CHEMICAL COMPOSITIONS OF CHONDRULES AND MATRICES IN THE ALH-77015 CHONDRITE (L3)

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***Abstract*:** The chondrules and matrices in ALH-77015 chondrite (L3) were analyzed with an electron probe microanalyzer. The matrices are relatively homogeneous, whereas the chondrules show a wide compositional variation. There is a clear compositional gap between the matrices and the chondrules and between olivines in the chondrules and those in the matrix. Fragmentation of chondrules cannot explain the chemistry of the matrices.

A clear correlation between Ca and Al has been noted in the chondrules. The correlation can be interpreted by assuming that the chondrules were formed from the solar nebula through the crystallization of anorthite and Ca-rich pyroxene.

1. Introduction

It is perhaps no exaggeration to say that the most important data required in understanding the origins of not only droplet chondrules but also chondrites are the precise and reliable data of the chemical compositions of chondrules and matrices in unequilibrated chondrites. However, neither enough nor reliable data have been reported so far on the chemical compositions of chondrules and matrices. It is the purpose of this paper to present such data obtained on the droplet chondrules and fine-grained matrices in the ALH-77015 chondrite (L3). Based on these data, we propose some restrictions to the process of formation of the droplet chondrules.

2. Sample

The ALH-77015 chondrite belongs to L3 group according to Antarctic Meteorite Newsletter, Vol. 2 (1979). The chondrite is composed of abundant droplet chondrules, mineral fragments and a minor amount of fine-grained matrix material. Lithic fragments and opaque chondrules are not observed in the thin section we studied.

Some chondrules contain Ca-rich pyroxene which occur surrounding porphyritic olivines and Ca-poor pyroxene crystals. Clear glasses are frequently observed in many chondrules. In this chondrite, a unique chondrule which consists of albite, silica mineral, ferropseudobrookite and glass has been found, about which a report is made in this issue, FUJIMAKI *et al.* (1981).

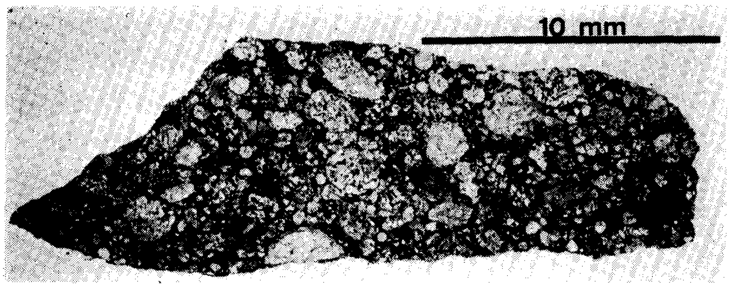

Fig. 1a. *Whole specimen taken at low magnification.*

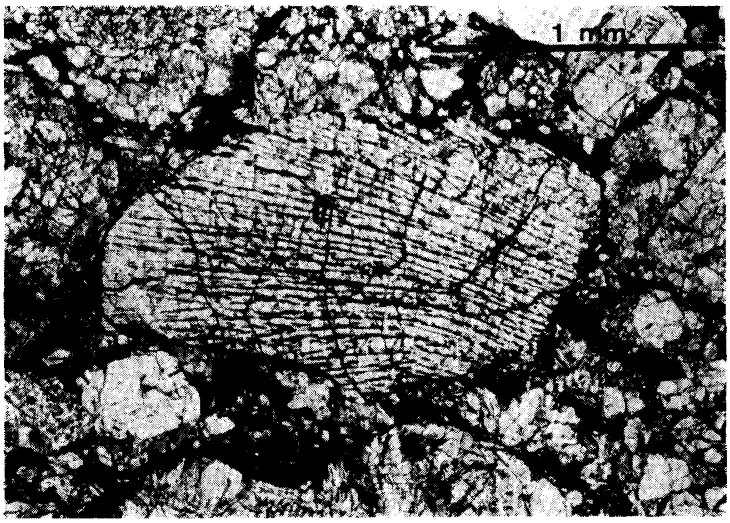

Fig. 1b. *Radial pyroxene chondrule (No. 2) with low Ca-pyroxene and pigeonites.*

