ANTARCTIC METEORITES: PETROLOGY AND CHEMISTRY OF 77001 (L6), 77002 (L5) AND 77299 (H3).

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We have undertaken a study of three allocated Antarctic meteorites obtained during the 1977-1978 expedition led by William Cassidy to the Allan Hills. Classification, preliminary petrography and electron microprobe data by Mason (1) may be summarized as follows: ALHA-77001 is described as a typical L6 chondrite with poorly defined chondrules and major olivine (Fa_{25}) and orthopyroxene ($Wo_{1.7}En_{77}Fs_{21}$). Plagioclase ($Ab_{83}An_{11}Or_6$) is present in association with Ni-Fe, troilite, chromite, diopside and merrillite. ALHA-77002 is an L5 chondrite with prominent and well defined chondrules, having uniform olivine (Fa_{25}) and pyroxene ($Wo_{1.2}En_{77}Fs_{22}$) compositions and plagioclase averaging $Ab_{84}An_{10}Or_6$. Troilite, Ni-Fe metal, and chromite are also present. ALHA-77299 was tentatively classified as an H3 chondrite, which is confirmed by our major element and mineral chemistry data. A variety of chondrules are present having olivine (Fa_{11}-Fa_{21}) and orthopyroxene (CaO=0.4-1.2 wt%) in the range Fs_{15}-Fs_{20}. Polysynthetically twinned clinopyroxene, troilite and Ni-Fe metal are dispersed throughout the chondrite.

Our preliminary study of these three meteorites has focused on the petrography and mineral chemistry of chondrules, the chemistry of the opaque minerals, and the analysis of bulk chemistry.

Chondrules:

The chondrules in 77299 (H3) and 77002 (L5) were characterized optically on the basis of a modified version of the system developed for the Allende meteorite (2). This modification was necessary because of abundant orthopyroxene, and because glassy and devitrified-glass chondrules, similar to those found in the lunar soils, are present in significant concentrations. Readily identifiable chondrules were not observed in the L6 (77001) chondrite. Table 1 lists the number and the percentages of chondrule types observed in small single, polished-thin sections of 77299 and 77002. For both meteorites, anhedral olivine or pyroxene chondrules are the dominant type, followed by barred crystalline types, skeletal types, recrystallized olivine, glassy types, and plagioclase-rich chondrules. Sample 77299 has olivines in chondrules and discrete crystals in the groundmass that are uniform in composition with 80% (47 of 59 analyses) of our data falling within the Fa_{16}-Fa_{20} range established by Van Schmus and Wood (3), thereby supporting Mason's (1) initial classification that 77299 is an H3 chondrite. However, the recrystallized olivine chondrules range from $Fa_{1.5}$-$Fa_{14.0}$, exhibit weak core-mantle zoning ($Fa_{1.6}$-$Fa_{4.8}$), and are compositionally similar to the range determined for this class of chondrules in the Allende meteorite (2). Olivines in the partially equilibrated L5 (77002) chondrite range from Fa_{22}-Fa_{25} with the exception of one discrete olivine crystal which is $Fa_{19.6}$. The range of the equilibrated L6 (77001) olivines is extremely narrow ($Fa_{24.4}$-$Fa_{25.3}$), confirming Mason's (1) determination of Fa_{25}.

Opaque Mineralogy: Reflection microscopy and electron microprobe data on the three meteorites show that kamacite, taenite, troilite and chromite are present. Troilite is the dominant phase in the L5 chondrite (77002) in association with minor, discrete homogeneous γ iron (33.2-47.4 wt% Ni) and α iron (6.6-7.4 wt% Ni). Cobalt concentrations are uniformly low reaching a maximum of 0.21 wt% in γ iron and a maximum of 0.97 wt% in α iron. Chromite is present as a minor constituent of olivine-rich chondrules and is also present as large (~250 μm) irregular crystals with triple junctions that form discontinuous mantles on chondrules. Compositionally, the spinels are low Mg-Al-Ti chromites (Table 2) that fall within the L field as outlined by Bunch and Olsen (4). The relatively high ferric iron contents of the spinels in 77002 (calculated assuming stoichiometry) are probably not a reflection of the original conditions of crystallization, but are due rather to terrestrial weathering as evidenced by large concentrations of goethite and the incipient alteration of troilite and kamacite.

