHA77081, H?, photomicrograph of thin section (width of field is 2.0 mm); an equigranular aggregate consisting mainly of olivine and orthopyroxene (white to gray) with accessory nickel-iron, troilite, and chromite (black).

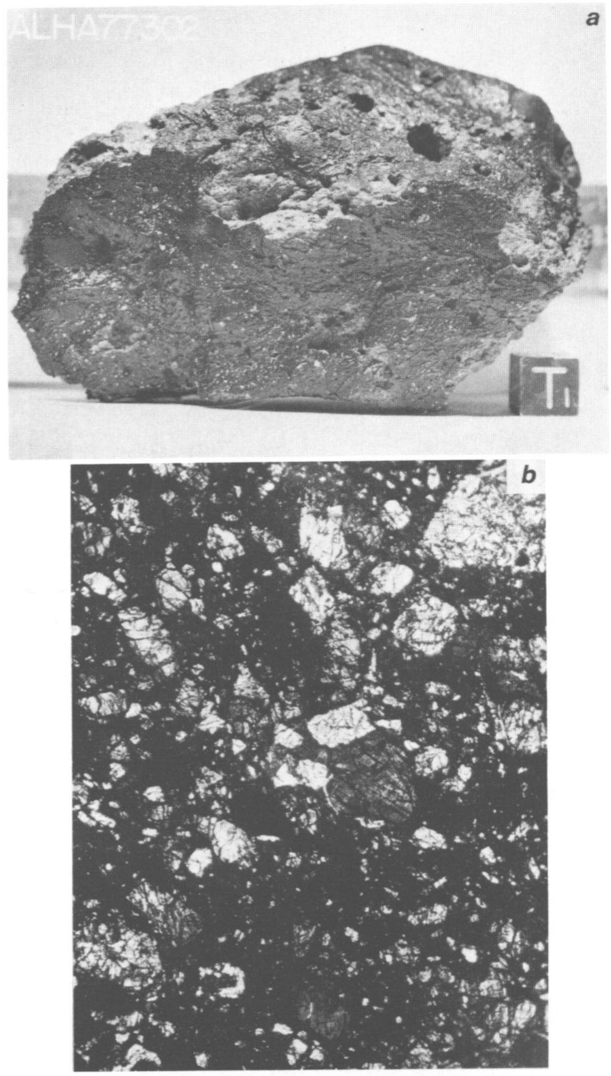


FIGURE 32.—ALHA77302, eucrite: *a*, Most of the surface is coated with black glassy fusion crust. *b*, Photomicrograph of thin section (width of field is 2.0 mm); an aggregate of plagioclase (white) and pigeonite (light to dark gray) clasts in a comminuted groundmass largely made up of the same minerals.

fusion crust covers about 70% of the surface. In places the fusion crust has been plucked away leaving large cavities randomly distributed on the surface of the stone. The material in these cavities is fresh and unweathered and shows feldspar cleavages. One surface has a large 2-cm protruding gabbroic clast, which is obviously coarser grained and darker in color than the bulk meteorite. Plagioclase crystals in this clast are several millimeters long. Another surface has an irregularly shaped clast that differs in texture and color from the rest of the stone.

The thin section (Figure 32*b*) shows that this meteorite is a brecciated pyroxene-plagioclase achondrite (eucrite). It consists largely of pigeonite (~60%) as brown grains, up to 2 mm, and plagioclase (~35%) as colorless grains, up to 4 mm, in a comminuted groundmass of these minerals. A little troilite ($<1\%$) and rare minute grains of nickel-iron are present. Fusion crust rims part of the thin section. No evidence of weathering is visible. Microprobe analyses show a range of compositions in the pigeonite: Wo_{3-14}, En_{32-56}, Fs_{37-64}; a few grains of subcalcic ferroaugite averaging Wo_{25} En_{27} Fs_{48} were also analyzed. Plagioclase ranges in composition from An_{75} to An_{94}.

The section contains a large (6 mm) fine-grained enclave of similar composition.

Miyamoto, Takeda, and Yanai (1979) have investigated both ALHA76005 and 77302 and comment: "The similarity of textures and pyroxene compositions of ALHA76005 and 77302 suggests that these meteorites are the fragments of one and the same fall."

Diogenite

Figure 33

ALHA77256 (676 g).—The meteorite is rounded, with the approximate dimensions 9.5 × 7.5 × 6.75 cm; it appears to be a complete stone (Figure 33*a*). Patches of dull black fusion crust are randomly distributed over 15% of the surface. The crust appears to have been abraded away from the remaining surface. The areas lacking fusion crust are weathered and vary in color from yellowish brown to grayish green. Several patches of iron-oxide staining are present.

The thin section (Figure 33*b*) consists almost entirely (~97%) of coarse (grains up to 6 mm) orthopyroxene clasts, with comminuted grain boundaries; microprobe analyses give the composition $Wo_2Fs_{23}En_{75}$. Some orthopyroxene grains contain small blebs of clinopyroxene, with composition $Wo_{46}Fs_8En_{46}$. Accessory minerals include plagioclase (~1%), troilite (<1%), and very rare minute grains of nickel-iron. A small area of limonite was noted, and moderate limonitic staining along grain boundaries. A chemical analysis of 77256 is given in Appendix 2.

Ureilite

Figure 34

ALHA77257 (1996 g).—The approximate measurements of the meteorite are 16 × 11 × 9.5 cm; it is not a complete stone (Figure 34*a*). About one-half of the surface is rounded and mostly covered with fusion crust 2 mm thick. Three fracture planes bound the remainder of the stone. The fusion crust is dark brown with areas of reddish (iron oxide?) staining. Small areas of the

