

# CHEMICAL COMPOSITIONS OF THE ALH-77302 POLYMICT EUCRITE

Takaaki FUKUOKA

*Department of Chemistry, Faculty of Science, Gakushuin University,  
Mejiro 1-chome, Toshima-ku, Tokyo 171*

and

Noboru NAKAMURA

*Department of Earth Sciences, Faculty of Science, Kobe University,  
Rokkodai, Nada-ku, Kobe 657*

**Abstract:** The abundances of 16 major, minor, and trace elements (Fe, Na, Cr, Co, Sr, Ba, Sc, La, Nd, Sm, Eu, Tb, Yb, Lu, Hf and Ta) in two matrices, one fusion crust, 10 igneous clast samples of ALH-77302 polymict eucrite have been determined by instrumental neutron activation analysis. The abundances of 14 minor and trace elements (K, Rb, Sr, Ba, La, Ce, Nd, Sm, Eu, Gd, Dy, Er, Yb and Lu) in a matrix sample of ALH-77302 have been also determined by mass spectrometric isotope dilution method.

The chondritic normalized REE patterns of the matrices, fusion crust, and igneous clasts are similar to those of known non-cumulative eucrites. The La abundances in the clasts range from the lowest La abundance in the previously reported non-cumulative eucrites to the highest one. The chemical features of the ALH-77302 polymict eucrite have been discussed in more detail.

## 1. Introduction

For the better understanding of processes of the most primitive differentiation events in our solar system associated with crust formation, it is very interesting to study the igneous process of the parent body of basaltic achondrite, which probably had the layered structure. The close relationship among various basaltic achondrites (*i.e.*, eucrites, diogenites, and howardites) was pointed out by MOORE (1962) and MASON (1967). This relationship is supported by oxygen isotope data (CLAYTON *et al.*, 1976). DUKE and SILVER (1967) suggested that howardites were mechanical mixtures of eucrites and diogenites on the basis of the petrographical, mineralogical, and chemical data. TAKEDA (1979) proposed a layered-crust model of a howardite parent body by mineralogical investigations. From siderophile element data, CHOU *et al.* (1976) and FUKUOKA *et al.* (1977) found the chondritic component in howardites in addition to the eucritic and diogenitic components.

For the purpose of studying large-scale differentiation processes in the basaltic achondrite parent body, the use of howardite has an advantage; a howardite contains

both eucritic and diogenitic clasts which have possibly been produced on a single parent body. Polymict breccias of the eucritic composition, on the other hand, are thought to be better samples for studying surface materials of the parent body. The polymict eucrites have been interpreted to be lithified regoliths produced by impact of various-sized meteorites, that is, various depths of excavation of the crust on their parent body.

The ALH-77302 meteorite is a polymict eucrite which was collected in the Allan Hills region by the U.S.-Japan team during the 1977-78 Antarctic field season (MASON, 1978). In this paper, we report chemical compositions (mainly trace elements) of matrices, fusion crust, and clasts extracted from the ALH-77302 meteorite, as a part of consortium study of formation processes of the parent body of basaltic achondrite.

## 2. Samples and Experimental

A sliced ALH-77302 meteorite specimen, about 6-7 mm thick, was obtained from the National Institute of Polar Research. The surface of the specimen was partly contaminated by the cutting saw. The contaminations were eliminated by grinding with a diamond disk under dry condition. More than 20 of eucritic igneous clasts and several carbonaceous-chondrite-like clasts were easily recognized in the matrix materials of the cleaned surface of the specimen. After mapping of the location of the clasts and phenocrysts on the surface of the specimen by taking close-up photographs, the clasts, fusion crust, and matrices were extracted from the specimen by stainless steel tweezers under a binocular microscope.

The abundances of 16 major, minor, and trace elements (Fe, Na, Cr, Co, Sr, Ba, Sc, La, Nd, Sm, Eu, Tb, Yb, Lu, Hf, and Ta) in two matrices, one fusion crust, and 11 samples of 10 clasts have been determined by instrumental neutron activation analysis (INAA). The extracted sample chips were weighed by an electro-microbalance (CAHN 26). The samples were heat-sealed in quartz tubes. The samples (1.3-17.1 mg) were activated with thermal neutron for 267 hrs at 10 MW ( $3 \times 10^{13}$  n/cm<sup>2</sup> s) in JRR-3 nuclear reactor of the Japan Atomic Energy Research Institute. Glass chips (NAGASAWA *et al.*, 1978), which were made from the standard rock of the Geological Survey of Japan, JB-1 and the U. S. Geological Survey (U.S.G.S.) standard rock BHVO-1, were also activated as standard and/or control samples. A blank quartz vial was also activated for the check of the impurities in the quartz vials. After 5-7, 8-14, and more than 30 days cooling, the  $\gamma$ -ray spectroscopies of the activated samples with the quartz vials were carried out on a  $\gamma$ -ray spectrometer with a Ge (Li) detector, repeatedly. The counting periods of the 1st, 2nd, and 3rd counts were 1 hr, 2-7 hrs, and 5-10 hrs, respectively.

