MINERALOGICAL CHANGES DURING TERRESTRIAL WEATHERING OF ANTARCTIC CHONDRITES. J.L. Gooding, Planetology Group, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, U.S.A.

Introduction. Field and laboratory observations of meteorites recovered from Antarctica have shown that many of the specimens are significantly weathered (1, 2). Consequently, detailed knowledge of the processes and products of meteorite weathering is required in order to analytically reconstruct meteorite "finds" and to quantitatively assess the degree of preservation of rare or unusual specimens which might later become subjects for intense study of their pre-terrestrial properties. Furthermore, study of weathered Antarctic stony meteorites might provide insight into possible processes by which mafic and ultramafic extraterrestrial igneous rocks decompose in environments which may be analogous to those on the surface of Mars. Accordingly, a detailed study of six weathered ordinary chondrites from Allan Hills, Antarctica was performed with emphasis placed on identification of mineralogical features which might be correlated with previously observed (3-6) geochemical effects of Antarctic weathering.

Samples and Methods. The following documented chips were studied: ALHA76006,3 (chemical-petrologic type H6), 76008,6(H6), 77155,13(L6), 77270,15(L6), 77272,31 (L6), 77296,9 (L6). Each chip of ~ 5g represented the outer ~1-2 cm portion of its respective parent stone and, after stereomicroscopic examination, was multiply sliced using a diamond wafer-blade saw with dry (< 0.2% water) isopropanol as coolant. Following reflectance spectrophotometric scans (0.35-2.5μm) of its two sides, each slice was prepared as a diamond-polished thin-section using dry isopropanol as the polishing medium. Whole-rock splits (~ 0.6-1g) of the surface (outer ~ 0.5 - 1 cm) portions of each chip were individually crushed in a compressed sapphire mortar and pestle and pulverized (to $\leq$ 50 μm particles) in air using a WIG-L-BUG automatic stainless steel ball mill. The resultant powders were studied by x-ray diffractometry (XRD), visible/near-infrared (VIS/NIR) reflectance spectrophotometry, and differential thermal analysis (DTA). Surfaces of selected whole-rock chips were examined by scanning electron microscopy (SEM). Electron microprobe analyses are planned.

Chips comparable to the ALHA specimens in size and parent stone surface proximity were selected from stones recovered in 1912, 1931, and 1968 from the Holbrook, Arizona (L6) chondrite shower. The latter specimens constitute a known chondrite weathering sequence (7) and were studied in parallel with the ALHA samples as temperate-environment reference samples.

Surface Morphologies and Mineral Deposits. The ALHA77 samples show clear evidence for fracturing and partial exfoliation of fusion crust. The fracture patterns are crudely polygonal and resemble similar but better developed patterns on the surface of Holbrook 1968. ALHA76006,3 and 77296,9 possess notable surface deposits of yellow-brown and white phases, respectively, which are probably secondary minerals. Unfortunately, the dissemination of the particles and their sensitivity to SEM electron bombardment has inhibited their identification and comparison with the carbonates and sulfates previously observed (8) on the surfaces of other ALHA meteorites. However, the unusual mamillary to botryoidal phase which lines fractures on 77296,9 (Fig. 1) contains K and S and may be a sulfate.

Bulk Mineralogy. XRD patterns of all ALHA specimens are dominated by olivine and pyroxene with only traces of identifiable weathering products (mostly hematite). Clay minerals and zeolites are being carefully sought although their presence has not been confirmed. The absence of reproducible

water absorption bands in their respective reflectance spectra suggests that both the ALHA and weathered Holbrook samples contain only minor amounts of hydrous minerals although the diagnostic spectral bands may be partially or totally masked by opaque phases (9, 10).