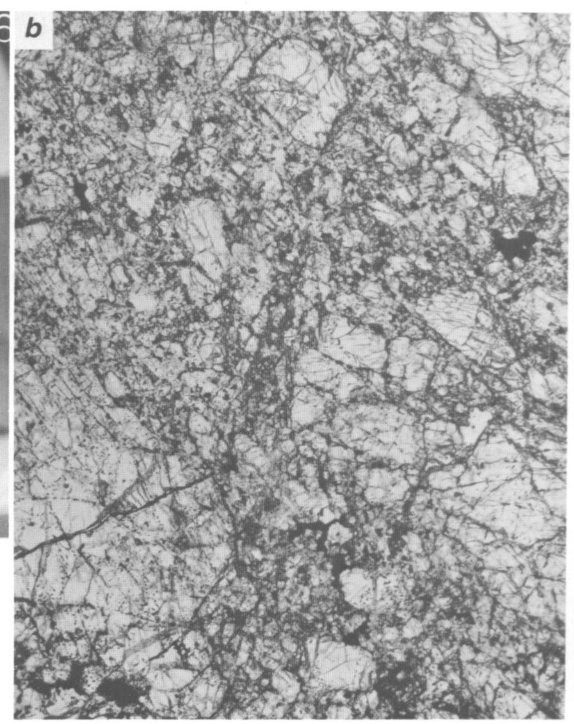
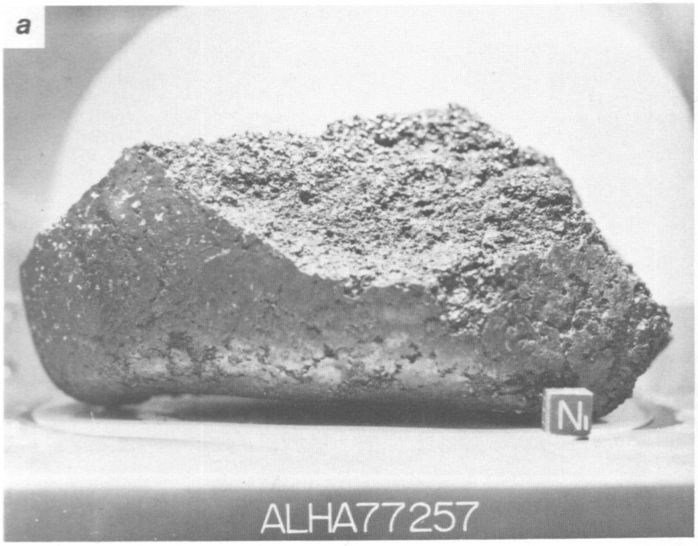


Figure 33.—ALHA77256; diogenite: *a*, Residual patches of black fusion crust coat part of the surface. *b*, Photomicrograph of thin section (width of field is 2.0 mm); consists almost entirely of orthopyroxene clasts with comminuted grain boundaries; black is limonite and troilite.



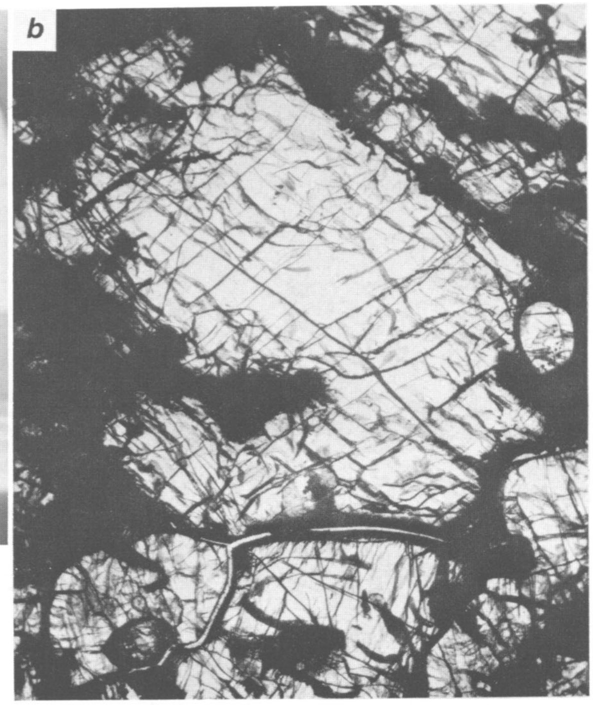


FIGURE 34.—ALHA77257, ureilite: *a*, Part of the surface is rounded and covered with fusion crust; the other part is an irregular fracture. *b*, Photomicrograph of thin section (width of field is 2.0 mm); large grains of olivine and pyroxene in black carbonaceous matrix.

fusion crust have been plucked away, revealing the crystalline fabric beneath. The fracture surfaces are rough, on a millimeter scale, dark brownish black, and moderately weathered with small patches of iron oxide stain. Small white to transparent anhedral grains occur on the surface of the meteorite, where they are visible in the field photographs. The grains are aligned in a strip across the broken surface and part of the fusion crust. An X-ray powder photograph shows that these grains are hydromagnesite mixed with other phases (Marvin, pers. comm.) The interior consists of grains with well-developed crystal faces set in a black, fine-grained matrix. Some grains are covered with a dark stain and others are milky white.

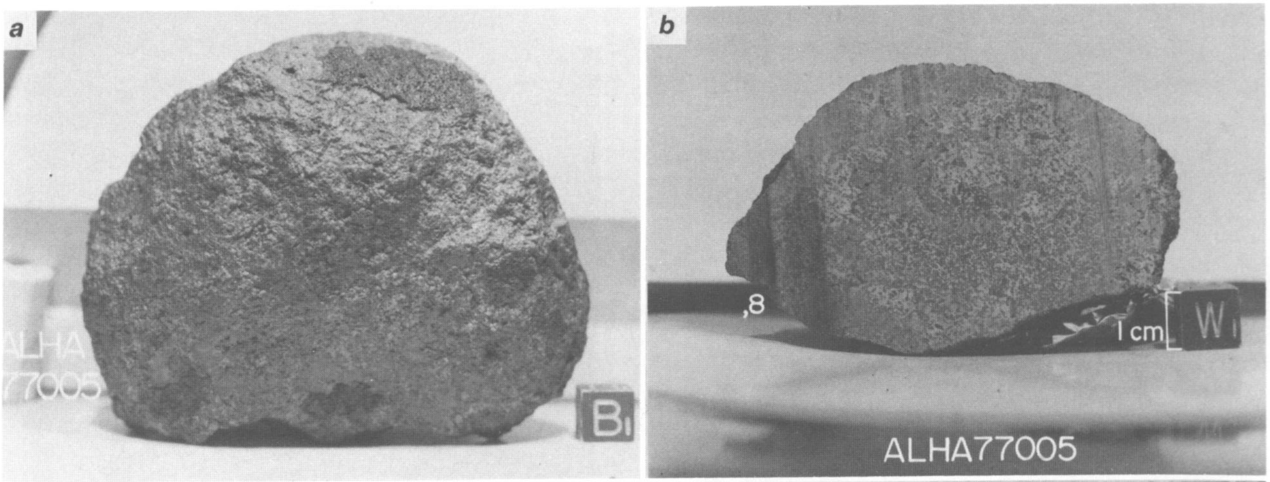
The thin section (Figure 34*b*) consists almost entirely of anhedral to subhedral olivine (~80%) and pyroxene (~15%); the minerals are fairly coarse-grained, with olivine grains up to 4 mm, pyroxene to 3 mm. The olivine grains show undulose extinction. The pyroxene shows coarse polysynthetic twinning. Grain boundaries are marked by a concentration of carbonaceous material; trace amounts of troilite and nickel-iron, partly altered to limonite, occur along grain boundaries. Microprobe analyses show olivine of variable compositions (Fa_{9-23}, average Fa_{13}) and with unusually high Ca (0.2% to 0.3%) and Cr (0.3% to 0.4%) contents. The pyroxene is a low-calcium clinopyroxene with composition averaging $Wo_7En_{81}Fs_{12}$. The meteorite is extremely resistant to cutting and polishing, which probably indicates the presence of diamond, as in other ureilites.