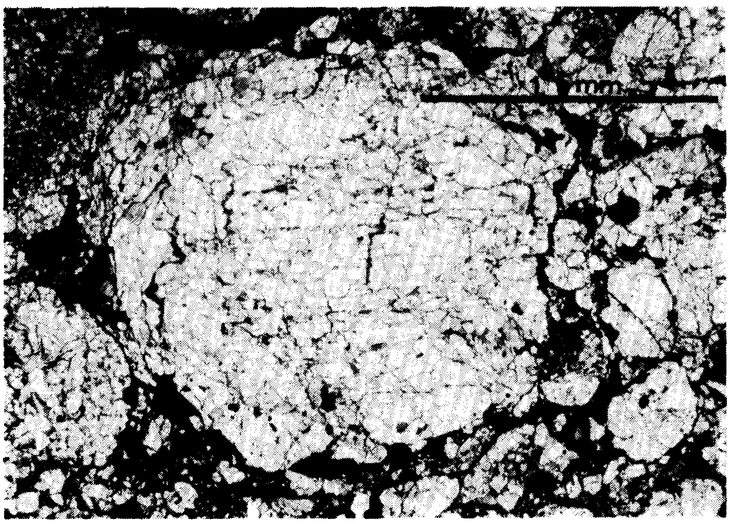

Fig. 1c. *Barred olivine chondrule (No. 4).*

Fig. 1. *Photomicrograph of the thin section of ALH-77015 (L3) chondrite.*

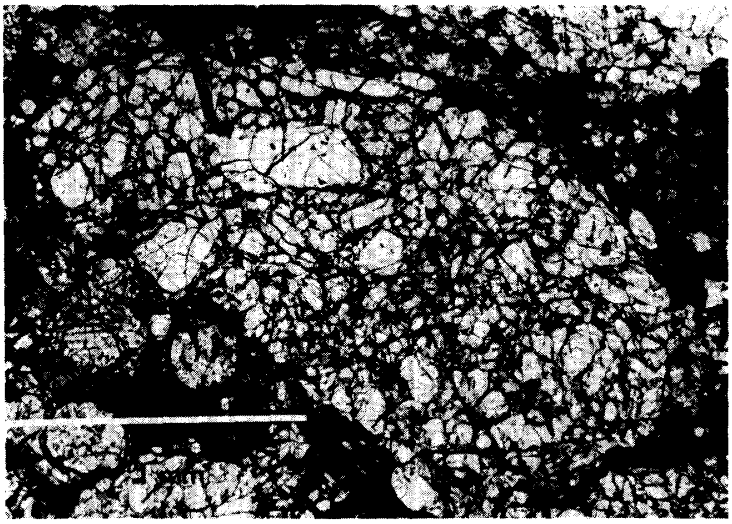

Fig. 1d. *Porphyritic chondrule (No. 31).*

Fig. 1e. *Radial pyroxene chondrule (No. 52).*

Fig. 1f. *Fine-grained matrix.*

The representative microphotographs are shown in Figs. 1a–1f.

3. Analytical Procedure

Chemical analyses were carried out with a HITACHI X-560S electron probe microanalyzer using an energy-dispersive analytical system. The accelerating voltage is 20 kV and the beam current is 0.15 nA in a farady cup. Details of the analytical technique using this type of microanalyzer and the accuracy of the results will be reported shortly, FUJIMAKI and AOKI (1981), but it can be said that a remarkably high accuracy and a high speed can be achieved with this technique.

Bulk chemical compositions of the chondrules and matrices were determined by the defocussed beam technique, approximately 30 μm in diameter. Our microanalyzer can determine simultaneously all major and minor elements involved in the analyzed area or point. In the case of chondrule the defocussed beam was traversed once slowly by hand which takes more than 500 seconds, whereas in the case of matrix the defocussed beam was kept still.

The apparent weight percentage of oxides was obtained through the conventional ZAF correction. Then the broad beam correction was applied by multiplying a factor to the apparent weight percentages according to IKEDA (1980). The broad beam correction factors used in this study are according to those proposed by IKEDA (1980).

4. Results and Discussion

The representative analytical results of the chondrules are presented in Table 1, those of matrices in Table 2 and those of the olivines and low Ca-pyroxenes in Table 3.

Table 1. Representative bulk composition of chondrules.

No.	1	2	3	4	5	6	7	9	10
SiO_2	51.98	50.86	43.37	39.29	49.77	46.26	49.03	56.49	53.77
MgO	19.84	21.26	30.19	34.74	26.53	35.35	32.32	25.97	28.61
FeO	19.18	20.10	20.44	18.97	15.85	10.48	6.98	11.57	12.44
Al_2O_3	1.04	1.48	1.93	2.77	1.67	2.86	4.40	1.51	1.03
CaO	1.07	1.44	2.06	1.44	1.37	2.20	2.59	1.66	0.74
Na_2O	0.45	0.94	0.44	0.40	1.04	0.76	1.75	0.92	0.65
K_2O	0.14	0.05	0.01	—	0.02	0.02	0.10	—	0.05
Cr_2O_3	0.69	0.62	0.46	—	0.76	0.35	0.70	0.48	0.77
MnO	0.69	0.48	0.34	0.19	0.49	0.26	0.10	0.21	0.35
TiO_2	*—	—	—	—	—	0.09	0.12	—	—
NiO	0.35	0.48	0.21	—	0.14	0.61	0.76	0.56	0.32
FeS	1.10	0.63	—	0.16	2.03	0.16	0.14	—	0.44
Total	97.33	98.43	99.45	97.96	99.67	99.40	98.95	99.35	99.17

* not detected.

Table 1. (*Continued*).

