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ON ANTARCTIC METEORITES



17-19 February 1983

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TOKYO

国立極地研究所

The Eighth Symposium on Antarctic Meteorites

Programme

17 - 19 February, 1983

National Institute of Polar Research, Tokyo

Thursday, February 17, 1983

0900-1200      Registration      Auditorium (6th Floor)

\* - Speaker

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  - 2 1020 - 1035 Mason B. and Yanai K.\*  
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  - 3 1035 - 1045 Yanai K.\* and Kojima H.  
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  - 5 1055 - 1110 Kojima H.\* and Yanai K.  
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  - 6 1110 - Matsumoto Y. Yanai K.\* and Kojima H.  
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  - 9 1145 - 1200 Nakamura N.\* Nishikawa Y. Terakado Y. Goto Y. Okano O.  
and Honma H.  
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Chairman: Hiroshi Takeda

- 10 1300 - 1325 Clarke, Jr. R. S.\*  
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- 11 1725 - 1740 Mori H.\* and Takeda H.  
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- 12 1340 - 1355 Takahashi E.\* Ito E. and Matsui Y.  
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- 13 1355 - 1410 Kimura M.\*  
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- 14 1410 - 1425 Matsunami S.\*  
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- 15 1425 - 1455 Wood. J. A.\*  
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- 16 1455 - 1510 Fujii N.\* Miyamoto M. Ito K. and Hamano Y.  
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- 18 1605 - 1625 Ikeda Y.\*  
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- 19 1625 - 1645 Nishida T.\*  
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- 20 1645 - 1705 Nagata T., Masuda A. and Taguchi I.\*  
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- 21 1705 - 1730 Fisher R. M.\* Szirmai A. and Nagata T.  
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- 25 1015 - 1030 Nagahara H.\*  
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- 26 1030 - 1055 Delaney J. S. Takeda H. Prinz M.\* and Nehru C. E.  
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- 27 1055 - 1110 Takeda H.\* Mori H. Delaney J. S. Prinz M. and  
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- 29 1125 - Fukuoka T.\* and Ikeda K.  
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- 30 Fukuoka T.\* and Ikeda K.  
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- 35 1405 - 1420 Onuma H.\* Clayton R. N. Mayeda T. K. Ikeda Y. and Yanai K.  
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- 40 1540 - 1605 Grady M. M., Wright I. P., Matthey D. P., Fallick A. E.  
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- 49 1000 - 1030 Bogard D. D.\*  
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- 50 1030 - 1045 Takaoka N.\*  
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- 51 1045 - 1100 Nagao K.\* Takaoka N. and Saito K.  
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- 55 1130 - 1145 Funaki M.\* and Nagata T.  
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- 56 1145 - Nagata T. \*and Funaki M.  
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## SEARCH FOR YAMATO METEORITE IN DECEMBER 1981

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\*\*Department of Petrology, Mineralogy and Economic Geology, Tohoku University, Sendai 980.

The Japanese field party visited Yamato Mountains in December 1981 to carry out earth science investigations including search for Yamato Meteorite. The total amount of collected meteorites are 133. They were mainly found on Meteorite Ice Field south of Yamato Mountains, especially in the vicinity of Minama-Yamato Nunataks where 70 % of collected specimens were obtained. Meteorites with the maximum diameter of over 3 cm are 21 in number. The largest one is 27 cm in diameter and 10.5 kg in weight. Preliminary examination suggests that specimens include 121 chondrites, 2 achondrites and 7 carbonaceous chondrites.

The searched area was investigated also in 1879-1980 season. It is difficult to know the collected specimens were exposed from the ice sheet after the previous search, because most of them are small in size and could have been escaped from search eyes. However, it can be said that the Minama-Yamato Nunataks area is one of the meteorite-concentrated places in the Yamato Mountains region. The bare ice area around small nunataks seems to be most promising area for meteorite search where subglacial rock rise causes sluggish ice flow to bring meteorites in ice upward but does not impede ice movement completely.

Re-search for meteorites in the hexagonal grid with an area of 2 km<sup>2</sup> set up in 1975-1976 season near Motoi Iwa was carried out for the measurement of ratio of meteorite appearance from the ice sheet. Two small specimens were found in the grid. Meteorites within the grid were thought to be completely collected in 1979. Therefore, the rate of appearance due to 6.4 cm/year ablation of ice was one meteorite per year per 2 km<sup>2</sup>.

## A REVIEW OF THE YAMATO-74 METEORITE COLLECTION

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Examination of the specimens and petrological investigation of their section of many of them, and review of the literature, has enabled the classification of 537 out of a total of 663 meteorites in the 1974 Yamato collection, including all those weighting more than 100 g. The classified meteorites include 1 pallastite, 3 ureilites, 22 diogenites (all paired), 3 eucrites, 3 C2 chondrites, 11 H3 chondrites, 3 L3 chondrites, 31 H4 chondrites, 3 L4 chondrites, 212 H5 chondrites (of which 149 are probably pieces of a single meteorite,) 4 L5 chondrites, 192 H6 chondrites (of which 143 probably pieces of a single meteorite), 44 L6 chondrites, and 3 LL4 chondrites.

Table. Data on classified 1974 Yamato meteorites

Name Number	Weight(g)	Class & Type	%Fa in olivine	%Fs in low-Ca pyroxene	Degree of Weathering
Yamato-74001	246.1	H5	16		C
74002	69.7	LL4	27.9	22.9	A
74005	3.8	Dio			A
74007	162.3	L6	25.5	21	
74010	298.5	Dio	-	24	A
74011	206.0	Dio	-	24	A
74012	75.4	H5	19.6	17.6	B
74013	2059.5	Dio	-	24	A
74014	2347.9	H6	19.1	16	B
74015	88.0	L6 (or LL)	26.7	22.1	
74021	39.3	H5 (or 4)	19.9	18.1	C
74022	34.7	L5 (or LL)	26.7	22.1	A
74024	50.0	L3	22.8	10.5	A
74028	90.2	L6 (or 5)	25.4	22.1	
74031	6.1	Dio			A
74035	115.7	L6	24.5	21	B
74036	201.4	L6	25.2	21	B
74037	591.9	Dio	-	24	A
74038	208.9	H5	18.9	17	B
74039	47.6	L6	25.8	22.5	A
74044	51.8	Pa1	12.3	-	B
74048	67.1	LL6	30.3	25.6	B
74049-064	491.9	H4	19.0	16-21	B
74065-066	24.5	L6	25.1		A
74070-075	194.2	H5	18.5	16.3	B
74077	5575.1	L6			A
74079	620.8	H5	15	19	
74080	536.9	L6	23	25	A
74081	102.5	H4	20.7	17.9	C
74082	179.8	H4	19.3	15-18	B
74094	867.2	H6	19	19	C
74096	16.1				A
74097	2193.9	Dio	-	24	A

Table (continue)

Name Number	Weight (g)	Class & Type	%Fa in olivine	%Fs in low-Ca pyroxene	Degree of Weathering
74104-108	447.1	H5	18.9	16.8	A/B
74109	43.5				A
74110	90.1	L6	21.4	19.2	C
74111	58.0	H4	19.4	18.3	
74115	1045.1	H5	18.1	16.0	B
74116	68.9	L5	24.6	20.5	C
74117	80.2	L6	25.5	22.1	
74118	845.1	L6			A
74120	90.5	L6	25.6	22.2	B
74123	69.9	Ure	21.6	18.2	B
74124	62.3	H4	18.5	15.8	B
74125	107.0	Dio	-	24	A
74236	14.5	Dio			A
74130	17.9	Ure	22	17.9	C
74136	725.0	Dio	-	24	A
74138-142	69.1	H3	16.9	13.4	A/B
74144	141.4	L6	24.8	21.9	B
74150	33.4	Dio			A
74151	49.1	Dio			A
74155-156	3788.1	H4	17.2-19.5	18	A
74157-158	135.6	L6	22.5	22.0	B
74159	98.2	Ure	-	35-65	A
74160	31.4	LL6(or 7)	30	24	
74162	3.9	Dio			A
74163	134.2	H5	17.7		C
74164	248.8	L6	25.1	21	A
74165	203.4	L4	25.2	19-25	C
74166-170	6.9	H3	19.0	20.8	B
74173-181	89.5	L6	24.0	20.3	B
74182-185	16.8	L6	25	21	
74187-188	13.3	H5	18.0	17.1	C
74190	3235.7	L6	24.6	21.1	A
74191	1091.6	L3	18.8	4-25	A
74192	420.3	H5(or 6)	18.2	15.8	C
74193	1818.5	H5(or 4)	19.1	17.3	B
74194-342	719.3	H5	19.1	17.7	C
74344	1.4	Dio			A
74347	7.8	Dio			A
74348-353	43.2	H4	18.0	16.6	C
74354	2721.1	L6	24.2	20.8	
74355	82.9	L4	24.9	21.4	B
74356	10.0	Euc	-	62	A
74362	4175.0	L6	25.1	20.9	A
74364	717.8	H4	17.7	16.0	B
74367	165.6	L6	26.0	22.0	A
74368	7.8				A
74371	5067.9	H5	18.6	17	A
74372	84.6	L6	25.2	21.8	B
74374	205.2	H6	18.4	16	
74375	92.7	H4	18.1	15.6	C
74376	120.0	L5	24.7	21.3	B
74379-416	64.2	H5	18.0	16.6	C

Table (continue)

Name Number	Weight(g)	Class & Type	%Fa in olivine	%Fs in low-Ca pyroxene	Degree of Weathering
74417	44.5	H3	13.7	10.9	A
74418-436	719.0	H6	19	19	C
74441	27.4	L3	1.5-31.3	2.0-29.4	B
74442	173.3	LL4	29.0	21-25	A
74445	2293.2	L6	24.9		C
74447	14.3	H6			
74448	17.7	Dio			A
74450	235.6	Euc	-	30-65	A
74452	33.9	L6(or 5)			A
74454	578.8	L6	23.6	20.8	A
74455	114.1	L6	25.0		A
74457	120.8	L5	25.3	22	B
74459-602	5138.8	H6	18.8	17.4	C
74546	7.3	Dio			A
74603	188.7	L4	21.8	20.4	C
74605	580.8	L6			B
74606	2.9	Dio			A
74609	257.2	H5	17		C
74610	46.8	H4	17.9	15.8	B
74613-638	144.4	H6	18		C
74640	1065.9	H6	19.0	17	C
74641-642	15.1	C2			A
74646	554.7	LL6	29.1	24.8	A
74647	2323.8	H5	19.0		A
74648	185.5	Dio	-	24	A
74650	163.2	L6	22		A/B
74652	7.9	L6			
74659	18.9	Ure	8	8	B
74662	150.9	C2			A
74663	213.9	L6	26		B

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 Pal: Pallasite, Dio: Diogenite, Ure: Ureilite, Euc: Eucrite

## A REPORT OF THE PROCESSING ON THE YAMATO-79 AND BELGICA-79 METEORITES

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Yamato-79 meteorites were collected by the 20th and 21th Japanese Antarctic Research Expeditions(JARE) from October 1979 to January 1980. These meteorite collections were shipped frozen from Antarctica to National Institute of Polar Research(NIPR), Tokyo. Then they were stored under the frozen condition (about  $-20^{\circ}\text{C}$ ) until they have been dried in a cabinet which was full by the nitrogen gas. After drying all of the meteorite specimens were numbered, weighed, photographed with six sites of them by both color and black and white films, and described briefly by a macro and/or microscopic techniques. These specimens were chipped to take a small fragment from which double polished thin section was made to identify and classify. This processing were done under a clean air through a filters in the bench which is prepared in the relatively clean room. After then all specimens were stored in an airconditioned room. This system of the processing in NIPR is similar to NASA's one without using a clean nitrogen cabinet in which U.S. collections of the Antarctic meteorites were processed completely and stored.

The Yamato-79 meteorite collections were processed except several carbonaceous chondrites by the processing system which was mentioned above. But three carbonaceous chondrites were processed by using NASA's curatorial facilities where is in NASA-Johnson Space Center, Houston. Total number of the collections is 3767 specimens and about 320 kg in weight including relatively large number of unique specimens such as lodranite, shock-melted chondrites, several kind of carbonaceous chondrites and achondrites which are eucrites and diogenites in majority. The collections were classified preliminarily as follows: 4 irons, 1 lodranite, 1 ureilite, 31 carbonaceous chondrites including the largest specimen (about 25 kg in weight), 32 diogenites, 3 howardites, 43 eucrites and large number of chondrites in which several unique specimens are included.

Belgica-79 meteorites were collected by the 20th JARE in December 1979. Five meteorite specimens were also processed including one carbonaceous chondrite which is the largest one of them, and the others are chondritic specimens.

Several hundred meteorite specimens of the both collections have been provided to scientists and scientific groups in Japan and foreign countries for the detail studies.

## CLASSIFICATION OF THE UNEQUILIBRATED ORDINARY CHONDRITES

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Ten specimens of the Yamato meteorites are classified as unequilibrated ordinary chondrites on the basis of microscopic observations and the chemical compositions of olivines and low-Ca pyroxenes. All of them shows a close-packed aggregate of chondrules and chondrule fragments, and always contains some clear glass, with interstitial fine-grained matrix. These specimens were classified as follows:

H3 : Y-74138, Y-74142, Y-74417, Y-790461, Y-791047, Y-791087

L3 : Y-74024, Y-74441

LL3: Y-790448, Y-74660(tentative).

It is recognized that these unequilibrated ordinary chondrites are divided into three types with mode of histograms of Fe contents (in atomic %) of olivines and low-Ca pyroxenes.

Type A: Fe contents of olivines and pyroxenes range widely from 0 to 30% in the each chemical type. There is no clearly peaks in their histograms and shows the largest % M.D.(Fig 1). So the specimens included in this type are not able to be classified with data on compositions of olivines and pyroxenes. This type is as same as the unmetamorphosed or slightly metamorphosed ordinary chondrite (Dodd and Van Schmus 1967).

Y-74417, Y-74441, Y-74660, Y-790448 and ALH-77011 belong to this type.

Type B: Fe contents of olivines and pyroxenes range widely like type A. Histograms of Fe contents of pyroxenes lack modes as same as type A, however these of olivines show distinct modes. And the highest peak of the Fe contents of the olivines is the same as this of the equilibrated H, L and LL-group chondrite (Fig 2).

Y-74024, ALH-77278 and ALH-77299 belong to this type.

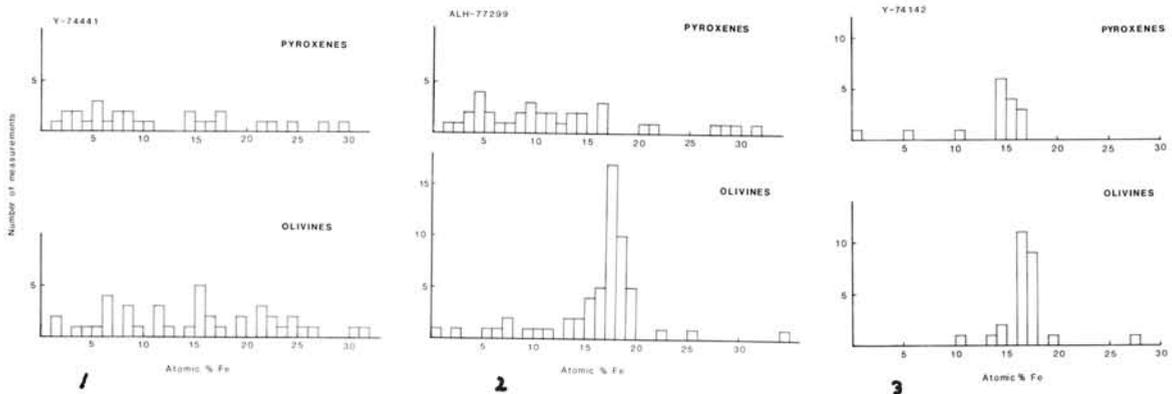
Type C: Fe contents in olivines and pyroxenes vary, however both histograms show clear modes, and the highest peaks are similar to these of the equilibrated chondrites (Fig 3).

Y-74138, Y-74142, Y-790461, Y-791047 and Y-791087 belong to this type.

As mentioned above, the degree of metamorphism is gradually increase from A to C. Types as H, L, LL in the silicate minerals are already recognized in the unequilibrated ordinary chondrites.

## REFERENCES

Dodd R.T., Van Schmus W.R. and Koffman D.M.(1967) A survey of the unequilibrated ordinary chondrites. *Geochim. Cosmochim. Acta* 31, 921-951.



A STONEY-IRON METEORITE: Yamato-75274

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A stoney-iron meteorite has been identified in the Yamato collections. This meteorite is a small, irregular fragment partly coated with dark brown fusion crust, and shows light brown olivine grains, in much darker metal and pyroxene. The specimen is granular and consists mainly of nickel-iron, olivine and pyroxene, with minor clinopyroxene and troilite. Weathering is considerable with brown limonitic staining around metal grains and silicates.

Microscopically, the meteorite shows granoblastic texture; olivine is euhedral to subhedral (max. 1.1 mm in diameter), several small orthopyroxene inclusions. Orthopyroxene is smaller than olivine in grain size, but is subhedral and contains small inclusions of olivine. Metal appears to enclose the other minerals sometimes.

Compositional analyses on the constituent minerals were carried out by automatic JEOL733 electron microprobe, using 3 spectrometers. The results give olivine composition averages Fa3.9 (range Fa3.6-4.7), orthopyroxene Fs3.9 (range Fs3.5-4.3). Mg contents of its olivine and orthopyroxene are higher than the Lodran and Yamato-791493. Clinopyroxene (En53.7 Fs1.6 Wo44.6) is recognized in rare case. The metal composition averages 6.5% Ni with little variation.

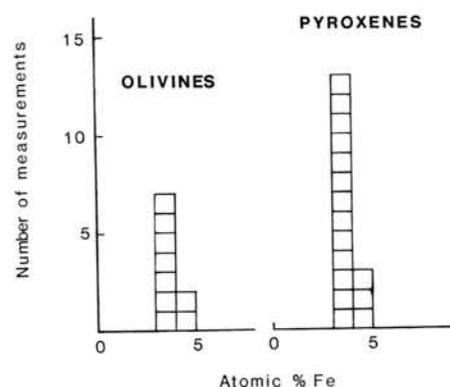
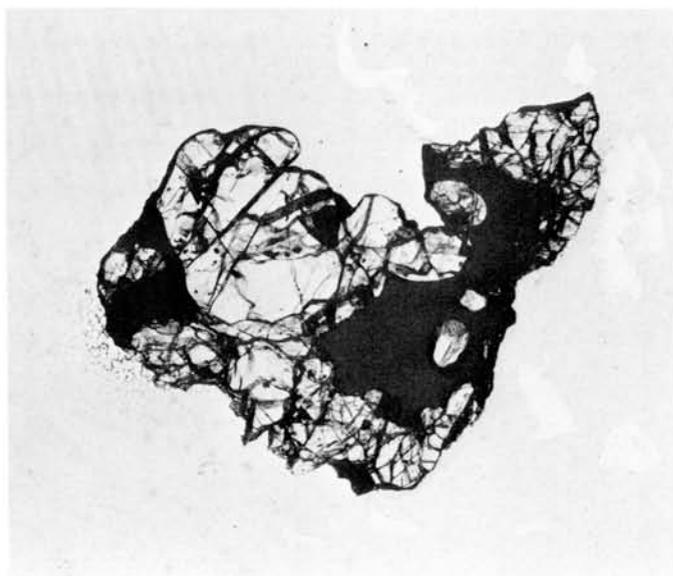
The meteorite is similar to the Lodran meteorite and Yamato-791493 meteorite in texture and mineral assemblages, but is largely different in mode and mineral compositions (Bird P. W. and Wasson, J. T., 1976 Prinz et al., 1978, Yanai K. and Kojima H. 1982).

#### REFERENCES

Bird R. W. and Wasson, J. T. (1976). Mineralogical Magazine, 40. p.721-735.

Prinz M., Klimentidis R., Harlow G. E. and Hewins R. H. (1978). Proc. Lunar Planet. Sci. Conf. IX, p.919-921.

Yanai K. and Kojima H. (1982) Meteoritics (Abstract).



## OLIVINE-WHITLOCKITE CLASTS IN THE Y-75097 L CHONDRITE

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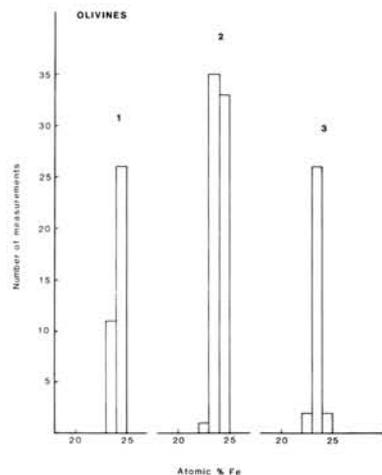
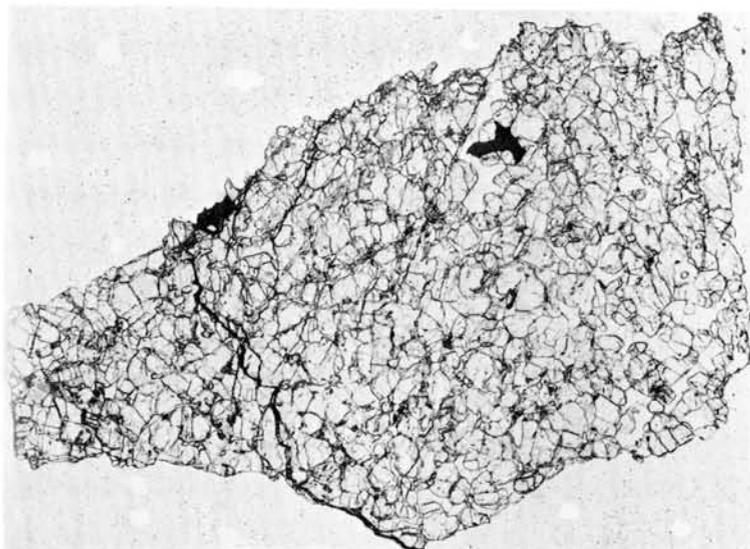
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A relatively large clast, 2.5x2.5x1.0 cm in diameter, is recognized in the Yamato-75097 L6 chondrite. Shiny black fusion crust on one exterior surface is distinguished clearly from dull black fusion crust of the host meteorite. A portion of the shiny black crust is removed, exposing a light gray to white material which seems to be a lithic clast. There is a little difference in each grain size in the clast, in which the center portion is relatively coarser than others. Some black veinlets by shock cross through the clast.

Microscopically, the clast is a fine-medium grained aggregate consisting mainly of olivine with minor interstitial whitlockite and plagioclase, and a little chromite. Plagioclase is isotopic and is presumably maskelynite. Pyroxene, Nickel-iron and troilite were not identified. Compositional analysis on the constituent minerals were carried out by JEOL733 electron microprobe. The results give olivine composition average Fa 24.2 (range 23.5-25.0, %MD=1.1), maskelynite (An15 Ab75 Or10) and whitlockite (Mg 3.60, FeO 0.37, CaO 44.97, Na<sub>2</sub>O 2.81, P<sub>2</sub>O<sub>5</sub> 47.62 wt%). Olivine composition is very similar to host's one.

Physical and petrographical features of the Y-75097 chondrite(host) are as following: This specimen is a nearly complete stone covered with 2/3 mm thick, blackish brown fusion crust. Areas devoid of fusion crust are observed along edges of this subangular stone, and are weathered to a yellowish brown color. The interior material is light gray in color with small brown oxidation haloes. Chondritic structure is present, but chondrules and chondrule fragments show extensive integration with granular groundmass, which consists of olivine and pyroxene with minor amounts of plagioclase, nickel-iron, and troilite. Chondrule types include granular olivine and olivine-pyroxene, barred olivine, and weakly radial pyroxene. The stone is traversed by thin black veinlets produced by shock. Some small lithic fragments are present. Compositions of olivine and pyroxene are average Fa24.2 (range 23.0-25.3, %MD1.5) and Fs20.1 (range Fs19.3-21.5, %MD 2.2) respectively.



THE NI, FE AND CO CONTENTS OF METAL PHASES IN THE ALLENDE, HOLBROOK AND NUEVO MERCURIO CHONDRITES

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The determination of Ni-Fe distribution pattern, and Ni and Co contents of metal phases are considered to be useful in finger-printing individual meteorites (Smith, 1980). Such a technique could be applied to establish affinities among large groups of meteorites such as those recovered from Antarctic blue ice. It may be also be use of in solving problem concerning the identity of certain specimens collected from different localities or perhaps mislabeled specimen in meteorite collections.

The analytical data listed in Table 1 were performed using an ARL EMX microprobe fitted with three wavelength-dispersive (WDA) and Ortec energy-dispersive (EDA) spectrometers of the University of Alberta. Ni and Co counts by WDA and Fe counts by EDA are measured on a series of standards including pure Ni, Fe and Co, and four intermediate Ni-Fe alloys. Corresponding intensities are measured on as many randomly chosen points on the sample grains as possible. The third polynomial fit to standard Fe-Ni data is obtained by program "FENICO". The sample concentrations are determined by reference to the polynomial function. The Co concentrations are determined by reference to a Co metal standard with empirical correlations for background and matrix effects made by the program. The program then gives output automatically as raw and 100% normalized data. The samples used in this study are five chondrites; that is, two Allende C3V, two Holbrook L6, and one Nuevo Mercurio H5 chondrites.

The following results are summarized in this study (*cf.* Table 1 and Fig. 1):

(1) The Co values reported here, together with seven other chondrites reported by Smith (1980), support that the Co contents in ordinary chondrites show overlapping ranges among H, L and LL groups. The number of plotted regions, concentration state of points within each region, and best fitting to a regression equation are characteristic of individual groups and petrologic types.

(2) Holbrook L6 chondrites consist of nearly obvious four regions; that is, kamacite (Ni<10; 38.5 vol.%), taenite (25<Ni<47; 22.0 vol.%), tetrataenite (48<Ni<60; 8.4 vol.%) and intermediate phase of plessite (10<Ni<25; 31.1 vol.%).

(3) Nuevo Mercurio H5 chondrite consists of obvious three regions; that is, kamacite (76.8 vol.%), taenite (14.1 vol.%) and tetrataenite (9.1 vol.%).

(4) Allende C3V chondrites show a clear region of Ni-rich phases (Ni>60; 97.5 vol.%) with small scattered region of tetrataenite (2.5 vol.%), and extraordinary high Ni and Co contents. Almost absence of any composition in the lower Ni and Co range is characteristic of Allende chondrite.

(5) Correlations between Co-Ni and between Fe-Co are completely disordered in Allende chondrites, though correlations between Ni-Fe in the five chondrites are almost strong those represented by linear regression equation.

(6) The great differences in the variation patterns of Ni-Fe and Co-Ni from one chondrite to another even with the same group petrologic type, as well as the differences in the average Ni and Co contents of the metal phases, suggest a convenient method for "finger-printing" meteorites (*cf.* Smith, 1980).

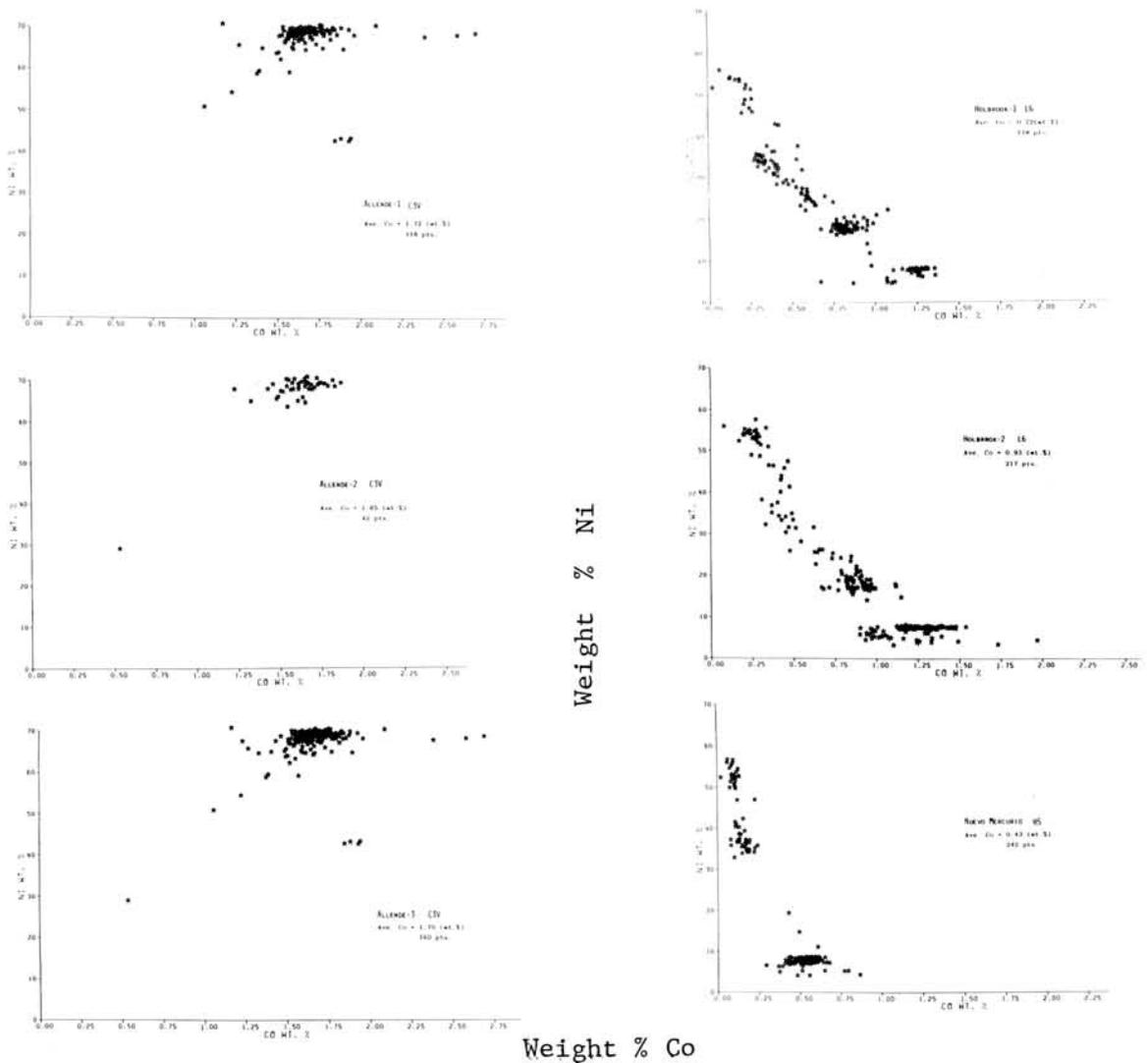
References: Smith, D.G.W. (1980) Canadian Mineralogist, 18, pp.433-442.