Compositional data on the pyroxene in this meteorite have been provided by Takeda, et al. (1978). A chemical analysis is given in Appendix 2.

ACHONDRITE, UNIQUE

FIGURE 35

ALHA77005 (483 g).—The meteorite (Figure 35*a*), approximately 9.5 × 7.5 × 5.25 cm, is well rounded on all faces except one, which is a partially broken surface. Small thin patches of dark fusion crust, randomly distributed, cover approx-



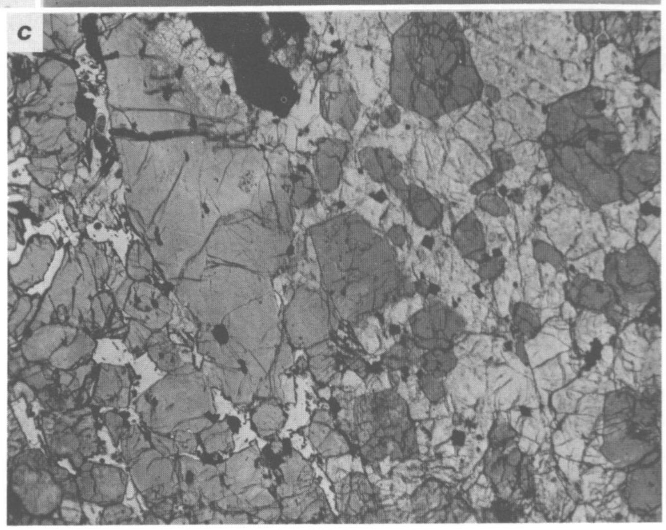


FIGURE 35.—ALHA77005, unique achondrite: *a*, Well-rounded stone with small areas of fusion crust. *b*, Sawn surface, showing areas of impact melting (finer grained). *c*, Photomicrograph of thin section (width of field is 2.0 mm); large grains of olivine (medium gray) and orthopyroxene (pale gray); white is maskelynite, black is mostly chromite.

imately 5% of the surface. Parts of the stone are covered by lighter colored vitreous rind that apparently is the lower portion of the fusion crust that has been abraded. Some partially melted crystals merge with the glassy rind. On the cut surface this specimen appears to be unweathered (Figure 35*b*). The variation in color suggests heterogeneity on a centimeter scale. Areas of the cut surface show voids as much as 2 mm in diameter. The larger voids have a crystalline structure on the surface; however, no crystals extend into the cavity.

The thin section (Figure 35*c*) shows that this meteorite is an achondrite with the following modal composition (volume percent): olivine ~55, pyroxene ~35, maskelynite ~8, opaques (mostly chromite, a little ilmenite, and trace amounts of troilite) ~2. Olivine occurs as somewhat rounded anhedral to subhedral grains, as much as 2 mm long, and has an unusual pale brown color; microprobe analyses show a mean composition of Fa_{28}. Pyroxene occurs as colorless prismatic crystals as much as 6 mm long, commonly poikilitically enclosing olivine; some crystals show coarse polysynthetic twinning; the composition ranges somewhat, averaging $Wo_5Fs_{23}En_{72}$. Maskelynite is present as laths interstitial to olivine and pyroxene; it has labradorite composition (An_{53}) and contains 0.2% to 0.3% K_2O. The meteorite has been shocked severely, as shown by the presence of maskelynite, undulose extinction in the pyroxene, and areas of apparent shock melting. No signs of weathering were observed.

ALHA 77005 is a unique achondrite. The olivine is comparable in composition to that in chassignites, the pyroxene to that in diogenites, and the bulk composition will thus be intermediate between these two classes of achondrites. These classes of meteorite, however, are almost plagioclase-free. Maskelynite of the composition of ALHA77005 is known only in the Shergotty and Zagami achondrites, meteorites which differ markedly from ALHA77005 in that they contain no olivine and consist largely of calcium-rich clinopyroxene.

A detailed account of the petrography of ALHA77005 has been published by McSween, Taylor, and Stolper (1979). A chemical analysis is given in Appendix 2.

Stony-Irons

Mesosiderite

Figure 36

ALHA77219 (637 g).—The specimen (Figure 36*a*) is a fragment (12 × 8 × 7 cm) from a larger stone. It is partly rounded, partly subangular, and covered with a dark brown weathering rind. Glassy, dark greenish black, angular to subangular inclusions up to 1 cm across are visible on the weathered surface; these are probably pyroxene clasts.