No.	11	13	14	15	16	21	22	23	24
SiO_2	50.92	50.93	49.89	48.53	49.49	47.04	49.88	45.11	49.42
MgO	23.52	24.36	33.36	26.51	34.55	30.58	32.93	27.94	35.63
FeO	11.93	17.78	10.35	19.30	9.07	18.08	8.50	17.36	7.38
Al_2O_3	3.51	2.10	2.05	1.25	2.09	1.77	2.75	2.48	2.24
CaO	2.81	1.67	1.39	0.86	1.22	1.47	1.94	1.76	1.33
Na_2O	1.57	0.35	1.04	0.57	0.89	1.00	1.04	1.02	0.73
K_2O	0.08	—	0.04	0.10	0.02	0.02	0.04	0.03	0.04
Cr_2O_3	0.50	0.66	0.56	0.66	0.90	0.67	0.83	0.69	0.71
MnO	0.38	0.16	0.21	0.46	0.05	0.33	0.32	0.36	0.24
TiO_2	0.08	—	0.04	—	0.07	0.06	0.06	0.09	0.09
NiO	0.16	0.62	1.56	0.88	0.83	0.31	0.15	0.61	0.68
FeS	1.59	0.25	0.36	0.16	0.19	0.30	1.50	0.71	0.82
Total	97.04	98.88	100.44	99.28	99.36	101.95	99.93	98.14	99.32

No.	26	32	34	36	37	38	39	42	43
SiO_2	49.21	47.27	47.59	47.41	45.62	52.68	53.87	44.29	53.75
MgO	31.17	25.81	38.42	36.58	36.52	33.87	32.21	30.14	25.21
FeO	10.15	18.61	8.82	6.98	11.58	5.48	5.95	15.46	9.74
Al_2O_3	2.65	2.58	1.51	2.85	1.44	2.09	2.12	1.97	2.86
CaO	2.18	1.78	0.91	2.00	1.04	1.30	1.68	1.72	2.14
Na_2O	0.70	1.08	0.92	1.18	0.93	1.08	0.74	1.04	1.17
K_2O	0.02	0.07	0.02	0.10	0.02	0.03	0.02	0.03	0.06
Cr_2O_3	0.95	0.70	0.66	0.63	0.64	0.73	0.53	0.67	0.62
MnO	0.29	0.38	0.28	0.20	0.24	0.22	0.17	0.05	0.34
TiO_2	0.09	0.06	0.02	0.06	0.02	0.06	0.07	0.05	0.09
NiO	0.41	0.41	0.22	0.41	0.57	0.41	0.48	0.46	0.54
FeS	0.41	0.41	0.44	0.41	0.41	1.07	0.52	1.83	1.70
Total	98.24	98.63	99.81	98.80	98.84	98.93	98.38	99.00	98.23

No.	44	46	50	51	52	54	55	57	58
SiO_2	57.34	54.82	45.51	42.62	56.44	43.20	52.45	46.20	52.45
MgO	13.81	28.91	21.40	27.71	26.83	26.63	26.78	30.19	28.68
FeO	20.35	7.67	24.59	23.13	9.08	22.37	17.16	14.49	21.09
Al_2O_3	2.16	2.26	2.20	2.24	2.41	1.75	1.76	2.49	2.37
CaO	1.35	1.97	2.08	1.61	1.94	1.72	1.28	2.08	2.05
Na_2O	1.14	1.13	1.71	1.13	1.20	1.02	0.53	1.23	1.34
K_2O	0.08	0.10	—	0.04	0.02	0.09	—	0.20	0.09
Cr_2O_3	0.49	0.66	0.70	0.67	0.83	0.59	0.63	0.71	0.73
MnO	0.50	0.48	0.41	0.36	0.47	0.37	0.10	0.34	0.46
TiO_2	0.06	0.07	0.05	0.04	0.06	0.02	—	0.06	0.04
NiO	0.40	0.38	0.18	0.58	0.21	0.60	0.68	1.04	0.32
FeS	0.71	0.38	0.69	0.55	0.27	0.49	0.36	1.64	0.82
Total	98.39	98.82	100.53	100.68	99.76	98.83	101.72	100.66	101.13

Table 2. Representative bulk composition of matrices.

No.	1	3	23	25	26	33	34	35	47
SiO_2	33.20	30.60	34.31	35.76	34.61	37.52	38.02	37.63	33.78
MgO	20.84	20.71	20.51	20.95	25.88	21.91	20.97	20.32	25.26
FeO	35.31	37.74	37.35	37.92	33.89	35.95	36.86	34.40	31.73
Al_2O_3	2.37	1.84	1.85	2.02	1.53	2.32	2.01	3.79	1.77
CaO	1.87	1.84	0.17	0.14	0.20	0.19	0.30	0.82	0.17
Na_2O	1.60	1.03	0.74	0.59	0.76	0.66	0.69	1.48	0.63
K_2O	0.19	—	0.11	0.12	0.03	0.10	0.07	0.13	0.09
Cr_2O_3	0.40	0.91	0.50	0.47	0.68	0.45	0.37	0.41	0.53
MnO	0.37	0.47	0.63	0.56	0.46	0.56	0.53	0.52	0.36
TiO_2	*—	—	—	—	0.02	0.06	—	0.06	0.05
NiO	0.94	1.31	0.57	0.90	0.86	0.46	0.20	0.58	1.41
FeS	0.41	1.84	0.33	0.27	1.07	0.40	0.27	0.33	0.80
Total	93.87	91.92	93.28	99.25	99.92	101.45	100.69	101.06	96.58

* not detected.