Table 1. Ni, Fe and Co contents and the statistical data of Nuevo Mercurio, Allende and Holbrook chondrites.

Sample	No.	%Ni(wt%)	%Fe(wt%)	%Co(wt%)	r (%Ni-%Fe)	r (%Co-%Ni)	r (%Fe-%Co)
Nuevo Mercurio (H5)	242	15.89(1577) <sup>*</sup>	83.68(1660)	0.43(18)	-0.9999 (I) <sup>**</sup>	-0.9534 (L)	0.9526 (E)
Allende-1 (C3V)	42	68.81(53)	29.54(54)	1.65(12)	-0.9782 (E)	-0.3693 (E)	-0.2047 (I)
Allende-2 (C3V)	118	68.41(468)	29.87(463)	1.72(18)	-0.9999 (L)	-0.2776 (L)	0.2415 (P)
Allende-3 (C3V)	160	68.52(403)	29.78(399)	1.70(17)	-0.9992 (I)	-0.2570 (L)	0.2167 (E)
Holbrook-1 (L6)	178	22.31(1309)	76.97(1277)	0.72(35)	-0.9999 (I)	-0.9283 (E)	0.9268 (P)
Holbrook-2 (L6)	217	18.04(1546)	81.03(1511)	0.93(38)	-0.9999 (I)	-0.9524 (L)	0.9503 (E)

<sup>\*</sup> Numbers in parentheses are standard deviation referring to the last decimal place.  
<sup>\*\*</sup> Correlation coefficient (r) of best fitting to linear (L), exponential (E), logarithm (L) or power (P) equation.

Fig. 1. Variation of Co with Ni content of the metal phases of Allende, Holbrook and Nuevo Mercurio chondrites.



## Rb-Sr isotopic systematics of the Antarctic H-chondrites

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The Rb-Sr isotopic systematics studies for non-antarctic chondrites have been reported by several groups (e.g. Gopalan and Wetherill, 1968; Wasserburg et al., 1969; Minster et al., 1979) for past fifteen years. From these studies, important aspects of chondrites chronologies have been clarified. However, because of limited data from different institutes, critical meaning of the Rb-Sr ages of chondrites, i.e. age differences among different chondrite groups and with different petrologic types, or the difference between the Rb-Sr age and those obtained by other chronological methods is still debatable problem. In order to examine more detailed chronological features of the early history of chondrites, we have initiated the Rb-Sr and Sm-Nd isotopic study of the Antarctic chondrites as well as the non-antarctic one. In this work we examined the Rb-Sr isotopic systematics of the whole-rock specimens from the antarctic and non-antarctic finds and falls to check a possible terrestrial weathering effect on the Rb-Sr system and to clarify general feature of the Rb-Sr system of the Antarctic H-chondrites.

The chemical separation of Rb-Sr and concentration analyses were performed at Kobe university. The chemical processes were carried out under low blank level. The precise Sr isotopic analyses at Okayama University has been well-established as exemplified by our work on the Chassigny meteorite (Nakamura et al., 1982). The typical  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio obtained for the NBS 987 Sr standard (100-300ng Sr) is  $0.710228 \pm 0.000020$  (2 sigma mean) for five runs. At present stage, our results are not sufficient to draw confirmable view points for the samples. The preliminary results for the following Antarctic and non-antarctic H-chondrites will be presented at the symposium; Antarctic; Y-74155, Y-74371, Y-74492, Y-790986; Non-antarctic; Brownfield, Clovis, Grady (Finds), Allegan, Jirin (Falls).

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## THE LAZAREV, ANTARCTICA METEORITE

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The first meteorite found in Antarctica, the Adelie Land chondrite, was found in 1912 by an Australian party. The first metal meteorite, and the second meteorite from Antarctica, was found nearly 50 years later on the opposite side of the continent. Ravich and Revnov (1963) reported finding it on January 21, 1961 while they were part of a USSR team doing geologic field work in the Humboldt Mountains in central Queen Maud Land. Two specimens were found close together on a small ledge near the base of a mountain slope 30 to 40 meters from the surrounding glacier. The 6 to 7 kg mass is now in Leningrad and the 2 kg mass is in Moscow. Although several studies have been made of this meteorite, its exact classification remains uncertain. Hoping to resolve this difficulty, we requested sample material from the Mining Institute, Leningrad. A 76 g specimen was provided through the courtesy of Dr. V. D. Kolomenskyi and Professor Dimitry P. Grigoriev.

Ravich and Revnov (1963) characterized the meteorite as a coarse octahedrite containing 10.05% Ni, 0.67% Co, and 0.23% Co. They considered their report to be preliminary. Buchwald (1975) examined both pieces superficially and reported that a medium octahedrite classification based on band widths of  $0.8 \pm 0.2$  mm was more appropriate. He suggested that on the bases of its composition, structure, and the suspected presences of olivine grains that the specimens might well be metal-rich portions of a pallasite. Zaslavskaya and Kolesov (1980) confirmed the medium octahedrite classification and discussed its metallography in some detail. They reported that they could not find olivine, and that their trace element data was inconsistent with any of the resolved chemical groupings of iron meteorites. They considered it anomalous.

Our observations essentially confirm the earlier work and add additional data. A new chemical analysis gives 9.69% Ni, 0.63% Co, and 0.19% P, and new trace element data also do not fit the resolved chemical groups for iron meteorites or the two pallasite groupings of Scott (1977). Electron microprobe traverses for Ni, Co, and P across kamacite, taenite, and plessite structures show interface compositions and elemental distribution gradients that are those of a very slowly cooled meteorite. They are comparable to traverses over similar structures in the Brenham pallasite. Tetrataenite can be resolved optically in a few locations at kamacite interfaces, also suggesting a slowly cooled meteorite. Olivine was not observed.

Chromite is a prominent minor mineral in our Lazarev specimen which contains two large Reichenbach lamellae. Their central chromite cores are  $7.8 \times 0.04$  mm and  $8.3 \times 0.09$  mm. A 1.8 mg euhedral crystal of chromite was recovered from dissolution of the sample for chemical analysis. Electron microprobe

analyses indicate that all three of these chromites are unusually pure Fe-Cr end members, essentially  $\text{FeCr}_2\text{O}_4$ . The 1.8 mg crystal was broken for X-ray examination and found to contain within it a tiny enstatitic pyroxene. Detailed crystal structure refinements of these two "coexisting phases" are in progress, with special attention being given to those parameters which may help to elucidate their cooling histories. The chromite cell is  $a = 8.3756 \pm 0.0005 \text{ \AA}$ , and preliminary data on the enstatite cell indicates that it may have a similar composition to the enstatites reported for pallasites by Buseck (1977).

Buchwald's suggestion that an effort should be made to find olivine in the Lazarev meteorite remains valid. Although our data are inconclusive, it is certainly possible that Lazarev is one of the several chemically ungrouped pallasites.

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## A STUDY OF SHOCK-PRODUCED VEINS IN ORDINARY CHONDRITES.

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Crosscutting glass veins and closed melt pockets occur in many meteorites and lunar samples. The veins and melt pockets are thought to represent shock melting induced by hypervelocity impact processes. We present a brief description of some shock veins in two L-group ordinary chondrites, Tenham and Yamato 790959, with reference to the origin of ringwoodite.

Tenham

The Tenham meteorite is an equilibrated olivine-hypersthene chondrite (L6) with a network of thin black veins running throughout its entire body (1), (2). The black veins are noted for the occurrence of ringwoodite,  $\gamma$ -form of  $(\text{Mg,Fe})_2\text{SiO}_4$  as the xenocrysts of small blue grains (3). A fuller description of the shock veins, as well as shock deformation features of wall rocks, is given in Table 1 in comparison with those of the Y790959 chondrite.

Y790959

The Y790959 meteorite is a shocked L6 chondrite. The meteorite shows abundant black veins. However, the vein has no sharp boundary with wall rocks. The distinction between vein materials and wall materials is vague. The meteorite has very distinct features from those of Tenham as is shown in Table 1. The features of Y790959 can be interpreted to have resulted from thermal annealing event after shock. Tenham doesn't show so extensive post-shock annealing.

In summary, the difference in the shock deformation features between Tenham and Y790959 can be attributed to thermal annealing event after shock. We propose that the absence of ringwoodite in Y790959 may be due to reversion of this phase by post-shock thermal annealing.

We thank Natn'l Inst. of Polar Res. and Dr. B. Mason for samples.

Table 1. Comparison of shock deformation features in Tenham and Y790959.

		Tenham	Y790959
Shock vein	Contacts of veins with wall materials	sharp	vague
	Metal-sulfide spherules with eutectic intergrowth	present	absent
	Olivine xenocryst	largely transformed to ringwoodite	recrystallized to sub-microscopic new olivine grains (probably reverted from ringwoodite)
Wall rock	Optical features of shock deformation in olivine	extensive fracturing & mosaic extinction	extensive fracturing & undulatory extinction
	Maskelynite	clear isotropic glass	devitrified glass

- References: (1) Binns (1967) *Earth Planet. Sci. Lett.* 2, 23-28.  
(2) Price et al. (1979) *Contrib. Mineral. Petrol.* 71, 211-218.  
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MELTING OF A YAMATO L3 CHONDRITE (Y74191) AT HIGH PRESSURES;  
PART I, MELTING RELATIONS UP TO 30 KBAR.

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Terrestrial planets may have undergone intensive melting and subsequent igneous fractionation processes during and/or immediately after their formation. In order to study details of the initial igneous processes occurred particularly on the earth, we have planned a series of high-pressure melting study using different rock types of meteorites up to about 300kbar. In this report we note melting behaviours of a L3 chondrite (Y74191) up to 30 kbar as a reconnaissance of the main project.

Melting experiments were carried out with a piston-cylinder type solid-media apparatus at the Institute for Thermal Spring Research (ITSR). A 1/2-inch diameter talc-pyrex-graphite-sintered Al<sub>2</sub>O<sub>3</sub> assembly was employed with a graphite capsule (2.4 mm diam., 3.5 mm long) as a sample container. Experimental run products were polished and phases were identified under a reflected light microscope and also by an electron microscope (JEOL-100) at the ITSR. Chemical analysis of the run products was made also at the ITSR with an electron microprobe X-ray analyzer (JEOL-5A).

Two types of starting materials were prepared from the same meteorite: Starting Material-I; the rock was powdered in an agate mortar and then kept in an oven at 110°C.

Starting Material-II; the rock powder (I) was heated in an 1-atmosphere furnace at 900°C for 4 hr under oxygen fugacity equivalent to the iron-wüstite buffer.

The starting material-I represents the bulk chemical composition of the chondrite but may contain small amount of water. The starting material-II, on the other hand, was dried completely but most of its FeS reacted with CO<sub>2</sub>/H<sub>2</sub> gas in the 1-atmosphere furnace and formed FeO.

The solidus of the starting material-II was determined to be ~1200°C, ~1300°C, and ~1400°C at 5, 15 and 25 kbar, respectively. Major constituent minerals of the run products quenched at temperatures slightly above the solidus are, olivine (Fo~70), orthopyroxene, ferrobasaltic silicate melts (FeO~20 wt.%), Fe-Ni metal and FeO.

The solidus of the starting material-II is defined by the eutectic melting of Fe-Ni alloy with FeS and is approximately at 1000°C at all pressures studied. At 15 kbar, the composition of the sulfide melt changes gradually with temperature being the Fe-Ni alloy as a coexisting phase up to 1400°C. At higher temperatures, the Fe-Ni alloy and FeS form a homogeneous melt phase. At 15 kbar, silicate melt probably rich in K<sub>2</sub>O and sulfur first appears at about 1200°C in the vicinity of the Fe-Ni-S melt.

An interesting observation made is such that the ferro-basaltic melt (FeO~18 wt.%) was segregated on the bottom of the experimental charge in two runs at about 15 kbar and 1400°C using the starting material-I. The boundaries between the segregated basaltic melt and the residual solids are sharp and the melt on the whole exhibits a convex outline. This observation might suggest a possibility that the density of the ferro-basaltic melt is heavier than the coexisting olivine (Fo~78) and orthopyroxene at the high pressure (Stolper *et al.*, 1981). The temperature distribution in the furnace assembly, stress distribution, and other possible reasons for the liquid segregation, however, must be examined thoroughly before final conclusion is made.

If terrestrial planets were formed from ordinary chondritic materials and have melted extensively in their early stages, the first melt fractions produced at about 1000°C were Fe-Ni sulfide melt close to the eutectic compositions in the system Fe-Ni-S (Usselman, 1975). Upon further melting, silicates begin to melt at 1200° to 1300°C in the pressure range up to 30 kbar and would have formed small amount of potassic melt (Takahashi and Kushiro, 1983). At temperatures 1400° to 1500°C, substantial amounts of ferro-basaltic silicate melts were produced and all the metal phases may have dissolved in the Fe-Ni-S melt by this time. Large scaled gravitational settling may have taken place during this stage of melting. If the iron-rich silicate melts were indeed denser than the coexisting olivine and orthopyroxene, the gravitational separation would have resulted in formation of Fe-Ni core containing substantial amount of sulfur, a deeper zone of silicate mantle enriched in Fe, Ca, Al and SiO<sub>2</sub> relative to shallower zone which was formed from the floated olivine and orthopyroxene.

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CHEMICAL AND PETROLOGIC RELATIONS BETWEEN CONSTITUENT UNITS  
IN ALH-77249 CHONDRITE (L3)

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ALH-77249 chondrite consists of various petrologic units as follows.

Constituent Units of ALH-77249	
Chondrules	
Lithic Inclusions	
	Fine-grained Lithic Fragments (FGF)
	Coarse-grained Lithic Fragments (CGF)
	Dark Inclusions (DI)
	Amoeboid Olivine Inclusion (AOI)
	Others
Mineral Fragments (MF)	
	Silicate Mineral Fragments
	Opaque Mineral Fragments
Matrix (MT)	

( ): Abbreviations

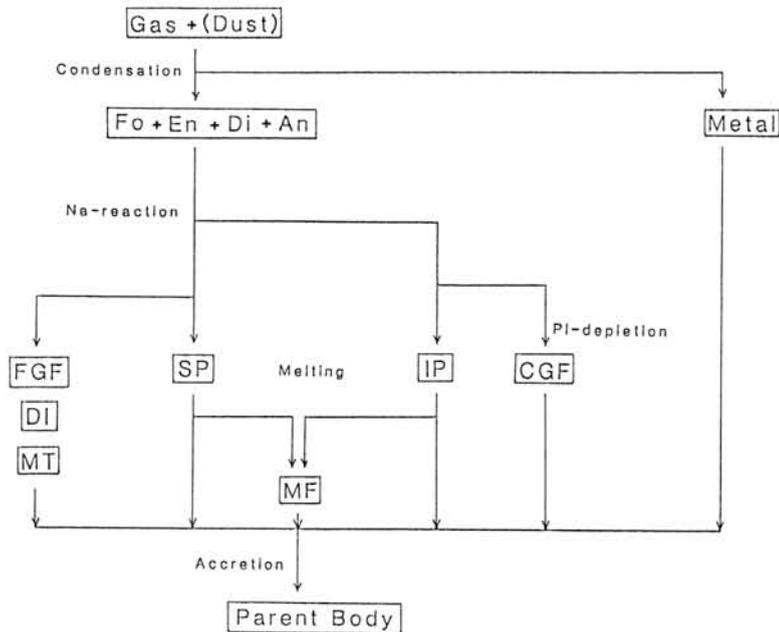
Chondrules often contain various amounts of glass, and melting and crystallization occurred in chondrules. Chondrules occupy about 50 volume percent of this chondrite. Coarse-grained lithic fragments contain no or rare glass, and olivine and pyroxene are equilibrated in them. Fine-grained lithic fragments mainly consist of fine-grained minerals, less than a few microns, and contain no glass. Dark inclusions, rarely found, consist of matrix-like dark materials with small amounts of fine-grained silicate and opaque minerals. This chondrite contains only one amoeboid olivine inclusion which is uncommon material in ordinary chondrites. Silicate mineral fragments consist of one or a few olivine and/or pyroxene crystals. Most of them seem to have been derived from chondrules, because these minerals often show the similar occurrence as minerals in chondrules. Matrix fills the interstices among other units.

Chondrules are classified into three types, SP, IP, and N of Ikeda (1980), based on their bulk chemical compositions. SP-types are most common in chondrules, and N-types are rarely found. Chemical compositions of fine-grained lithic fragments and dark

inclusions correspond to SP-type, whereas coarse-grained lithic fragments to IP-type.

ALH-77249 chondrite is similar to ALH-77015 (L3) studied by Nagahara (1981) and Fujimaki et al. (1981), on the basis of chemical compositions of chondrules and matrices. It seems that both chondrites have been derived from common parental material.

Chemical and petrological data show the relations between the constituent units of ALH-77249 chondrite as follows; 1) normative plagioclase contents in coarse-grained lithic fragments are fairly depleted rather than those in chondrules, 2) normative olivine/pyroxene ratios of fine-grained lithic fragments and dark inclusions are fairly uniform in comparison with those of chondrules, and 3) generally Fe/Mg ratios of bulk compositions increase from IP-chondrules and coarse-grained lithic fragments, through SP-chondrules and fine-grained lithic fragments, to dark inclusions and matrix. These features indicate that the constituent units of chondrites have been derived through various reactions from original condensates, before accretion to parent body. Following figure show a possible genetical relations between the units.



A Note on the Inclusion of ALH-77004: A Surface Regolith  
of L Chondritic Parent Body

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An inclusion in ALH-77004 (H4 chondrite) has been studied in detail, using electron-microprobe analysis.

The inclusion (1.4 cm in maximum diameter) contains many submm-size fragments of various chondrules, rocks and crystals. Rounded to angular fragments of relatively small sizes (up to 1.2 mm in thin section) make up about 70% of the inclusion and are usually distinguishable from the dark matrix which is composed of fine-grained clastic fragments. They show evidences of varying degree of recrystallization. On the basis of the composition of olivine, these fragments can be divided into two groups; fayalite-rich and fayalite-poor groups. The fayalite-rich group is characterized by (1) olivine of composition ranging from Fa<sub>21</sub> to Fa<sub>35</sub> with average of Fa<sub>24-25</sub>, (2) homogeneous composition of olivine and low-Ca pyroxene, and (3) relatively higher degree of recrystallization ranging from petrologic type 4 to 6 of Van Schmus and Wood (1967). It is suggested that the fragments of this group may have been derived from L chondrites. On the contrary, the fayalite-poor group is characterized by (1) magnesian olivine (Fa<sub>8</sub>-Fa<sub>20</sub>), (2) heterogeneous composition of olivine and orthopyroxene. The amount of fragments of the latter group are much less than those of the former.

Chromite occurs mostly in the matrix and rarely in olivine of fragments of fayalite-rich group as fine-grained inclusions. It frequently coexists with Fe-Ni metal and troilite. The compositions are variable from grain to grain and the range is somewhat wider than that of chromite in equilibrated ordinary L chondrites (Bunch et al., 1967). Fe-Ni metals, which occur in matrix and fragments, are mostly made of kamacite and zoned taenite and sometimes contain plessite. Kamacite and taenite show more variations and enrichment in Co content than those in most equilibrated L chondrites (Afiattalab and Wasson, 1980); in kamacite Co ranges from 0.8 to 1.4 wt% and Ni from 5 to 7.5 wt%, whereas in taenite Co ranges from 0.5 to 1.1 wt% and Ni from 20 to 52.5 wt%.

From these observations, it is suggested that the inclusion was a surface regolith of L chondrite parent body. The lithic fragments contained in the inclusion are greatly variable in metamorphic grade, suggesting that their source area was complex, and have not been suffered from thermal metamorphism after the inclusion was compacted. Therefore, the following possibility can be considered; impact cratering process during the excavation of planetesimals caused fragmentation of L chondrites with variable degree of equilibration and these fragments were deposited on a planetesimal and compacted.

FORMATION OF CHONDRULES AND CAI'S FROM INTERSTELLAR GRAINS  
ACCRETING TO THE SOLAR NEBULA

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Both Ca,Al-rich inclusions (CAI's) and chondrules appear to have been formed by high-temperature processing of precondensed material in the solar nebula (e.g., 1,2). Several possible sources of heat in the nebula have been suggested: compression by shock waves generated in the body of the nebula (3); shear friction caused by differential rotation of materials at different radial distances in a turbulent nebula (4,5); and lightning discharges due to charge separation between differentially rotating layers in the nebula (6). The nature of the heat source is still very uncertain, but the abundance of CAI's and especially chondrules in chondritic meteorites suggests that a major, pervasive stage or aspect of nebular evolution was at work.

In this paper I discuss another possible mode of chondrule and CAI formation, suggested by R. B. Larson (7), which may have operated while the protosun and nebula were forming from infalling interstellar gas and dust. Modelling of the formation of the protosun by self-gravitative collapse has shown that it occurred non-homologously, *i.e.*, at first the central portion of the volume of interstellar material that was to become the solar system fell together, forming a very small ( $\sim 1$  Jupiter mass) protosun; then over a period of  $\sim 10^6$  yr, additional material from farther out in interstellar space continued to fall onto the protosun (8). At the surface of the protosun, infalling material would have been decelerated from  $\sim$ free-fall velocity to  $\sim$ zero velocity in a standing shock front. There the kinetic energy of infalling material was converted to heat ( $T$  as much as 8000 K), most of which was promptly radiated away. Thus newly-arriving material went through a rapid heating-cooling cycle.

The nebula would also have been bounded by an accretion shock front, though peak temperatures experienced by material falling onto the nebula would have been less at increasing distances ( $r$ ) from the protosun, since the free-fall velocity ( $v$ ) and hence the kinetic energy of infalling material vary as  $v^2 \sim 2GM/r$ . Larson (7) suggested that interstellar dust falling through sufficiently close-in, hot zones of the nebular accretion shock would have been processed into CAI's.

It is not easy to estimate the effects of such an experience on arriving interstellar dust. Thermal regimes in the vicinity of the shock front would be complex and far from thermal equilibrium. The interstellar gas and dust at great distances from the protosun/nebula would have been very cold,  $\sim 10$  K. As the material fell toward the nebula its temperature would increase somewhat, as it absorbed radiation from the protosun's shock front. At this time grains would probably be warmer than the gas, since

they absorb radiation more efficiently than gas. Ices and possibly more refractory organic compounds (kerogens), if they are present in the original interstellar grains, may have been vaporized/pyrolyzed at this stage.

When the infalling material crossed the shock front, the gas would suddenly become much hotter than the grains, since (a) the incompressible grains would not be decelerated as abruptly as the gas, but would for a time continue at high velocities through the gas, therefore much of their original kinetic energy would remain for a time in that form; (b) the grains can radiate energy much more efficiently than the gas, so they more readily lose whatever heat comes to them, to the  $\sim 10$  K environment of space.

It is likely that most of the heating experienced by grains was not due to radiation from the surrounding hot gases, since this is a relatively inefficient process, but was caused by ablational friction of the grains as they moved forward through the now-decelerated gas (analogous to ablation of the surfaces of meteoroids in the earth's atmosphere).

Finally, after the grains slowed and the gas and grains moved into the body of the nebula, both would cool by radiation and approach mutual thermal equilibrium.

Much would have depended on the size distribution of grains falling through the shock front. The interstellar dust that reddens starlight and causes absorption at, e.g.,  $10\mu\text{m}$ , is very small ( $<0.1\mu\text{m}$ ). Such dust would be decelerated rapidly in the nebula, and its large surface/volume ratio would make radiation so efficient that the grains would probably never get very hot (an effect that protects small interplanetary dust particles entering earth's atmosphere, as pointed out by Whipple (9)). However, some degree of agglomeration of the dust may have occurred, either during infall toward the nebula (10,11), or even in interstellar space (12,13). Clumps of dust would get hotter than individual grains in the shock front, perhaps even to the point of melting (chondrules), ablating, and even distilling (CAI's). And, being less rapidly decelerated, these molten objects would tend to overtake and sweep up smaller grains that had been promptly decelerated.

I believe this possible heating mechanism in the solar nebula should be given serious consideration. It provides an explanation for the relatively rapid cooling rates of chondrules ( $\sim 1$  K/min for some types (14)); and the enigmatic Al-rich concentric objects found in complex CAI's (15,16) may have been formed by the ablation of Ca-rich liquid from incoming particles that had been partially melted and distilled.

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## SHAPE AND ANISOTROPY OF Fe-Ni GRAINS IN ANTARCTIC CHONDRITES

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The texture of metal grains in chondrites, such as the irregular shape (1) and anisotropic orientations (2,5), could provide some information about the degree of lithification or the strength as well as the evolutionary process of chondritic parent bodies (3). We studied the relationship between the shape irregularity of Fe-Ni grains (1) and the strength (4) of H-, L-, and LL-chondrites. We report in this paper the anisotropic orientation and the shape of Fe-Ni grains in the same specimens from both photographic observations and magnetic susceptibility measurements.

By using the method described in (5), the magnetic susceptibility anisotropy of chondrites were measured and listed in Table 1. The ratio of the maximum ( $K_1$ ) and minimum ( $K_3$ ) principal susceptibilities represents a measure of the volumetric average of orientation and shape distributions of Fe-Ni grains. L-chondrites are more anisotropic than others and LL-chondrites have little anisotropy, among chondrites studied. Since the relative shape of averaged susceptibility ellipsoid is described by the parameter A, which is defined by  $\tan^2 A = (K_2 - K_3)/(K_1 - K_2)$ , the values of A are also listed. There are both prolate ( $0^\circ \leq A \leq 45^\circ$ ) and oblate ( $45^\circ \leq A \leq 90^\circ$ ) ellipsoids, unlike the results of (5). It may partly due to the inaccuracy for small sample volume (0.05 to 0.3 cc) and the heterogeneity of chondrites.

To see if the orientation distribution of each Fe-Ni grain depends on its shape and size, the largest axial length (a) and the semi-major one (b) of every metal grain were measured on photographs (x100), which cover about 20 mm<sup>2</sup> of polished chondrite surface. The orientation of the longest axis  $\theta$  was then measured referring to an arbitrary coordinate system fixed on the each specimen. Three mutually perpendicular surfaces (named A, B, & C) were also studied for H4 (ALH-77233), H6 (ALH-77115), L4 (ALH-77230), and L6 (ALH-78105), as reported in (1). In Fig. 1.,  $\theta$  is plotted as a function of (a-b)/a, in which open circles are used for grains larger than 0.01 mm and small dots are for smaller grains. L-chondrites show obviously anisotropic orientation, while H-chondrites are less anisotropic irrespective of the metamorphic grade. The projections of magnetic susceptibility ellipsoid to corresponding surfaces of chondrites are also illustrated in Fig. 1, in which a long bar represents the major axis and shorter one does semi-major axis. The contrast in the degree of anisotropy between L- and H-chondrites may be relevant to the previous observations of the strength (4), that is, H-chondrites showed a narrow range with higher strength.

At the early stage of chondritic parent body formation, there should be sufficient intergrain spaces where Fe-Ni grains and other matrix materials could occupy. The degree of anisotropy would increase as the deformation proceeded under anisotropic stress, such as the implantation of planetesimals onto the surface of growing parent body (5) and thermal stresses (6). However, it would be reduced by the thermal effect which anneals stressed conditions. The effects of mechanical deformation and thermal recrystallization of Fe-Ni grains may cancel with each other during thermal metamorphism and impact process at fragmentation stage of chondritic parent bodies. The difference in anisotropy of Fe-Ni grains between H- and L-chondrites may suggest different mechanical conditions for each type of parent body. It is likely that L-chondrite parent body was more strongly or heterogeneously deformed than H-chondrite parent body.

Table 1. Magnetic susceptibility anisotropy, volume fraction, and shape parameter (SP) of Fe-Ni grains, logarithmic ratio of VFR and porosity.