The thin section (Figure 36*b*) is dominated by large orthopyroxene clasts (up to 6 mm across) in a groundmass consisting largely of crushed and comminuted orthopyroxene (grains up to 0.6 mm across). The groundmass also contains about 20% of nickel-iron (kamacite and taenite) in grains averaging about 0.3 mm, occasional grains of plagioclase (An_{90}), troilite, chromite, merrillite, and a silica polymorph (probably tridymite). The groundmass encloses a rounded aggregate (3 mm across) of fine-grained (up to 0.15 mm) olivine, composition Fa_{26}. The composition of the orthopyroxene clasts and groundmass is somewhat variable, Fs_{24-28}, with CaO ranging from 0.5% to 2.3%; one grain of diopsidic pyroxene was analyzed, Wo_{43} En_{45} Fs_{12}. The major material of this

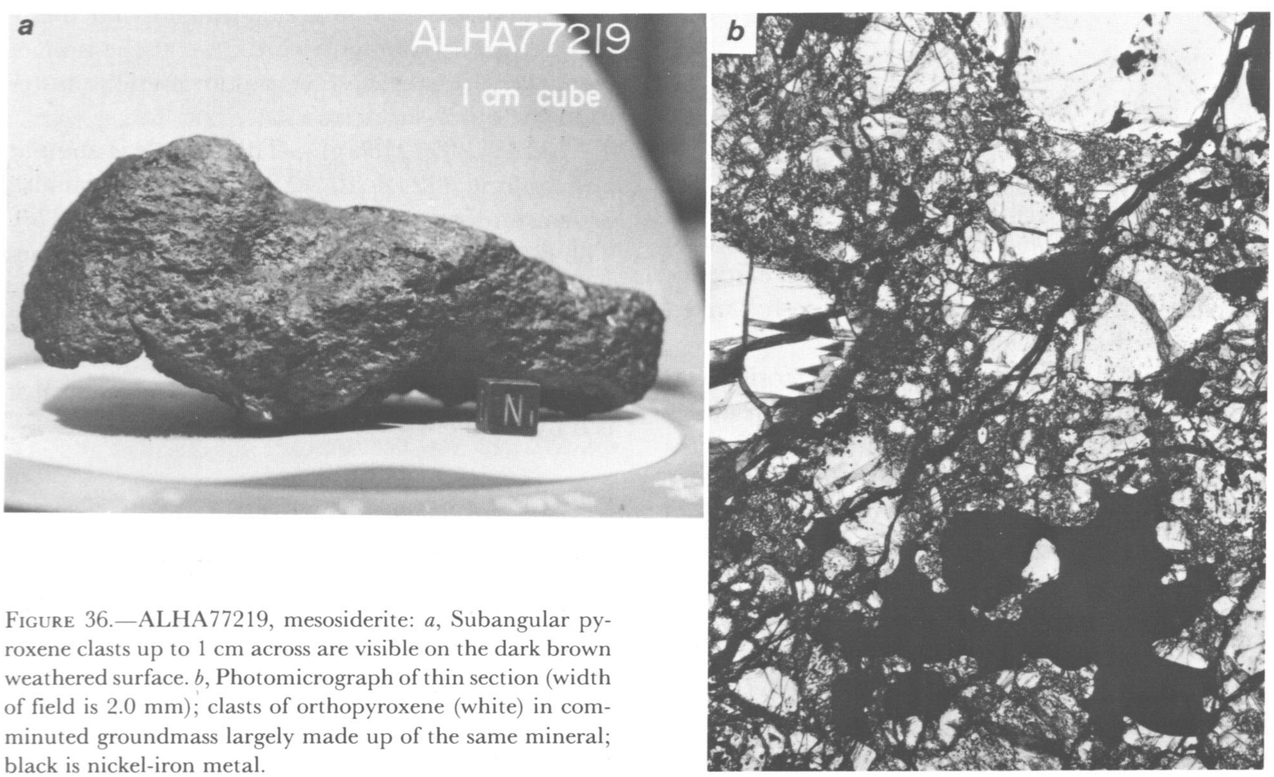


Figure 36.—ALHA77219, mesosiderite: *a*, Subangular pyroxene clasts up to 1 cm across are visible on the dark brown weathered surface. *b*, Photomicrograph of thin section (width of field is 2.0 mm); clasts of orthopyroxene (white) in comminuted groundmass largely made up of the same mineral; black is nickel-iron metal.

section is characteristic of a diogenite; however, the presence of a considerable amount of nickel-iron and the olivine enclave suggests a possible affinity to the mesosiderites.

The identification as a mesosiderite has been confirmed by examination of a cut surface of the whole specimen. A chemical analysis is given in Appendix 2.

Irons

FIGURE 37

ALHA76002 (1510 g).—This meteorite, collected by the 1976–77 party, has been described by Olsen, et al. (1978:213–214) as follows:

> The bulk nickel content is 6.36%, essentially that of its kamacite. The major phase in the meteorite is kamacite with only a minor amount of taenite that occurs as darkened plessite areas. The largest plessite area found in a polished section of 20 × 25 mm is only 160 × 800 μm. Thus, in the polished section no Widmanstatten pattern was evident, and no kamacite band width could be measured.... In terms of its structure, mineralogy, and major element chemistry Allan Hills #2 [now 76002] is like group IIB and IIA irons, however, in terms of its trace elements (Ga and Ir) it is associated with the coarse and medium octahedrites of group IA.

The following trace elements were recorded (in ppm): Ga 93, As 10, W 1.3, Re 0.26, Ir 2.3, Au 1.4, Cu 135. Olsen, et al. (1978:213) note the presence of schreibersite and the absence of troilite in the material studied. They also comment on the presence of a 4 mm thick heat-affected zone on the outer edge of the meteorite, evidence that very little weathering or oxidation has taken place since this iron fell.

PGPA77006 (19068 g).—This meteorite was collected in January 1978 at the foot of Purgatory Peak in the Victoria Valley, about 100 km southeast of Allan Hills, by Steven Kite of a University of Maine party. When found, it was partly buried in gravel and sand, and part of the exposed surface had a metallic sheen, produced by the sand-blasting effect of the winds.

The meteorite is approximately conical in form, 19 cm across the base and 18 cm high (Figure 37*a*). The surface shows shallow regmaglypts, and occasional deeper cylindrical pits, which probably represent burned-out troilite inclusions (residual troilite is present in the bottom of one of them). The area that was buried is clearly marked by a thin adhering crust of iron oxide and cemented sand grains. No trace of fusion crust remains, which suggests that this meteorite may be an old fall (but relatively rapid abrasion of the surface is to be expected under the climatic conditions at the site of the find).

ALHA77255 (765 g).—The sample is shaped like a boomerang and is approximately 15.5 × 7.0 × 1.5 cm (Figure 37*b*). The two flat surfaces, B and T, have an iridescent goldish red sheen on the brownish black fusion crust. The B surface is darker brownish red than the other surfaces and is concave. Small regmaglypts, ~1 mm or less in depth, are present on the T and N surfaces. All corners on the specimen are smooth and rounded.