The abundances of 14 minor and trace elements (K, Rb, Sr, Ba, La, Ce, Nd, Sm, Eu, Gd, Dy, Er, Yb, and Lu) in a matrix have been determined by the mass spectrometric isotope dilution method. The mass spectrometric procedures employed in

this work were basically the same as our regular methods (MASUDA *et al.*, 1973; NAKAMURA, 1974).

### 3. Results and Discussion

The analytical results for the matrices, fusion crust, and clasts extracted from the ALH-77302 polymict eucrite are shown in Table 1 together with the results for BHVO-1. The chondritic normalized rare earth elements (REE), Sc, Hf, and Ta abundances of these sample specimens are plotted on Figs. 1 and 2. The analytical results for the blank indicates the vial is amazingly clean. Therefore, no corrections were made for any of the results of the samples. The results for the U.S.G.S. standard rock, BHVO-1, show good agreements with those reported by TAYLOR and GORTON (1977), and MA (private communication, 1980).

The ALH-77302 meteorite was recognized as a polymict eucrite from the mineralogical and petrographical studies (MIYAMOTO *et al.*, 1979; SIMON and HAGGERTY, 1980). The chondritic normalized REE patterns of the matrices, a fusion crust, and lithic clasts show the monotonically enriched flat patterns with some negative and/or positive Eu anomalies compared to the chondritic pattern (Figs. 1 and 2). These features are similar to those of known non-cumulative monomict eucrite (CONSOLMAGNO

Table 1. Chemical abundances in the matrices, fusion crust, and clasts separated from the ALH-77302 polymict eucrite.

Sample	Wt mg	FeO %	Na <sub>2</sub> O %	Cr ppm	K ppm	Rb ppm	Sr ppm	Ba ppm	Sc ppm	Hf ppm	Ta ppm
Matrix A	12.1	19.0	0.43	3200			—	16	30	1.2	0.25
B	11.9	12.4	0.65	1860			—	37	29	2.4	0.41
C <sup>1)</sup>	6.3				622	0.704	78.0	37			
Fusion crust	5.4	19.7	0.39	2700			110	43	30	1.4	0.28
Clast A	9.3	15.2	0.51	2260			—	51	35	1.8	0.38
B	17.1	14.8	0.79	1620			100	41	23	1.2	0.27
C1	8.6	7.9	0.45	1010			52	23	22	2.5	0.44
C2	10.2	22.1	0.53	2980			—	57	35	1.5	0.29
C <sup>2)</sup>		15.6	0.49	2080			—	41	29	2.0	0.36
D	10.9	12.3	0.83	1650			—	61	34	3.4	0.52
E	14.1	19.8	0.38	2630			—	18	33	2.2	0.31
F	6.1	24.0	0.91	4010			110	75	48	3.0	0.41
G	4.5	17.9	0.48	2360			—	25	30	1.3	0.17
H	1.3	20.1	0.62	3230			—	98	28	1.4	0.32
I	2.9	21.1	0.29	3340			—	36	27	1.0	0.21
J	1.9	18.5	0.76	2380			130	71	29	2.3	0.32
BHVO-1 <sup>3)</sup>	2.2-10.4	11.2	2.37	267			330	130	33	4.6	<sup>5)</sup>
Errors (%) <sup>4)</sup>		1	1-6	1			25-30	20-80	1	3-7	10-30

Table 1. (Continued).