Sample	K1/K3	Fe-Ni grains		SP	-log(V/Vo)	Porosity
		A	(vol.%)			
ALH-77233 (H4)	1.405	42.5	6.3	6.0	0.28	5
ALH-77182 (H5)	1.205	36.2	4.1	4.7	0.28	15
ALH-77115 (H6)	1.318	65.6	4.9	4.6	0.20	(8)
Y -74191 (L3)	1.792	47.0	7.1	4.6	0.24	-
ALH-77230 (L4)	1.475	44.7	8.8	6.3	0.13	1
ALH-77254 (L5)	1.642	42.9	4.0	5.2	-0.04	18
ALH-78105 (L6)	-	-	2.3	5.0	-1.07	4
ALH-77231 (L6)	1.574	34.4	1.4	3.6	-0.76	(3)
Y -75258 (LL6)	1.047	39.1	0.9	3.7	-1.08	(33)
Y-790519 (LL)	1.328	31.4	-	-	0.31	7
Y-790723 (LL)	1.096	49.4	-	-	0.30	8
Y-790964 (LL)	1.094	46.4	-	-	0.43	16

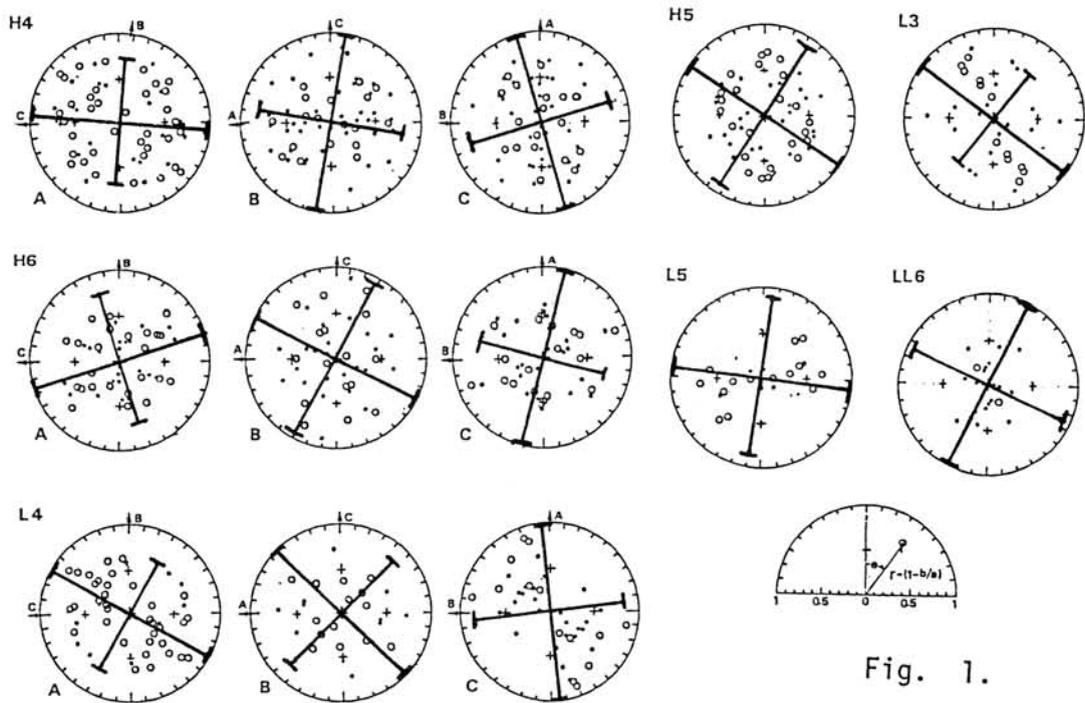


Fig. 1.

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**PETROGRAPHY AND CLASSIFICATION OF REFRACTORY INCLUSIONS IN THE ALLENDE C3(V) CHONDRITE**

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We have studied 189 refractory inclusions (CAI's and AOA's) in Allende by optical and scanning-electron microscopy. Refractory inclusions contain varying proportions of three distinct but fundamental constituents: (1) rounded, rimmed, Ca,Al-rich concentric objects; (2) porous, fine-grained, Ca,Si-rich chaotic material; and (3) porous, fine-grained, mafic inclusion matrix [1,2].

The traditional classification system for Allende refractory inclusions emphasizes differences between discrete classes of objects [3-5], obscuring the fact that there are chemical, mineralogical, and textural continua among many types of refractory inclusions. We have developed an alternate classification system (Fig. 1) that clarifies relationships between CAI's and AOA's.

There are two texturally-distinct varieties of olivine-rich inclusions in Allende: unrimmed olivine aggregates (Type 1 inclusions) and rimmed olivine aggregates (Type 5 inclusions). The most abundant constituent in both types of objects is inclusion matrix, which is recrystallized into granular rims in Type 5 inclusions. Rimmed olivine aggregates frequently contain Ca,Al-rich "xenoliths" that are complex aggregates of small concentric objects. The bulk compositions of the two types of olivine-rich aggregates overlap [6]: Type 5 inclusions are probably metamorphosed equivalents of Type 1 inclusions [2].

Three types of CAI's can be distinguished. In our classification system, the size and abundance of the constituent concentric objects, not mineral grain size, are the most important criteria for distinguishing among types of CAI's. Simple CAI's consist of a single concentric object. Complex CAI's are aggregates of concentric objects  $\pm$  chaotic material and inclusion matrix. Simple CAI's tend to be coarser-grained than complex CAI's, but simple and complex CAI's can be fine-, medium- or coarse-grained.

Complex CAI's occur in two textural varieties: unrimmed and rimmed. Unrimmed complex CAI's (Type 2 inclusions) are equivalent to irregular, fine-grained CAI's of [4]. These inclusions are aggregates of many tiny, rounded, spinel-rich concentric objects [7] and chaotic material embedded in two types of matrix: olivine-rich inclusion matrix, and a spinel + clinopyroxene-rich matrix that is a debris of fragments of concentric objects (not simply an aggregate of individual crystals). Type 2 inclusions are often mineralogically zoned [8], but their constituent concentric objects are so small that these complex CAI's do not have prominent internal/external rims visible by optical microscopy.

The other two types of CAI's (rimmed complex CAI's and simple CAI's) have prominent external or internal rims because they consist primarily of larger and (usually) coarser-grained concen-

tric objects than those that constitute Type 2 inclusions. Rimmed complex CAI's (Type 3 inclusions) are contorted, convoluted, botryoidal-to-sinuuous aggregates of several concentric objects, and occur in two mineralogical varieties: melilite-rich (= "fluffy" Type A CAI's of [9]) and spinel-rich (= "sinuous" CAI of [10,11]). There are also two mineralogical varieties of simple CAI's (Type 4 inclusions), most of which have been interpreted to be igneous objects [12,13]: melilite-rich (= "compact" Type A [9] and Type B CAI's [3]) and melilite-poor (= Type I CAI's [13]). Simple CAI's can be characterized as Ca,Al-rich chondrules [14].

Because refractory inclusions are aggregates of three fundamental constituents, several different varieties grade into each other chemically, mineralogically, and texturally. We demonstrate this by analyzing one suite in detail: olivine-rich aggregates → unrimmed complex CAI's → (spinel-rich) rimmed complex CAI's.

We have observed a continuous gradation in the mineralogy, composition, and texture of irregular, fine-grained refractory inclusions in Allende. This was also noted by [15,16] for fine-grained refractory inclusions in C3(O) chondrites, the bulk chemistry of which vary continuously between olivine-normative and spinel + clinopyroxene-normative end members (because these are the most abundant minerals in inclusion matrix and concentric objects, respectively). The class Type FAO was coined by [8] for fine-grained Allende inclusions mineralogically intermediate between olivine-rich aggregates (his Type AO) and unrimmed complex CAI's (his Type F).

Highly-fractionated Group II REE patterns and refractory trace-element depletions [14] are characteristic of, but are not limited to, "fine-grained" CAI's only. [17] identified olivine-rich aggregates ("fractionated AOA's") that also have these chemical features, and suggested that these inclusions were mixtures of an olivine-rich component (=inclusion matrix) and Group II CAI material (=spinel-rich concentric objects). The bulk composition and Group II REE pattern of a coarse-grained spinel-rich, rimmed complex CAI analyzed by [10] are identical to those of fine-grained (=unrimmed complex) CAI's. The simplest interpretation is that the two textural varieties of complex CAI's (unrimmed and rimmed) grade into each other as the size and abundance of their constituent concentric objects increase.

We have demonstrated that classifying refractory inclusions on the basis of their mineral grain size obscures some fundamental relationships among them. We also note that the term "coarse-grained" has been used inappropriately to describe many members of an important class of inclusions: melilite-rich complex CAI's (=fluffy Type A CAI's of [9]). A "coarse-grained" fluffy Type A CAI (CG-11 [18]) contains 77 vol. % fine-grained material. It is obviously inaccurate to describe an object in which fine-grained material is 3X more abundant than coarse-grained minerals as coarse-grained. The use of that term is based on petrological assumptions [9,18] that have no place in petrographical descriptions, and will lead to confusion: [14]

accurately describe many fluffy Type A CAI's as medium-grained. An advantage of our classification system (which is supported by chemical analyses performed since the traditional classification system was developed) is that it is based on the recognition of fundamental petrographic constituents, not on mineral grain size.

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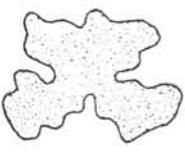
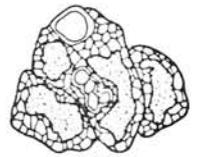
	TYPE 1	TYPE 2	TYPE 3	TYPE 4	TYPE 5	
Morphology and Textures:						
Characteristics:	Unrimmed olivine aggregates	Unrimmed complex CAI's	Rimmed complex CAI's	Simple CAI's	Rimmed olivine aggregates	
Vol %:	0.25	2.0	0.26	0.26	1.9	
Spinel chemistry:	Fe-sp >> Mg-sp	Fe-sp > Mg-sp	Fe-sp ~ Mg-sp	Fe-sp < Mg-sp	Fe-sp >> Mg-sp	
Melilite:	Absent	Uncommon	Common	Common	Absent	
Grossman <i>et al.</i> :	AOA	Fine-grained CAI's	Fluffy Type A CAI's	Compact Type A, B, I CAI's	AOA	
Wark:	Type AO	Type F, FAO	Coarse-grained CAI's	Coarse-grained CAI's	Type AO	
Mason and Taylor:	Group IV	Group II	Group III, VI	Group I, V	Group IV	
Key:						

Figure 1. A new classification system for refractory inclusions in Allende and a comparison with earlier classifications.

MAJOR CHEMICAL COMPOSITIONS OF THE CONSTITUENT UNITS OF  
THE ALLENDE METEORITE AND ANTARCTIC CARBONACEOUS  
CHONDRITES.

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The Antarctic carbonaceous chondrites, ALH-77003(C3), Y-790992(C3), ALH-77307(C3), Y-790123(C2), Y-75293(C2) and Y-74662(C2) consist of various constituent units such as inclusions, chondrules, mineral fragments and matrix. Among them, ALH-77003 and Y-790992 are similar to each other on the basis of the microscopic observation, and Y-790123 and Y-75293 also resemble each other. The major chemical compositions of the constituent units in these carbonaceous chondrites are analysed using a defocussed beam of an electron-probe microanalyser and are compared with those in the Allende meteorite.

The inclusions and chondrules of ALH-77003 and Y-790992 contain alkali contents similar to those of Allende whereas those of ALH-77307, Y-790123, Y-75293 and Y-74662 are depleted in alkali contents. The alkali depletion is considered to result from alteration on the parental body or gas reaction in primitive solar nebula prior to their accretion.

The matrices of the all carbonaceous chondrites are poorer in CaO contents than the matrix of Allende, although the  $\text{Al}_2\text{O}_3$ ,  $\text{Na}_2\text{O}$ , MgO and  $\text{SiO}_2$  contents of these matrices are not so different from those of Allende matrix. Many small fragments of calcite crystals occur as mineral fragments set in the matrices of Y-790123, Y-75293 and Y-74662, and one possibility of the CaO depletion in these matrices is the formation of calcite grains in the primitive solar nebula prior to the accretion onto their parental body.

Except for the above-stated points, the other chemical compositions of the constituent units of the carbonaceous chondrites resemble each other and these units are considered mainly to be solar nebular condensates at various temperatures.

## TEXTURES OF METALLIC MINERALS IN ALHA-77231

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Micro texture of Fe-Ni grains in ALHA-77231 (L6-condrite) has been studied by etching method to elucidate the history of the crystallization.

The specimen sliced were polished and etched in 2~5% nital for one hour. Etching patterns were observed by optical microscope of reflection type and scanning electron microscope.

The grains of metallic minerals are distributed isolately in the matrix of silicate minerals and take irregular, concave shapes. The characteristic texture just like a martensitic pattern was found in both kamacite and taenite grain respectively, and it is remarkable in the grain of large size.

Texture of kamacite : The direction of the etch pits shows that each grain consists of single crystal and lamellar band structures are developed in the definite direction. They often contain line defects too and some of them align in same direction. Kamacite grains show partially the compositional zoning, which is effectively revealed by back scatter electron image of scanning electron microscope.

Texture of taenite : In a large grain, which is surrounded by kamacite, the interior portions are occupied by the sets of lamella intersecting like the martensitic pattern( Fig.1,2). On the other hand taenite of high Ni-content shows the polycrystalline texture.

Ni-content range of the metallic grains analysed by electron microprobe is from 4.5% to 6.2% in kamacite and from 17.3% to 48.7% in taenite( plessite) in this experiment.

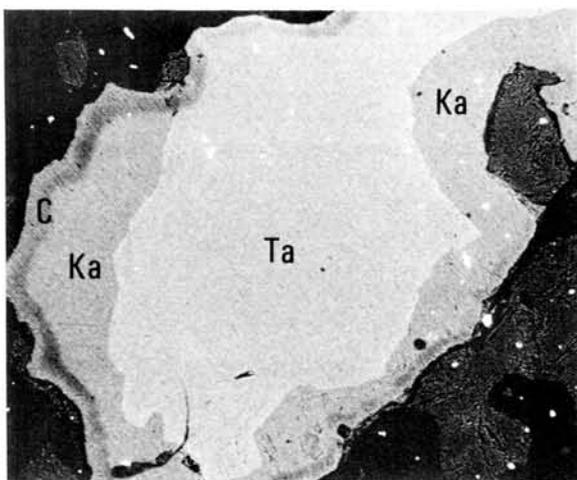


Fig.1 Composition image by SEM.  
C: Compositional zoning. X70.

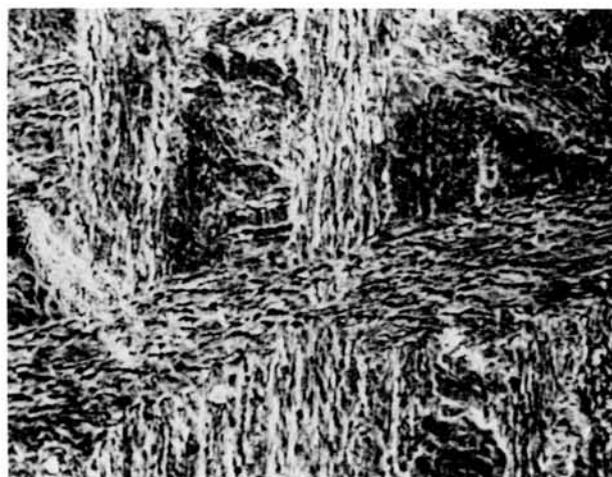


Fig.2 Photo by SEM. Center of taenite grain. Etched. X500.

Analytical Studies on the Antarctic Iron Meteorites, Yamato-790724, ALH-77263 and ALH-77289

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## I. Introduction

Three Antarctic iron meteorites, Yamato-790724, ALH-77263 and ALH77289, have been studied from the analytical point of view, in order to investigate chemical composition, segregation and morphology of elements and their compounds.

## II. Experimental

### (1) Elemental Analysis

Fourteen elements, Ni, Co, P, As, Au, Cr, Ga, Ge, Ir, Pt, Re, Ru, Sb and W were determined by neutron activation analysis and wet chemical analysis. Ni was determined by the nickel glyoxime gravimetric method and P by the molybdenum blue spectrophotometric method. The other 12 elements were determined by the activation method.

About 0.1 gram of sample was irradiated in F24C irradiation pit of the nuclear reactor, TRIGA Mark II, of Atomic Research Laboratory, Rikkyo University, cooled and analyzed by the Ge(Li) solid-state detector (Canberra Ind., 7100 type).

### (2) Compound Analysis

CMA (Computer aided Micro Analyzer)<sup>1)</sup> was used for measurement of element and compound distribution. SPEED (Selective Potentiostatic Etching by Electrolytic Dissolution)<sup>2)</sup> was employed for observation of compound morphology and PSPC (Position Sensitive Proportional Counter) was for X ray analysis of compounds.

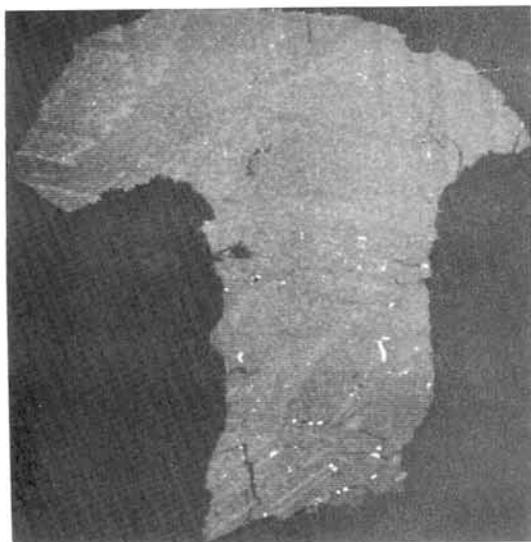


Fig.1 Segregation of Ni, Co and P in Yamato-790724, studied by CMA (original in colors): Ni, green; Co, blue; P, red; Probe size, 100 x 100  $\mu\text{m}$ ; Measured area, 50 x 50 mm

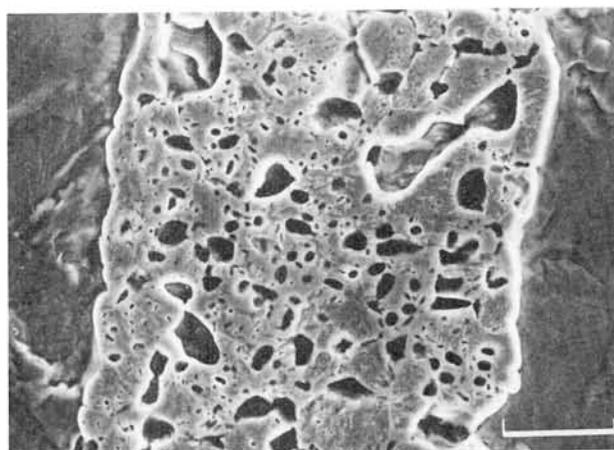


Fig.2 Observation of Ni-rich zone in Yamato-790724 by SPEED (Scale bar 10  $\mu\text{m}$ )

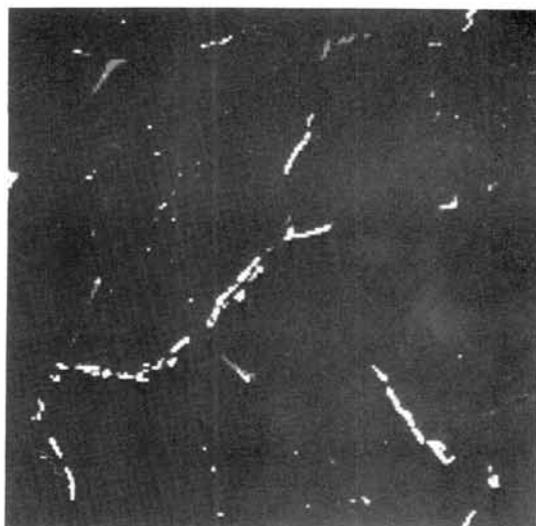


Fig.3 Segregation of  $(\text{Fe,Ni})_3\text{P}$  in ALH-77263, studied by CMA (Color photograph):  $(\text{Fe,Ni})_3\text{P}$ , yellow; Probe size,  $50 \times 50 \mu\text{m}$ ; Measured area,  $9 \times 9 \text{ mm}$

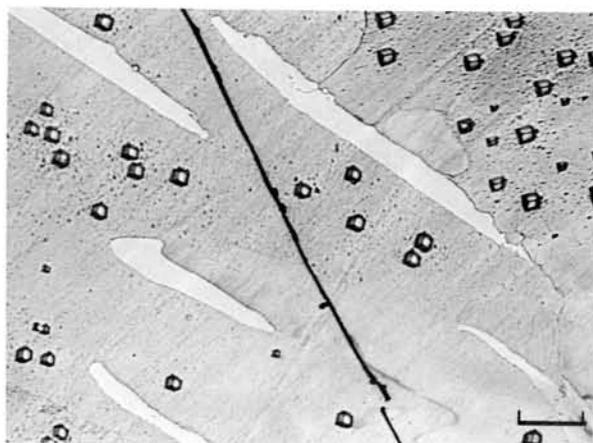


Fig.4 Observation of Ni-rich zone in ALH-77289 by SPEED (Scale bar  $20 \mu\text{m}$ )

### III. Results

#### (1) Classification

Yamato-790724 was tentatively classified into Group IIIA, containing 7.47% Ni, 0.45% Co and 0.12% P and ALH-77263 was classified into Group I, containing 6.78% Ni, 0.47% Co and 0.20% P. ALH-77289 was also classified into Group I, containing 6.79% Ni, 0.52% Co and 0.18% P. This classification was made according to the information summarized in Table 27 of Buchwald (1975), based mainly on Ni and P contents.

#### (2) Yamato-790724

Fig.1 shows segregation of Ni, Co and P, measured by CMA. The segregation tendency of Co was opposite to that of Ni. Sulphide,  $(\text{Fe,Ni})\text{S}$  and phosphide,  $(\text{Fe,Ni})_3\text{P}$  were found. Fig.2 shows one example of SPEED observations of Ni-rich zone. The Widmanstätten structure was unclear.

#### (3) ALH-77263

Phosphide,  $(\text{Fe,Ni})_3\text{P}$  was present along grain boundaries as shown in Fig.3. The Widmanstätten structure was unclear.

#### (4) ALH-77289

Phosphide,  $(\text{Fe,Ni})_3\text{P}$  was detected. The Widmanstätten structure was unclear. Ni-rich zones as shown in Fig.4 were found to contain 39.5% Ni and 59.0% Fe (wt.%, average value of five analytical points).

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METALLOGRAPHIC PROPERTIES OF ANTARCTIC ALLAN HILLS IRON METEORITES  
AND AN IRON METEORITE FROM XINGIANG PROVINCE, CHINA  
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The metallographic characteristics of three iron meteorites from the Allan Hills region in Antarctica have been examined by light and electron microscopy. Sample ALHA 77250 contains 6.75% Ni, 0.43% Co, 1.62% Si, and 0.25% P. Coarse (3 mm) kamacite bands, Newmann bands, and schreibersite regions are the dominant features of the microstructure. Sample ALHA 77283 contains 7.05% Ni, 0.4% Co, 7.6% Si, and 0.12% P. Cohenite particle, narrow tainite bands, and plessite regions are well distributed. Sample 77290 contains 6.96% Ni, 0.48% Co, 0.35% Si, and 0.3% P. Comb plessite, schreibersite, and grain boundary taenite are present. The iron meteorite from Xingiang Province, China contains 10% Ni, 0.5% Co, and 0.2% P, and has a density of 7.769. It exhibits a classic Widmanstätten pattern with a band width of 1 to 3 mm.

## PRESUMPTION OF THE THERMAL HISTORY OF THE Ym74646 CHONDRITE

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The thermomagnetic curves of Ym74646 chondrite are shown in fig.1 and 2, where the solid lines are after Funaki. We show the second and third runs of thermomagnetic curves of Ym74646 chondrite in fig.2 where the third run was measured after two years of the second run measurement (the grain sizes of the magnetic samples are 80-100 $\mu$  in diameter).

The thermomagnetic curve of the sample which was heated higher than 600°C has not been restored in a few years to that of the original sample (before heat treatment). The cause of this phenomenon may be due to the martensite transformation from bcc to fcc phases, not to the atomic diffusion. In order to confirm these results we investigated the magnetic properties of Fe-Ni alloys. The alloys were prepared by melting the elements in their proper compositions in an induction furnace under an atmosphere of purified argon gas. The purity of the raw materials was 99.9%.

In fig.3 we show the Mössbauer effect measurements and thermomagnetic curves of the 29at%Ni-Fe alloy which are original (before heat treatment) and after annealing at 800°C for 3 hours in a vacuum of  $10^{-3}$  pa. It is estimated that this original alloy contains 56% fcc phase from the analysis of the saturation magnetization measurement at room temperature.<sup>1,2)</sup>

On the other hand, the alloy of the same composition cooled slowly from the melting point to room temperature for 4 hours contains 77% fcc phase.

In fig.4 we show the thermomagnetic curves of the 29at%Ni-Fe alloys after two kinds of heat treatments : one is the block annealing ( $\sim 0.4\text{cm}^3$  bulk) at 800°C for 3 hours in vacuum of  $10^{-3}$  pa., and the other is the powder annealing (grain sizes of 90-200 $\mu$  in diameter) at the same condition.

From the above mentioned results and analyses we can presume the thermal history of Ym74646 chondrite as follows :

1. Chondrite has not been exposed to the temperature above 600°C.
2. If it had been heated, the temperature would have been higher than its melting point.

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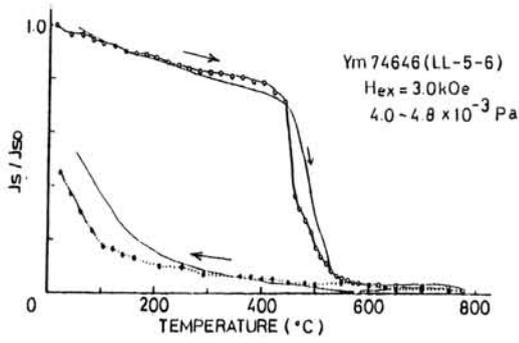


Fig. 1

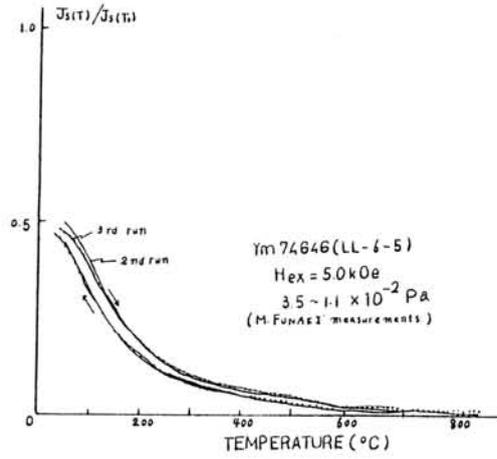


Fig. 2

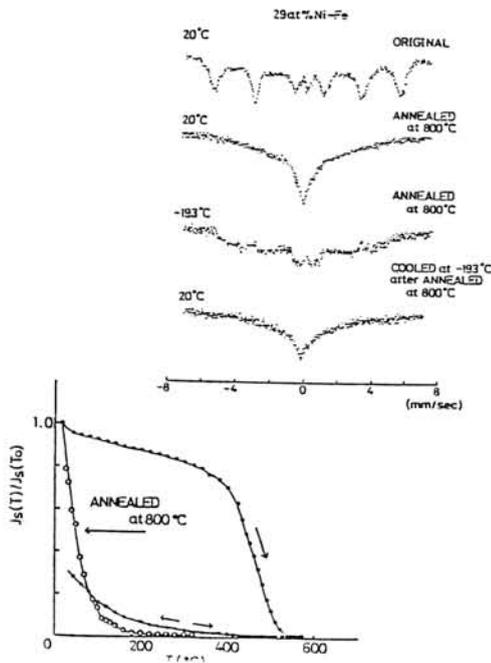


Fig. 3

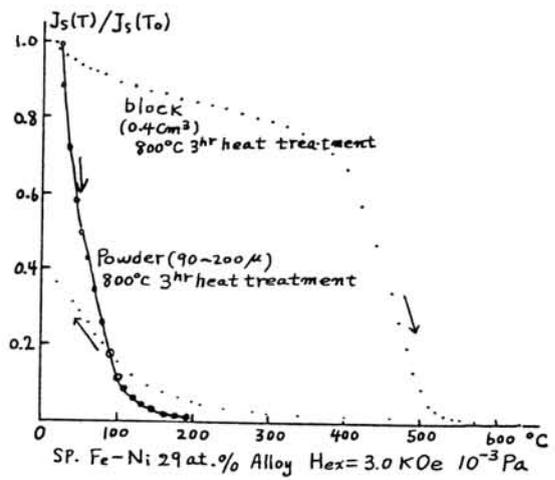


Fig. 4

## Extraterrestrial dust particles in Antarctic ice

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This work was started in order to examine whether the positive proof of cosmic dust accretes onto the Earth's surface exists in Antarctic ice and snow and the influx rate and the chemical composition of the cosmic dust is correlated with those of Antarctic meteorites or not.

Sample collections: Examined dust particles were collected from a bare ice at the Station 9 of the Allan Hills area ( Nishio and Annexstad, 1979, 1980 ) and from a part of the cored ice at the Mizuho Station with depths from 32 meters to 33.5 meters, cored during JARE-15. Dust particles filtered from melted ice were observed for their appearances, and spherical ones ( spherules ) with larger than several tens microns in diameter were picked up.