Table 3a. Representative composition of olivines in chondrules.

SiO_2	42.42	40.32	39.52	38.42	39.50	39.36	38.27	38.61
FeO	1.98	11.24	17.70	23.99	16.22	17.12	21.90	20.46
MnO	0.19	0.14	0.37	0.31	0.45	0.54	0.58	0.67
MgO	55.17	47.37	42.35	37.46	43.48	42.80	38.48	39.51
CaO	*—	0.09	0.22	0.08	0.11	0.03	0.10	0.12
Total	99.77	99.16	100.16	100.25	99.76	99.85	99.33	99.36
Si	1.005	1.003	1.004	1.004	1.001	1.001	1.002	1.003
Fe	0.039	0.234	0.376	0.534	0.344	0.364	0.480	0.032
Mn	0.005	0.003	0.008	0.007	0.010	0.012	0.013	0.015
Mg	1.947	1.756	1.603	1.459	1.642	1.622	1.501	1.931
Ca	—	0.002	0.006	0.002	0.003	0.001	0.003	0.003
Total	2.995	2.997	2.996	2.996	2.999	2.999	2.998	2.997
Fo	98.0	88.3	81.0	73.2	82.7	81.6	75.7	98.3
Fa	2.0	11.7	19.0	26.8	17.3	18.4	24.3	1.7

SiO_2	39.50	39.07	39.09	39.62	41.95	42.43	40.93
FeO	16.22	17.21	21.87	22.35	3.48	1.98	12.69
MnO	0.45	0.28	0.52	—	—	—	0.28
MgO	43.48	42.48	39.12	39.52	53.98	55.17	46.78
CaO	0.11	0.20	0.08	—	0.31	0.19	0.09
Total	99.76	99.23	100.62	100.99	99.66	99.77	100.76
Si	1.001	1.000	1.006	1.004	1.002	1.005	1.008
Fe	0.344	0.368	0.471	0.480	0.070	0.039	0.261
Mn	0.010	0.006	0.013	—	—	—	0.006
Mg	1.642	1.620	1.503	1.512	1.919	1.947	1.716
Ca	0.003	0.006	0.002	—	0.008	0.005	0.002
Total	2.999	3.000	2.994	2.996	2.998	2.995	2.993
Fo	82.6	81.4	76.1	75.9	96.5	98.0	86.7
Fa	17.4	18.6	23.9	24.1	3.5	2.0	13.3

* not detected.

Table 3b. Representative composition of olivines in matrix.

SiO_2	41.35	37.08	36.68	35.94	36.51	36.01	36.16	35.07
FeO	4.21	29.31	31.23	33.08	35.27	35.84	33.85	39.81
MnO	—	0.41	0.48	0.56	0.57	0.61	0.52	0.70
MgO	53.45	33.15	31.10	29.52	28.45	27.34	29.25	23.91
CaO	0.39	0.09	0.09	0.03	0.20	0.22	0.07	0.06
Total	99.40	100.04	99.57	99.13	100.99	100.02	99.85	99.95
Si	0.996	0.999	1.003	0.998	1.003	1.004	0.999	1.004
Fe	0.085	0.660	0.714	0.768	0.810	0.836	0.782	0.953
Mn	—	0.009	0.011	0.013	0.013	0.015	0.012	0.017
Mg	1.916	1.331	1.267	1.222	1.165	1.136	1.205	1.020
Ca	0.010	0.003	0.003	0.001	0.006	0.007	0.002	0.002
Total	3.006	3.001	2.997	3.002	2.997	2.996	3.001	2.996
Fo	95.8	66.8	64.0	61.4	59.0	57.6	60.6	51.7
Fa	4.2	33.2	36.0	38.6	41.0	42.4	39.4	48.3

SiO_2	36.60	36.94	36.16	35.23	35.91	35.23	36.57
FeO	32.68	32.99	35.07	36.99	35.04	36.13	29.95
MnO	0.55	0.55	0.70	0.63	0.61	0.56	0.48
MgO	30.36	30.41	28.02	26.41	27.90	27.09	32.51
CaO	0.05	—	—	—	0.09	0.12	0.11
Total	100.23	100.88	99.96	99.27	99.55	99.12	98.92
Si	1.001	1.003	1.005	0.994	1.002	0.995	0.998
Fe	0.747	0.750	0.815	0.876	0.818	0.853	0.668
Mn	0.013	0.013	0.017	0.015	0.015	0.013	0.011
Mg	1.237	1.231	1.160	1.114	1.161	1.140	1.132
Ca	0.001	—	—	—	0.003	0.004	0.003
Total	2.999	2.997	2.996	3.003	2.998	3.005	3.002
Fo	62.7	62.2	58.7	56.0	58.7	57.2	66.5
Fa	37.7	37.8	41.3	44.0	41.3	42.8	33.5

Table 3c. Representative composition of low Ca-pyroxene in chondrules.