Sample	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Gd ppm	Tb ppm	Dy ppm	Er ppm	Yb ppm	Lu ppm	Co ppm
Matrix A	2.7		4.4	1.58	0.63		0.38			1.4	0.21	6.9
B	3.5		—	2.45	0.80		0.46			2.3	0.35	5.9
C <sup>1)</sup>	2.00	5.87	4.21	1.40	0.53	1.89		2.41	1.50	1.56	0.238	
Fusion crust	3.3		5.9	1.86	0.60		0.45			1.9	0.31	9.0
Clast A	2.5		9.8	1.70	0.66		0.34			1.7	0.27	4.9
B	5.3		12	2.54	1.00		0.49			1.9	0.29	5.9
C1	2.2		—	1.27	0.70		0.37			1.8	0.26	14
C2	3.7		—	2.02	0.74		0.44			2.0	0.34	7.3
C <sup>2)</sup>	3.0		—	1.68	0.72		0.40			1.9	0.30	11
D	6.8		15	4.14	1.1		0.85			3.2	0.51	17
E	3.0		—	2.10	0.74		0.45			1.8	0.29	6.5
F	5.3		8.6	3.36	1.1		0.71			2.8	0.46	9.2
G	3.2		—	1.95	0.60		0.48			1.8	0.27	6.1
H	2.8		6.2	1.82	0.64		0.43			1.7	0.25	5.4
I	2.0		—	1.41	0.44		0.37			1.3	0.20	8.4
J	3.9		—	2.50	0.70		0.72			2.3	0.34	6.5
BHVO-1 <sup>3)</sup>	16.3		<sup>5)</sup>	6.05	2.2		0.78			2.0	0.29	48
Errors (%) <sup>4)</sup>	3-10		30-60	3-5	3-4		7-15			6-11	5-10	1-2

- 1) Values were obtained by mass spectrometric isotope dilution method. The analytical errors are about 2% for all elements.
- 2) The clast C was analyzed on two different chips C1 and C2 separated from the same clast. Values of clast C are weighted means of the values of clasts C1 and C2.
- 3) Values are averages of two analyses.
- 4) Errors for INAA are due to counting statistics.
- 5) The USGS standard rock BHVO-1 samples were used as Ta and Nd standard for INAA. The standard values of Ta and Nd in BHVO-1 were 1.3 and 27.8 ppm, respectively (MA, in private communication, 1980 and TAYLOR and GORTON, 1977).

and DRAKE, 1977). Therefore, this meteorite is also recognized as the affinity of eucrite from the chemistry.

The chemical differences among three matrices can be explained by possible sample heterogeneity because of the small size of the aliquot analyzed. However, the analytical results of matrix A show surprisingly good agreements with the values of the whole rock analyses of the ALH-77302 by SMITH and SCHMITT (1981).

The fusion crust consists mainly of matrix materials. NOTSU *et al.* (1978) showed that siderophile elements (Fe, Ni, Co, Ir, and Au), Na, and Cr were easily evaporated from the Allende bulk samples by heating experiment. NAGASAWA *et al.* (1979) found the large Ce depletion and extremely low Fe, Co, Na, and Cr in the cosmic spherule separated from deep sea sediments. They explained this Ce depletion was caused by

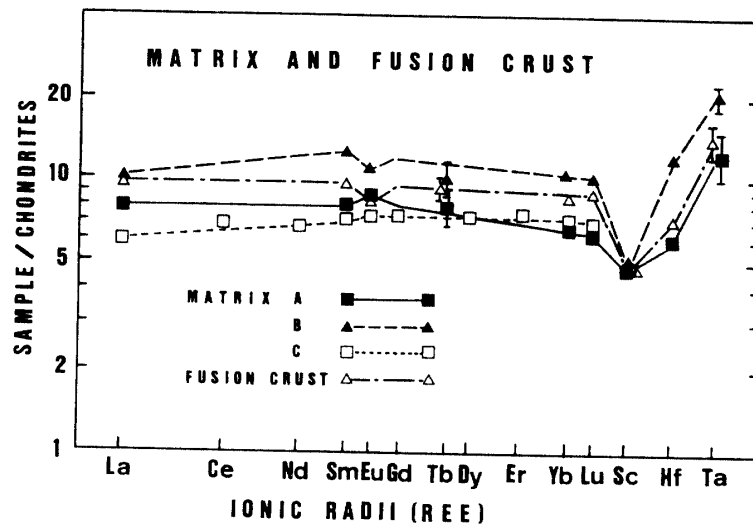


Fig. 1. Chondritic normalized abundances of REE, Sc, Hf, and Ta in matrices and fusion crust separated from ALH-77302.

high temperature heating in a high O/H environment at the time of entering the Earth's atmosphere. However, the analytical results of the ALH-77302 fusion crust did not show such depletions in the Fe, Co, and Cr abundances (Table 1). Thus, the fusion crust sample of this thickness (1–2 mm) as a whole apparently was not affected by such severe evaporation effect.