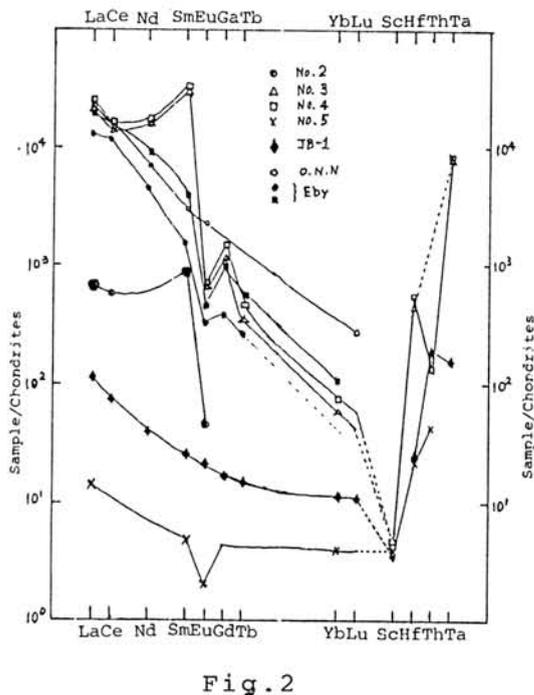
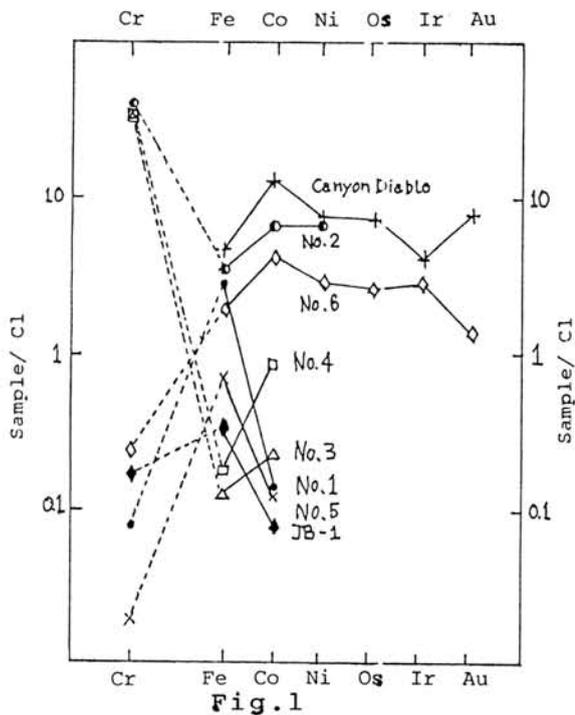
Qualitative analyses: Collected spherules were examined firstly about major chemical compositions and morphological features by SEM with EDXMA. Then individual spherule was X-rayed and photographed by means of Debye-Sherrer method with Mo-K $\alpha$  ray to get crystallographic and mineralogical informations.

Quantitative analyses: Spherules presumed to be extraterrestrial from the qualitative results were analyzed by INAA.

Results:

Allan Hills Spherules; two large spherules ( ALH-9-001 with 250  $\mu$ m in dia. and ALH-9-002 cited in Fig.1 as No.6 with 200  $\mu$ m in dia. ) were verified as chondritic particles. The EDXMA date ( Fe > Si > S > Ni > Mg ), the XDP date ( Fe-depleted olivine with magnetite ) and the INAA result ( shown in Table 1 and Fig.1 ) are consistent with each other and closely resembled to some kinds of chondrite and/or chondritic "Brownlee particles".

Mizuho Spherules; the spherule No.1 consists of Fe, Si and Mg ( from EDXMA ), and/or wüstite and Fe-depleted olivine ( from XDP ), but lacks in Ir, Os and Au ( from INAA ). Considering these results, the No.1 may be an ablation product of silicate phase of a meteorite. The No.2 has a stainless-steel-like composition but has a queer feature of R.E.E. pattern similar to the No.3 and the No.4. The No.3 and the No.4 are perovskite spherules with highly Cr content. R.E.E. patterns are very cur-



ious ( shown in Fig.2 ). It is a very interesting question where they came from.

Table - 1. Result of neutron activation analysis

Element	Mizuho Base ( Core: JARE 15- 53,55 )		Allan-Hills Canyon		JB-1 No.8 477.5	BHVO-1 No.9 352.4	
	No.1 1.4	No.2 0.8	No.3 1.3	No.4 0.6			No.5 6.4
weight(μg)	190(8)	102000	87100	86200	50 (9)	592	86.0
Na (%)	52.8	64.6	2.25	3.37	13.6	37.9	
K (%)			56(50)				
Ca (%)							
Cr (%)							
Fe (%)							
Co	61(4)	3330	117	416	56	2180	6500
Ni		71000(20)				31000(11)	[72500]
Os (ppb)						1300(50)	[3600]
Ir (ppb)						1500	[2100]
Au (ppb)						220 (6)	[1260]
La	230	7240	8250		4.8 (11)		
Ce	470 (6)	11700	14000				
Nd	173	10200(10)	10900(10)				
Sm	3(30)	5730	6440		0.98 (5)		
Eu		47 (4)	52 (4)		0.14(30)		
Gd		310(17)	366(15)				
Tb		16 (5)	20 (7)				
Yb		14(20)	17(30)		0.9 (25)		
Lu							
Sc		34.2	37.6	33.5	5.0		
Hf		86 (4)	110 (5)	44 (16)			
Th		160 (8)	5(33)	2 (35)			
Ta			180 (9)				

Numbers are in ppm, otherwise noted. Errors larger than 3% are shown in parentheses. Numbers in brackets are standard values.

FINE TEXTURE AND COOLING PROCESSES OF PYROXENE CHONDRULES  
IN L-GROUP CHONDRITESSeiko WATANABE, Masao KITAMURA and Nobuo MORIMOTODepartment of Geology and Mineralogy, Faculty of Science,  
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In order to clarify the cooling history of the equilibrated chondrites, fine structures and chemical compositions have been studied with the pyroxene chondrules of the L-group chondrites by analytical transmission electron microscopy. Specimens for electron microscopy were made by ion-thinning from pyroxene chondrules of the following meteorites: Yamato-74191 (L3), Allan Hills-77252 (L4), Fukutomi (L5) and Satsuma (L6).

Existence of the shock glass in a wide range in the chondrule in the Satsuma indicates the difficulty in obtaining informations of the cooling history from this chondrite. In the other three chondrites, which show no evidence of the shock deformation, pyroxene crystals consist of three regions different in texture and composition; core, mantle and marginal. The Ca-content of the pyroxenes increases from the Ca-free core through the mantle to the marginal region. Mantle and marginal pyroxenes in the Y-74191 have compositions in the range of  $Wo_{4-10}$  and  $Wo_{20-above\ 30}$ , respectively, with the approximately constant Fs-content (Fig.1); in the ALH-77252 and the Fukutomi,  $Wo_{0-8}$  and  $Wo_{6-below\ 20}$  with the increasing Fs-content to outwards. Apparent compositional gaps exist between the regions in the Y-74191, while no gap is observed between the mantle and marginal regions in the pyroxenes in the ALH-77252 and the Fukutomi.

The core pyroxenes with submicroscopic (100) polysynthetic twins is clinopyroxene-*P* in the Y-74191 and are orthopyroxene in the other two. The mantle regions are pigeonite-*P* with lamellae of augite (Fig.2). The Y-74191 and the other two have different lamellar orientations; in the Y-74191, "001" lamellae deviate as much as 15-20 degree from the exact (001) plane, while in the other two those deviate 5 degree or less. The mantle pyroxenes can be interpreted to have crystallized initially as clinopyroxene-*C*, followed by *C-P* transition and then exsolution. The marginal regions have the spinodal decomposition texture. Periodicities of lamellae are about 18nm in the L3, 16nm in the L4 and 24nm in the L5.

Above result seems to conflict with the prograde metamorphism model. If the compositional zoning patterns in pyroxenes in the equilibrated chondrites were caused during reheating, enough diffusion of Ca must have had occurred. However, the lamellar textures in the marginal pyroxenes rule out the Ca diffusion greater than 10nm. On the other hand, the retrograde metamorphism model can avoid such difficulty and seems to be preferable. Plagioclase crystals exist in the interstices of the Y-74191 chondrules, as reported on the other L3 chondrite (ALH-77015). This fact indicates crystallization of plagioclase does not require the reheating process and supports the retrograde metamorphism model.

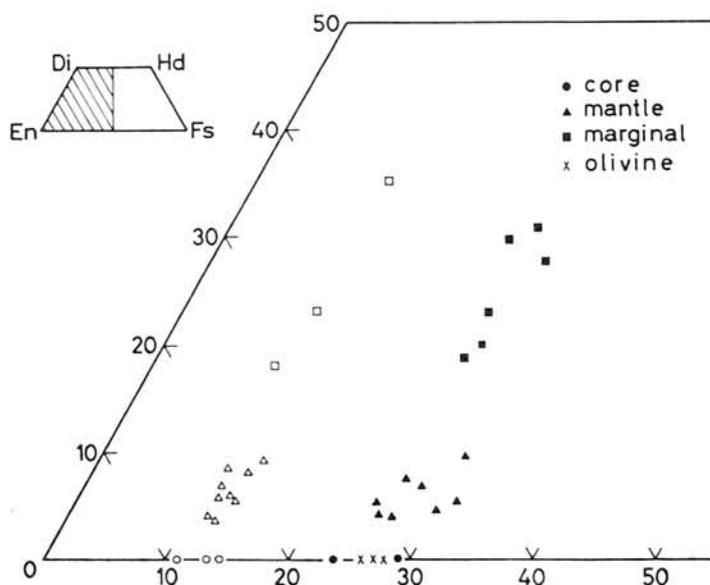


Figure 1 Chemical compositions of pyroxenes in the pyroxene-olivine chondrule (closed symbols) and the excentroradial pyroxene chondrule (open symbols; Yasuda, 1982).

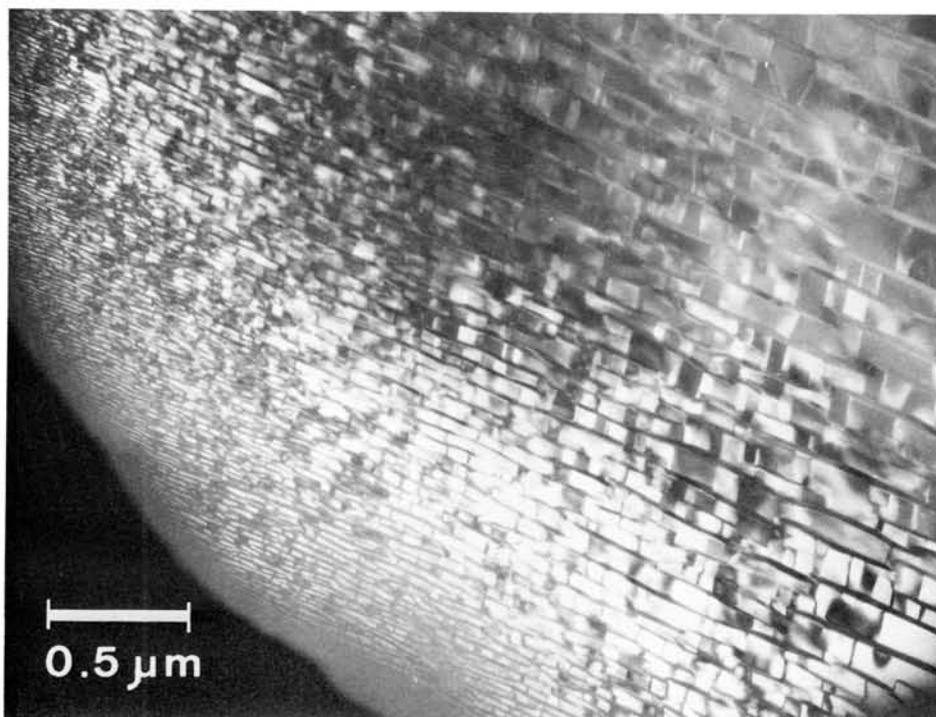


Figure 2 Electron micrograph of the mantle region. Fine exsolution lamellae of augite are observed in pigeonite which shows the antiphase pattern.

Porphyritic chondrules: evidence for incomplete melting of chondrules

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Relic olivine found in some type 3 ordinary chondrites (Nagahara, 1981a; Rambaldi, 1981) was the first direct evidence for the secondary origin of chondrules. Olivine grains enclosed in pyroxene phenocrysts of poikilitic chondrules show the same features as the relic olivine grains; dusty inclusions in the central portion and low CaO contents. So they are considered to be also relic minerals. Proportion of those relic-bearing chondrules occupies about half of the porphyritic chondrules, indicating that nearly half of the porphyritic chondrules were formed through incomplete melting of the precursor mineral clusters. Chemical and petrographic similarities between relic-bearing and relic-free chondrules that their bulk chemical compositions and occurrence are indistinguishable suggest that all the chondrules were formed from pre-existing minerals through complete or incomplete melting.

The porphyritic and microporphyritic textures were experimentally reproduced when the starting materials of mixture of minerals were heated at the temperatures of subliquidus temperature and cooled at various rates (Tsuchiyama et al., 1980; Tsuchiyama and Nagahara, 1981). The poikilitic texture was also reproduced by cooling from the subliquidus temperatures. The charges heated at 15° below the liquidus temperature for 2 minutes and cooled at rate of 800°/hr contain small euhedral olivine phenocrysts and interstitial pyroxene which poikilitically encloses olivine grains. Those cooled at rate of 5°/hr contain porphyritic pyroxene with poikilitically enclosed olivine, which resembles the poikilitic texture in natural chondrules. These results support the subliquidus heating of the porphyritic chondrules and show the possibility of incomplete melting for most porphyritic chondrules. Possibility of three stage cooling for porphyritic texture (Planner and Keil, 1982) is also present.

Compositional and oxygen-isotopic diversities among individual chondrules (Nagahara, 1981b; Gooding et al., 1980, 1982) require the clusters of minerals (mainly olivine, pyroxene and plagioclase) as the precursor of chondrules, and their formation would have been at the early stage of the solar system. In order to give the wide range of cooling rate estimated from recent experimental studies (Tsuchiyama et al., 1980; Tsuchiyama and Nagahara, 1981; Hewins et al., 1981; Planner and Keil, 1982), the nebula with abundant clusters and fine-grained materials (dust) must have been present in the optically opaque nebula which had played a role of insulation for the cooling chondrules. The mechanism of heating the nebula with clusters is still unknown.

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MODAL COMPARISON OF POLYMICT EUCRITES FROM YAMATO MOUNTAINS AND ALLAN HILLS, ANTARCTICA WITH OTHER BASALTIC ACHONDRITES.

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The modal compositions of seven Yamato and five Allan Hills polymict eucrites have been determined for comparison of these two groups, and also for comparison with the howardites and monomict eucrites. Modes were generated using an automated electron microprobe technique that analyses 9 elements at points on an orthogonal grid (1). Mineral identification was checked manually for consistence. Modes are given in Table 1.

The Yamato achondrites differ as a group from the Allan Hills specimens. Both suites are dominated by clinopyroxene ( $Wo > 5$ ) and feldspar but their pyroxene and plagioclase contents differ. The Yamato polymict eucrites contain less plagioclase ( $38.6\% \pm sd 2.5$ ) than the Allan Hills polymict eucrites ( $43.0\% \pm sd 2.1$ ) (1). These modal variations are consistent with the bulk chemical compositions of these meteorites (2-11) which show the Yamato polymict eucrites to have lower  $Al_2O_3$  and hence lower normative feldspar than the Allan Hills polymict eucrites (Y75015 which is feldspar rich is also  $Al_2O_3$  rich). The Allan Hills polymict eucrites have more variable feldspar contents than the Yamato specimens but this is caused by the small areas of three of the specimens studied. Allan Hills 78040 was examined independently as part of a NASA consortium and 3 large area thin sections have widely varying modes (Table 2). The variation within the complete Allan Hills suite of eucrites is less than that within ALHA78040. The Allan Hills specimens are petrographically very similar and are, therefore, probably all samples of a single meteorite. Similarly Y74159, 74450, 75011, and 75015 have clear petrographic and modal similarities and may also be samples of a single meteorite. The three Y-79 polymict eucrites are petrographically distinct from the Y-74 and Y-75 specimens and cannot be paired with them despite their modal similarities.

Modes of 8 eucrites (1, unpublished data) have higher feldspar contents than the Yamato polymict eucrites but are comparable with the Allan Hills specimens (Fig. 1). The Antarctic polymict eucrites have similar modes to 3 meteorites sometimes classified as howardites (ALHA 78006, Bialystok, Nobleborough), but using a revised classification scheme (12) all these meteorites and Macibini (13) become polymict eucrites. Most howardites have less than 35% feldspar (1) and greater pyroxene contents than the polymict eucrites. The pyroxene clasts in polymict eucrites show textural diversity similar to the howardites (2-4, 7-10) but most are compositionally eucritic pyroxenes. The modal pyroxene content of the polymict eucrites (Yamato 55%, Allan Hills 53%) is intermediate between eucrites (50%) and howardites (56-84%). The Allan Hills specimens overlap the range of the monomict eucrites (Fig. 1). The Yamato specimens contain more pyroxene and plot close to the howardites. The howardites and the polymict eucrites sample a continuum of polymict breccias ranging from pyroxenite rich howardites such as Y7308 (84% pyroxene) to the basalt rich Allan Hills suite (Fig. 1). The Allan Hills suite, although, modally similar to monomict eucrites is distinct from them because detailed petrography (6, 14) suggests that many clasts in them are **not** simply comminuted fragments of the eucrites. The Yamato specimens differ from the howardites

as they contain little or no diogenitic component. The observed enrichment of pyroxene in the Yamato compared with the Allan Hills specimens and the eucrites, appears to be caused by clast types that are uncommon as monomict meteorites. Some of the extra pyroxene (En<sub>55</sub>-En<sub>70</sub>) occurs as minerals and lithic clasts similar to the pyroxene rich cumulate Binda. Pyroxene more magnesian than En<sub>70</sub> is very rare in the Antarctic polymict eucrites although it is common in all known howardites. The Yamato specimens, therefore, highlight the importance of components other than diogenites and eucrites in the polymict basaltic achondrite suite. Detailed clast-by-clast petrographic and modal study of the Antarctic specimens is revealing a range of new mafic rock types comparable to that in howardites (15).

The Yamato specimens contain up to 1.4% olivine while the Allan Hills specimens contain only traces. This olivine differs from that in howardites as it is fayalitic (Fo<sub>15-30</sub>) and must be produced in rocks that are more Fe enriched than the eucrites. Alternately the survival of this olivine indicates that the Yamato specimens were not annealed (as breccias) to produce silica-pyroxene corona textures described by (16).

Modal study of the two major suites of Antarctic polymict eucrites has highlighted significant petrographic and mineralogical differences between these two groups and precludes the possibility that they all represent a single fall. The Yamato meteorites may represent at least 2 falls while the Allan Hills suite are probably samples of a single fall.

Acknowledgments: Research done under United States-Japan cooperative agreement. Funding by NASA, grant number NSG-7258. (M. Prinz, principal investigator).

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**NOTES:** PLPSC = Proc. Lunar Planet. Sci. Conf. : LPS = Lunar Planet. Sci. (Houston, Texas) Abstracts volumes : MNIPRSI = Mem. Natl Inst. Polar Res. (Japan) Spec. Issue : G.C.A. = Geochim. Cosmochim Acta.

TABLE 1: Modes of Yamato and Allan Hills polymict eucrites.

	Yamato							Allan Hills				
	74159 PB	74450 ,63C1	75011 ,87	75015 ,2	790007 ,91	790020 ,81	790260 ,71	76005	77302 ,33	78040 3 pts	78158	78165
olivine	0.4	0.1	1.4	1.0	1.1	1.0	nd	nd	nd	nd	nd	nd
Wo <5*	6.7	5.4	6.1	9.5	13.8	6.9	9.3	15.1	14.9	9.0	13.6	7.7
5<Wo<20*	40.2	29.8	37.1	29.2	35.5	36.9	31.9	25.4	29.7	31.6	21.2	29.1
Wo>20*	10.8	16.3	13.5	10.0	10.1	11.9	14.4	11.9	10.1	11.5	15.9	16.2
feldspar	37.6	39.2	36.5	43.3	35.7	39.2	40.1	42.9	39.9	42.6	45.9	43.5
silica	3.5	5.8	3.6	4.3	2.1	2.7	2.8	4.3	4.2	4.2	2.3	3.0
ilmenite	0.7	0.7	1.1	1.0	1.1	0.8	0.9	0.1	0.6	0.6	0.4	1.0
chromite	<0.1	0.1	0.2	0.3	0.3	0.3	0.2	0.3	0.1	0.1	0.1	0.3
phosphate	<0.1	0.1	0.3	0.2	nd	0.4	0.1	nd	0.2	0.2	nd	0.1
troilite	<0.1	1.8	0.2?	0.2	0.5	0.2?	0.3	nd	tr	0.3	nd	nd
metal	nd	nd	nd	nd	nd	nd	nd	nd	tr	0.1	0.3	nd
gypsum	nd	nd	nd	0.1	nd	nd	<0.1	nd	nd	nd	nd	nd
Area mm <sup>2</sup>	33.0	45.3	41.1	39.6	58.8	54.4	328	21.8	132.4	357.4	23.8	37.5
Points	925	960	963	957	897	830	3707	788	1175	2769	953	925

\* Pyroxene compositions are quoted in terms of their Wo content. Divisions do not represent structural identifications of the polymorphs of ortho- and clinopyroxene.

	Modes of Whole Rock ALHA78040			
	19	20	61	Mean
olivine	nd	nd	nd	nd
Wo<5	9.8	9.1	7.2	9.0
5<Wo<20	32.1	27.7	36.7	31.6
Wo>20	11.4	10.6	13.2	11.5
feldspar	41.2	47.1	38.4	42.6
silica	4.2	4.5	3.5	4.2
ilmenite	0.6	0.6	0.5	0.6
chromite	nd	tr	0.3	0.1
phosphate	0.3	tr	0.2	0.2
troilite	0.4	0.3	0.2	0.3
metal	nd	0.1	nd	<0.1
gypsum	nd	nd	nd	nd
Area mm <sup>2</sup>	160	119.3	78.1	357.4
Points	873	982	914	2769

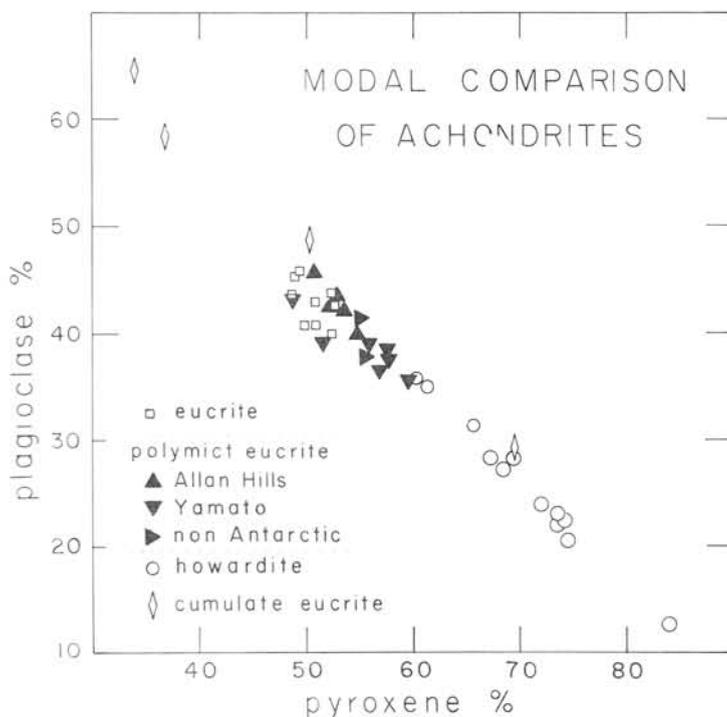


Fig.1 Modal feldspar vs total pyroxene contents of eucrites, cumulate eucrites, howardites and polymict eucrites. The Allan Hills polymict eucrites overlap the eucrite field but the Yamato meteorites are distinct and intermediate between eucrites and howardites. Diogenites contain nearly 100% pyroxene.

## MINERALOGICAL COMPARISON OF ANTARCTIC AND NON-ANTARCTIC HED (HOWARDITES-EUCRITES-DIOGENITES) ACHONDRITES.

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Howardites, eucrites and diogenites are a suite of meteorites closely related in their mineralogy, petrology and chemistry (1) and were proposed to have been developed on the same parent body (2). We call these meteorites as HED achondrites in this paper. Previous studies of HED achondrites in the museums of the world have helped elucidate the nature of the Antarctic achondrites. A large number of HED achondrites recovered from the Antarctica over the 10-year period by the Japanese (JARE) and U.S. expedition parties has contributed to reconstruct their parent body and the brecciation process (3). However, there are marked differences between the Antarctic and non-Antarctic achondrite collections (4). Diogenites and polymict eucrites are more abundant in the Antarctic collections and many of them have been proposed to be that several individual samples are fragments of the same meteorites (5,6). Thus the conclusions deduced from the study of only the Antarctic HED achondrites may be biased toward undesirable direction. Thanks to the U.S.-Japan cooperative agreement on the Antarctic meteorites, one of the authors (H.T.) had an opportunity to compare the Antarctic and non-Antarctic HED meteorites. This paper summarizes the results of this comparison on several items.

(1) Basaltic clast types: The polymict eucrites are the most abundant samples of the HED achondrites in the Antarctic and were first recognized in the Antarctic collection (7). They contain varieties of basaltic clasts which range from pigeonite vitrophyres, porphyritic basalt with hollow Mg-rich pigeonite phenocrysts and fethery matrix of Fe-rich pigeonites and plagioclases, variolitic, ophitic to subophitic basalts with mesostasis to equigranular basalts. Vitrophyres and porphyritic varieties have been rare among non-Antarctic main group eucrites. A large subophitic clast found in Y75011 are rich in mesostasis and are similar to Stannern (Constantinople) in their texture (Fig. 1).

(2) Chemical zoning of pigeonites: Majority of basaltic clasts in Antarctic polymict eucrites show characteristic chemical zoning in pigeonites. Only non-Antarctic eucrite of this type has been Pasamonte (7). Although Nuevo Laredo and Millbillillie exhibit fine subophitic texture with asicular plagioclase crystals, their chemical variation has been attributed to exsolution from a homogenous host. A part of the Nuevo Laredo trend which mimic the incomplete resolution of exsolution by the microprobe technique, has been found to be chemical zoning by this study. This trend is similar to that found in Y790266 clast, although pigeonites in Y790266 have a rare small Mg-rich core. The large Y75011 clast and similar small clasts in Y74450 and Y75015, reveal extensive chemical zoning from a very Mg-rich core  $\text{Ca}_4\text{Mg}_{70}\text{Fe}_{26}$  to Fe-rich rim adjacent to mesostasis. This type of clast preserves features which are least altered by the subsequent thermal annealing event.

(3) Pyroxene fragments from cumulate eucrites: The Binda inverted pigeonite has blebby augite inclusions which were interpreted to be produced by 'pearlite' transformation or decomposition at or little below the pigeonite eutectoid reaction line (Fig. 2). We found a similar inverted pigeonite in Serra de Magé was a decomposition product of the host phase between the (001) augite lamellae in a more Ca-rich pigeonite. The texture indicate that grain coarsening took place after inversion to orthopyroxene (Fig. 2). The Binda-like pyroxene occurs even in diogenites of the Y75032-type pyroxene. The small

fragments of the Binda-type pyroxene have been detected in five Yamato polymict eucrites (Y74159, Y74450, Y75011, Y75015, Y790007). The Moore County pyroxene with coarse (50 to 100  $\mu\text{m}$ ) exsolution lamellae with (001) in common is rather rare in these polymict eucrites. ALH78006 (Fig. 3) contains inverted pigeonites similar to Nagaria (Fig. 4), which has an order of magnitude thinner lamellae than Moore Co..

(4) Chromite clasts: Fragments of sub-mm sized chromites have been occasionally found in the Antarctic polymict eucrites, but such chromites have not been seen to our knowledge in crystalline eucrites. A crystal of such large chromite has been found in the Chervony Kut eucrite.

(5) Clouding in eucritic pigeonites: Fe-rich pigeonites in ordinary eucrites or main group eucrites have dust-like inclusions of opaque oxides known as clouding (8) in them. Such pigeonite is known in Y74356, only one monomict eucrite from the Antarctica. It is rare among the pigeonite fragments in the polymict eucrites. The beginning of clouding has been detected in a Y790266 clast by the ATEM technique. They are ilmenite platelets alligned on a certain crystallographic plane of submicroscopic fracturing.

The previous comparison between Antarctic and non-Antarctic achondrites has emphasized the differences. Monomict and crystalline eucrites and howardites are common HED achondrites in the non-Antarctic compilation and polymict eucrites and diogenites have been the dominant ones in the Antarctic (4). Many of the Yamato diogenites and polymict eucrites have been recognized as pieces of the single fall (5,6). A few non-Antarctic polymict eucrites have been identified, though they contain minor diogenites. In this study, many missing components in either groups have been identified in others.

Some features intermediate between the two groups have been recognized. For example, the chemical zonings in pigeonites of Y790266 and Nuevo Laredo revealed intermediate trends between the two extremes such as the Y75011 clast trend and the Juvinas trend, which is the trend connecting between the host and exsolved pair. Y790266 includes minor precipitated of ilmenite, which is extensive in the non-Antarctic ordinary eucrites. Stannern (9) may be the thermally processed analog of the Y75011 clast. The bulk chemistry of both are rich in  $\text{Na}_2\text{O}$  (9) and their textures are similar.

If we accept an idea that there is a gradational trend between the eucrites with lack of major exsolution and strongly-zoned pyroxenes, and those with features of subsequent heating episode, and that components (10) of plagioclase-cumulate eucrites and of ordinary eucrites with extended annealing in the polymict eucrites are small, we may have to revise the crust model of the howardite parent body as follows: [1] Plagioclase-cumulate eucrites may be early formed lunar crust-like terrain and basaltic eucrite clasts in the polymict eucrites may be a lava-like crusts, beneath which there may be the Binda-like cumulate eucrites and diogenites; [2] Ordinary eucrites might have remained beneath the crater floor after impacts and subjected to extended subsolidus annealing, whereas those excavated and incorporated into regolith were intact during the high temperature episode.

We thank NASA and Ministry of Education (Japan) for support of the research and NSF and Natl. Inst. of Polar Res. for the meteorite samples.