ALHA77263 (1669 g).—This orangish brown, angular sample is approximately 15.0 × 5.5 × 8.0 cm (Figure 37*c*). All surfaces have regmaglypts; however, the T surface has smaller regmaglypts, ~3 mm in diameter, than other surfaces that have regmaglypts as much as 1 inch in diameter. From field photographs it was determined that the T surface was in contact with the ice at the time of recovery; this surface has a more metallic luster than the other surfaces.

ALHA77289 (2186 g).—This sample is angular and oblong (22 × 10 × 5 cm). It is orangish brown and has many regmaglypts (Figure 37*d*). The B surface has radial and transverse flow lines resulting from its orientation during atmospheric entry. The B surface also shows a zone of preferential melting (?), ~1 cm wide, that penetrates through the sample to the T surface; however, it is only ~0.5 cm wide on this surface.

Discussion

W. A. Cassidy has provided the following list and notes on possible pairings of some of the ALHA77 meteorites.

H4: 004, 191, 192, 208, 224, 233.
H5: 014, 264; 021, 061, 062, 064, 071, 086, 088, 102; 118, 119, 124.
H6: 144, 148; 271, 288.

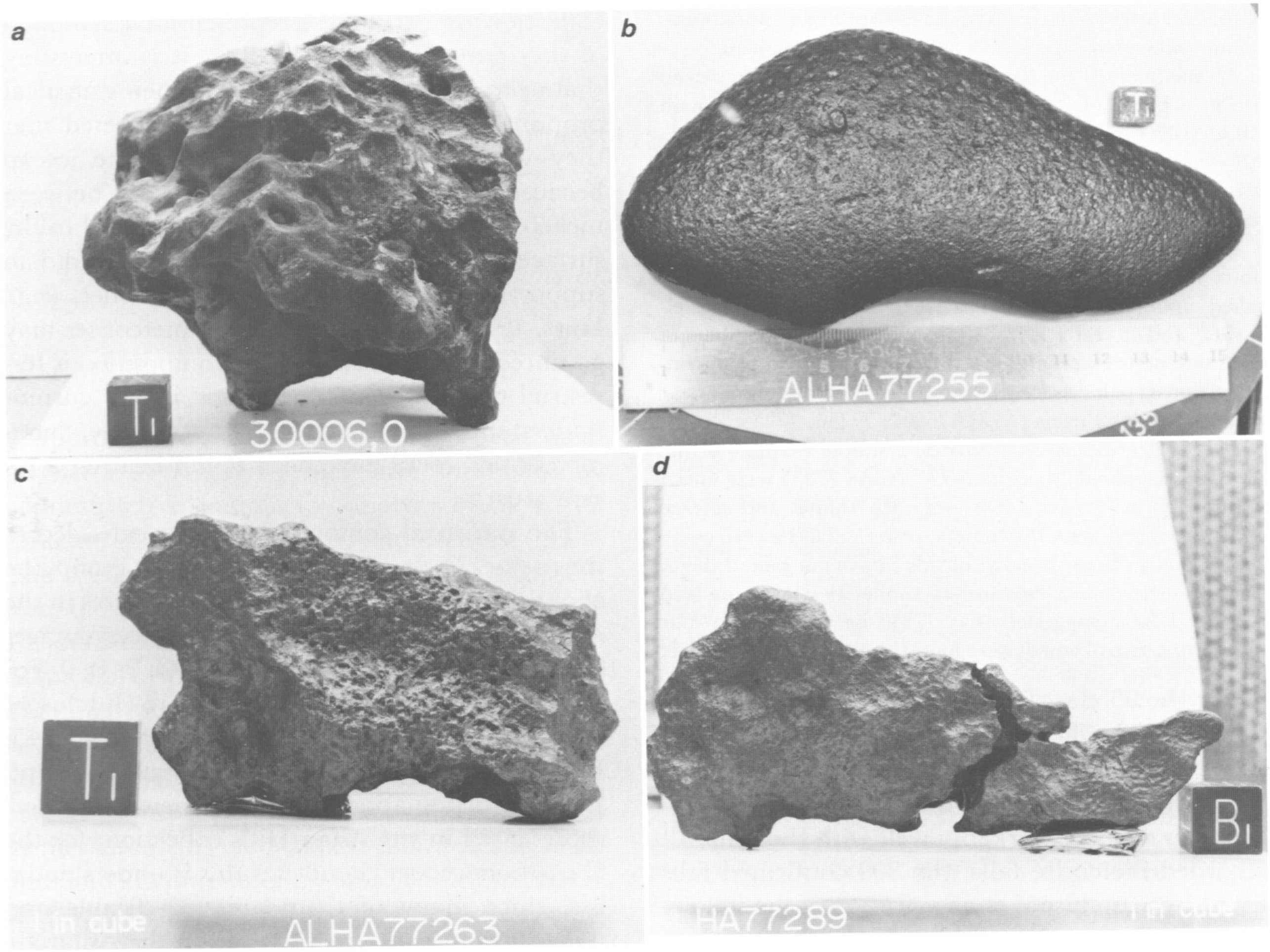


FIGURE 37.—Irons: *a*, PGPA77006, Purgatory Peak (width of specimen is 19 cm); the bright areas at the upper right are the sand-abraded surfaces; the lighter colored area on the lower left is the originally buried portion of the meteorite. *b*, ALHA77255, thin rounded specimen with small regmaglypts on the surface. *c*, ALHA77263, an irregular angular meteorite with a pitted surface (the surface illustrated was in contact with the ice at the time of collection). *d*, ALHA77289, an angular elongated meteorite with a deep fissure, probably a zone of preferential melting and ablation.

L3: 015, 160, 164, 165, 167, 249, 260; 033, 214.
L4: 215, 216, 217.
L6: 270, 277, 284; 001, 296, 297; 150, 305; 231, 272, 273, 280.
IRONS: 250, 263, 283, 289, 290.

Two meteorites discovered anywhere else on the Earth's surface but in Antarctica would be suspected of being a pair if they were picked up as close to each other as any two meteorites recovered at Allan Hills. Obviously, therefore, simple proximity cannot be used as the single criterion for pairing finds in Antarctica. In the above list the specimens were initially categorized according to their petrographic class, and pairings were then generally considered only within classes. There was one group of five specimens, of which three are found in this list (L6: 001, 296, and 297), and another group of 25, of which six are found in this list (H4: 004, 191, 192, 208, 224 and 233), where the field evidence strongly suggested pairing within each group.