SiO_2	56.26	55.92	55.12	57.97	56.99
TiO_2	—	—	—	—	—
Al_2O_3	0.44	0.44	0.39	0.40	0.27
Cr_2O_3	0.45	0.55	0.82	0.42	0.49
FeO	9.00	13.69	16.01	5.93	10.61
MnO	0.31	0.47	0.68	0.33	0.51
MgO	33.58	28.77	26.03	34.55	30.85
CaO	0.13	0.28	0.95	0.15	0.18
Total	99.17	100.13	100.00	99.75	99.91
Si	1.965	1.994	1.996	1.998	2.005
Ti	—	—	—	—	—
Al	0.018	0.018	0.017	0.016	0.011
Cr	0.012	0.016	0.023	0.011	0.014
Fe	0.269	0.408	0.485	0.171	0.312
Mn	0.009	0.014	0.021	0.010	0.015
Mg	1.748	1.529	1.405	1.775	1.618
Ca	0.005	0.011	0.036	0.005	0.007
Total	4.020	3.989	3.984	3.988	3.982
En	84.6	78.5	72.9	90.9	83.5
Fs	13.2	20.9	25.1	8.7	16.1
Wo	0.2	0.5	1.8	0.2	0.3

Table 3d. Representative composition of low Ca-pyroxene in matrix.

SiO_2	57.90	59.84	56.51	59.10	58.40	56.26	50.86
TiO_2	—	—	—	0.08	—	—	—
Al_2O_3	0.53	0.34	0.42	0.67	0.59	0.53	1.08
Cr_2O_3	0.46	0.60	0.77	0.44	0.82	0.61	0.85
FeO	5.31	3.35	9.47	2.26	2.82	14.24	19.81
MnO	0.06	0.02	0.67	0.17	0.37	0.45	0.46
MgO	35.97	36.74	30.99	37.45	36.04	28.34	21.81
CaO	0.22	0.07	0.31	0.39	0.45	0.66	1.34
Total	100.45	100.97	99.14	100.56	99.48	100.95	99.20
Si	1.978	2.010	1.998	1.989	1.995	1.994	1.962
Ti	—	—	—	0.002	—	—	—
Al	0.021	0.013	0.018	0.027	0.024	0.022	0.049
Cr	0.012	0.016	0.022	0.012	0.022	0.017	0.026
Fe	0.152	0.094	0.280	0.064			
Mn	0.002	0.001	0.020	0.005	0.011	0.014	0.006
Mg	1.832	1.839	1.633	1.879	1.834	1.496	1.253
Ca	0.008	0.002	0.012	0.014	0.016	0.025	0.055
Total	4.005	3.976	3.982	3.990	3.982	3.987	4.000
En	91.9	95.0	84.8	96.0	94.9	77.1	64.3
Fs	7.6	4.8	14.5	3.2	4.1	21.5	32.8
Wo	0.3	0.1	0.5	0.7	0.8	1.2	2.8
SiO_2	58.40	58.41	58.22	59.18	57.13	53.98	58.21
TiO_2	—	—	0.09	—	—	—	—
Al_2O_3	0.47	0.48	1.06	0.49	0.44	0.45	0.69
Cr_2O_3	0.35	0.54	0.64	0.30	0.49	0.64	0.37
FeO	4.10	2.50	4.20	3.37	7.02	18.27	3.85
MnO	0.22	0.30	—	0.21	0.31	0.35	0.21
MgO	35.58	36.74	35.47	36.91	33.67	24.60	35.92
CaO	0.09	0.24	0.45	0.09	0.15	1.00	0.13
Total	99.20	99.88	100.13	100.49	99.22	99.52	99.20
Si	2.005	2.003	1.984	2.000	1.992	1.984	1.998
Ti	—	—	0.002	—	—	—	—
Al	0.019	0.019	0.043	0.018	0.018	0.030	0.021
Cr	0.009	0.014	0.017	0.008	0.014	0.019	0.010
Fe			0.120	0.095	0.205	0.561	0.110
Mn	0.009	0.009	—	0.006	0.009	0.011	0.006
Mg	1.820	1.856	1.802	1.858	1.749	1.347	1.837
Ca	0.003	0.009	0.017	0.003	0.006	0.039	0.005
Total	3.981	3.980	3.984	3.988	3.992	3.991	3.999
En	93.7	95.8	93.7	94.9	89.2	69.1	94.1
Fs	6.0	3.6	6.1	4.8	10.4	28.8	5.6
Wo	0.1	0.4	0.8	0.1	0.2	2.0	0.2

4.1. Relationship between chondrules and matrix

It is immediately noticed in these tables that the chemical compositions of the chondrules vary considerably, in contrast to a narrow compositional range of the matrices. Generally the chondrules are enriched in MgO, whereas the matrices are depleted in MgO but enriched in FeO. All analytical results of the chondrules and matrices are plotted in the SiO_2-MgO-FeO diagram (Fig. 2), which clearly demonstrates that the matrices are plotted in a narrow FeO-rich region, whereas the plots of the chondrules scatter widely in the MgO-rich field. There is a distinct compositional gap between the two.