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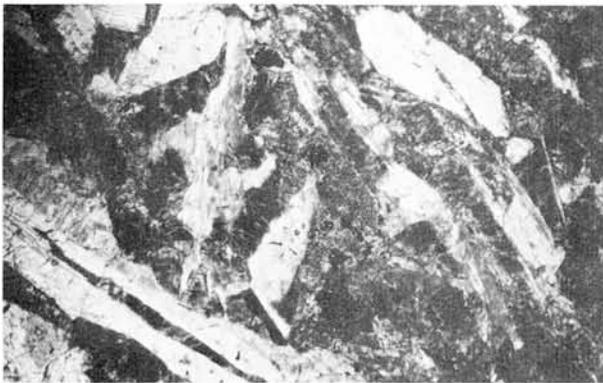


Fig. 1. Photomicrograph of a part of Stannern (Constantinople). Width is 3.2mm. Open. Note the clouding in pigeonites. Original mesostasis recrystallized to coarser ilmenites, silica and troilites.

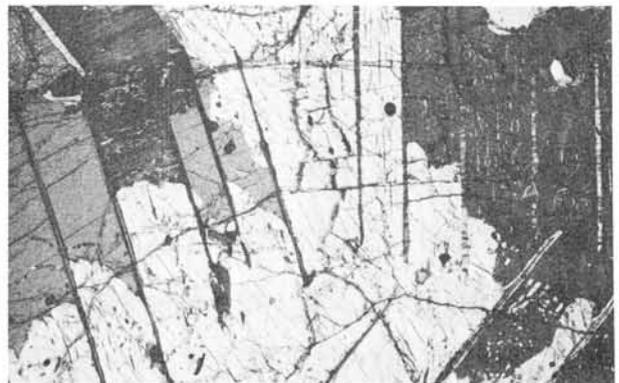


Fig. 2. Photomicrograph of inverted pigeonites from Serra de Magé. Lamellae are relicts of 4 different orientations of (001) augites. The white Opx region grows into other crystals of original pigeonites. Cross polarized light. Width 3.2mm.

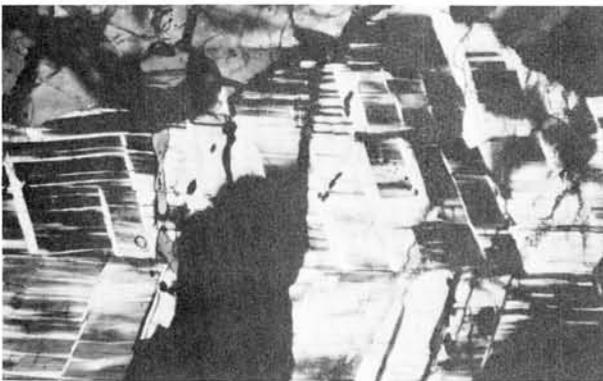


Fig. 3. Photomicrograph of twinned inverted pigeonite from Allan Hills 78006 polymict eucrite. Note similarity to that of Nagaria in Fig. 4. Cross polarized light. Width is 0.62 mm. The scale of Fig. 4 is the same as this.

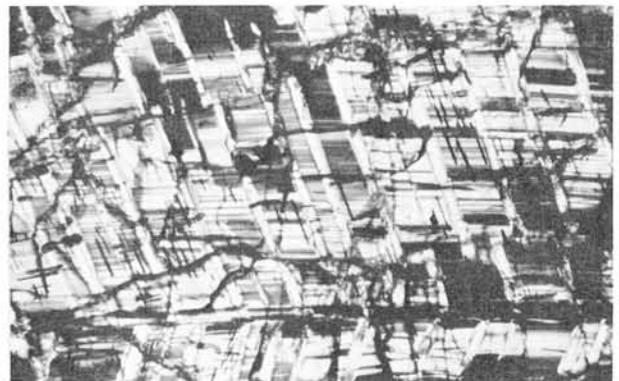


Fig. 4. Photomicrograph of twinned inverted pigeonite from Nagaria. Herring-bone shaped lamellae are remnant (001) augites exsolved from the original pigeonite. The host is partly inverted to orthopyroxene.

PARENT BODY OF ALH-765, AND -77302 POLYMICT EUCRITES BASED ON THE CHEMICAL COMPOSITIONS

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Polymict eucrite consists of many kinds of eucritic clasts and matrix which is mainly mixture of comminuted clasts. These components might be formed on the surface of a single parent body. For understanding the formation processes of the parent body of basaltic achondrite, the studies of the components in a polymict eucrite have advantage compared with the studies of monomict eucrites.

The abundances of more than 30 major, minor, and trace elements in 6 matrices, 11 igneous clasts, and 11 phenocrysts etc. extracted from the ALH-765 polymict eucrite and in 5 matrices, 18 igneous clasts, and 14 phenocrysts etc. from the ALH-77302 polymict eucrite have been determined by instrumental neutron activation analysis (INAA). After INAA, the abundances of the rare earth element (REE) in 3 matrices and 2 clasts from the ALH-756 and in 2 matrices and 2 clasts from the ALH-77302 have been determined by radiochemical neutron activation analysis (RNAA).

The REE abundances in the clasts from both meteorites range from the lowest REE abundance which found in the previously reported non-cumulative eucrites to highest one (Fig. 1 and 2, Consolmagno and Drake, 1977). Two clasts from the ALH-765 have REE patterns for cumulative eucrites. One of the patterns is similar to that of Moore County (Schnetzler and Philpotts, 1969). Another is similar to that of Serra de Magé (Schnetzler and Philpotts, 1969). The average abundances of REE and Na in the clasts of both meteorites are higher than those in the matrices (Fig. 1 and 2) as mentioned by Wooden et al. (1981) for Na abundances in polymict eucrites. The analytical results for phenocrysts are providing many new informations. In this report, we will discuss more about the formation processes of the parent body of the basaltic achondrite based on the analytical results.

References: Consolmagno et al (1977). GCA 41, 1271. Schnetzler and Philpotts (1969) In Meteorite Research, p.206. Wooden et al(1981) LPS XII, 1203.

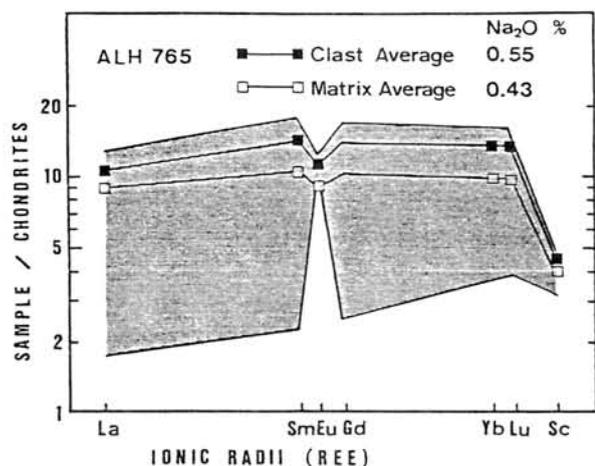


Fig. 1 The range of chondritic normalized REE and Sc abundances in the clasts of the ALH-765 polymict eucrite.

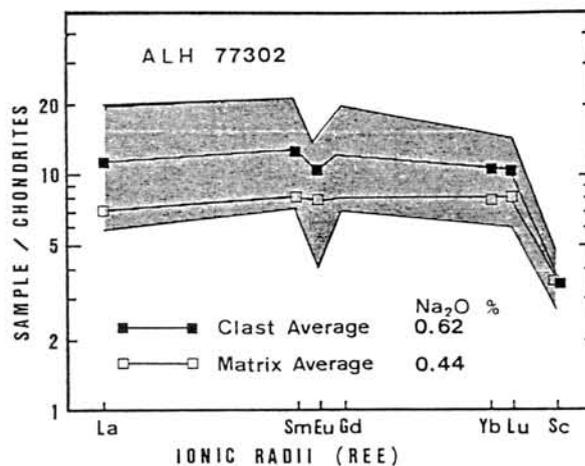


Fig. 2 The range of chondritic normalized REE and Sc abundances in the clasts of the ALH-77302 polymict eucrite.

## METAL GRAIN AND SIDEROPHILE RICH CLASTS IN ALH-765 POLYMICT EUCRITE

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In order to study the formation processes of the parent body of the basaltic achondrite, the abundances of more than 25 major, minor, and trace elements in matrices, igneous clasts, phenocrysts etc. extracted from the ALH-765 meteorite have been determined by instrumental neutron activation analysis (Ikeda and Fukuoka, 1983).

A metallic grain which had high concentrations of siderophile elements (Fe, Ni, Co, Ir, and Au), was found in the meteorite (Table 1). Two igneous clasts from the meteorite have anomalously high Co, Ni, Ir, and Au contents (Table 1). Although Ni, Ir, and Au in matrices from the ALH-765 could not be determined, Co contents in the matrices show scattered values compared to those for ALH-77302 (Fig. 1). Other chemical compositions in the matrices do not show such scattered values. This indicate presence of extra Co which is not contained in major mineral phase of the meteorite as seen in howardites (Fukuoka et al., 1977). These anomalous siderophile elements might be introduced to the surface of the parent body of this meteorite by the impact of meteorite which is rich in siderophile elements, such as chondrite or iron. This impact might produce polymict breccia on the surface of the parent body.

References: Ikeda, K. and Fukuoka, T. (1983) Abstract of the 8th Symposium on Antarctic Meteorites, in this volume. Fukuoka, T., Boynton, W.V., Ma, M.-S. and Schmitt, R.A. (1977) Proc. Lunar Sci. Conf. 8th, 187-210.

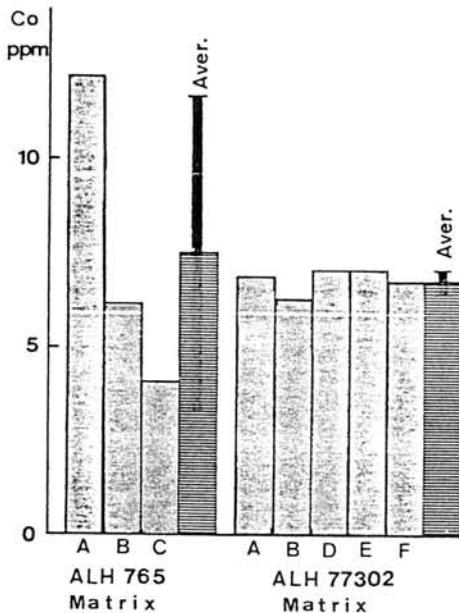


Fig. 1 Co contents in matrices from the ALH-765 and -77302 polymict eucrites.

Table 1 Siderophile elements contents in five igneous clasts and one metal grain from the ALH-765 polymict eucrite.

Sample	Wt mg	FeO %	Co ppm	Ni ppm	Ir ppb	Au ppb
ALH765						
Clast F	14.61	18.9	7.1	-	-	-
G	3.50	15.7	3.1	-	-	-
I	3.77	16.7	43.9	-	-	-
J	0.86	27.3	322	2600	89	95
K	3.28	32.6	902	9300	102	212
Metal	0.24	92.2(Fe%)	7550	48000	941	1450
Errors (%) <sup>1)</sup>		1	1-2	9-22	1-2	3-7

1) Errors are due to counting statistics.

## CHEMICAL COMPOSITIONS OF 5 YAMATO POLYMICT EUCRITES

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A block sample of Y-790260 meteorite, an igneous clast and a matrix sample extracted from Y-790266 meteorite, and three igneous clasts extracted from Y-74450, Y-75011, and Y-75015 meteorites were provided from National Institute of Polar Research of Japan. These meteorites were classified as polymict eucrites from the mineralogical and petrographical investigations (Takeda and Yanai, 1981). Three matrices were extracted from Y-790260 meteorite in our laboratory. The abundances of more than 25 elements in 4 igneous clasts and 4 matrices of these polymict eucrites have been determined by instrumental neutron activation analysis (INAA) and radiochemical neutron activation analysis (RNAA).

The analytical results by INAA except for three matrices from Y-790260 are shown in Table 1. The chondritic normalized rare earth elements (REE) patterns of the clasts extracted from Y-74450, -75011, -75015, and the matrix from Y-790266 show the monotonically enriched flat patterns with negative Eu anomalies compared to the chondritic pattern (Fig.1 and 2). These features are similar to those of known non-cumulative monomict eucrite (Consolmagno and Drake, 1977) and to those of the clasts and matrices extracted from ALH-765 and -77302 polymict eucrites (Fukuoka and Nakamura, 1981 and Ikeda and Fukuoka, 1983). The chondritic normalized REE pattern of the clast extracted from Y-790266 has large positive Eu anomaly (Fig.2) which is typical feature for cumulate eucrite (Consolmagno and Drake, 1977).

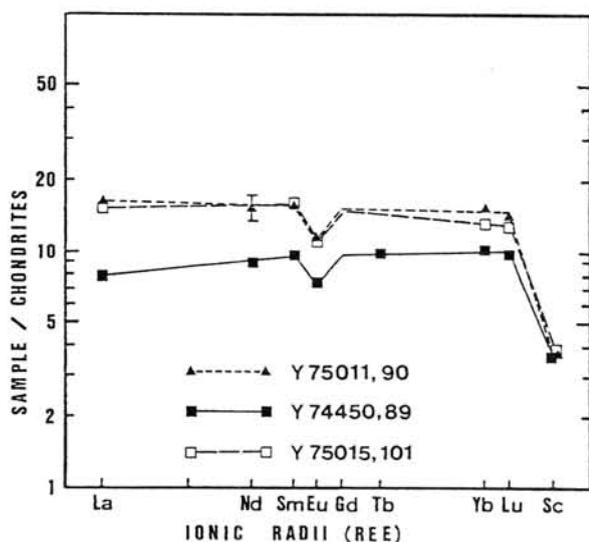


Fig.1 Chondritic normalized abundances of REE and Sc in three clasts extracted from Y-74450, -75011, and -75015 polymict eucrites.

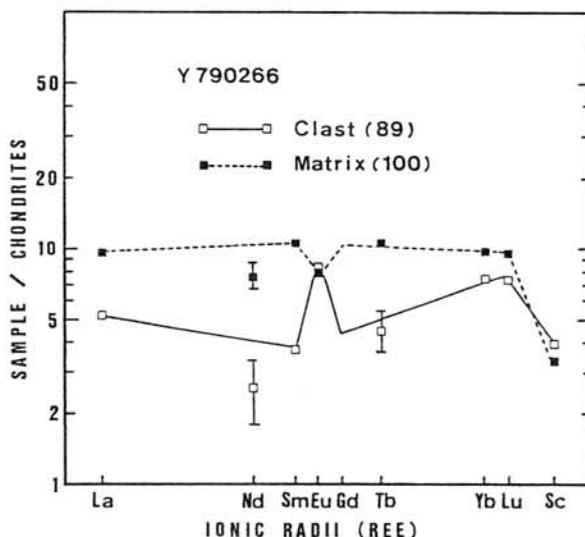


Fig.2 Chondritic normalized abundances of REE and Sc in a clast and a matrix extracted from Y-790266 polymict eucrite.

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Table 1 Chemical abundances in the clasts and matrix extracted from Y-74450, -75011, -75015, and -790266 polymict eucrites by INAA.

Sample	Method <sup>1)</sup>	Wt mg	TiO <sub>2</sub> %	Al <sub>2</sub> O <sub>3</sub> %	FeO %	MgO %	CaO %	Na <sub>2</sub> O %	MnO %	Cr ppm	K ppm	Sr ppm	Ba ppm	Sc ppm
Y74450,89	I-L	94.7			18.7	8.3	9.0	0.41		2090	-	-	72	28.6
	I-P	68.0	0.56	10.0			8.9	0.43	0.59					
Y75011,90	I-L	23.2			16.4	4.4	10.9	0.68		1760	-	-	170	29.0
	I-P	23.2	0.68	12.7			7.6	0.63	0.47					
Y75015,101	I-L	137.6			19.1	6.9	10.5	0.60	0.45	2210	480	-	74	31.5
	I-P	133.9	1.2	11.8						3440	-	79	51	31.4
Y790266,89	I-L	98.3			20.3	-	9.1	0.56		1840	-	-	84	26.3
	I-P	99.7	1.2	8.7			8.5	0.53	0.58					
Y790266,100	I-L		0.80	11.1	16.8	7.6	7.8	0.46	0.53					
	I-P		8-16	1	1	7-11	5	1	1	1	20	20	15-25	1
Errors (%) <sup>2)</sup>	I-L													
	I-P													

Sample	Method <sup>1)</sup>	La ppm	Nd ppm	Sm ppm	Eu ppm	Tb ppm	Yb ppm	Lu ppm	Hf ppm	Th ppm	V ppm	Ta ppm	Co ppm
Y74450,89	I-L	2.7	5.8	1.59	0.55	0.47	2.3	0.33	2.2	0.30	61	0.19	8.1
	I-P												
Y75011,90	I-L	5.6	9.9	3.12	0.87	0.48	3.5	0.48	3.2	0.44	39	0.43	9.7
	I-P												
Y75015,101	I-L	5.2		3.06	0.81		2.9	0.44	1.9	1.65	57	0.27	8.3
	I-P												
Y790266,89	I-L	1.8	1.7	0.72	0.61	0.21	1.6	0.25	4.8	0.27	71	0.46	5.0
	I-P												
Y790266,100	I-L	3.3	4.9	2.13	0.62	0.51	2.2	0.32	2.2	0.26	56	0.17	5.5
	I-P												
Errors (%) <sup>2)</sup>	I-L	3	10-30	1	1-4	10-20	3	3	4	10-15	6-11	10-15	1-2

1) I-L: INAA by long neutron irradiation, I-P: INAA by pneumatic irradiation system.

2) Errors for INAA are due to counting statistics.

## CHEMICAL COMPOSITIONS OF HIGHLY METAMORPHOSED YAMATO LL CHONDRITES

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Y-790143, -790345, -790519, -790723, and -790964 meteorites in Yamato-79 meteorite collections are black colored unique meteorites with many elongated voids. Petrographical observations show these meteorites suffered high metamorphism by heavy shock. The major chemical compositions of the meteorites are close to those of LL group chondrite (Kojima and Yanai, 1981 and Yanai et al., 1981). Another unique Yamato meteorite, Y-74160 had been recognized as recrystallized LL chondrite by the bulk chemistry and petrographical observation (Takeda et al., 1979).

In order to know the influences on the chemical compositions including trace elements in above meteorites by high metamorphism in this study, the abundances of 20 major, minor, and trace elements (Ti, Al, Fe, Mg, Ca, Na, Mn, Cr, V, Sc, La, Sm, Eu, Yb, Lu, Co, Ni, Ir, Au, and Zn) in the meteorites have been determined by instrumental neutron activation analysis (INAA). Sample specimens were provided from National Institute of Polar Research of Japan.

The analytical results are shown in Table 1. Cl chondrites normalized abundances of 14 elements are also shown in Fig. 1. Major chemical compositions in the meteorites show similar values and are close to those of LL chondrite group (Table 1). Cl chondrites normalized abundances of Cr, Sc, La, Sm, Co, and Ni are also close to those of LL-6 chondrites (Fig.1). However, Zn contents in Y-790143 is anomalously low compared to those in other Yamatoes and LL-6 chondrite (Table 1 and Fig. 1). Because zinc is one of the volatile elements, Zn in Y-790143 was possibly lost by shock thermal-metamorphism.

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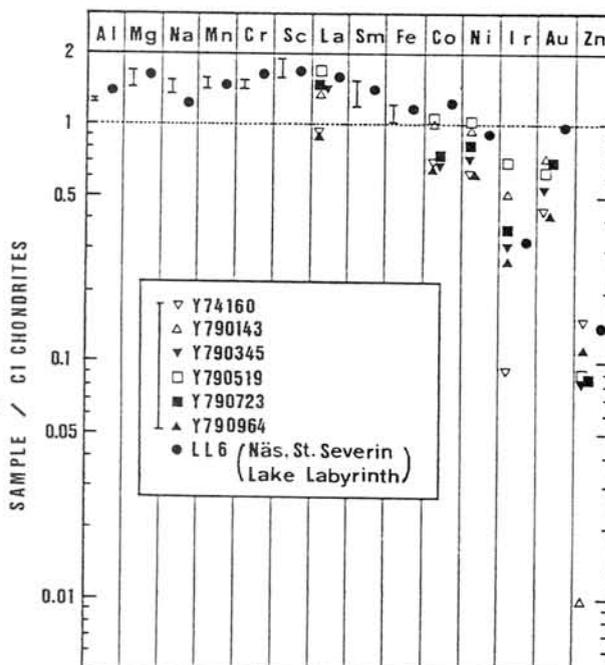


Fig.1 Cl chondrites normalized abundances of 14 elements in six highly metamorphosed Yamato LL chondrites.

Table 1 Chemical abundances in Y-74160, -790143, -790345, -790519, -790723, and -790964 meteorites by INAA.

Sample	Wt mg	TiO <sub>2</sub> %	Al <sub>2</sub> O <sub>3</sub> %	FeO <sup>3)</sup> %	MgO %	CaO %	Na <sub>2</sub> O %	MnO %	Cr ppm	V ppm
Y74160,94	100.6	0.36	2.0	22.5	27.0	1.6	0.92	0.39	3820	82
Y790143,82	115.8	-	2.1	24.9	23.7	1.6	0.94	0.34	3350	66
Y790345,91	149.0	-	2.0	25.7	22.9	1.5	0.97	0.34	3520	64
Y790519,91	103.2	-	2.0	26.8	23.7	1.7	0.94	0.34	3540	75
Y790723,92	108.8	0.18	2.0	23.6	24.0	1.8	0.94	0.35	3420	63
Y790964,90	109.7	0.55	2.0	23.1	26.2	2.1	1.06	0.37	3430	87
Errors (%) <sup>1)</sup>		20-40	3-5	1	3	10-15	1	1	1	3-7

Sample	Sc ppm	La ppm	Sm ppm	Eu ppm	Yb ppm	Lu ppm	Co ppm	Ni ppm	Ir ppb	Au ppb	Zn ppm
Y74160,94	8.4	0.23	0.20	0.075	0.24	0.029	340	6730	49	71	46
Y790143,82	8.8	0.33	0.21	0.066	0.17	0.036	490	10100	268	118	3
Y790345,91	8.7	0.35	0.22	0.084	0.20	0.042	330	7510	160	89	25
Y790519,91	11.7	0.42	0.23	0.063	0.18	0.018	500	11200	365	103	27
Y790723,92	8.1	0.37	0.22	0.086	0.21	0.037	350	8730	192	115	26
Y790964,90	9.3	0.22	0.18	0.061	0.22	0.035	310	6460	139	68	35
Errors (%) <sup>1)</sup>	1	4-8	1	10-20	7-9	7-20	1	1	1	1	7-10 <sup>2)</sup>

1) Errors are due to counting statistics.

2) Except for Y790143 (42%).

3) Total iron contents were calculated as FeO.

## CURRENT STATUS OF ORGANIC ANALYSIS OF ANTARCTIC METEORITES

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To date the organic composition of three Antarctic carbonaceous chondrites has been investigated. The three meteorites are: Allan Hills 77306 (C2), Allan Hills 77307 (C3) and Yamato 74662 (C2). Kotra (1) has studied the amino acids and hydrocarbons in all of these three carbonaceous chondrites. Cronin et al. (2) and Holzer and Oro (3) have also analyzed samples of Allan Hills 77306. This paper will summarize the current status of understanding of the organic composition of Antarctic meteorites. Experimental details can be found in the references cited.

The unique environment of the Antarctic was expected to have preserved the fragile carbonaceous chondrites in their pristine state especially with respect to the organic content. Analysis of amino acids from aqueous extracts and hydrocarbon analysis of benzene-methanol extracts has shown this to be true. Great care was taken in the collection and subsequent handling of the meteorite specimens to avoid terrestrial contamination.

In the C2 meteorites the exterior and interior fractions contained nearly equal abundances of amino acids in both the hydrolyzed and unhydrolyzed extracts (1,2,4). The Allan Hills 77307 (C3) sample contained no extractable amino acids. Furthermore, for several amino acids the amount of D and L enantiomers in the exterior and interior fractions was nearly the same (1,3). Therefore, the near equal abundances and the racemic nature of the amino acids in both the fractions showed that the organic matter was indigenous and extraterrestrial and that the Antarctic meteorites are uncontaminated by terrestrial organic matter.

Benzene-methanol extracts of C2's showed that normal alkanes were the dominant hydrocarbons. Smaller amounts of aromatic hydrocarbons were also detected. For the alkanes, neither an odd over even preference nor a bimodal distribution were observed. Small quantities of pristane and no phytane were detected. Thus, these are uncontaminated. The Allan Hills 77307 (C3) sample showed a homologous series of n-alkanes which is possibly of terrestrial origin. But the absence of extractable amino acids rules out terrestrial microbial contamination. Procedural blanks indicate that these hydrocarbons may have been introduced after collection in the field but before analysis (1). Pyrolysis studies by Holzer and Oro (3) indicated no gross contaminant hydrocarbons in Allan Hills 77306.

The clean nature of these carbonaceous chondrites has encouraged investigations to determine specific precursor materials of amino acids. Kotra (1) presented preliminary evidence for the presence of two dipeptides in Yamato 74662. A more detailed study by Walters et al. (5) confirmed the presence of glycyl-glycine and alanyl-alanine in low amounts.

The terrestrial ages of Antarctic meteorites are as much as 500,000 years (6). Some aspects of their post-fall history have been discussed by

Gibson and Kotra (7). Lipschutz (8) has noted that, in general, interior samples of Antarctic specimens (rich or poor in volatiles) seem compositionally unaffected by weathering. Exterior samples (to about 1cm depth) indicate potential contamination by C and alkalis, possibly other elements or loss by leaching. Analysis of over 30 Antarctic specimens showed that more than two-thirds of the meteorites do not contain enriched total carbon values resulting from weathering processes. Despite the obvious evidence of some form of chemical or physical weathering on a number of Antarctic meteorites the organic content seems to have been well preserved. The abundances of amino acids and hydrocarbons are comparable to other carbonaceous chondrites of the same sub-group and character (e.g. Murchison, Mighei, Nogoya, etc.).

Thus the studies to date indicate that Antarctic carbonaceous chondrites are a unique collection of pristine, essentially organically unaltered specimens. Therefore they are the ideal samples for further organic analysis of meteorites. Carbonaceous chondrites remain the only source in nature of prebiotic molecules available for analysis. A deeper understanding of the formation and evolution of organic matter in the solar system may be obtainable from the Antarctic carbonaceous chondrites.

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## ORGANIC COMPONENTS OF CARBONACEOUS CHONDRITE ALHA 77307

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The catalog number of the specimen used in this investigation is ALHA 77307,51 (C3), the sample having been divided into exterior with crust (2.85 g) and interior (2.00 g) and each sample having been wrapped with aluminum foil. Kallemeyn and Wasson (1982) suggested that Allan Hills A77307 is a member of CM-CO clan.

Current work has been done on the exterior. The whole of the exterior was washed with hexane in Soxhlet extractor. The hexane washes contained free sulfur as a main component and crystals of free sulfur (confirmed by mass spectrometry) was afforded on evaporation of the solvent at room temperature. No remarkable free sulfur was extracted from a lump (2.76 g) of Allende (C3) by the same procedure and hydrocarbones (probably contaminating materials during storage) were detected by GC-MS. GC-MS analysis of the residue after removal of sulfur in the hexane washes is under way.

The washed meteorite was crashed into powder and C, H, N, S elemental analysis was carried out on the powder (Table 1). The powder was heated in direct inlet system and the high and low resolution mass spectra of the vaporising organic material were recorded at many different temperature.

The powdered meteorite (2.80 g) was extracted with hexane and mass spectra of the extract were taken using GC-MS and direct inlet system. The spectra showed the presence of free sulfur as a main component. Precise examinations on the hexane extract after removal of sulfur by passing through an activated copper column are in progress.

The remaining powder was extracted with benzene-methanol (2:1). The low resolution mass spectra measured by GC-MS suggested much lower content of free sulfur in the extract than those in the hexane washes and the hexane extract. Evapora-

tion of the solvent gave a colorless amorphous solid (7 mg) which did not give any remarkable mass spectrum on measurement by direct inlet system suggesting the necessity of the chromatographic separation and concentration of the extract. Investigations on the concentrated fractions obtained after silica gel column chromatography are under way.

Table 1. Elemental (C, H, N, S) composition of exterior of ALHA 77307,51 washed with hexane.

Combustion temp (°C)	additive	C(%)	H(%)	N(%) <sup>a)</sup>	weight of sample (mg)
890	CuO	0.73	0.76	0	8.401
970	none	0.76	0.83	0	8.954
1030	none	0.77	0.77	0	9.088
1060	WO <sub>3</sub>	0.74	0.78	0	9.380
		S(%) <sup>b)</sup>			
		2.06			5.169
		2.30			3.249

Determined using YANACO MT-2 elemental analyzer for C, H, and N. a) No nitrogen was detected at these sample size. b) Combustion in flask method were applied.

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CHEMICAL AND OXYGEN ISOTOPIC COMPOSITIONS OF SEVERAL ANTARCTIC UNEQUILIBRATED ORDINARY CHONDRITES.

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Mayeda et al. (1980) discovered a new  $^{16}\text{O}$  mixing line defined by oxygen isotopic compositions of several inclusions in an ordinary chondrites, ALHA-76004(LL3) meteorite. The new  $^{16}\text{O}$  mixing line is quite different from the carbonaceous chondrite mixing line (Clayton et al., 1977), being displaced higher  $^{17}\text{O}/^{16}\text{O}$  by about 3 ‰ on the oxygen three isotope diagram. The new line passes through the bulk compositions of H-chondrites and L- and LL- chondrites (Clayton and Mayeda, 1978), and coincides with the best-fit line determined by individual chondrules from ordinary chondrites (Godding et al., 1980).

We have determined oxygen isotopic compositions of three whole rocks of ALHA-76004(LL3), Y-77015(L3) and Y-790448(L3), two Ol-Px aggregates in Y-790448, two Ol-Px aggregates in ALHA-76004, one Ol-Px aggregates in ALHA-77015, and five fragments (about 10 mg) of Y-74191(L3).