The first group of five consisted of three specimens found only centimeters apart that appeared to be fragments of a single mass, and two specimens discovered together only 40 m away that appeared to be fragments of a single mass. All five were picked up in a part of the Allan Hills ice patch where much smaller specimens appear to have been blown across the ice until stopped by a fringing snowfield. This size discrepancy, combined with the fact that meteorites the size of the two original masses of these five specimens apparently do not blow across the ice, suggest an original pairing.

All members of the second group (25 pieces) were picked up on a patch of ice physically separated from the main Allan Hills occurrence by about 5 km of snow-covered ice. All were obvious fragments of larger masses, and all looked very similar. No meteorites of other types have yet been found on this patch of ice.

Among the remaining suggested pairings, general proximity within the Allan Hills site was the principal criterion relied upon, although this is weak for the reason given earlier, and it really is uncertain whether any members of the same petrographic group should be excluded from consideration as pairs, as long as they have been discovered near Allan Hills. The irons (ALHA76002, 77250, 77255, 77263, 77283, 77289, and 77290) provide a simple example of the problems involved. Specimens 77250 and 77255 were found within 500 m of each other, yet their shapes and surface textures suggest great differences, either in Ni/Fe or in entry velocity, or in both. Because of this I have not paired them. On the other hand, because of similarities in shape and texture, I have suggested that 77250 be paired with four other irons, two of which were found about 3 km from 77250.

For the 95 classified specimens from the 1976–77 and 1977–78 Allan Hills collection, the following percentages are obtained: chondrites, 87; achondrites, 5; irons, 7; stony-irons 1. These percentages agree remarkably well with those for all recorded meteorite falls; the 809 confirmed falls listed by Hutchison, et al. (1977) give the following percentages: chondrites, 85; achondrites, 8; irons, 6; stony-irons, 1. Thus the Allan Hills collection appears to be a representative sampling of the terrestrial meteorite flux. It is interesting that iron meteorites are present in their statistical proportion, although it might be expected that they would sink to the bottom of the icecap because of the great density difference between nickel-iron and ice, and never be returned to the surface. So far no evidence has been found to support the suggestion by some researchers (e.g., Huss, 1977) that a percentage of meteorites may go unrecognized because their composition is terrestrial or at least nonmeteoritic in our current understanding. Certainly no apparently "nonmeteoritic" rocks have been found bearing a fusion crust.

The statistical comparison can be extended to the major classes of the most abundant group, the chondrites. For the 81 classified chondrites in the Allan Hills collection, the following percentages are obtained: L, 48; H, 45; LL, 5; C, 2; E, 0. For the 643 classified chondrites listed by Hutchison, et al. (1977), the percentages are as follows: L, 45; H, 40; LL, 8; C, 5; E, 2. The E (enstatite), C, and LL chondrites appear to be somewhat underrepresented in the Allan Hills collection; for the C (carbonaceous) chondrites this is understandable, since many of them are very friable and would disintegrate rapidly even in the Antarctic climate.

Terrestrial Ages

J. C. Evans and L. A. Rancitelli

Approximate terrestrial ages have been measured on 27 Antarctic meteorite specimens by nondestructive gamma ray analysis of their ^{26}Al contents (Evans, Rancitelli, and Reeves, 1979). The specimens include 20 chondrites collected from the Allan Hills region in the 1977–78 season, 4 chondrites and 1 achondrite collected from the Allan Hills in 1976–77, a chondrite from the Yamato Mountains, and the chondrite discovered in Adelie Land in 1912 by the Mawson Expedition. The ^{26}Al contents of these samples are compared with expected saturation values established by measurements on ordinary chondrites from 14 finds and 22 contemporary falls (Table 2). Several of the Antarctic meteorites have also been analyzed for ^{36}Cl, ^{53}Mn, and ^{21}Ne (Table 3).

The calculated terrestrial residence times for the 27 specimens range from less than 0.1 to about 0.7 million years (Table 2). These include the oldest terrestrial ages ever measured on chondrites. When compared with the contemporary find and falls, the Antarctic specimens show a perceptible shift toward lower ^{26}Al values and hence older terrestrial ages (Figures 38, 39). The ^{26}Al values also show a bimodal distribution in which 11 of the 12 H-type chondrites have apparent terrestrial ages of less than 300,000 years, and 8 of the 12 L-type chondrites have estimated terrestrial ages of more than 400,000 years. The three oldest finds, with ages approaching 700,000 years, include an L3, an L5, and an L6 chondrite.

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TABLE 2.—^{26}Al content of Antarctic meteorites (expected saturation value: L = 59 ± 9, H = 55 ± 8)

Meteorite	*Class*	*Weight counted* (g)	^{26}Al (dpm/kg)	*Terrestrial age* (my)
ALLAN HILLS (ALHA)				
76004	LL3	52.5	58 ± 2	<0.2
76005	Eu	337	89 ± 2	<0.1
76006	H6	271	51 ± 1	<0.2
76007	L6	78.5	45 ± 1	<0.4
76008	H6	281.3	11.2 ± 0.4	<0.1
77002,9	L5	73.4	30 ± 3	<0.7 ± 0.2
77003,7	H3	272.4	45 ± 5	<0.5
77014,5	H5	137.2	55 ± 3	<0.2
77015,5	L3	131.8	36 ± 4	<0.7
77025	H5	18.7	54 ± 5	<0.2
77062	H5	16.3	47 ± 5	<0.3
77071	H5	10.5	55 ± 6	<0.2
77081	H?	8.4	42 ± 4	<0.5
77086	H5	18.7	58 ± 6	<0.1
77115,4	?	137.5	48 ± 3	<0.4
77118	H5	7.6	53 ± 5	<0.2
77124	H5	4.1	70 ± 7	<0.1
77140,7	L3	30.8	40 ± 4	<0.6
77144	H6	7.6	56 ± 6	<0.2
77150	L6	57.9	43 ± 4	<0.5
77164	L3	38.0	44 ± 5	<0.5
77167,3	L3	184.6	37 ± 2	<0.6
77214,12	L3	758.6	56 ± 6	<0.2
77272,7	L6	272.1	35 ± 4	<0.7
77299,13	H3	106.7	43 ± 4	<0.4
ADELIE LAND				
USNM 2318	L5	64	50 ± 2	<0.3
YAMATO MTS				
7301(J)	H4	521	26 ± 3	<0.1