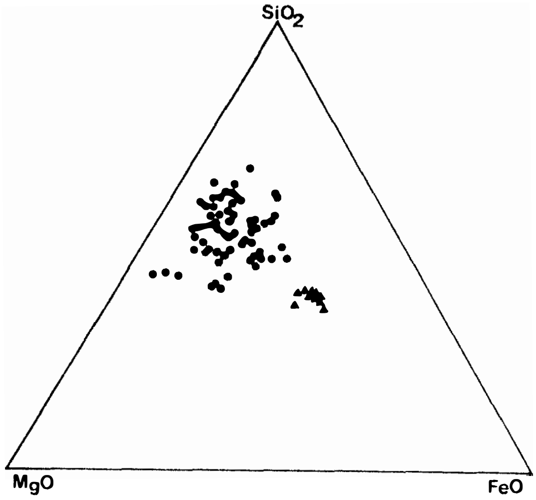

Fig. 2. SiO_2-FeO-MgO plots of chondules (solid circles) and matrix (triangles).

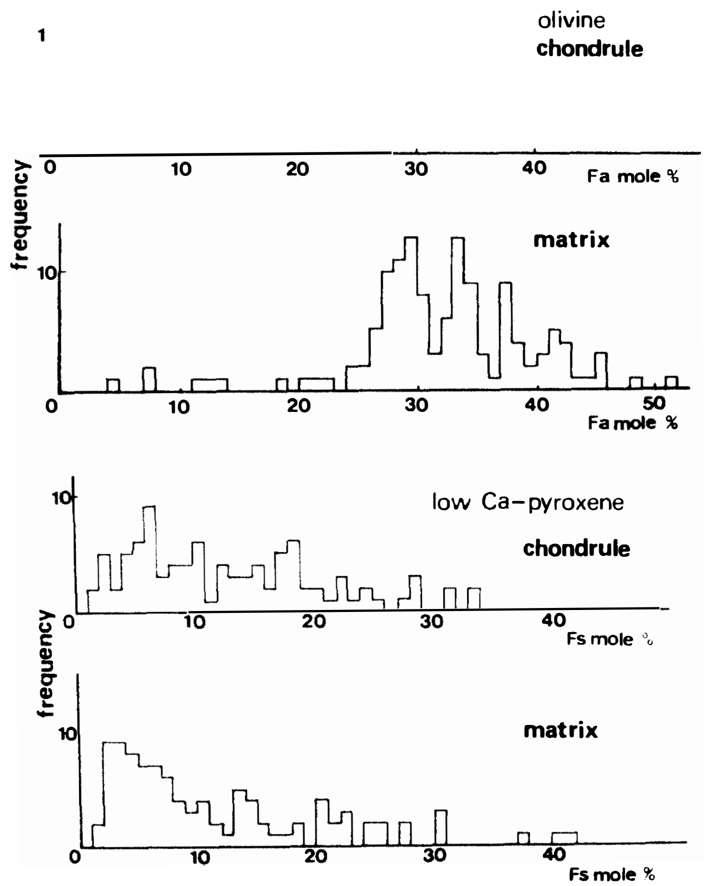

Fig. 3. Histograms of olivine and low Ca-pyroxene compositions of chondrules and of matrix.

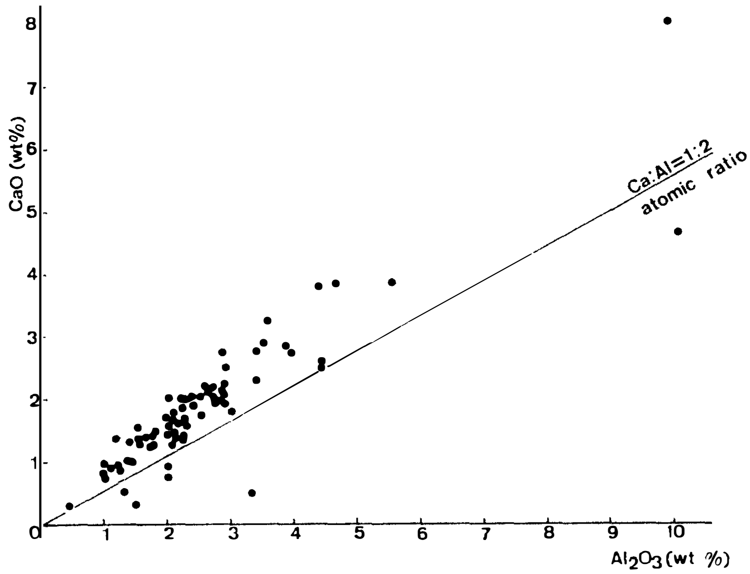

Fig. 4. CaO vs Al_2O_3 variations in chondrules.