The whole rock data of the three chondrites are plotted near the mixing line of ALHA-76004. However, their oxygen isotopic compositions slightly deviate from the equilibrated L- and LL-chondrite range. Five fragments of ALHA-76004 also show a wide range of the isotopic compositions, one fragment belonging to the equilibrated H-chondrite range, three fragments to the L- and LL-chondrite range, and one fragment depleting in  $^{16}\text{O}$  far from the L- and LL-chondrite range. These fragments do not make a mass fractionation line and seem to fall on a mixing line of slope-1. The Ol-Px aggregates of Y-790448, ALHA-76004 and ALHA-77015 are plotted along the mixing line of ALHA-76004. There is a weak relationship between oxygen isotopic compositions and Fa contents of olivines in these aggregates,  $^{16}\text{O}$  components decreasing with decreasing Fa contents in the range from  $\delta^{18}\text{O} = +3\%$  to  $\delta^{18}\text{O} = +5\%$ , although FeO contents

of the bulk aggregates show no systematic relationship with the oxygen isotopic compositions. The  $\text{Na}_2\text{O}$  contents of the bulk aggregates seem to increase with decreasing  $^{16}\text{O}$  components.

These oxygen isotopic data indicate the mixing of two gas and/or dust reservoirs, which have different isotopic compositions, for the origin of the most unequilibrated ordinary chondrites.

OXYGEN ISOTOPES IN CHONDRULES OF ORDINARY AND CARBONACEOUS CHONDRITES.

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Previous oxygen isotope studies of individual chondrules from unequilibrated ordinary chondrites [1, 2] have shown that: (1) chondrules have variable isotopic compositions, scattering about a slope-1 line on the three-isotope plot, (2) the isotopic compositions bear no relationship to the iron group of the parent meteorite, (3) the isotopic compositions bear no evident relationship to textures or chemical compositions of the chondrules, except for a weak correlation with total iron content. These data have been interpreted as resulting from isotopic exchange between hot silicates and a surrounding nebular gas during chondrule formation [3].

We present new isotopic and chemical data on 21 chondrules from a carbonaceous chondrite (Allende), which support the silicate-gas exchange hypothesis, and which provide possible additional links between the unequilibrated ordinary chondrites and the carbonaceous chondrites. The samples analysed consisted of eight barred olivine, one excentroradial pyroxene, and 12 porphyritic chondrules, characterized by SEM and/or optical microscope examination of polished surfaces, and by EDAX broad-beam major element analysis

The oxygen isotope data define a trend not previously observed in meteorites. The chondrules define a band, possibly nonlinear, from the vicinity of  $\delta^{18}\text{O} = -2.6\%$ ,  $\delta^{17}\text{O} = -6.5\%$  to  $\delta^{18}\text{O} = +3.8\%$ ,  $\delta^{17}\text{O} = +1.5\%$ . This trend has a slope distinctly greater than one; at its lower end, it intersects the mixing line for Allende Ca-Al-inclusions; at its upper end it approaches the ordinary chondrite chondrules trend. The barred olivine chondrules trend to have higher iron contents. Several detailed features of the trend imply that it was generated by exchange of  $^{16}\text{O}$ -rich precursors with an external reservoir. However, the deviation of the chondrule trend from the Allende

inclusion line requires separate external reservoirs for the two classes of object from the Allende meteorite.

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## CHARACTERISTIC STRUCTURAL AND COMPOSITIONAL ORDERING OF EXTRATERRESTRIAL PLAGIOCLASES

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Miura (1983a,b) points out that formation process of chondrite can be shown by statistical analyses of structural and compositional ordering factors. The purpose of this study is to present new comprehensive data on the structural and compositional orderings of plagioclase in meteorites.

The samples used in this study are twenty five Y-75 L4,5 chondrites (*cf.* Miura, 1982) and five additional chondrites. To confirm the results, the previously reported data are statistically analysed for EETA79006 polymict eucrite (Simon *et al.*, 1982), Adams H5 chondrite (Fodor *et al.*, 1980), Gomez L6 chondrite (Sipiera *et al.*, 1980), fifteen lunar (Fronde1, 1975), thirty two igneous (Deer *et al.*, 1963), eighteen metamorphic (Deer *et al.*, 1963; Ribbe and Smith, 1966), and ten synthetic glassy plagioclases.

The following results are summarized in this study:

(1) Table 1 and Fig. 1 show the results of statistical analyses between An content and (Al/Si) ratio (designated as An-T) and between An content and (Ca/Na) ratio (designated as An-M) in terrestrial and extraterrestrial plagioclases. Almost all plagioclases show lower value of correlation coefficient ( $r$ ) of the An-T relation deviated from ideal linear equation. A strong ordering in T site atoms is observed in terrestrial and lunar plagioclases, and *vice versa* in meteoritic plagioclases (Miura, 1983a,b).

(2) Meteoritic plagioclases show completely disordered correlation between An-T. This suggests that rearrangement of sluggish T atoms fails to occur at low to medium temperature of impact metamorphism.

(3) The  $r$  values of polymict eucrite EETA79006 and some of Allende C3V chondrite are nearly 0.9 close to those formed at higher temperature.

(4) Different formation processes between chondrule and matrix, and between glassy and crystalline plagioclases of matrix in Y-75135,93 chondrite are indicated by a remarkably contrast of completely disordered (in the chondrule, and glassy one in the matrix) and weakly ordered (in the matrix, esp. crystalline one) correlations between An-T (Miura, 1983a,b).

(5) The  $r$  values of An-T and An-M of synthesized glassy plagioclases are not similar to those of L, LL and H chondritic plagioclases, but to those of lunar and terrestrial plagioclases crystallized at higher temperature.

(6) Negative  $r$  value of An-T relation consists of various data of formation process difficult to simulate to one regression line. It is also found that An content of meteoritic plagioclase obtained from working-line of standard T ratio is considered to be initial composition (*i.e.* fingerprints of paleocompositions).

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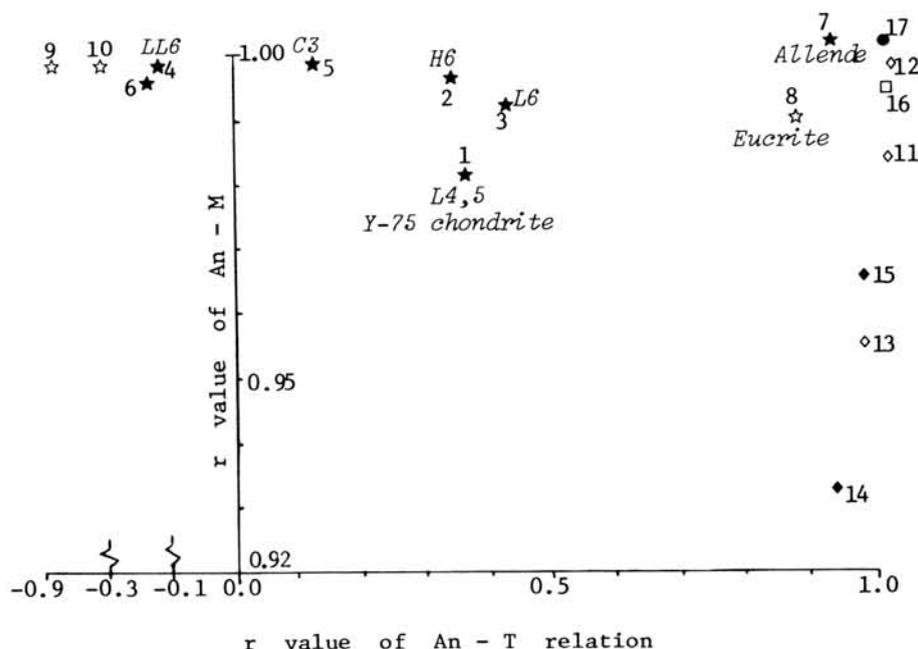
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Table 1. Relationship and correlation coefficient between (Al/Si), or (Ca/Na) and An content in terrestrial and extraterrestrial plagioclases.

Sample	An - T	An - M	No. in Fig. 1
Extraterrestrial: Y-75 chondritic meteorites [37]*	weak (.353) I <sup>** #</sup>	strong(.980) E	1
H6 Y-74640,81 [12]	weak (.355) I	strong(.995) E	2
L6 ALH769,75 [14]	weak (.429) I	strong(.993) I	3
LL6 Y-75258,97 [10]	random(-.237) L	strong(.998) E	4
C3 ALH77307 [5]	random(.133) P	strong(.997) E	5
C3V Allende-1 [10]	random(-.244) I	strong(.996) E	6
C3V Allende-2 [4]	strong(.919) I	strong(.999) E	7
EETA79006 polymict eucrite [20]	strong(.867) E	strong(.990) E	8
H5 Adams chondrite [5]	random(-.887) I	strong(.998) E	9
L6 Comez chondrite [4]	random(-.355) L	strong(.999) P	10
Lunar Basalt [5]	strong(.990) E	strong(.983) E	11
Lunar anorthosite [5]	strong(.999) E	strong(.998) E	12
Lunar soil & breccia [5]	strong(.974) E	strong(.955) E	13
Terrestrial : Igneous [32]	strong(.926) I	strong(.932) P	14
Metamorphic [18]	strong(.972) P	strong(.965) P	15
Synthetic : Glassy EPMA standards [10]	strong(.998) E	strong(.994) E	16
Ideal : Theoretical [10]	strong(1.00) I	strong(1.00) P	17

\* Numbers of crystals calculated are shown in square brackets.  
 \*\* Numbers in parentheses are correlation coefficient (r) of An-T or An-M. X-axis: An content; Y-axis: M or T ratio.  
 # Best fitting of r value to linear(I), exponential(E), logarithm(L) or power(P) equation.

Fig. 1. Structural and compositional orderings based on correlation coefficients(r) of An-T and An-M relations in terrestrial and extraterrestrial plagioclases. Reference numbers correspond to sample listed in Table 1.



THE EFFECT OF WEATHERING ON THE  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  AGES OF ANTARCTIC METEORITES

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Since Antarctic meteorites have been found on ice surfaces, they are regarded to have been subject to the weathering effect. Even if we tried to remove weathered portions from them before using for  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  analysis as much as possible, the results show that some samples were affected by the weathering to some extent. Hence, it is indispensable to examine the effect of weathering on the  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  ages of Antarctic meteorites in more detail. In order to study this point, two Antarctic meteorites were selected.

The sample ALH-761 (L6) is a block with a diameter of about 20 cm. From this sample, the outermost part, the intermediate part and the innermost part were prepared. The outermost part is fragile and oxidized to some extent. The intermediate part also includes the oxidized portions. The innermost part is relatively fresh. They were irradiated in JMTR with the fast neutron flux of about  $10^{19}$  nvt together with the MMhb I as an age standard. Three parts show similar plateau-like  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  ages of about 4470 ~ 4490 Ma up to 900°C. In the 1000°C fraction, however, the samples from the outermost and the intermediate parts show high  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  ages of more than 4600 Ma. In this fraction, the amount of released  $^{36}\text{Ar}$  also increased. The sample from the innermost part does not show such a high age nor any increase in the released fraction of  $^{36}\text{Ar}$ . Hence, the apparent high  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  ages may be attributed to the incorporation of terrestrial atmospheric Ar in some phase like hematite which might be changed from goethite during neutron irradiation.

Similar results were obtained for the other sample ALH-77288 (H6), whose original size is about 10 cm in diameter. From this sample, the outermost and the innermost parts were prepared for  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  analysis. The outermost part was seriously oxidized and the innermost part was oxidized with lesser degree. Plateau-like ages of about 4470 ~ 4500 Ma are observed for these samples in the 1000 ~ 1300°C fractions. However, apparently high  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  ages of more than 4600 Ma are observed in the 800 ~ 900°C fractions in the outer part, where the released fraction of  $^{36}\text{Ar}$  also increased. These results suggest that the oxidized parts might add the atmospheric components, which causes the apparent increase in the  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  age in the intermediate temperatures (around 800 ~ 1000°C). These components might not be removed by conventional preheating, but may be reduced by preheating of the sample under vacuum before neutron irradiation.

## CARBON-14 AGES OF ANTARCTIC METEORITES

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$^{14}\text{C}$  has been measured in five stony meteorites including AHL-769, AHL-77231 and three falls. The terrestrial ages of Antarctic meteorites were obtained by comparing the  $^{14}\text{C}$  activities with those of falls.

Carbon was collected as  $\text{CO}_2$  from meteorites by the combustion in oxygen gas. Approximately 20 g meteorite sample was ground in an alumina mortar overnight. The powdered sample on a platinum boat was dried at  $110^\circ\text{C}$  for several hours and heated at  $1000^\circ\text{C}$  in a quartz tube with oxygen atmosphere. The gases in the quartz tube were circulated through a tube at  $500^\circ\text{C}$  which contained  $\text{CuO}$ , platinized asbestos and silver wool and then bubbled through Van Slyke solution. The  $\text{CO}_2$  in the oxygen was absorbed by 1N NaOH solution. After 4 hours of absorption, 0.01N  $\text{KMnO}_4$  solution was added to confirm no sulfite in NaOH solution. On the addition of  $\text{HClO}_4$ , the  $\text{CO}_2$  was evolved and recovered in a liquid nitrogen trap. The amount of the  $\text{CO}_2$  gas was measured volumetrically. The  $\text{CO}_2$  was reacted with metallic lithium to form lithium carbide and was converted with water to acetylene, which was stored for later  $^{14}\text{C}$  analysis.

The  $^{14}\text{C}$  content in the acetylene gas was measured by the  $\beta$ -ray counting with a proportional counter. The proportional counter with  $53.0\text{ cm}^3$  sensitive volume was prepared for the measurements of  $\beta$ -activities in a small amount of carbon ranging from 10 to 100 mg in weight. The background of the counter was  $0.334 \pm 0.007$  cpm, so that the upper limit of measurable terrestrial age was approximately 30,000 years when 20 g meteorite sample was available.

HIGH SENSITIVITY STABLE ISOTOPE MEASUREMENTS OF CARBON, NITROGEN  
AND HYDROGEN IN YAMATO METEORITES

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Five Yamato meteorites: Two ureilites and three carbonaceous chondrites (two type CM's and a Cr) have been studied by stepwise combustion, in order to distinguish carbon-, nitrogen- and hydrogen-bearing phases on the basis of release temperature and isotopic composition. Only very small amounts of sample are required: A 20 mg meteorite chip is adequate for characterization of all three elements.

The combustion technique allows resolution of weathering products (formed during the lifetime of the samples on the Antarctic ice) and other terrestrial contaminants. Phases of exotic isotopic composition have also been recognized using this technique in carbonaceous and ordinary chondrites:  $\delta^{13}\text{C}$  up to +1100 per mil PDB (Swart et. al., 1983),  $\delta^{15}\text{N}$  down to -270 per mil AIR (Wright et. al., 1983),  $\delta^2\text{H}$  up to +5700 per mil SMOW (McNaughton et. al., 1982). Fresh Antarctic meteorites, whose contamination histories are less subject to the influence of terrestrial organic inputs, are ideal specimens for further characterization of light element stable isotope anomalies.

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LPSC XIV (abstract)

## Measurement of terrestrial age of meteorite

by thermoluminescence technique

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Thermoluminescence (TL) of Antarctic meteorites, ALH77256-90(D), ALH77294-81,82(H5), ALH765-75,85(Eu), ALH768-83(H6), ALH77272-83,84(L6) was measured. Ordinary chondrites were brighter than Eucrite and Diogenite wasn't bright.

ALH77294-81, ALH765-75 and ALH768-83, which were with fusion crust, were cut into several portions at intervals of 1.5mm in parallel with the surface. The TL depth dependence was investigated. It was suggested from the TL depth dependence that the low temperature glow in the outermost portion was produced by terrestrial radioactivity.

So far terrestrial age of meteorite by TL technique was estimated from the magnitude of fading of the low temperature glow at the inner portion. In this time, we try to estimate terrestrial age from terrestrial radioactivity produced TL. But the low temperature glow of the outermost portion was too weak, then only ALH768-83 was determined to be exposed by 370 rad. Assuming that the kinetics is first-order, the meteorite has been stored at  $-20^{\circ}\text{C}$ , life time is  $8 \times 10^4$  years and terrestrial dose-rate 17 mrad/year, the terrestrial age of ALH768-83 becomes  $2.5 \times 10^4$  years.

SR AND ND ISOTOPIC CHARACTERISTICS OF FIVE YAMATO POLYMICT EUCRITES. Wooden<sup>1</sup>, J.L., Takeda<sup>2</sup>, H., Nyquist<sup>3</sup>, L.E., Wiesmann<sup>4</sup>, H., and Bansal<sup>4</sup>, B. <sup>1</sup>Lunar and Planetary Institute, 3303 NASA Rd. 1, Houston, TX 77058, <sup>2</sup>Mineralogical Institute, Faculty of Science, Univ. of Tokyo, Hongo, Tokyo 113, Japan, <sup>3</sup>SN4, Johnson Space Center, Houston, TX 77058, and <sup>4</sup>Lockheed, 1830 NASA Rd. 1, Houston, TX 77058.

Five Yamato polymict eucrites (74159, 74450, 75011, 75015, and 790266) have been analyzed for Rb, Sr, Sm, and Nd concentrations and Sr and Nd isotopic compositions (Table 1). Thin sections of the analyzed samples have been characterized by mineralogical techniques. The Yamato samples were analyzed as part of a larger project, that includes the Allan Hills and Elephant Moraine polymict eucrites, with the goal of surveying the Sr and Nd isotopic systematics of the Antarctic polymict eucrites. Some of the early results of this project were reported in (1). A more complete set of isotopic data is now available, and some of the conclusions of the earlier work will be modified.

The majority of the Antarctic polymict eucrites define a Rb-Sr isochron of  $4.63 \pm 0.19$  Ga with an initial Sr ratio of  $0.69897 \pm 3$  ( $\lambda^{87}\text{Rb} = 1.39 \times 10^{-11}/\text{yr}$ ). This age and initial Sr ratio are in good agreement with the results (2) for the non-Antarctic eucrites. Of the five Yamato samples analyzed only the subsamples from 790266 have Rb-Sr systematics that differ significantly from the population that define the 4.63 Ga isochron. A small (~50 mg), fine-grained clast from the matrix of 790266 has a model initial Sr ratio at 4.56 Ga of 0.69917 and a sample from 0.65 grams of homogenized matrix, a model initial ratio of 0.69908. The model initial ratio for a larger, med-grained clast is slightly high (0.69904) but not significantly different from the 4.63 Ga isochron. There is a subset of the polymict eucrite data consisting of samples from ALHA 78132 that indicates an imprecise Rb-Sr age of about 4.0 Ga. This age may reflect a general resetting of the Rb-Sr system of this sample as the result of post-crystallization processes, and approximately 4.0 Ga K-Ar ages have been reported for Yamato 74159 and other non-Antarctic eucrites (3). However, the possibility that ALHA 78132 is younger or had an initial Sr ratio less than 0.69897 cannot be eliminated.

The Sm-Nd isotopic data for the Antarctic polymict eucrites scatter about a 4.56 Ga reference isochron with an initial Nd ratio very similar to that of Juvinas. The  $^{147}\text{Sm}/^{144}\text{Nd}$  ratio for "whole-rock" samples in the data set has a large range (from 0.179 to 0.230). This ratio for nine of ten Yamato subsamples has a very small range (0.188 - 0.193). In addition these nine samples have the highest average Sm, Nd, Rb, and Sr concentrations. The tenth subsample, a large clast from 790266, has distinctly different Sm and Nd concentrations and Sm/Nd ratio, but Rb and Sr concentrations typical of this group. The  $^{143}\text{Nd}/^{144}\text{Nd}$  ratio of this sample is aberrant and will be repeated. The average initial Nd ratio at 4.56 Ga for the other nine samples is 0.50601 compared to a chondritic value for the JSC laboratory of 0.50598.

The Sr and Nd isotopic systematics of the Yamato polymict eucrites taken as a group show no unusual features with respect to the majority of planetary materials formed about 4.56 Ga ago. Their tight grouping of Rb, Sr, Sm, and Nd concentrations and Sm/Nd ratios strongly indicate that the five samples analyzed form a single population possibly from a single fall. This conclusion is in agreement with our mineralogical observation that all these Yamato polymict eucrites contain unique mineral and lithic clasts. The Yamato population is distinct from the compositional averages of the Allan Hills and Elephant Moraine samples but they show some overlap when all samples are

plotted together. Compositional differences between clast and matrix samples for all Antarctic polymict eucrites continue to exist but with some exceptions. The compositional features of all Antarctic polymict eucrites suggest that they represent separate falls from a single or group of closely related sources which have some compositional distinctions from the source(s) of many non-Antarctic eucrites. The Rb, Sr, Sm, and Nd concentrations of the Yamato samples are uniformly high and are most like those of eucrites whose compositions have been explained as the result of fractionation of more primitive eucritic melts or as smaller degrees of partial melting than that that produced the more mafic, less trace element enriched melts (4). Among the Antarctic polymict eucrites the most likely candidates for a "parental" melt from which the Yamato samples may have fractionated are ALHA 77302 and 78132.

We thank National Institute of Polar Research for the consortium samples. A part of research done under United States - Japan cooperative agreement.

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Table 1. Sr and Nd Isotopic Data for the Yamato Polymict Eucrites.

Sample	ppm	ppm	$\frac{87}{86}\text{Rb}$	$\frac{87}{86}\text{Sr}$	ppm	ppm	$\frac{147}{144}\text{Sm}$	$\frac{143}{144}\text{Nd}$
	Rb	Sr	$\frac{86}{86}\text{Sr}$	$\frac{86}{86}\text{Sr}$	Sm	Nd	$\frac{144}{144}\text{Nd}$	$\frac{144}{144}\text{Nd}$
Y74159,97 WR Matrix	0.467	78.3	0.0173	0.70010 ± 4	2.39	7.57	0.1907	0.511833 ± 20
Y74450,63A WR Crystal-rich matrix	0.281	77.3	0.0105	0.69970 ± 2	2.60	8.31	0.1892	0.511720 ± 27
Y74450,63 D+G WR Matrix	0.337	77.5	0.0126	0.69986 ± 4	2.50	7.88	0.1918	0.511776 ± 28
Y75011,73 WR Matrix	0.358	84.2	0.0123	0.69973 ± 4	2.74	8.70	0.1906	0.511738 ± 30
Y75011,84B WR Clast	0.246	81.3	0.0087	—	3.073	9.652	0.1925	0.511792 ± 23
Y75015, 20B' WR Clast-rich matrix	0.297	84.3	0.0102	0.69964 ± 2	3.13	9.90	0.1911	0.511782 ± 22
Y75015,20E+F WR Matrix	0.425	83.6	0.0147	0.69995 ± 3	2.65	8.45	0.1898	0.511781 ± 27
Y790266,94,99 WR Matrix	0.341	80.6	0.0122	0.69988 ± 3	2.550	8.117	0.1900	0.511791 ± 24
Y790266,60,96-98 WR Clast	0.310	85.6	0.0105	0.69973 ± 3	0.884	2.469	0.2165	—
Y790266,94,99 WR Fine-grained clast #1	0.497	78.5	0.0183	0.70037 ± 3	2.671	8.582	0.1882	0.511728 ± 27

## Ce anomaly in REE patterns of Antarctic eucrites

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We have reported that all of Antarctic eucrites studied by us have a Ce anomaly in REE patterns.<sup>1)</sup> It is considered that Ce is more volatile than other REE at higher oxygen partial pressures. Therefore, Ce anomaly can be one of indicators of oxidizing conditions for meteorite formation in gaseous phase. Only a few non-antarctic meteorites show the Ce anomaly; Khohar and Barwise chondrites, Melrose-b howardite and giant olivine chondrule and hibonite inclusion from Allende meteorite. (It is added that all chips from these meteorites do not always show the Ce anomaly.) On the other hand, the Ce anomaly is observed for all of six Antarctic eucrites analyzed thus far. REE abundances for 27 Antarctic meteorites have been determined by isotope dilution method. Among them, the Ce anomaly is observed for six eucrites (all cases studied), two diogenites and a unique achondrite ALH-77005. Further, Yb and Lu deviate from other REE lines in REE patterns of the Antarctic eucrites.

There remains a question whether the Ce anomaly of Antarctic eucrites was caused by a pre-terrestrial process or by a terrestrial effect. To consider the weathering effect, we have determined REE abundances for an inner part of ALH-78132 eucrite in the present study, in contrast to the previous studies in which REE abundances were determined for outer parts of the eucrite specimens. Further, in this study, Ce isotopic abundance data have been newly added for ALH-78132 eucrite.

Fig. 1 shows REE patterns for some chips of ALH-78132 eucrite. ALH-78132,78 is a specimen from the inner part of this meteorite and ALH-78132,71 and 79 are specimens from the outer part of the ALH-78132 eucrite. ALH-78132,78 and 79 are taken from the same slice. ALH-78132,71a, b and c are different chips from the ALH-78132,71. Fig. 1 shows the following results. (1) Inner part of this eucrite (ALH-78132,78) shows a negative Ce anomaly. (2) ALH-78132,71c displays distinct REE pattern from the patterns of ALH-78132,71a and b. However, all of three REE patterns of ALH-78132,71a, b and c show a positive Ce anomaly.

Thus, the degree of Ce anomaly is heterogeneous in ALH-78132 eucrite. The negative Ce anomaly is observed for an inner part of the eucrite ALH-78132,

whereas outer part chips display a positive Ce anomaly. Further, light REE (except Ce) depletion is observed for some specimens from a outer part of the eucrite (ALH-78132,71a and b). Heterogeneous distribution of Ce anomaly suggests that Ce anomaly observed for Antarctic eucrites have been produced by the terrestrial processes rather than the pre-terrestrial processes.

The Ce isotopic composition is measured for ALH-78132,71c and Pasamonte eucrites and Jilin chondrite. (Experimental procedures have been shown in a paper by Tanaka and Masuda.<sup>2)</sup>) The results of Ce isotopic composition are as follows:

ALH-78132,71c;  $^{138}\text{Ce}/^{142}\text{Ce} = 0.022849 \pm 3$

Pasamonte ;  $^{138}\text{Ce}/^{142}\text{Ce} = 0.022852 \pm 2$

Jilin ;  $^{138}\text{Ce}/^{142}\text{Ce} = 0.022853 \pm 6$ .

ALH-78132,71c has a somewhat smaller  $^{138}\text{Ce}/^{142}\text{Ce}$  value compared with that for Pasamonte and Jilin meteorite. Assuming the present observed value for La/Ce abundance ratio and  $T=4.56$  G.y., a value of 0.022844 for  $^{138}\text{Ce}/^{142}\text{Ce}$  is calculated for this ALH-78132,71c. Although these data of Ce isotopic abundance are preliminary, it is probable that La/Ce variation presently observed was not produced at 4.56 G.y. ago.

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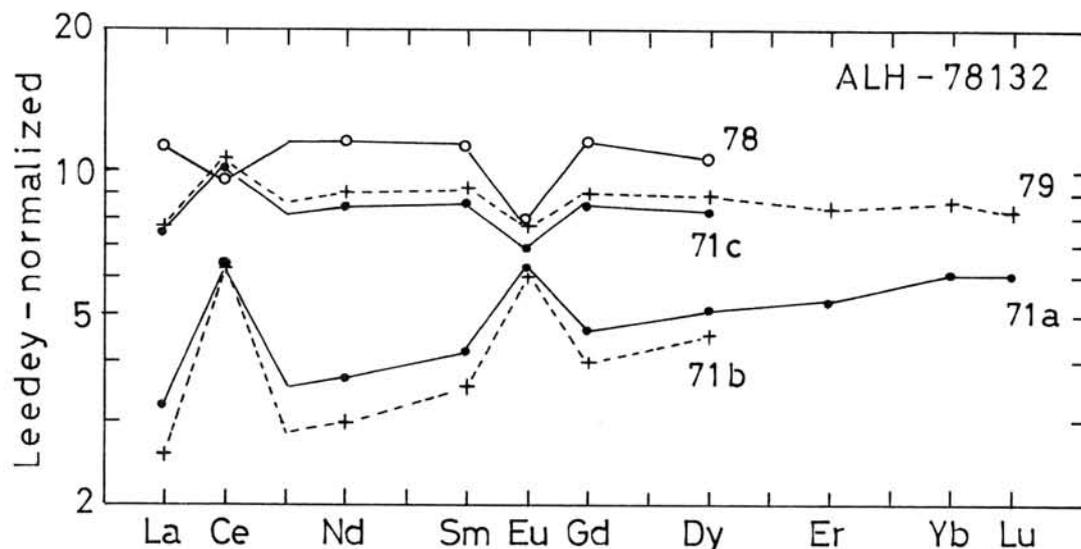


Fig. 1 Chondrite (Leedey)-normalized REE patterns for some chips of ALH-78132 eucrite.