Two specimens, ALHA76008 and ALHA-77002, which were suspected on the basis of their

TABLE 3.—Class and ^{36}Cl, ^{53}Mn, and ^{21}Ne content of Antarctic meteorites

Meteorite	*Class*	^{36}*Cl** (dpm/kg Fe)	^{53}*Mn** (dpm/kg Fe)	^{21}*Ne exposure age* (my)
ALHA 76008	H6	9.6 ± 0.6[a]	22 ± 5[c]	1.5[e]
ALHA 77002	L5	4.7 ± 1.1[a]	104 ± 6[b]	13[d]
Yamato 7301(J)	H4	18 ± 1[a]		

* Expected saturation value: ^{36}Cl = 24.5 ± 3.6[f]; ^{53}Mn = 450 ± 90[b].

References: [a] Nishiizumi, personal communication; [b] Nishiizumi, 1978; [c] Nishiizumi, Imamura, and Honda, 1979; [d] Takaoka and Nagao, 1978; [e] Fireman, Rancitelli, and Kirsten, 1979; [f] Begemann and Vilcsek, 1968.

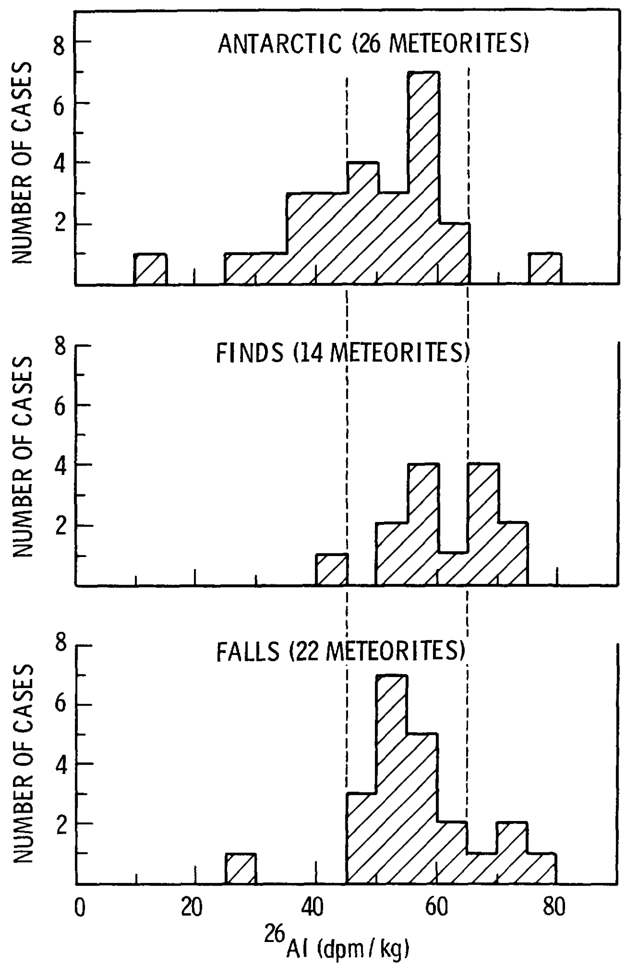

FIGURE 38.—^{26}Al content of H- and L-type chondrites normalized to L-type composition.

low ^{26}Al contents of having terrestrial ages of 1 million years or more, proved to have ^{36}Cl contents indicative of short residence times (Table 3). In both cases, the data are interpreted as reflecting a two-stage history of cosmic ray bombardment involving a fairly recent breakup in space of a body to its pre-atmospheric size, followed by a short terrestrial residence time. The Yamato chondrite, 7301(J), appears to have had a similar history.

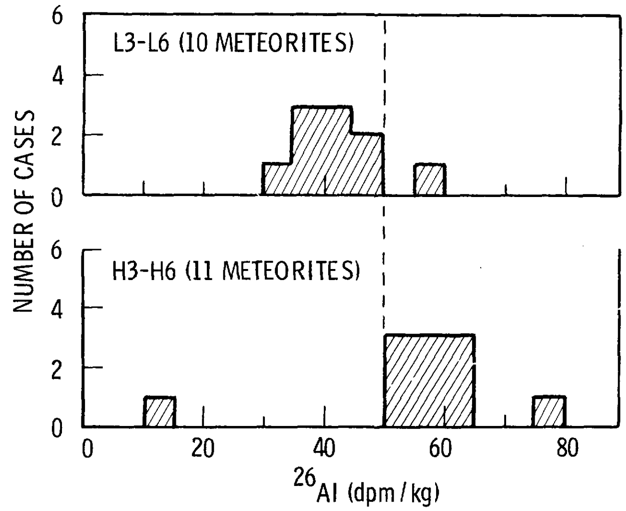

FIGURE 39.—^{26}Al content of Allan Hills chondrites by class normalized to L-type composition.

The old terrestrial ages of Antarctic chondrites have introduced a new and exciting element, not only into meteorite research but, for the first time, have provided the possibility of utilizing meteorites as time probes of a terrestrial process. Measurements of isotope pairs should make it possible to span a range of terrestrial ages extending from the present back 15 million years to the middle Miocene when the Antarctic icecap is believed to have been approximately its present size, but was soon to undergo a significant expansion (Shackleton and Kennett, 1975). The large concentrations of meteorites found on two sides of the continent could well yield specimens old enough to give new information on the age and motion of portions of the Antarctic icecap.

Appendix 1

Characterized Meteorites from the 1977–78 Allan Hills Collection

(listed in numerical sequence)

Class and type: A = achondrite, unique; C = carbonaceous chondrite; Di = diogenite; Eu = eucrite; H = high-iron chondrite; L = low-iron chondrite; LL = low-iron low-metal chondrite; M = mesosiderite; Ur = ureilite. Type is indicated by the digit following the letter.
Olivine composition in mole percent Fe_2SiO_4 (Fa).
Pyroxene (orthopyroxene or low-Ca clinopyroxene) composition in mole percent $FeSiO_3$ (Fs).
Degree of weathering: A = minor; metal flecks have inconspicuous rust halos, oxide stain along cracks is minor. B = moderate; metal flecks show large rust halos, internal cracks show extensive oxide stain. C = severe; specimen is uniformly stained brown, no metal survives.