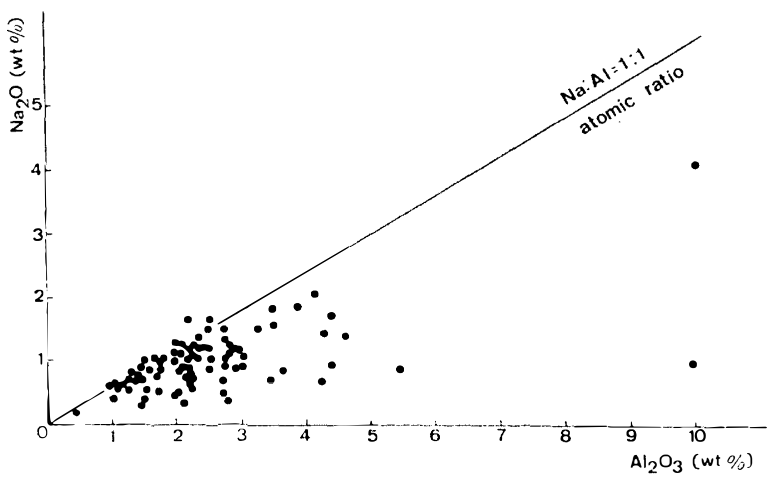

Fig. 5. Na_2O vs Al_2O_3 variations in chondrules.

The chemical compositions of olivines and low Ca-pyroxenes are plotted in Fig. 3. The two minerals have wide compositional ranges. The olivines in the chondrules are relatively enriched in MgO, whereas those in the matrix are enriched in Fa molecules. The distinct compositional difference between the two groups can be recognized in Fig. 3. The compositional ranges of low Ca-pyroxenes in the chondrules and those in the matrix are nearly the same.

The present data imply that the fragmentation of the chondrules as suggested by REID and FREDRIKSSON (1967) cannot explain the chemical compositions of the matrices and the olivines in matrix. It is also impossible to expect the materials forming fine-grained matrices change into chondrules by re-heating (*e.g.*, CAMERON, 1966; KING *et al.*, 1972; KIEFER, 1975), while keeping their original compositions unchanged.

4.2. *Chemical compositions of chondrules*

The chondrules are more enriched in Na_2O, MgO, Al_2O_3, CaO and TiO_2 than the matrices.

It is important to find some correlations among the elements in chondrules in understanding the origin of chondrule. Indeed, many investigators have emphasized the importance (*e.g.*, WALTER and DODD, 1972; OSBORN *et al.*, 1973; LUX *et al.*, 1981). Fig. 4 and Fig. 5, respectively, show the relationships between Ca and Al, and Na and Al found in the present chondrules.

Ca and Al are the high-temperature condensation elements and they might have behaved as a coherent chemical group. A good correlation between Ca and Al can be recognized (Fig. 4). The solid line in Fig. 4 shows the Ca/Al ratio of anorthite. Most of the data are plotted above the line. This Ca/Al correlation may be explained by not only the direct condensation model proposed by WOOD (1963) and BLANDER and KATZ (1967) but also by the model proposed by CAMERON (1966), KIEFER (1975) and GOODING *et al.* (1980).

According to the direct condensation model, the droplet chondrule condensed at a high temperature should be enriched in refractory elements, and those condensed at a low temperature should be depleted in these elements. The observed Ca-Al correlation can be explained by the model because the Ca-rich chondrules are enriched in Al and the Ca-poor chondrules are depleted in Al.

On the other hand, the latter model can also explain the Ca-Al correlation. In this model, Ca and Al have crystallized from a solar nebula as anorthite and aluminous Ca-rich pyroxene at a high temperature. And they were the precursors of chondrules. The precursors rich in anorthite and aluminous Ca-pyroxene must be enriched in Al and Ca, but those poor in anorthite and aluminous Ca-pyroxene must be depleted in Al and Ca. Consequently, the observed Ca-Al correlation can be produced.

Na is one of the low-temperature condensation elements, judged from the calculation LARIMER and ANDERS (1967) and GROSSMAN and LARIMER (1974). Thus, it is not necessary that Na was condensed together with Al. However, Na abundance of the chondrules increases as Al increases, although the correlation is poor and not as good as the Ca-Al correlation (Fig. 5). According to the direct condensation model, the chondrules formed at a high temperature should be enriched in refractory elements such as Ca and Al and depleted in volatile elements such as Na. According to the direct condensation model, Na should decrease as Al increases. The direct condensation model cannot give an appropriate account for the present data. Since Ca-rich pyroxene can have a minor amount of Na, the observed Na-Al relation may be explained on this basis, if we assume the existance of precursors. The precursors rich in pyroxene will form Ca, Al and Na-rich chondrules, whereas those depleted in pyroxene component will result in Ca, Al and Na-poor chondrules.

The chemical compositions of the chondrules are plotted in Fig. 6 by atomic ratio. IKEDA (1980) proposed that the chondrules in the ALH-764 (LL3) could be divided into three groups in these figures. However, the chemical compositions of the ALH-77015 chondrite cannot be divided into three groups, and are widely scattered and continuous.