The L6 (77001) chondrite contains abundant γ+α iron in sealed, mutual grain boundary contacts. In these large assemblages, the Ni and Co contents vary from 5.3-6.3 wt% Ni and 0.8-1.1 wt% Co in α-iron, and from 26.9-28.0 wt% Ni and 0.2-0.6 wt% Co in the γ-iron. Small discrete grains of γ iron (14-20% Ni) are also present within or interstitial to olivine, and based on the distribution of iron among metal, olivine and pyroxene (5) and the expression:

$$\log fO_2 = 2 \log X\text{Fa} - 20980/T^0\text{K} + 7.2$$

for Fa_{25} and an assumed equilibration temperature of 880^0C (6) the $fO_2=10^{-15.3}$, a value that is approximately 2 orders of magnitude higher than that estimated by Williams (6), but well within the range calculated for L-type chondrites. Chromites in the L6 chondrite are rounded and strongly fractured but are compositionally similar to the spinels in 77002 (Table 2).

The H3 chondrite (77299) contains a spectacular, but complex array of textural intergrowths between kamacite and taenite that fall into the following classes: (1) polygonal clear α iron with Neumann bands and polygonal interstitial inclusions of γ iron; (2) irregular inclusions of γ in non-polygonal α; (3) coarse lamellar γ in α; (4) fine lamellar γ in α; and (5) wavy lamellae of α in γ. The lamellae are not strictly comparable to the Widmanstätten texture of iron meteorites insofar as they exhibit pinch and swell structures, bifurcations, and swirls, but they do appear to be controlled by {111} planes of orientation, modified by partial recrystallization. Compositionally, the taenites in these five classes of assemblages form a distinct bimodal distribution: polygonal inclusions (in polygonal α-iron), coarse lamellar γ-iron, and the class 5 γ host with wavy α lamellae, have Ni contents in the range 37-41 wt%; irregular inclusions in non-polygonal kamacite, and fine lamellae of γ, lie between 48 and 52 wt% Ni. The kamacite component of these assemblages contain 3.2-6.8 wt% Ni and the preferred partitioning of Co into the α-iron (0.6 wt% *versus* 0.1 wt% in γ) is similar to the distribution determined for the L5 and L6 chondrites. Application of the band-width, diffusion-controlled technique for the determination of cooling rates has not been attempted because of the irregular nature of taenite lamellae. Troilite is an abundant constituent of 77299 and although a proportion of troilite exhibits polygonal recrystallization and shock-induced twinning, an approximately equal proportion is twin-free, suggesting a pre-shock history for some components of meteorite. Neumann bands, as noted above, are restricted to recrystallized polygonally structured kamacite, and this feature, coupled with the bimodal distribution of taenite compositions, may support a two stage model for the formation of the meteorite. Chromites (~20μm maximum) are present in chondrules as euhedral to subhedral crystals, and as anhedral crystals in the groundmass. The spinel compositions are remarkably similar to those present in the L5 and L6 chondrites differing only in having slightly lower TiO_2 and Al_2O_3 contents, and correspondingly higher values of Cr_2O_3 (Table 2).

Bulk Chemistry: Major element data by XRF (7) are given in Table 3. Chips of approximately 1.3g were crushed in boron carbide and a 300mg aliquant taken for analysis. Prior to fusion for analysis, the aliquants were heated in air at 950^0C for 12 hrs in order to oxidize metallic iron. Inevitably, the bulk of the sulfur is lost. Experiments currently in progress aim at eliminating this loss during sample preparation. The compositional data, in particular the total iron content, Fe/Si and Mg/Si ratios, confirm the mineralogically based classification of these samples. All are ordinary chondrites, 77299 belonging to the H-group and 77001 and 77002 to the L-group. Ahrens and co-workers (8,9,10) have stressed that although most lithophile element ratios (e.g. Ca/Si, Al/Si, Mg/Si, Ti/Si) are distinctly different between the principle chondrite types, the dispersion within each of these types is remarkably small. Our data fall within the narrow limits established by these authors for the H- and L-type chondrites. These same authors have also suggested that there may be small but real evidence of fractionation of Si/Ti and Si/Mg within the ordinary chondrites between the H- and L-types. Our results support this suggestion, the Si/Ti and Si/Mg ratios for 77299 are distinctly lower than those for 77001 and 77002. We note that 77001 and 77002 are very similar in composition. However, the difference in metamorphic grade (L5 vs. L6) preclude the possibility that they are fragments from the same meteorite.