ALHA number	*Weight* (grams)	*Class & type*	*%Fa in olivine*	*%Fs in pyroxene*	*Degree of weathering*	*ALHA number*	*Weight* (grams)	*Class & type*	*%Fa in olivine*	*%Fs in pyroxene*	*Degree of weathering*
77001	252	L6	25	21	B	77160	70.4	L3	3–46	6–40	C
77002	235	L5	25	22	B	77164	38.1	L3	6–39	3–41	C
77003	780	H3	4–48	2–25	A	77165	30.5	L3	8–33	6–35	C
77004	2230	H4	17–20	15–27	C	77167	611	L3	2–41	3–17	C
77005	483	A	28	23	A	77177	368	H5	18	16	C
77014	309	H5	18	17	C	77182	1109	H5	19	17	B
77015	411	L3	1–21	4–24	C	77190	387	H4	17–19	15–22	C
77021	16.7	H5	18	17	C	77191	642	H4	16–18	14–16	C
77025	19.4	H5	18	17	C	77192	845	H4	16–18	15–21	C
77033	9.3	L3	8–38	8–9	C	77208	1733	H4	17	14	C
77061	12.6	H5	18	17	B	77214	2097	L3	1–49	4–23	C
77062	16.7	H5	18	17	B	77215	820	L4	22–26	9–21	B
77064	6.5	H5	18	17	B	77216	1470	L4	23–26	10–19	A/B
77071	10.9	H5	18	17	B	77217	413	L4	17–25	9–26	B
77074	12.1	H5	18	17	B	77219	637	M	26	24–28	B
77081	8.6	H?	11	11	B	77224	787	H4	19	17	C
77086	19.4	H5	19	17	C	77230	2473	L4	22–25	18–29	B
77088	51.2	H5	19	17	C	77231	9270	L6	24	21	A/B
77102	12.3	H5	19	15	B	77233	4087	H4	14–21	15–17	C
77118	7.8	H5	19	17	C	77249	504	L3	7–35	2–25	C
77119	6.4	H5	18	17	C	77250	10555	iron			
77124	4.4	H5	19	16	C	77252	343	L4	22–28	2–22	B
77140	78.6	L3	8–44	2–17	C	77254	246	L5	23	20	A/B
77144	7.9	H6	19	17	B	77255	765	iron			
77148	13.1	H6	18	16	C	77256	676	Di		23	A/B
77150	58.3	L6	25	22	C	77257	1996	Ur	9–23	12	A
77155	305	L6	24	20	A/B	77258	597	H6	18	16	B/C

ALHA number	Weight (grams)	Class & type	%Fa in oli-vine	%Fs in pyrox-ene	Degree of weather-ing
77260	744	L3	7–23	1–28	C
77261	412	L6	24	21	B
77262	862	H4	15–19	13–16	B
77263	1669	iron			
77264	11.0	H5	19	16	A/B
77269	1045	L6	24	22	B
77270	589	L6	24	21	A/B
77271	610	H6	18	16	A
77272	674	L6	24	20	B/C
77273	492	L6	24	20	B
77277	143	L6	24	20	A/B
77278	313	LL3	11–29	9–21	A
77280	3226	L6	24	21	B
77281	1231	L6	24	20	B
77282	4127	L6	24	20	B
77283	10510	iron			
77284	376	L6	25	21	A/B
77285	271	H6	18	16	C
77288	1880	H6	19	17	B
77289	2186	iron			
77290	3784	iron			
77294	1351	H5	17	15	A
77296	963	L6	24	21	A/B
77297	952	L6	24	20	A
77299	261	H3	11–21	15–20	A
77300	235	H5	18–19	15–17	C
77302	236	Eu		37–64	A
77304	650	LL3	18–27	13–19	B
77305	940	L6	24	21	B/C
77306	19.9	C2			A
77307	181	C3	1–30	1–12	A

Appendix 2

Chemical Analyses of Some Allan Hills Meteorites

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Constituent	*77003*	*77005*	*77214*	*77219*	*77256*	*77257*	*77278*	*77299*
Fe	4.50	n.d.	2.02	23.63	n.d.	n.d.	2.23	12.26
Ni	1.37	0.01	1.18	2.86	0.01	0.08	1.03	1.67
Co	0.07	$<$0.01	0.06	0.10	$<$0.01	$<$0.01	0.05	0.08
FeS	4.85	$<$0.1	5.73	1.10	0.15	$<$0.01	6.17	5.23
SiO_2	34.19	42.40	37.73	32.27	52.15	41.12	41.03	35.94
TiO_2	0.14	0.46	0.11	0.16	0.16	0.04	0.12	0.11
Al_2O_3	2.89	3.14	2.30	3.93	1.56	$<$0.1	2.26	2.27
Cr_2O_3	0.49	1.05	0.49	0.63	1.06	0.70	0.50	0.41
FeO	21.78*	19.85	19.63*	15.84*	16.07	13.57	16.79*	13.15*
MnO	0.31	0.46	0.33	0.41	0.47	0.38	0.34	0.30
MgO	23.53	28.16	22.69	12.56	26.48	39.66	24.08	22.50
CaO	2.22	3.39	1.70	3.14	1.50	1.07	1.90	1.81
Na_2O	0.56	0.48	0.82	0.15	0.04	0.03	0.82	1.08
K_2O	0.06	0.04	0.07	0.03	0.01	0.01	0.10	0.12
P_2O_5	0.23	0.41	0.21	0.30	0.01	0.06	0.20	0.22
$H_2O(+)$	1.01	n.d.	2.34	1.02	n.d.	n.d.	1.20	1.15
$H_2O(-)$	0.88	0.02	0.95	0.61	0.02	0.18	0.38	0.56
C	0.28	0.02	1.08	0.15	0.03	3.34	0.16	0.38
Total	99.36	99.89	99.44	98.89	99.72	100.24	99.36	99.24
Total Fe	24.51	15.43	20.77	36.64	12.49	10.55	19.20	25.80

n.d. = not determined.

* Weathered meteorite in which all FeO and Fe_2O_3 is reported as FeO.

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