Clasts H, I, and J were recognized as carbonaceous chondrite clasts on account of their color and texture before INAA. Although carbonaceous chondrites show high enrichment of siderophile elements compared with achondrite, the analytical results of clasts H, I, and J did not show such high enrichment of siderophiles. Namely, no Ni, Au, and Ir could be detected in the clasts. Co contents in the clasts are also extremely low compared with those (about 500 ppm) in carbonaceous chondrites (Table 1). On the contrary, the chemical features of these three clasts are close to those of eucrites. Therefore, it should be considered that clasts H, I, and J are eucritic clasts rather than carbonaceous chondrite clasts.

The REE abundances of the clasts show the widespread eucritic REE abundance suit (Table 1 and Fig. 2). Although the lowest La abundance (2.0 ppm) of clast I is comparable with the La abundance (1.94 ppm) of the Sioux County which has the lowest La abundance among the previously analyzed non-cumulative eucrites, the highest La abundance (6.8 ppm) of clast D is higher than that (5.15 ppm) of the Stanern which has the highest La among the previously analyzed non-cumulative eucrites (FUKUOKA *et al.*, 1977; CONSOLMAGNO and DRAKE, 1977). Recently, CHRISTOPHE MICHEL-LÉVY *et al.* (1980) presented the new REE abundances for the Bouvante eucrite which was found at Bouvante, France in 1978. The La abundance (6.8 ppm) of clast D is also comparable to this new La abundance (6.1 ppm) of the Bouvante. Clast B shows

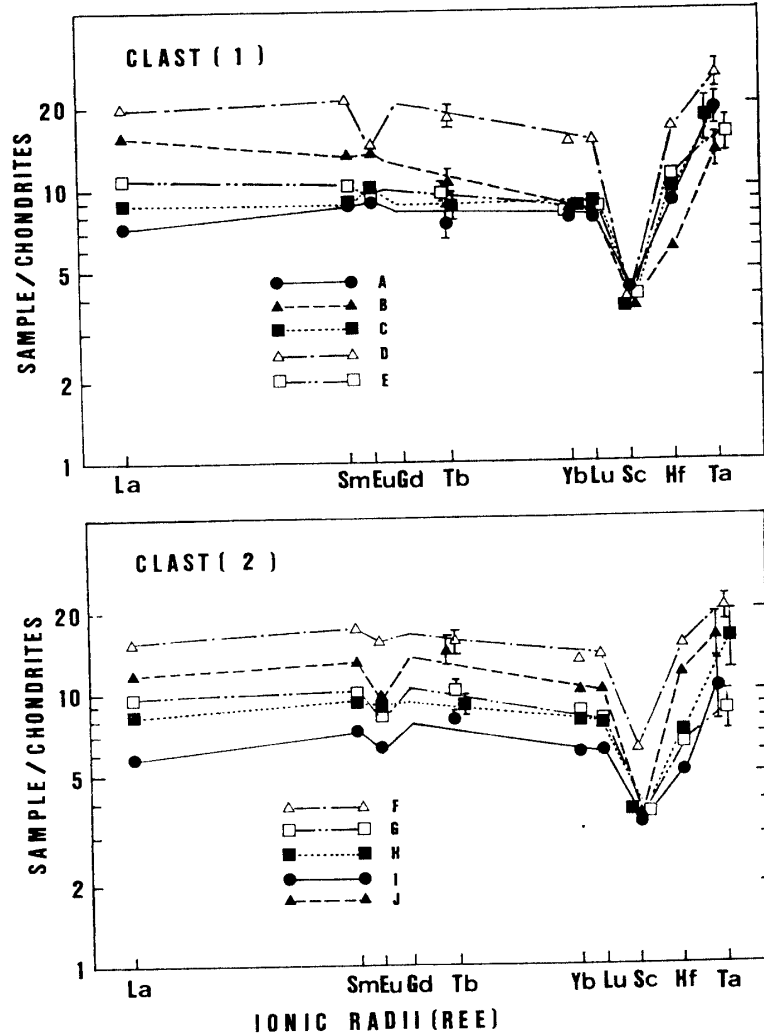


Fig. 2. Chondritic normalized abundances of REE, Sc, Hf, and Ta in clasts separated from ALH-77302.

the fractionated chondritic normalized REE pattern, in which light REE are enriched relative to heavy REE (La/Lu: about 2, Fig. 2). This REE pattern is the most fractionated one among the REE patterns of the clasts which were analyzed in this study. Because these characteristics of the clasts imply that this polymict eucrite includes possible resultants of various degrees of magmatic differentiation, it is expected that the chemical features can play an important role for the investigations of the igneous process on the parent body of the ALH-77302 polymict eucrite.