References: (1) Mason B. in Antarctic Meteorite Newsletter (1978) Vol 1, no 1, Meteorite Working Group, eds. (2) Simon S.B. and Haggerty S.E. (1979) This volume. (3) Van Schmus W.R. and Wood J.A. (1967) Geochim. Cosmochim. Acta, 31, 747-765. (4) Bunch T.E. and Olsen E. (1976) Geochim. Cosmochim. Acta, 39, 911-927. (5) Larimer J.W. (1968) Geochim. Cosmochim. Acta, 32, 1187-1207. (6) Williams R.J. (1971) Geochim. Cosmochim. Acta, 35, 407-411. (7) Norrish K. and Hutton J.T. (1969) Geochim. Cosmochim. Acta, 33, 431-453. (8) Ahrens L.H., Von Michaelis H., Erlank A.J. and Willis J.P. (1969) in Meteorite Research (ed. Millman P.M.) p. 166-173, Reidel, Holland. (9) Von Michaelis H., Ahrens L.H. and Willis J.P. (1969) Earth Planet. Sci. Lett. 5, 387-394. (10) Ahrens L.H. and Von Michaelis H. (1969) Earth Planet. Sci. Lett., 5, 395-400.

Table 1. Abundances of Chondrule Types.

Type	H3		L5	
	77299,25		77002,28	
Euhedral olivine	2	3.2%	3	8.1%
Anhedral olivine or pyroxene	24	38.1	12	32.4
Barred olivine or pyroxene	12	19.0	6	16.2
Glassy/skeletal olivine or pyroxene	7	11.1	7	18.9
Recrystallized olivine	8	12.7	3	8.1
Plagioclase-rich	2	3.2	0	0.0
Glassy	6	9.5	2	5.4
Other	2	3.2	4	10.0
Total	63	100.0%	37	100.0%

Table 2. Chromite Compositions

Type	H3	L6	L5
Sample #	77299,25	77001	77002,28
SiO_2	0.25	0.09	0.09
TiO_2	1.66	3.05	2.53
Al_2O_3	4.92	5.50	5.77
Cr_2O_3	57.65	55.47	55.49
$Fe_2O_3^*$	1.57	1.21	2.01
FeO	30.13	30.77	30.05
NiO	<0.05	<0.05	<0.05
MnO	0.89	0.96	0.96
MgO	2.22	2.70	2.78
CaO	<0.05	<0.05	<0.05
ZrO_2	<0.05	<0.08	<0.05
Nb_2O_3	<0.05	<0.07	<0.05
Total	99.42	99.92	99.70

*Calculated based on stoichiometry.

Table 3. Bulk Chemistry

Type	H3	L6	L5
Sample #	77299,23	77001,18	77002,24
SiO_2	33.50	38.40	38.40
TiO_2	0.10	0.10	0.10
Al_2O_3	1.90	2.23	2.11
Cr_2O_3	0.53	0.54	0.53
$Fe_2O_3^*$	35.90	29.60	29.30
NiO	2.09	1.59	1.71
MnO	0.30	0.34	0.35
MgO	21.30	23.70	23.70
CaO	1.58	1.74	1.86
Na_2O	N.A.	N.A.	N.A.
K_2O	0.16	0.13	0.10
P_2O_5	0.25	0.25	0.24
S	0.14	0.12	0.14
Total	97.80	98.70	98.50
Fe/Si	0.800	0.576	0.570
Si/Ti	261	299	299
Si/Mg	1.22	1.25	1.25

*Total iron as Fe_2O_3

N.A. - not yet available