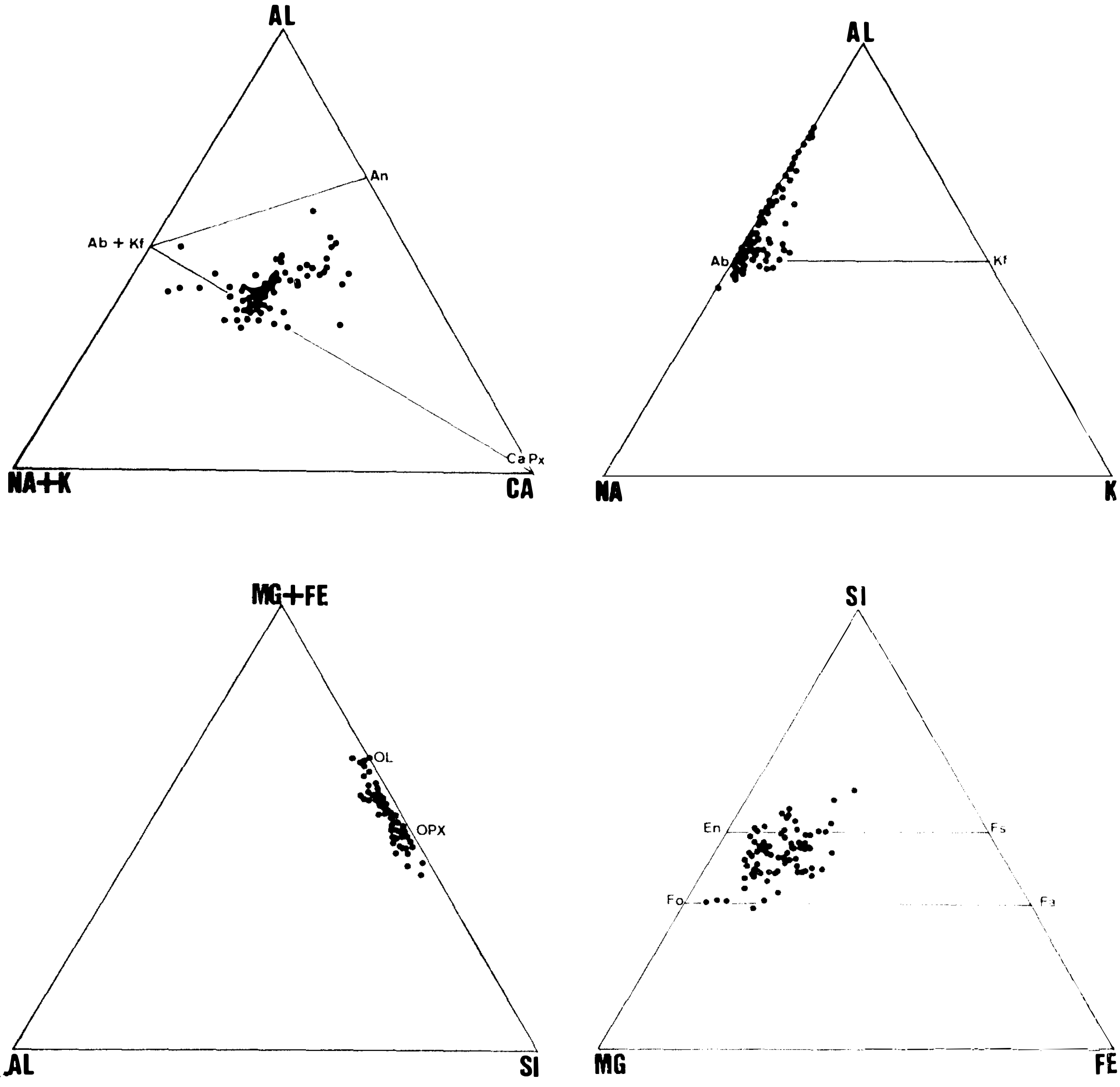

Fig. 6. Chemical compositions of chondrules are shown by the atomic ratios. An, Ab, Kf, CaPx, Ol, Px, Fo, Fa, En, and Fs are anorthite, albite, K-feldspar, Ca-rich pyroxene, Olivine, Ca-poor pyroxene, forsterite, fayalite, enstatite and ferrosilite, respectively.

5. Summary

The matrices are enriched in FeO, whereas the chondrules in MgO. The chemical compositions of the matrices are relatively homogeneous, whereas those of the chondrules vary widely. There are distinct compositional gaps between the chondrules and the matrices and between the olivines in the chondrules and those in the matrix, demonstrating that fragmentation of the chondrules cannot produce the fine-grained matrix material.

The Ca-Al correlation is recognized for the chondrules. This correlation can be interpreted as due to that both elements had condensed as precursors having compositions of anorthite and aluminous Ca-rich pyroxene from the high-temperature solar nebula. The Na-Al relation cannot be accounted for by the direct condensation model.

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