The chemical differences between chips C1 and C2 of the clast C are due to the small size of the sample and the heterogeneous nature of this clast (Table 1). Although clast G was small in sample size, the chemical abundances of this clast are

similar to those (especially REE) of clast E (Table 1 and Fig. 2). This implies that clasts E and G are possibly the same clast.

WOODEN *et al.* (1981) observed that the clasts have higher Na and lower Fe concentrations than most of other eucrites including the matrices by the chemical studies of the Allan Hills polymict eucrites including the ALH-77302. They suggested that the matrices of the Allan Hills polymict eucrites cannot be derived by comminution of material with the compositions of the clasts. However, our analytical results of the ALH-77302 could not reveal such discrepancy between matrix and clast. Our results are generally consistent with the previously reported values for the monomict eucrites, although the values in this study are widespread compared with the previously reported ones for the monomict eucrites.

CHOU *et al.* (1976) and FUKUOKA *et al.* (1977) observed the presence of chondritic component in howardites. When the polymict eucrites were formed in the similar manner to the howardites, the matrices of the polymict eucrites should include chondritic component. However, we could not observe the presence of chondritic component in the matrices. The concentrations of the only analyzed siderophile element Co in the matrices were lower than those in howardites, although the Co contents of the clasts of the ALH-77302 are comparable to those for monomict eucrites. This may suggest that distribution of chondritic components is heterogeneous in polymict eucrites and/or that the presence of chondritic components is related to the mechanism of the formation of breccias excluding diogenite components on parent body regoliths.

NAKAMURA and MASUDA (1980) found the large positive Ce anomaly in the chondritic normalized REE pattern of whole rock of the ALH-765 polymict eucrite. The existence of the Ce anomaly in differentiated meteorite is very important for studying the igneous process on the parent body and for understanding the cosmochemical process as discussed in NAKAMURA and MASUDA (1980) and MASUDA and TANAKA (1980). The Ce anomaly may indicate the O/H ratio in the environment of the igneous process on the parent body or it may also indicate the O/H ratio in the environment where source materials of the parent body had been produced. The ALH-765 and -77302 polymict eucrites are the fragments of one and the small fall (MIYAMOTO *et al.*, 1979). Therefore, it is possible that the ALH-77302 has positive Ce anomaly in the chondritic normalized REE pattern. The Ce abundances of matrices and clasts could not be determined by INAA, because of the interference of the photo peak of  $^{59}\text{Fe}$   $\gamma$ -ray to the photo peak of  $^{141}\text{Ce}$   $\gamma$ -ray for Ce determination, however the Ce abundance (5.87 ppm) of matrix C of the ALH-77302 was analyzed by the mass spectrometric isotope dilution method. The chondritic normalized REE pattern of matrix C may show small positive Ce anomaly (Fig. 1). The difference of two polymict eucrites in Ce anomalies may suggest that two meteorites are not originally the same and/or that the Ce anomaly distribution is heterogeneous in the polymict eucrite.

In this paper, we have reported the chemical data for the understanding of the igneous process on the parent body of basaltic achondrite. The major chemical com-

positions and petrographical data are provided for the same samples used in this study as a part of the consortium study now. After completion of those studies, more detailed discussions will be given elsewhere.

### Acknowledgments

We appreciate the members of the field party of the U.S.-Japan Antarctic Research Expedition in 1977 and the National Institute of Polar Research for providing the ALH-77302 meteorite. We are grateful to Prof. K. YAMAKOSHI for his help in the  $\gamma$ -ray counts of INAA, Prof. H. TAKEDA for helpful comments, Prof. H. NAGASAWA for his critical reading of this manuscript, and Ms. Y. MAKOSHI for isotope dilution analyses with the mass spectrometer. For  $\gamma$ -ray counts of INAA, the  $\gamma$ -ray spectrometer and the Ge(Li) detector of the Institute for Cosmic Ray Research, University of Tokyo were used.

This work was financially supported in part by the Grant in Aid for Scientific Research from the Ministry of Education, Science and Culture, and by the Research Center for Nuclear Science and Technology, University of Tokyo.