Relative Degrees of Weathering. The ratio of spectral reflectance at 0.5 μm to that at 0.6 μm, an index previously identified (9) as a useful monitor of weathering effects in stony meteorites, is correlated with absolute reflectance of blue light (0.45 μm). Both parameters sympathetically decrease in numerical value as fresh, pastel blue-gray stones weather progressively toward hues of orange, due to iron (III) oxide formation. These indices clearly show that the four ALHA77 chondrites correspond to respective degrees of weathering which distinguish each from the others and from the weathered Holbrook samples (Fig. 2). The two ALHA76 chondrites, though, are more similar in their degrees of weathering and appear to be as altered as the most intensely weathered Holbrook (1931) sample. In fact, the NIR spectra of the ALHA76 samples are nearly indistinguishable from those of the ALHA77 samples and belie the differences which should be observable between fresh H6 and L6 chondrites (10).

A comparison of DTA curves (Fig. 3) shows that the small but sharp endotherm at ~ 160°C, which is attributable to the crystal structural inversion of troilite (11), is less intense in weathered chondrites relative to fresh Holbrook 1912. Furthermore, thermal activity at temperatures > 400°C increases with degree of weathering. Endotherms over the ~ 400 - 600°C range are crudely similar to those of hydrated Mg-carbonates whereas weak endotherms at ~ 800°C may be due to $CaCO_3$, thereby supporting previous geochemical evidence (6) for carbonate formation during weathering of Antarctic stony meteorites. DTA evidence for release of loosely bound water (broad endotherms <200°C) is noticeably absent although further analyses of greater sensitivity are in progress.

Among the ALHA samples studied here, terrestrial residence ages have been determined only for 76006, 76008, and 77272 (3, 4). These ages may correlate crudely with mineralogical indices of weathering since 77272 (>34, $\leq$ 700 x 10^3y) is clearly less weathered than 76008 (> 32, $\leq$ 1500 x 10^3y). However, 76006 (> 32, $\leq$ 200 x 10^3y) appears to be as badly weathered as 76008. Detailed mineralogical studies of other weathered stony meteorites for which terrestrial age data are available are being planned.

Acknowledgement. This work was supported by the NASA Planetary Geology Program under contract NAS 7-100 to the Jet Propulsion Laboratory.

References. (1) Olsen, E.J., Noonan, A., Fredriksson, K., Jarosewich, E., and Moreland, G. (1978) Meteoritics, 13, 209-225. (2) Marvin, U.B. and Mason, B. (1980) (Eds.) Smithsonian Contr. Earth Sci. 23, 50 pp. (3) Fireman, E.L. (1979) Proc. Lunar Planet. Sci. Conf. 10th, 1053-1060. (4) Evans, J.C. and Rancitelli, L.A. (1979) Lunar Planet. Sci X, LPI, Houston, TX, 373-375. (5) Biswas, S., Ngo, H.T., and Lipschutz, M.E. (1980) Z. Naturforsch. 35a, 191-196. (6) Gibson, E.K. Jr. and Andrawes, F.F. (1980) Proc. Lunar Planet. Sci. Conf. 11th, in press. (7) Gibson, E.K. Jr. and Bogard, D.D. (1978) Meteoritics, 13, 277-289. (8) Marvin, U.B. and Motylewski, K. (1980) Lunar Planet. Sci. XI, LPI, Houston, TX, 669-670. (9) Salisbury, J.W. and Hunt, G.R. (1974) J. Geophys. Res., 79, 4439-4441. (10) Salisbury, J.W., Hunt, G.R., and Lenhoff, C.J. (1975) Mod. Geol., 5, 115-126. (11) Craig, J.R. and Scott, S.D. (1974) In Sulfide Mineralogy, Mineral. Soc. Amer., CS1-CS110.

WEATHERED ANTARCTIC CHONDRITES

Gooding, J.L.