## Strontium, cerium and neodymium isotopes of ALH 765 meteorite

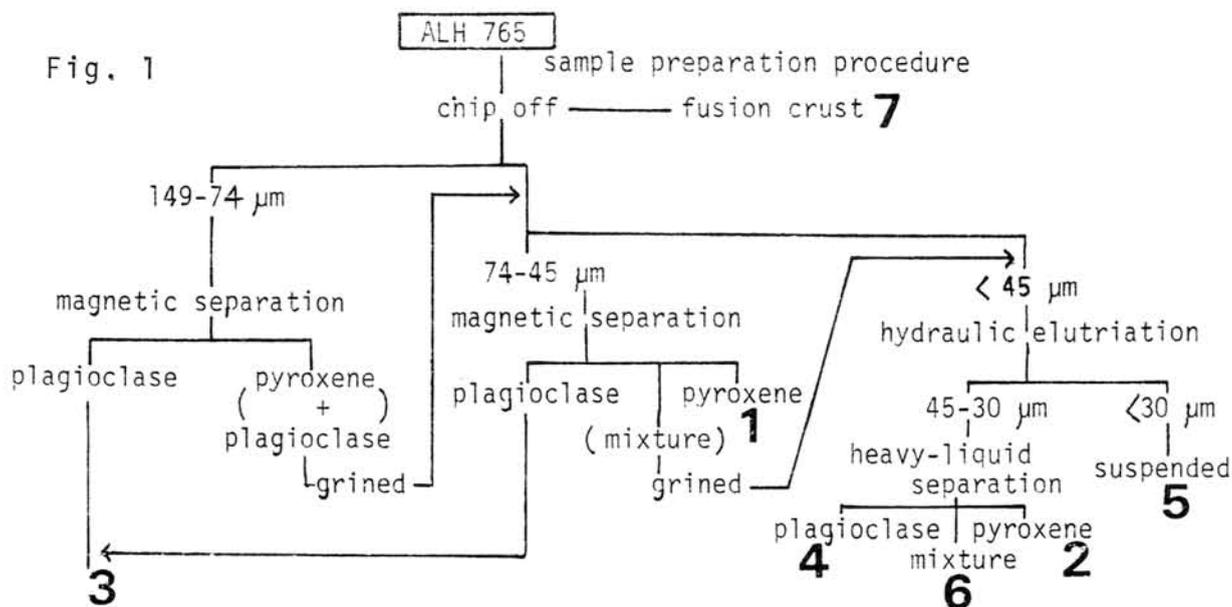
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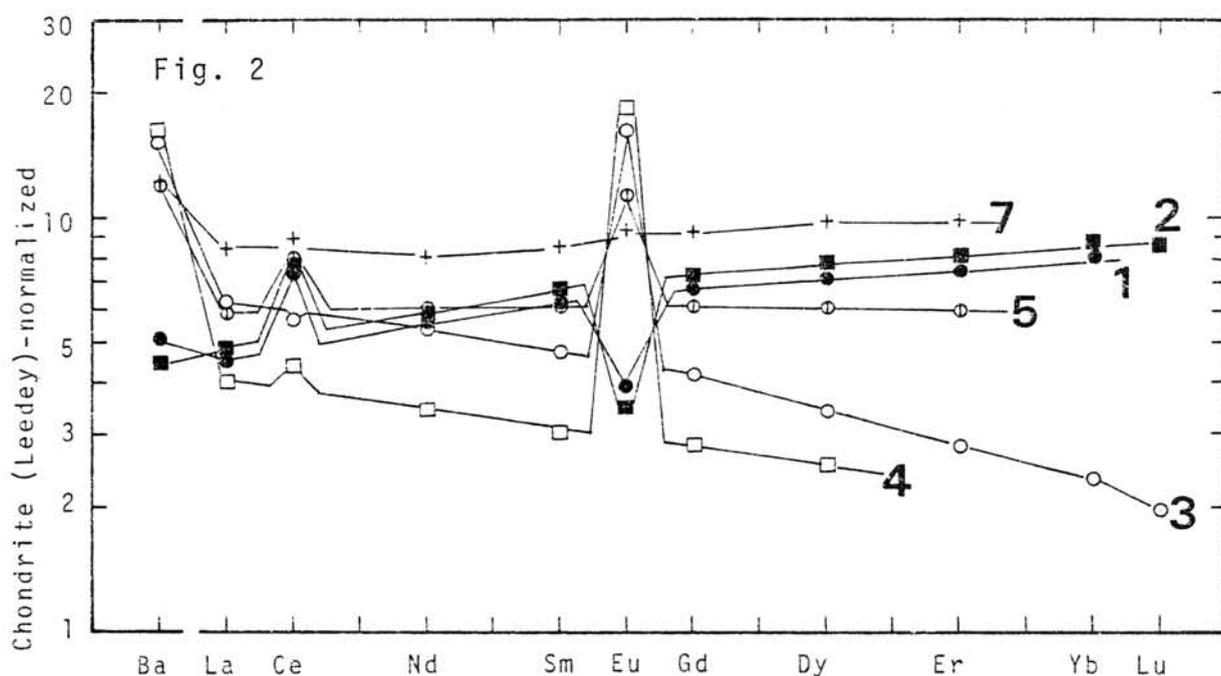
ALH 765 is one of the biggest eucrites found in Antarctica. Many petrographical and chemical examinations have been done for the meteorite. One of the remarkable features is its positive Ce anomaly. Mineral separates of the meteorite also show various (positive and negative) Ce anomalies (Nakamura and Masuda, 1980). On the contrary, another rare earth elements analysis of the same meteorite shows no Ce anomaly for both bulk sample and its clast sample (Grossman et al., 1981).

To clarify these different results, ALH 765 eucrite is further examined on its rare earth elements, Rb, Sr, Ba abundances and Sr, Nd and Ce isotopic compositions. A new dating technique " $^{138}\text{La}$ - $^{138}\text{Ce}$  method" was developed recently (Tanaka and Masuda, 1982). Pyroxene and plagioclase are separated from the meteorite for both 149-45  $\mu\text{m}$  and 45-30  $\mu\text{m}$  fractions. Fusion crust and fine fraction (less than 30  $\mu\text{m}$ ) are also examined (Fig.1).

Chondrite-normalized rare-earth patterns are shown in Fig. 2. Numerals in Fig. 2 are the same as those of sample fractions in Fig. 1. Pyroxene fractions (1 and 2) show clear positive Ce anomaly. However, no definitive Ce anomaly is seen on plagioclase fractions (3 and 4).



Sm-Nd mineral isochron age of the meteorite agrees with those of Moore County and Juvinas within the uncertainty.  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopic ratio of plagioclase is quite low ( $^{87}\text{Sr}/^{86}\text{Sr} \approx 0.6996$ ). This isotopic ratio suggests that the meteoritic Sr is not contaminated with terrestrial Sr so much. We could expect lower  $^{138}\text{Ce}/^{142}\text{Ce}$  ratio, from its formation age (4.5Ga) and low La/Ce ratio, than that of Ce-normal eucrite. However,  $^{138}\text{Ce}/^{142}\text{Ce}$  ratio (0.022852) of pyroxene cannot be distinguished from those of Ce-normal eucrites (Shimizu, Tanaka and Masuda, this volume).



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## SIMS MEASUREMENT OF Mg ISOTOPIC RATIOS IN ALH-77307 AND -77278 CHONDRITES

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We have reported that excess  $^{24}\text{Mg}$  have been discovered for the Al-poor and Mg-rich portions of matrix parts of the Yamato-74191 (L3) and Allende (C3) chondrites.<sup>1,2)</sup>

This excess  $^{24}\text{Mg}$  together with the excesses of  $^{26}\text{Mg}$  ( $^{26}\text{Al}$ ) and  $^{16}\text{O}$  in primitive meteorites are thought to be the clear evidence for the injection of the supernova ejecta which had exploded a few million years prior to the solidification of the minerals in the primitive meteorites.

In order to search for the anomalous  $^{24}\text{Mg}$  in some other primitive meteorites which belong to the class of the petrologic type 3, ALH-77307 (C3) and ALH-77278 (LL3) have been analyzed with an ion microprobe mass analyzer.

12 keV oxygen ions were used as primaries. The diameter and the current of the primary ion beam on the sample surface were 100 - 200  $\mu\text{m}$  and 0.8 - 3  $\mu\text{A}$ , respectively. Samples were polished and ultrasonically cleaned in acetone. In order to avoid charge build-up to the insulator samples, electron spray was used. Mass scanings were repeated 10 times in one run and 3 to 5 runs were carried out at each probed portion. The control of the detecting system, the calculation of data and the statistical procedures were done by using a microcomputer system developed by ourselves.

$^{24}\text{Mg}/^{25}\text{Mg}$  and  $^{26}\text{Mg}/^{25}\text{Mg}$  ratios were calculated from the raw secondary ion intensities and the deviations ( $\delta$  values) of these ratios from the ratios for the terrestrial forsterite samples from Ehime Pref., Japan (laboratory standard) were also calculated.

The results obtained are shown in Fig. 1 as three isotope plot. In the figure, a straight line with the slope of -1 corresponds to the normal mass fractionation line through the point

of laboratory standard forsterite. The abscissa represents  $\Delta_{24/25}$ , and the ordinate,  $\Delta_{26/25}$ .

In case of ALH-77278, the data plot near the point for the laboratory standard and no anomaly has been observed. In case of ALH-77307, the plotted points deviate from the origin and these deviations show the contribution of the hydride ions of magnesium which are considered to be originated from water trapped in the specimen.

Any anomaly has not yet been observed in both the specimens.

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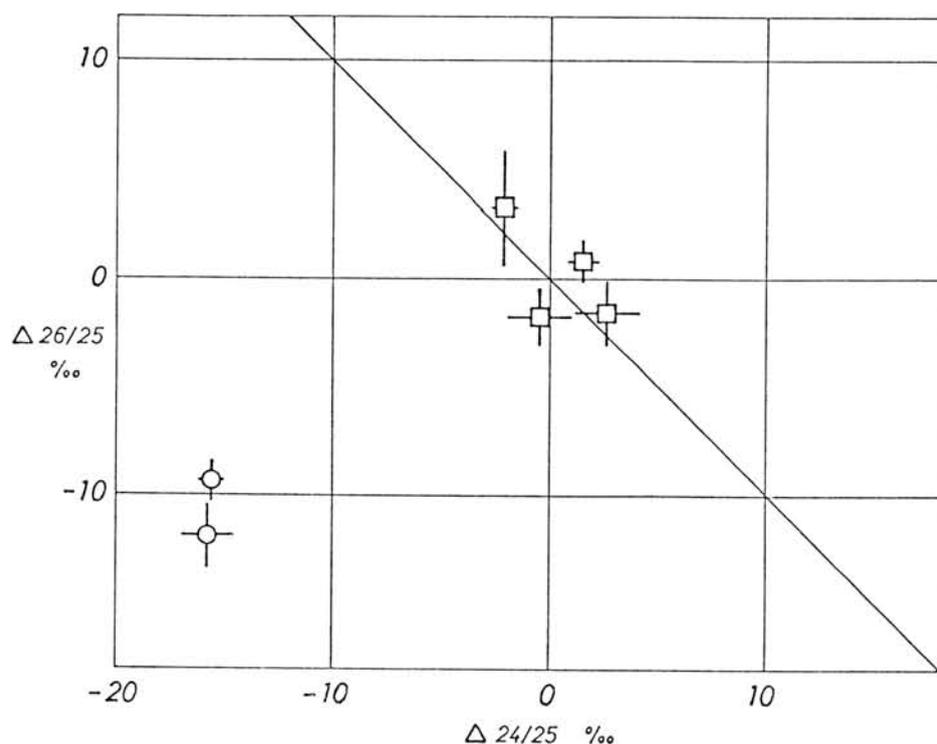


Fig.1 Three isotope plot of magnesium for the specimens of ALH-77307 and ALH-77278. The origin corresponds to the isotopic ratios for the terrestrial forsterite (laboratory standard) from Ehime Pref., Japan.

○:ALH-77307, □:ALH-77278

## Cosmogenic Be-10 in Meteoritic Irons and Stones.

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As part of a program which involves the survey of cosmogenic nuclides in meteorites, especially antarctic meteorites(1), we have started to measure cosmogenic Be-10 (half life: 1.5 million y.) in meteoritic stones and irons.

Recently accelerator mass spectrometry (AMS) has been developed to detect very minor long-lived nuclides. Our group in Tokyo has succeeded in measuring Be-10 at the levels of  $10^{-10}$ — $10^{-11}$  in Be-10/Be-9 using 0.1–1 mg size BeO samples (2, 3). The Tandem Van de Graaff accelerator at Univ. Tokyo has been modified for this purpose. The background is found to be better than  $10^{-13}$  in Be-10/Be-9 and the reproducibility is estimated at ca 5% under the most favorable conditions, which enable us to perform the most reliable determinations of Be-10 in extra-terrestrial materials at the current stage (4, 5, 6).

Some preliminary data tabulated in Table 1, already indicate some important features of the Be-10 contents in meteoritic stones and irons. Some of the older reliable data obtained by beta countings can also be compared with present data.

(1). The Be-10 contents, at the saturation level, seem to be rather constant among stone phases of ordinary size chondrites. The productions of Mn-53, for example, vary between 250–600 dpm/KgFe depending on the preatmospheric size and the depth of specimens in the body. The constancy seems equivalent, or even better than the productions of K-40, Ar isotopes, and Cl-36 (the medium energy products) in metal phases.

(2). Be-10 production in the metal phases is seen to be one of the highest energy products, as are Al-26, Na-22, and Ne isotopes in irons. Our data of Be-10 in Emery mesosiderite, the smallest stony iron, indicate the highest production rate. The comparison can be made with the Udei Station, iron meteorite, which has the highest Mn-53. The Mn-53 / Be-10 ratio is proportional to the shielding effects: the former has 40 whereas the latter has 120. The two data in the table might indicate the two extremes respectively.

As we have learned so far, simultaneous Be-10 determinations in both stone and iron phases, will supply us with crucial parameters to the shielding effects

resulting in the patterns of cosmogenic nuclide productions. In the near future we may extend our work along this line. The samples such as Y74192, 74663, 74165 will be useful specimens to be explored.

(3). The irradiation histories of Y74028 and Y74116 are found to be unique, and these two samples seem to be a pair and experienced a multi-exposure irradiation in space in the past. The low value of Y74065 is understood to be the result of near surface irradiation for the larger body, which is much larger than ordinary size chondrites.

Table 1. Be-10 content in Meteorites.

Name	Class	Be-10 dpm/kg	sample	Be carrier	Be-10/Be-9 $\times 10^{-12}$
in stones.					
Yamato					
74028	L6	8.9 ± 0.7	414mg	543 μ g.	115 ± 9
74065	L6	10 1	216	2400	15 2
74116	L5	6.4 0.6	734	733	100 10
74117	L6	20 2.6	430	513	286 38
74192	H6	20 2.0	770	771	340 30
74663	L6	23 1.5	384	525	282 19
75108	L6	25 3	318	513	260 30
in irons.					
Emery	mesosid.	7.9 0.6	299	504	80 4
Udei	Station iron	5.0 0.4	330	504	56 2

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## Distribution of Rare Earth Elements in Enstatite Chondrite

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Rare Earth Elements(REE) distributions were studied for three enstatite chondrites, Abee(E4), Indarch(E4) and Qingzhen(E3). Fractional dissolution method was used for phase separation. Powdered meteorite samples were soaked successively in acetate buffer solution(pH 5), EDTA-ammonia solution(pH 10) and 6N-HCl. Residual phases were decomposed with HF and HClO<sub>4</sub>. Major and trace elements were measured by a method of neutron activation.

Host Phase of REE in Abee It is well known that REE are highly concentrated in Ca-phosphate in ordinary chondrite(Ebihara and Honda, 1982). Enstatite chondrite, however, comprises phosphide in place of phosphate as a P-bearing mineral. Sears et al.(1982) inferred that REE are located largely in the oldhamite, CaS. CaS is known to be dissolved easily in water. Shima and Honda(1967) found that 89% of total Ca was recovered in acetate buffer solution, whereas only 0.3% of Sm dissolved in this fraction. Most of REE were found to be leached in the next step, EDTA treatment. We repeated several times these two steps with different conditions. Preliminary results are tabulated below. Most of Ca is found to be always recovered in acetate solution. REE, on the other hand, is not so straightforward, that is, they were leached in the first step along with Ca one time and in the following step with EDTA the other time. Thus, REE do not always follow Ca. This suggests that the oldhamite is not the host phase of REE in Abee.

We are discussing the possible host phase for REE based on the data from not only Abee but the other two chondrites, and considering the possibility of chemical fractionation between lanthanoid and actinoid in enstatite chondrite.

exp.#	element	fraction(%)					
		acetate			EDTA		
		1	2	3	1	2	3
1*	La	-	x	x	(71)	x	x
	Sm	0.3	x	x	70	x	x
	Ca	89	x	x	1.4	x	x
2	La	-	5.1	x	63	16	18
	Sm	0.3	0.84	x	69	13	17
	Ca	74	12	x	2.3	2.2	9.7
3	La	-	14	11	33	43	x
	Sm	-	7.2	6.6	45	39	x
	Ca	87	4.0	-	-	8.1	x
4	La	56	23	x	20	1.1	-
	Sm	49	16	x	25	3.8	2.7
5	La	84	6.6	x	4.0	1.4	3.6
	Sm	77	14	x	5.8	1.1	1.5

\*:Shima and Honda(1967)

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## He, Ar ISOTOPES AND K-Ar AGES OF DIAMONDS

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We have examined more than 40 diamond stones for He and Ar isotopic ratios, noble gas abundance and K content. Most of diamonds were from unspecified mines in South Africa, but some were identified to come from Premier and Finsch Mines. We used a single diamond stone of about 1 carat for the analyses.

 $^3\text{He}/^4\text{He}$ 

$^3\text{He}/^4\text{He}$  ratio ranged from less than  $10^{-7}$  to  $3.4 \times 10^{-4}$ . Three stones had the ratio larger than  $10^{-4}$  and two of them exceeded the  $^3\text{He}/^4\text{He}$  ratio of planetary He-A ( $^3\text{He}/^4\text{He} = 1.4 \times 10^{-4}$ ). There was clear positive correlation between  $^3\text{He}/^4\text{He}$  ratio and the amount of  $^3\text{He}$ , that is, higher the isotopic ratio, more abundant the amount of  $^3\text{He}$ . Diamonds with  $^3\text{He}/^4\text{He}$  ratio of more than  $5 \times 10^{-5}$  had  $^3\text{He}$  content of about  $10^{-11}$  ccSTP/g, whereas those with  $^3\text{He}/^4\text{He}$  less than  $5 \times 10^{-6}$  had almost two orders of magnitude smaller  $^3\text{He}$  than the former. Since the extremely high  $^3\text{He}/^4\text{He}$  ratio could be preserved only in an environment where U/ $^3\text{He}$  ratio is extremely low, we suggest that primitive helium was trapped by the diamonds soon after the formation of the earth and the helium isotopic ratio was quenched due to extremely low content of U and Th in the diamonds.

K-Ar ages

K-Ar isochron dating was applied to four cogenetic diamond stones from Premier Mine. However, because of the extremely low K-content (less than 0.7 ppm), we did not observe radiogenic  $^{40}\text{Ar}$ . The measured  $^{40}\text{Ar}/^{36}\text{Ar}$  ratio (about 500) many represent either the initial isotopic ratio of the trapped Ar or the blank Ar, since the hot blank Ar generally exceeded the extracted Ar.  $^3\text{He}/^4\text{He}$  ratio measured for two of the Premier Mine gave  $1.8 \times 10^{-5}$  and  $8.0 \times 10^{-6}$  respectively, which are likely to represent the initial isotopic ratio of the trapped He.

We also applied a conventional K-Ar dating to 8 diamond stones from unspecified mines in South Africa. Some diamond gave an apparent K-Ar age of about 4.5 b.y.

Noble gas elemental abundance

All the diamonds analysed for noble gas abundance showed the similar characteristic abundance pattern to that generally observed in mantle-derived material such as volcanic rocks or xenoliths, that is, the elemental abundance relative to air noble gas abundance showed systematic decrease with smaller mass number.

## MARTIAN ATMOSPHERIC GASES TRAPPED IN THE EETA79001 SHERGOTTITE?

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The EETA79001 meteorite, found in Antarctica in 1979, has been identified as a fourth member of the rare class of achondrites known as Shergottites (1,2). Although EETA79001 is not identical in mineralogy to the other three Shergottites, it has been linked to the Shergottites by its petrologic relationships (1,2) its trace element abundances (3), its oxygen isotopic composition (4), the presence of shock effects which have been radiometrically dated at 180 MY (5), and isotopic indications of a young igneous age of  $\sim 1.3$  Gy (5,6). EETA79001 has two distinct igneous lithologies and contains abundant inclusions and veins of shock-melted glass presumably formed during the dated shock event. Several investigators have concluded that the Shergottite--and Nakhilite--achondrites must have formed on a geologically complex and relatively large parent body, which through a process of elimination, was deduced to be the planet Mars (see 7 for a summary).

To determine the nature of trapped noble gases detected in EETA79001 during radiometric dating, we measured the isotopic composition of He, Ne, Ar, Kr, and Xe from stepwise temperature extractions of whole rock (WR) samples of both igneous lithologies (A and B), of two glass inclusions, of a feldspar separate from lith-B, of a pyroxene separate of lith-A (only Ar measured), and of ALHA77005 WR. Shock altered phases of EETA79001, i.e., glass and feldspar, contained significant quantities of trapped Ar, Kr, and Xe, whereas the other phases and ALHA77005 contain much lower amounts, if any, of trapped gas. This trapped gas was released at higher extraction temperatures ( $\sim 1100$ - $1300^\circ\text{C}$ ) and showed elemental ratios similar to those measured for the Martian atmosphere by Viking (8), but distinct from trapped gas in chondrites, from solar wind-implanted gases, and from the typical pattern of adsorbed terrestrial atmospheric gases.

Those samples with trapped gases also contained amounts of  $^{40}\text{Ar}$  far in excess of that which could have formed in situ since the 180 MY shock age or the  $\sim 1.3$  Gy formation age. One glass sample, for example, contained  $\sim 40$  times the amount of  $^{40}\text{Ar}$  which would be expected from in situ decay of K in 1.3 Gy and  $\sim 55$  times the amount of spallation  $^{36}\text{Ar}$  which would be expected from cosmic ray interactions. The sum of the Ar isotopic data suggest the presence of two trapped Ar components, one with a  $^{40}\text{Ar}/^{36}\text{Ar} > 2000$  and a second with a much lower  $^{40}\text{Ar}/^{36}\text{Ar}$ . In contrast to  $^{40}\text{Ar}$ ,  $^4\text{He}$  concentrations are low and are all consistent with  $^4\text{He}/\text{U-Th}$  ages of less than 180 MY. The  $^4\text{He}/^{40}\text{Ar}$  ratio in EETA79001 has been fractionated by a factor of  $\sim 30$  compared to the expected production ratio, probably before introduction of trapped gas into the meteorite.

Xenon in EETA79001 is characterized by large excesses of isotope  $^{129}\text{Xe}$  ( $^{129}\text{Xe}/^{132}\text{Xe} > 2$ ) in those samples which contain trapped gases, but the general absence of excess  $^{129}\text{Xe}$  in those samples which do not contain trapped gases. The measured  $^{129}\text{Xe}/^{132}\text{Xe}$ , as well as measured  $^{40}\text{Ar}/^{36}\text{Ar}$ , tend to be largest in those high-temperature extractions which released the largest amount of trapped gas. These observations, along with the young igneous age of the Shergottites, make it unlikely that the excess  $^{129}\text{Xe}$  comes from in situ decay of  $^{129}\text{I}$ , but rather indicate that the excess  $^{129}\text{Xe}$  is part of the trapped component.

All analyzed samples of EETA79001 showed significant excesses in  $^{128}\text{Xe}$ ,  $^{80}\text{Kr}$  and  $^{82}\text{Kr}$  which are almost certainly the result of neutron capture by

stable isotopes of iodine and bromine. This neutron-capture component was released at lower extraction temperatures than the trapped gases and may be of an entirely different origin. An origin by cosmic ray spallation is ruled out because of the low relative abundances of  $^{78}\text{Kr}$ ,  $^{124}\text{Xe}$ , and  $^{126}\text{Xe}$ . Abundances of cosmic ray spallation He, Ne, and Ar are also quite low in EETA79001 and suggest an exposure age of  $<1$  MY, or about a factor of three lower than the other three Shergottites (assuming comparable shielding for all Shergottites).

We have considered several possible origins for the noble gases contained in EETA79001 (Table 1). These are 1) gas from the Martian atmosphere trapped in EETA79001 by the shock event, 2) trapped gas in chondritic material somehow transferred to EETA79001, 3) adsorbed gas from the Earth's atmosphere, and 4) indigenous gas which might be contained in a differentiated asteroidal parent body. Trapped gas in EETA79001 appears more consistent with an origin from the Martian atmosphere than with other possible sources. This conclusion is largely independent of those petrological, chemical, and chronological data which have previously been used to infer a Martian origin for S-N-C meteorites.

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Table 1

CHARACTERISTIC OF EETA79001 NOBLE GASES	CONSISTENT WITH ORIGIN FROM:			
	MARS ATM.	CHONDRITIC CONTAMINANT	EARTH ATM. (ADSORBED)	ACHONDRITIC PARENT
1) Relative Ne, Ar, Kr, Xe Abundances	yes	no	unlikely	unlikely
2) Trapped Ar component with $^{40}\text{Ar}/^{39}\text{Ar} > 2000$	yes	maybe	no	unlikely
3) Low $^4\text{He}/^{40}\text{Ar}$	maybe	unlikely	yes	unlikely
4) Trapped Xe component with $^{129}\text{Xe}/^{132}\text{Xe} \geq 2$ ; Absence of excess $^{129}\text{Xe}$ in lithology A W.R.	yes	unlikely	no	no
5) Neutron-capture component	maybe	maybe	no	unlikely

## Noble Gases in ALH-77257 Ureilite

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ALH-77257,64 ureilite (bulk) was analysed for noble gas concentrations and isotopic compositions. Part of result is listed in Table 1. Neon is a mixture of trapped and cosmogenic gases. About 70% of  $^{20}\text{Ne}$  determined is the trapped gas. Although we found no evidence of trapped He, it may reside since planetary-type He and Ne always occur together in nearly constant proportion. The isotopic ratios of Ne fit a correlation line given from other ureilites (non-antarctic)[1], which passes through Ne-C[2].

Large amounts of heavy noble gases are concentrated. As shown in Figure 1, noble gas concentrations in the bulk of ALH-77257,64 ureilite is practically same as those in Dyalpur, which has the highest noble gas concentrations of ureilites[3]. A clear difference is found in the  $^{84}\text{Kr}/^{132}\text{Xe}$  ratio between both ureilites, however. The  $^{84}\text{Kr}/^{132}\text{Xe}$  ratio for ALH-77257,64 is 0.577 and rather similar to that for Novo Urei[3,4], while the ratio for Dyalpur is more than one. This may reflect selective enrichment of Xe due to difference in trapping condition or fractional loss of other noble gases.

The  $^{40}\text{Ar}/^{36}\text{Ar}$  ratio is 0.227. The low  $^{40}\text{Ar}/^{36}\text{Ar}$  ratio and the high  $^{36}\text{Ar}$  concentration make this meteorite suitable for a study of primordial  $^{40}\text{Ar}/^{36}\text{Ar}$  ratio. Separation and noble gas analysis of carbonaceous veins are in progress.

The Kr isotopic ratios  $^{80}\text{Kr}:^{82}\text{Kr}:^{83}\text{Kr}:^{84}\text{Kr}:^{86}\text{Kr} = 3.985\pm 0.038 : 20.30\pm 0.10 : 20.20\pm 0.08 : 100 : 30.98\pm 0.15$  agree with those for Kenna bulk. The Xe isotopic ratios  $^{124}\text{Xe}:^{126}\text{Xe}:^{128}\text{Xe}:^{129}\text{Xe}:^{130}\text{Xe}:^{131}\text{Xe}:^{132}\text{Xe}:^{134}\text{Xe}:^{136}\text{Xe} = 0.471\pm 0.010 : 0.414 \pm 0.007 : 8.26\pm 0.09 : 103.8\pm 0.8 : 16.39\pm 0.11 : 81.77\pm 0.29 : 100 : 37.88\pm 0.20 : 31.49\pm 0.30$  also agree with those of Kenna-type Xe[5], and distinct from the isotopic composition from AVCC-Xe.

Cosmic-ray exposure and K-Ar ages are calculated tentatively to be  $T_{21} = 6.7$  Ma and  $T_{40} = 3.8$  Ga (under an assumption of 60 ppmK[6]), respectively. The  $(^3\text{He}/^{21}\text{Ne})_c$  ratio is 3.26, unusually low relative to other ureilites. This means preferential loss of  $^3\text{He}$  and/or  $^3\text{H}$ , or heavy shielding for cosmic-ray

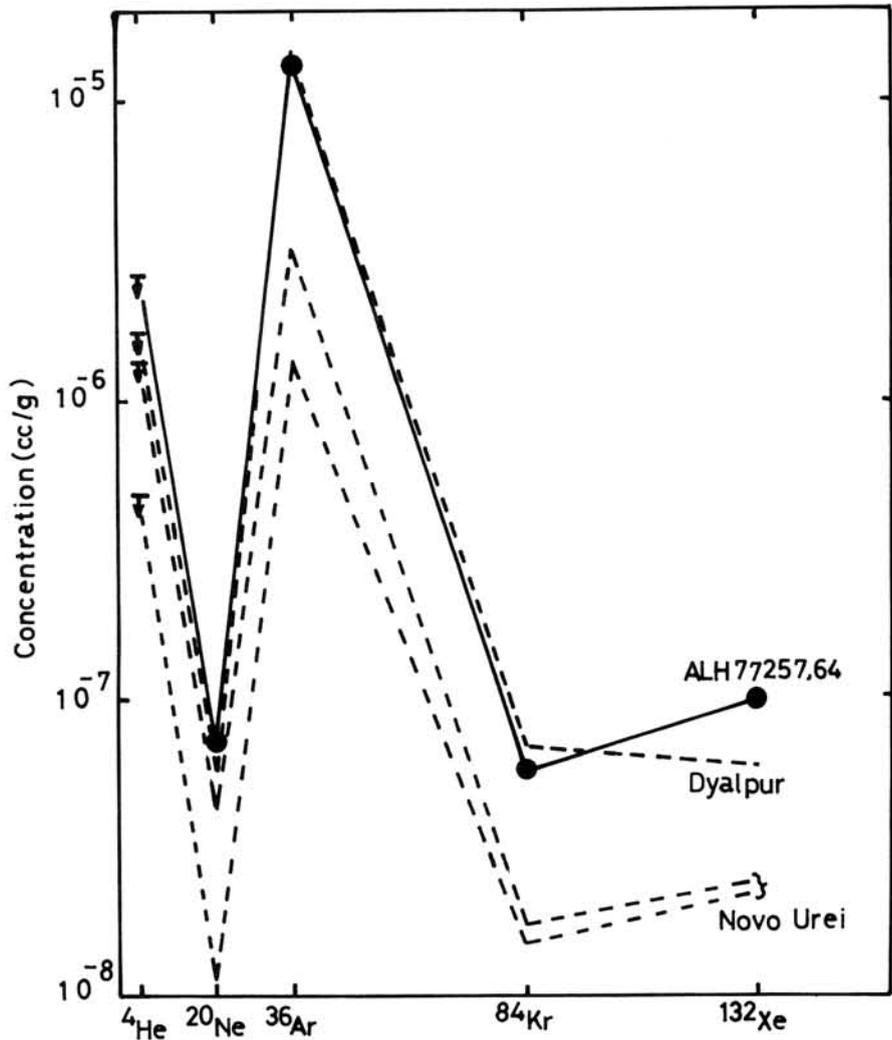
irradiation in a large meteoroid. A selective loss of  $^3\text{H}$  from kamacite fine grains is suggested.