### References

- CHOU, C. L., BOYNTON, W. V., BILD, R. W., KIMBERLIN, J. and WASSON, J. T. (1976): Trace element evidence regarding a chondritic component in howardite meteorites. *Proc. Lunar Sci. Conf.* 7th, 3501-3518.
- CHRISTOPHE MICHEL-LÉVY, M., JÉROME, D. Y., PALME, H., SPETTEL, B. and WÄNKE, H. (1980): The Bouvante eucrite. *Meteoritics*, **15**, 272.
- CLAYTON, R. N., ONUMA, N. and MAYEDA, T. K. (1976): A classification of meteorites based on oxygen isotopes. *Earth Planet. Sci. Lett.*, **30**, 10-18.
- CONSOLMAGNO, G. J. and DRAKE, M. J. (1977): Composition and evolution of the eucrite parent body: Evidence from rare earth elements. *Geochim. Cosmochim. Acta*, **41**, 1271-1282.
- DUKE, M. B. and SILVER, L. T. (1967): Petrology of eucrites, howardites and mesosiderites. *Geochim. Cosmochim. Acta*, **31**, 1637-1665.
- FUKUOKA, T., BOYNTON, W. V., MA, M.-S. and SCHMITT, R. A. (1977): Genesis of howardites, diogenites, and eucrites. *Proc. Lunar Sci. Conf.* 8th, 187-210.
- MASON, B. (1967): The Bununu meteorite and a discussion of the pyroxene-plagioclase achondrites. *Geochim. Cosmochim. Acta*, **31**, 107-115.
- MASON, B. (1978): Antarctic meteorite data sheet, sample No. 30302. *Antarct. Meteorite Newsl.*, **1**(2), 37.
- MASUDA, A., NAKAMURA, N. and TANAKA, T. (1973): Fine structures of mutually normalized rare-earth patterns of chondrites. *Geochim. Cosmochim. Acta*, **37**, 239-248.
- MASUDA, A. and TANAKA, T. (1980): Rare earth element distribution in the Melrose-b howardite: Pre-terrestrial negative Ce anomaly. *Earth Planet. Sci. Lett.*, **49**, 109-116.
- MIYAMOTO, M., TAKEDA, H. and YANAI, K. (1979): Eucritic polymict breccias from Allan Hills and Yamato Mountains, Antarctica. *Lunar and Planetary Science X*. Houston, Lunar Planet. Inst., 847-849.
- MOORE, C. B. (1962): The petrochemistry of the achondrites. *Researches on Meteorites*, ed. by C. B. MOORE. New York, Wiley, 164-178.
- NAGASAWA, H., YAMAKOSHI, K. and SHIMAMURA, T. (1979): Trace element concentrations in silicate



- spherules from oceanic sediments. *Geochim. Cosmochim. Acta*, **43**, 267-272.
- NAKAMURA, N. (1974): Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. *Geochim. Cosmochim. Acta*, **38**, 757-775.
- NAKAMURA, N. and MASUDA, A. (1980): REE abundances in the whole rock and mineral separates of the Allan Hills-765 meteorite. *Mem. Natl Inst. Polar Res., Spec. Issue*, **17**, 159-167.
- NOTSU, K., ONUMA, N., NISHIDA, N. and NAGASAWA, H. (1978): High temperature heating of the Allende meteorite. *Geochim. Cosmochim. Acta*, **42**, 903-907.
- SIMON, S. B. and HAGGERTY, S. E. (1980): Antarctic meteorites: A petrographic study of ALHA77302. *Lunar and Planetary Science XI*. Houston, Lunar Planet. Inst., 1033-1035.
- SMITH, M. R. and SCHMITT, R. A. (1981): Preliminary chemical data for some Allan Hills polymict eucrites. *Lunar and Planetary Science XII*. Houston, Lunar Planet. Inst., 1014-1016.
- TAKEDA, H. (1979): A layered-crust model of a howardite parent body. *Icarus*, **40**, 455-470.
- TAYLOR, S. R. and GORTON, M. P. (1977): Geochemical application of spark source mass spectrography-III. Element sensitivity, precision and accuracy. *Geochim. Cosmochim. Acta*, **41**, 1375-1380.
- WOODEN, J., REID, A., BROWN, R., BANSAL, B., WIESMANN, H. and NYQUIST, L. (1981): Chemical and isotopic studies of the Allan Hills polymict eucrites. *Lunar and Planetary Science XII*. Houston, Lunar Planet. Inst., 1203-1205.

*(Received June 25, 1981; Revised manuscript received September 7, 1981)*