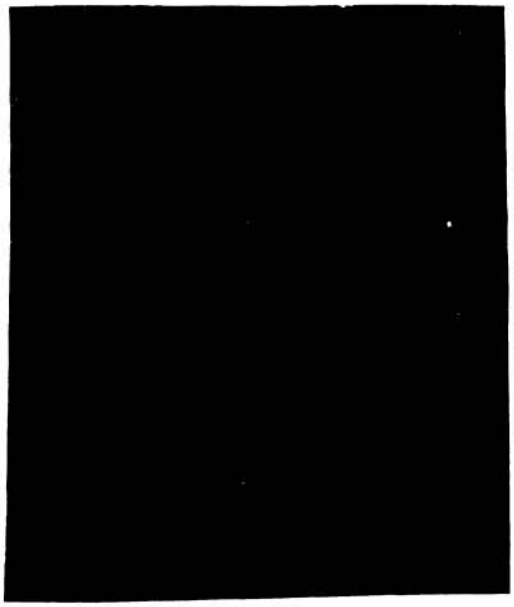

Figure 1. SEM image (140X) of possible sulfate fracture fillings on the surface of ALHA77296,9. Energy-dispersive x-ray analysis indicates that the botryoidal phase is enriched in K and S relative to the surrounding surface.

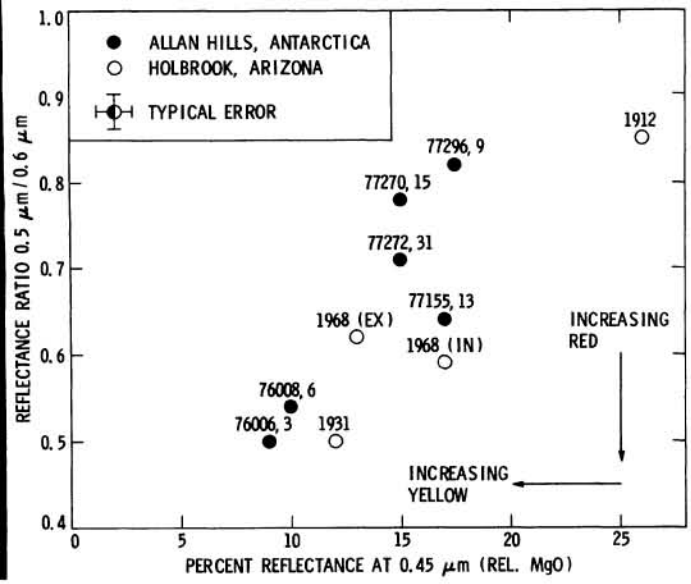

Figure 2. Spectral reflectance characteristics of weathered chondrites. Each point is the average of three analyses of pulverized surface (outer ~ 0.5-1 cm) specimens. Exterior (EX) and interior (IN; > 1 cm depth) specimens of Holbrook 1968 are contrasted. Progressive weathering is accompanied by increasing orange color as indicated by the trend from upper right to lower left.

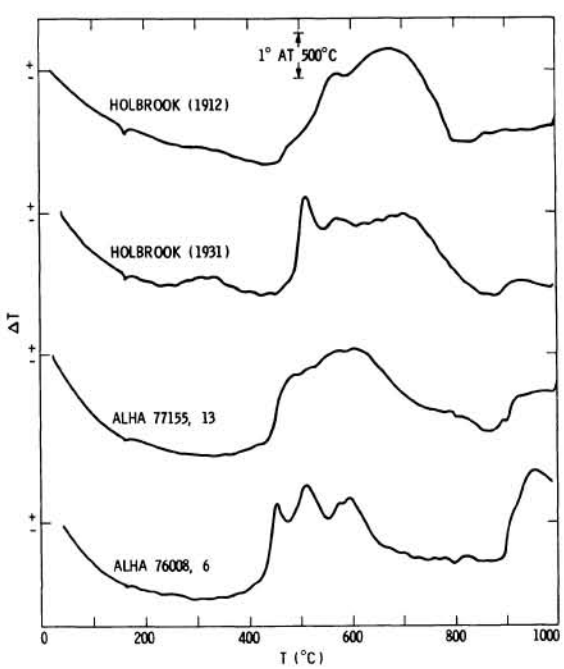

Figure 3. DTA curves of weathered chondrites compared with that of fresh Holbrook 1912. Samples (221-232 mg) were run in vacuum at 10°C/min against Al_2O_3 (195-223 mg) as reference. Loss of FeS during weathering indicated by gradual disappearance of the small, sharp endotherm at ~ 160°C from top to bottom curves.