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Table 1. Noble gas concentrations and isotopic ratios of He, Ne and Ar ( $10^{-8} \text{ cm}^3 \text{ STP/g}$ )

$^3\text{He}$	$^4\text{He}$	$^3\text{He}/^4\text{He}$	$^{20}\text{Ne}$	$^{21}\text{Ne}$	$^{22}\text{Ne}$	$^{36}\text{Ar}$	$^{38}\text{Ar}$	$^{40}\text{Ar}$	$^{40}\text{Ar}/^{36}\text{Ar}$	$^{84}\text{Kr}$	$^{132}\text{Xe}$
11.8	312	0.0378	10.6	3.68	4.92	1320	246	300	0.227	5.66	9.81
		+0.0008							+0.005		

Fig.1.  
Concentration  
of trapped gases.



## RARE GAS STUDIES OF THE ANTARCTIC METEORITES

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The concentrations of rare gases and isotopic compositions of He, Ne and Ar were determined in the antarctic meteorites by rare gas mass spectrometry. The results are shown in Table 1. Seven Yamato meteorites and Bruderheim (Berkeley standard sample) listed in lower columns of Table 1 were analyzed by a mass spectrometer constructed recently in Okayama University of Science. The rare gas data for Bruderheim were in agreement with those reported by other authors. Xe isotopic compositions for these meteorites and Kr isotopic composition for Y75015 (Eucrite) were also measured by the mass spectrometer.

Cosmic-ray exposure ages  $T_{21}$  for the ordinary chondrites were calculated by the concentrations of cosmogenic  $^{21}\text{Ne}$  and the production rate, for which correction of shielding effect was applied by the same procedure previously described<sup>1)</sup>. Y74011 diogenite and Y75015 eucrite showed long exposure ages of 45 and 42my, respectively. The age for diogenite is longer than those for Y74013 and Y74097 (32 and 35my)<sup>2)</sup>. Y75031 iron meteorite has long exposure age.

K-Ar ages,  $T_{40}$ , for chondrites were calculated by the  $^{40}\text{Ar}$  concentrations and the mean concentrations of K=850ppm.

ALH77257 ureilite has very low  $^{40}\text{Ar}/^{36}\text{Ar}$  ratio and high concentration of Ar, which indicates the primitive Ar. Xe isotopic ratios for Y74115, Y74073, Y74192, Y74015, Y75289 and Y75258 were understood in terms of mixture between AVCC-Xe, cosmogenic Xe and excess  $^{129}\text{Xe}$ . Kr and Xe for Y75015 eucrite were mostly cosmogenic. High  $^4\text{He}$  concentration for this eucrite indicate high U concentration of more than 60ppb on the assumption that the age of  $< 4.5\text{by}$  and  $\text{U}/\text{Th}=3.6$ .

ALH77214(L3) chondrite belongs to the group consisted of ALH-77015, -77167 and -77260 L3 chondrites<sup>1)</sup>. Y74165(L4) chondrite has practically equal rare gas composition found in the group of Y-75097, -75102, -75108, -75271 L-chondrites<sup>1)</sup>. Rare gas compositions, exposure and K-Ar ages are in good agreement with those for the each group.

The concentrations of trapped Ar and Xe are correlated with the petrologic type of chondrite. The trapped  $^{36}\text{Ar}$  and  $^{132}\text{Xe}$  concentrations for the chondrites studied suggest the petrologic type for the chondrites as follows;

Type 6: Y74107(H6,5), Y74234(H), Y74165(L4), Y74455(L6,5),  
Y74650(L6), Y74663(L6), Y74115(H6), Y74073(H4),  
Y74015(L5), Y75258(LL6)

Type 5: Y74364(H), Y74192(H6), Y75289(L5).

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Table 1.  
Rare gas compositions, cosmic-ray exposure ages and gas retention ages.

Meteorite	$^4\text{He}^*$	$\frac{^3\text{He}}{^4\text{He}}^\#$	$^{21}\text{Ne}^*$	$\frac{^{22}\text{Ne}}{^{21}\text{Ne}}^\#$	$\frac{^{20}\text{Ne}}{^{22}\text{Ne}}^\#$	$^{36}\text{Ar}^*$	$\frac{^{38}\text{Ar}}{^{36}\text{Ar}}^\#$	$\frac{^{40}\text{Ar}}{^{36}\text{Ar}}^\#$	$^{84}\text{Kr}^\$$	$^{132}\text{Xe}^\$$	$T_{21}$ (m.y.)	$T_{40}$ (b.y.)
Y74107 (H6,5)	408	12.1	2.32	1082	838	0.778	507	3043	0.707	1.25	4.6	2.9
Y74234 (H)	14.2	95.0	0.662	1136	880	1.66	239	267.5	3.05	0.712	1.5	1.0
Y74364 (H)	1345	9.35	1.61	1272	821	1.13	402	3924	2.00	2.17	6.2	3.9
Y74165 (L4)	291	125	10.0	1062	863	2.35	480	108.3	0.763	1.08	17	0.64
Y74455 (L6,5)	923	41.0	5.35	1276	817	0.683	1076	5915	0.662	0.573	2.2	3.7
Y74650 (L6)	1333	14.3	3.55	1126	836	0.618	579	6695	0.830	0.892	8.0	3.7
Y74663 (L6)	986	26.3	3.29	1256	819	0.696	665	6330	0.958	1.11	11	3.8
ALH77214(L3)	1005	4.14	0.896	1385	2467	91.8	187	33.5	63.2	46.7	1.9	3.3
Y74011 (Di)	623	143	23.3	1085	843	0.870	1421	53.3	0.276	0.046	45	
ALH77257(Ur)	330	39	3.7	1.33	2250	1200	190	0.28	6.3	8.8		
Y74044 (Pls)	151	305	3.11	1119	846	1.72	1441	13.4	0.212	0.057		
Y75031 (Iron)	2629	310	10.2	1066	883	34.5	1566	1.91	0.531	0.056	430	
Y74115 (H6)	1570	10.2	2.67	1142	818	0.790	675	7140	0.681	1.20	6.9	4.2
Y74073 (H4)	365	24.1	1.31	1205	851	0.679	497	3496	0.584	1.11	4.2	2.9
Y74192 (H6)	3260	24.4	14.1	1086	836	2.02	927	2694	0.781	1.70	29	4.2
Y74015 (L5)	157	94.4	3.90	1095	864	0.510	811	251.4	0.469	0.733	7.7	0.35
Y75289 (L5)	1620	13.1	4.52	1104	850	1.22	567	4460	0.567	1.65	9.3	4.2
Y75258 (LL6)	1730	24.6	6.75	1109	851	1.21	763	4057	0.374	0.776	14	4.3
Y75015 (Eu)	10100	9.98	15.3	1161	816	6.71	1493	376.6	0.602	0.891	42	
Bruderheim	557	96.4	10.5	1088	848	1.49	1052	751.8	0.463	0.947		

\* Concentrations of He, Ne and Ar are given in unit of  $10^{-8}$  cm<sup>3</sup> STP/g.

§ Concentrations of Kr and Xe are given in unit of  $10^{-10}$  cm<sup>3</sup> STP/g.

# Isotopic ratios except  $^{40}\text{Ar}/^{36}\text{Ar}$  are shown in per mill.

## THE SPECTRAL REFLECTANCE OF MINERALS IN ORDINARY CHONDRITES

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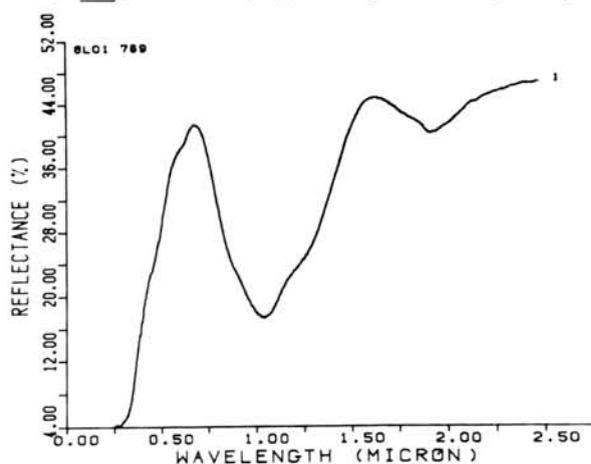
The mineral assemblages of asteroidal surface materials have been studied on the basis of the comparisons between the spectral reflectances of asteroids and those of meteorites[e.g. 1]. It is, however, necessary to deduce the chemical compositions and amounts of the constituent minerals of the surface, from the spectral reflectance data of the asteroid. In order to make basic reflectance data[2,3], we tried to measure the spectral reflectances of the constituent minerals of meteorites.

The spectral reflectance measurements were made with a Beckman UV 5240 spectrophotometer equipped with an integrating sphere. Halon was used as a standard. The details of the instrumentation and measurement are described in [4,5]. The ALH-769(L6 ordinary chondrite, [6]) meteorite was used for the measurements. The sample was crushed in a clean agate mortar and sieved. The sample was separated into main minerals, olivine, pyroxene, and feldspar with an isodynamic magnetic separator(Frantz, L-1). As was shown in [4], the reflectivity of powder sample increases with the diminution of the grain-size when the grain-size is less than  $\sim 200\mu\text{m}$ , and the absorption band strength around  $1\mu\text{m}$  becomes fairly weak when the size is less than  $\sim 46\mu\text{m}$ . Taking into consideration the grain-size of minerals contained in the L6 chondrite, we used the 74-46  $\mu\text{m}$  sample.

Because the shape of the absorption band of  $\sim 1\mu\text{m}$  is almost symmetrical [1], this sample seems to consist almost entirely of olivine grains(Fig. 1). However, the absorption band of  $\sim 1.9\mu\text{m}$  is probably due to a small amount of pyroxene contained in the sample measured. The maximum value of the reflectivity ( $\sim 45\%$ ) is considerably lower than that of olivine ( $\sim 90\%$ ) from San Carlos, Arizona[4]. The UV drop-off is steeper than that of San Carlos. These differences in the spectra between the chondritic olivine and that from San Carlos seem to be mainly dependent on (1) the influence of the weathering of ALH-769, (2) the differences in impurities or inclusions contained in these olivines and (3) incompleteness of the mineral separation. Although our mineral separation technique is with minor defects, our results show that the spectral reflectance of major minerals contained in ordinary chondrite can be measured.

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Fig. 1. Spectral reflectance curve of the olivine(74-46  $\mu\text{m}$  in size) contained in ALH-769(L6).



## PRESENCE OF PERIODICITY IN METEORITE FALLS

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In the Chinese historical records, there is a large set of systematic records on meteorite falls. S. Chang and Z. Yu(1981) made a time series analysis of the annual number of fall records of meteorites in China by calculating autocorrelation, and found two cyclic periods; 240 years and 60 years. In this continuing work, we made a spectral analysis of the same data by maximum entropy method (MEM) to deduce the more accurate periodicity of meteorite falls. The MEM spectral analysis is supposed to be appropriate for analyzing the hidden periodicity in the finite time series superimposed on random noise. The detected periods in the meteorite falls data in China are shown in the table below in comparison with the result of the same analysis on the number of witnessed meteorite falls in the whole world.

Though the reliability of the result remains to be studied further, the series of periods found in meteorite falls, appear to be related closely with the revolutional period of Jupiter (11.862 years). As shown in the last column, each of the observed periods is identified approximately with the integer multiple of the half period of Jupiter's orbital motion. The orbital parameters of asteroids are clustered as a result of gravitational resonance with the Jupiter's revolution. This may suggest a possibility that Jupiter's perturbation is contributing to the periodic components of meteorite falls.

Detected period, year			multiple	
Ancient China (AD.620-1459)	Recent China (AD.1460-1943)	Whole World (AD.1800-1974)	N	11.862N
11.9	-	11.1	1	11.86
17.8	17.9	17.7	1 1/2	17.79
23.8	23	23.8	2	23.72
28, 32.5	30	30	2 1/2	29.65
-	35	-	3	35.58
39.8	-	-	3 1/2	41.51
-	49	-	4	47.44
-	53, 55	-	4 1/2	53.37
-	60	-	5	59.31
66.7	-	67	5 1/2	65.24
-	107	-	( 9	106.75)
111	-	-	( 9 1/2	112.68)
154	-	-	( 13	154.23)
-	255	-	(21 1/2	255.03)

## CHINESE METEORITES AND THE INORGANIC HYPOTHESIS OF OIL GENESIS

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At March 8, 1976 an unprecedented scale of meteorite shower had occurred in the Jilin region, Jilin province of China. The total weight of Jilin meteorite had reached more than 2,000 kg, and the largest one of the pieces of meteorite is 1,770 kg weight. The petrological-chemical classification of Jilin meteorite belongs to H<sub>5</sub> chondrite. According to the result of organic analysis, the Jilin meteorite contains n-Alkanes, aromatic hydrocarbons, isoprenoids, organic pigments, porphyrin compounds, and amino acids. These organic compounds are main compositions of petroleum. So far, people has been studying them as an evolution of the origin of life. About that phase, we would not give any opinion, but we think, the existence of these organic compounds in Jilin meteorite shows the evolution of the origin of life rather than the evolution of oil generation. Discovery of hydrocarbons in meteorite is not first time, so that we can say that is not caused by the pollution on the earth's surface. Why do the oil matters be here? Jilin meteorite composed mainly of olivine and pyroxene which are like the compositions of the upper mantle of the earth. On the basis of above points, we offer an inorganic hypothesis of petroleum generation of the earth. We think that the hydrocarbons could composed of oxide of carbon and hydrogen under catalysis of olivine and pyroxene in the upper mantle of earth. And after that, it migrated towards the earth's crust and in the way it polymerized and formed petroleum. This paper have criticized the organic hypothesis of oil genesis yet.

COMPOSITION OF THE NATURAL REMANENT MAGNETIZATION OF  
Ym 75097 (L4) CHONDRITE

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In general, the natural remanent magnetization (NRM) of the ordinary chondrites are fairly unstable against AF demagnetization compared with the acondrites and the carbonaceous chondrites. The main reason is estimated due to the small coercive force ( $H_c$ ) of representative magnetic grains (Fe-Ni alloy). Usually, the coarse metallic grains have unstable NRM and low  $H_c$  values than small one. In the ordinary chondrites, the occupied mass of coarse grains is extremely larger than that of small grains. From the viewpoints, if the all coarse grains are discarded from the ordinary chondrites, the NRM stability may be improved.

The NRM of Ym 75097 (L4) is fairly unstable against AF demagnetization up to 800 Oe peak. From the magnetic hysteresis analyses, the whole sample of this meteorite has low  $H_c$  and  $H_{RC}$  (remanent coercive force) values as 7.8 and 151 Oe respectively. The metallic grains separated by a magnet have similar  $H_c$  and  $H_{RC}$  values to the whole sample. However the silicate grains have high  $H_c$  and  $H_{RC}$  as 59.8 and 537 Oe respectively. The thermomagnetic curve of the whole sample is very similar to that of metallic grains, but it is different for silicate grains.

According to the microscopic observation, fine metallic grains, less than 10 microns in diameter, are wrapped up in the silicate grains, and large metallic grains, over 30 microns in diameters, are enclosed with the silicate grains. Based on these distribution of metallic grains, the metals in Ym 75097 were dissolved by the hydrochloric acid. It is expected that the fine metallic grains are survived by protection of silicates.

The results of the chemical dissolution of Ym 75097 are shown that the  $H_c$  and  $H_{RC}$  values are increased with the decrease of saturation magnetization ( $I_s$ ) as shown in Fig.1. Since the directional NRM of fine metallic grains are scattered, it seems that this meteorite were not heated up to the curie point.

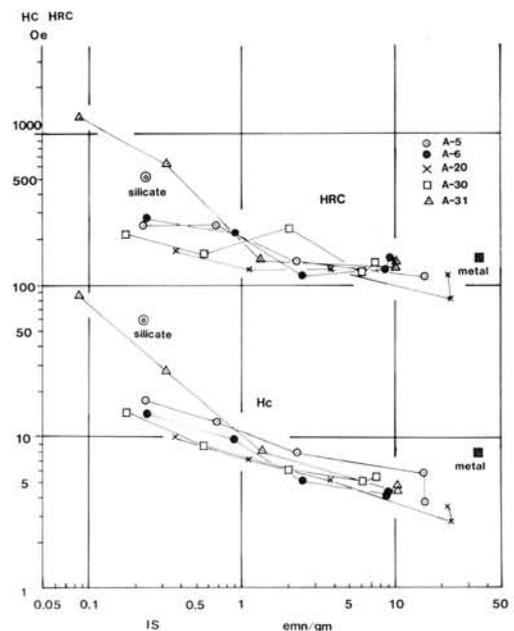


Fig. 1 The variation of  $H_c$  and  $H_{RC}$  against chemical dissolution of metallic grains in Ym 75097.

## PALEOINTENSITY OF METEORITES

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Paleointensity studies of various kinds of meteorites have been carried out by several investigators. It appears that the most plausible paleointensity data of meteorites obtained to date are about 1 Oe for carbonaceous chondrites and about 0.1 Oe or less for the achondrite group (1). The observed complexity of meteorite paleomagnetism is due to the presence of unequilibrated plessite phase in most chondrites and achondrites. In addition, tetrataenites and pyrrhotites play an important role in NRM of some stony meteorites. It seems thus that a special paleomagnetic study scheme will have to be newly established particularly for meteorites.

### 1. Experimental techniques.

In all experiments at elevated temperatures, a meteorite sample is shielded at an end of a long evacuated ( $p \sim 10^{-4}$  Torr) capsule made of silica or hard glass which contains a sufficient amount of metallic Ti powder at the other end. This technique originally proposed by Taylor (1979) has been proved to be much effective in absorbing gases in various meteorite minerals by the Ti powder, so that the magnetic characteristics of a meteorite are not chemically altered by heating to elevated temperatures (2).

### 2. Paleointensity of ALH-77302 eucrite.

By use of the above-mentioned technique, the thermal demagnetization characteristics of NRM and the paleointensity ( $F_p$ ) of ALH-77302 eucrite are determined by Königisberger-Thellier method (K-T method). NRM of ALH-77302 is thermally demagnetized completely by heating to 530°C. As far as NRM of ALH-77302 is attributable to the TRM mechanism,  $F_p \sim 0.2$  Oe, as shown in Fig. 1.

### 3. Paleointensity of Allende (C<sub>3</sub>) chondrite.

In addition to several previous works by Butler (1972), Banerjee et al (1972), Nagata (1979) and Gus'kova (1979), NRM of Allende C<sub>3</sub> chondrite has been examined in some detail by Sugiura et al (1979)(3) and Wasilewski et al (1981)(4). These new results have shown that NRM of the Allende is not simple and not sufficiently interpreted yet, because of a magnetic contribution of iron sulfide grains.

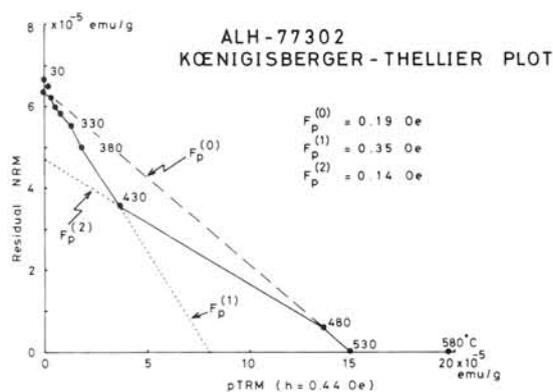


Fig. 1

(i) 15 specimens are cut out at random from a block of the Allende. The NRM intensity ( $I_n(0)$ ) of all these specimens ranges between 2.0 and 2.5 emu/g and their directions are in agreement with one another within  $\pm 9^\circ$  in angle. Hence, NRM of the Allende is satisfactorily uniform.

(ii) NRM of the Allende is satisfactorily stable against the AF-demagnetization, since  $I_n(100)/I_n(0)$  ranges between 0.89 and 1.01, where  $I_n(100)$  denotes the residual NRM intensity after AF-demagnetizing to 100 Oe. peak, as shown in Fig. 2 (top).

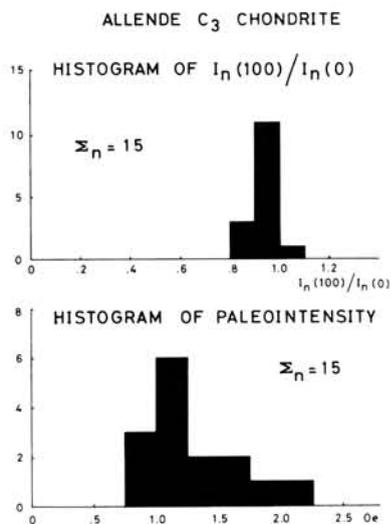


Fig. 2

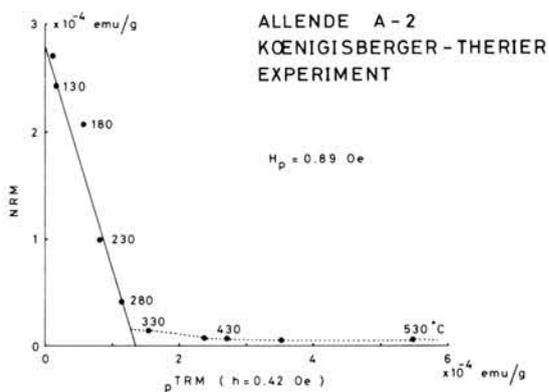


Fig. 3

(iii) NRM of all the Allende specimens is thermally demagnetized almost completely by heating up to 330°C, as shown in Fig. 3 for example. For a specimen shown in a (K-T) diagram in Fig. 3, the paleointensity can be determined as  $F_p \approx 0.9$  Oe.

(iv)  $F_p$ -values of the Allende specimens range from 0.8 Oe to 2.0 Oe, as shown by a histogram of Allende  $F_p$  in Fig. 2 (bottom).

(v) EPMA analyses show that opaque minerals in the Allende are taenite (30% Fe, 68% Ni, 2% Co), pentlandite (63% (Fe, Ni), 37% S) and troilite or pyrrhotite (63% (Fe, Ni), 37% S), and that no magnetite can be detected. The thermomagnetic curve indicates that the major ferromagnetic constituent in the Allende is dominantly 68% Ni taenite (and probably magnetite too).

(vi) As far as NRM of the Allende is attributable to the taenite

magnetization, it is highly probable that the observed NRM was acquired by the taenite phase when it was cooled down from about 300°C in a magnetic field of (1~2) Oe. However, a possibility that the NRM was acquired by the pyrrhotite as TCRM cannot be rejected, since Curie point of pyrrhotite is 320°C.

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PIEZOREMANENT MAGNETIZATION AND SHOCK REMANENT  
MAGNETIZATION OF METEORITES

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Mechanical compressive shocks on natural rocks in the presence of a magnetic field (H) result in an acquisition of the so-called shock remanent magnetization (SRM), which is much larger than the ordinary isothermal remanent magnetization (IRM) acquired in the same magnetic field, particularly when H is very small (1).

(1) SRM of meteorites

Since most meteorites were severely impacted in the extraterrestrial space, they ought to possess SRM if a weak magnetic field were present when they were impacted. The acquisition of SRM by meteorites including Antarctic meteorites is experimentally demonstrated. General characteristics of meteorite SRM (in comparison with those of meteorite IRM) are essentially same as those of SRM of terrestrial igneous rocks.

(2) PRM of meteorites

SRM is equivalent to PRM which can be acquired in the same magnetic field by a static compression, P, which is equal to the maximum pressure of a mechanical impact for SRM. Hence, PRM characteristics of meteorites are quantitatively examined in the present work. Fig.1 shows an example of the standard PRM,  $I_R''(H+P+PoHo)$ , of a H-chondrite, Jilin.

As shown in the example,  $I_R''(H+P+PoHo)$  is generally expressed by  $I_R''(H+P+PoHo) \approx CHP$ , (C is a constant), provided  $H \ll KP$ , where K is theoretically given as  $K=3 \lambda_S / \sqrt{2} J_S$  with  $\lambda_S$ =averaged isotropic magnetostriction coefficient and  $J_S$ =spontaneous magnetization of average ferromagnetic grains in a rock sample (2). Similar PRM characteristics hold also for other stony meteorites.

If the observed natural remanent magnetization (NRM) of these meteorites assumes SRM acquired by a mechanical impact of 10 k bar in the maximum compression in the presence of a magnetic field  $H^*$ ,  $H^*$  values are evaluated as given in the following table.

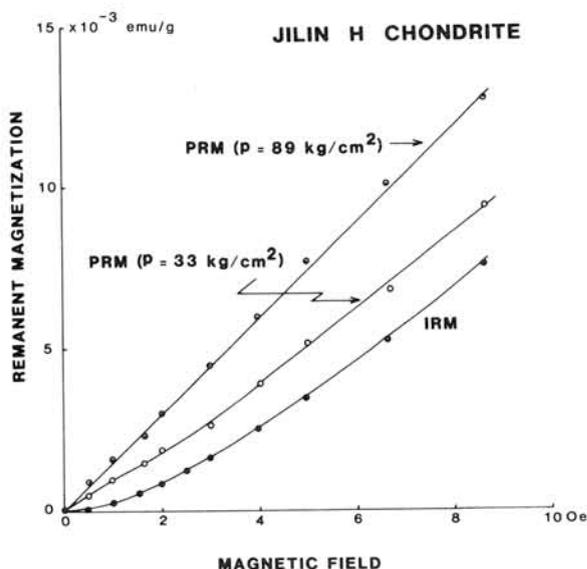


Fig. 1

	Mt. B-b (H <sub>6</sub> )	Jilin (H)	ALH-76009 (L <sub>6</sub> )	YM-74013 (Di)	unit
NRM	1.12x10 <sup>-4</sup>	8.38x10 <sup>-3</sup>	1.06x10 <sup>-4</sup>	3.46x10 <sup>-5</sup>	(emu/g)
C	3.1 x10 <sup>-6</sup>	1.8 x10 <sup>-5</sup>	1.6 x10 <sup>-6</sup>	2.4 x10 <sup>-8</sup>	(emu/g/Oe bar)
H*	0.0036	0.038	0.0066	3.2	(Oe)

It seems highly probable that NRMs of Mt. Baldr-b, Jilin and ALH-76009 were acquired as SRM because the AF-demagnetization curves of their NRM are similar to those of their SRM, in addition to a very small values of their H\*. NRM of YM-74013 diogenite is very stable and its H\* value is unreasonably large, suggesting that it is TRM or TCRM.

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## MAGNETIC REMANENCE PROPERTIES OF ORDINARY CHONDRITES

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A study of the magnetism of meteorites is very important since it can reveal an existence of the magnetic field in the early solar system. Among the meteorites, many of the carbonaceous chondrites possess stable NRM and, hence, have been extensively studied in order to obtain the intensity of the early magnetic field. On the other hand, the NRMs of ordinary chondrites are less stable and are in general not appropriate for the standard approach of the paleo-intensity study (see review by Nagata, 1979). However, since in general all the ordinary chondrites have NRM, the study of the NRM may give a useful information as for the history of these ordinary chondrites. In these studies, the origin of the NRMs should be examined first.

In the present study, the remanence properties of twenty-two ordinary chondrites including eleven Antarctic chondrites have been examined. AF demagnetization of the NRMs was made progressively with fine steps of 0.5mT up to 10mT, 1.0mT up to 20mT, and 2.0mT for the larger field. The intensity of NRM ranges from 1 A/m to 100 A/m, and the MDF ranges from 0.4 mT to 10 mT. No systematic difference in intensity and stability was observed between H- and L-group chondrites. It is worth noting that the magnetic susceptibility of the H-group chondrites is larger by about a factor of three than that of the L-group chondrites reflecting their metal contents. The results of the AF demagnetization indicate that most of the present samples consist of at least two components of remanences with different stability. This fact implies that two or more mechanisms are responsible for the acquisition of the NRMs of the present samples. IRM acquisition, viscous decay of IRM and ARM properties were observed in order to investigate the origin of these components of the magnetization. The magnetic stability of the soft components resembles with that of IRM. But the required magnetic field is much larger than the present geomagnetic field. In most of the samples, VRM acquired on the earth's surface is not sufficient to explain the total remanence. The stability of the hard components is similar to the stability of ARM. These components may be attributed to an extra-terrestrial origin.

## Reference

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