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# PRELIMINARY EXAMINATION OF THE YAMATO-86032 LUNAR METEORITE: II. MAJOR AND TRACE ELEMENT CHEMISTRY

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***Abstract:*** The chemical composition of the new lunar meteorite Yamato-86032 has been studied by several laboratories in a consortium study. A preliminary report on the first analytical results from seven laboratories is given in this paper. The meteorite, which is the largest lunar meteorite recovered so far, is more heavily shocked than the other five lunar meteorites, which makes it difficult to classify the rock exactly. Although it may be classified as an anorthositic breccia the trace element composition of Y-86032 is somewhat different from the composition of the other known lunar meteorites. The major element chemistry of Y-86032 is similar to the other lunar meteorites, except for the iron content, which is lower by a factor of about 1.4. Since the magnesium abundance is nearly identical there is a disparity in the *mg* ratio. The REE abundances in Y-86032 are very low and comparable to Y-82192/3. There is no evidence of any KREEP component. The abundances of several lithophile and incompatible elements are lower in Y-86032 than in the other lunar meteorites. The siderophile element contents are low and vary between individual chips. Sc, Cr, Mn, and Co have significantly lower abundances than in Y-82192/3. The chemical investigations demonstrate that Y-86032 is a new and important sample from the lunar highlands.

## 1. Introduction

Yamato-86032 was found in Antarctica by a JARE team in 1986 and recognized as an unusual specimen. A preliminary investigation by YANAI *et al.* (1987) demonstrated that this specimen is another lunar meteorite. Petrological studies showed that the sample is similar to the paired lunar meteorites Yamato-82192 and Y-82193. For a complete description of the first studies, the allocation, and mineralogical and petrological investigations of Y-86032 see TAKEDA *et al.* (1988, 1989).

Yamato-86032 is very important, since it is the largest lunar meteorite recovered so far (648.43 g weight), allowing more generous allocations than for the other lunar meteorites, which have weights of less than about 50 g. Complicated and mass-consuming analyses and studies of spatially different samples from one large rock can be performed. This allows to address some very important questions, such as: Is this sample different from other lunar meteorites?; What can we learn about impact on the moon?; What are the internal chemical variations within one sample?; What are the implications about the heterogeneity of the lunar regolith?; Is this sample paired with other lunar meteorites?; and others. Regardless of the anwsers to all these questions Y-86032 is a valuable addition to our collection of lunar rocks.

## 2. Samples and Analytical Procedures

The investigation of Y-86032 is organized as a consortium study. Details concerning the sample preparation and allocation procedures at the National Institute of Polar Research in Tokyo can be found in TAKEDA *et al.* (1989). The present investigators received the Y-86032 samples during early 1988. All samples were taken from one part of the rock. Additional allocations will include samples from other parts of the rock for studies of the heterogeneity of the meteorite.

So far, complete data from six laboratories (Vienna, UCLA-Los Angeles, Houston, Mainz, Tokyo, and Bern) plus a major element analysis (Tokyo) are available for this preliminary report. All laboratories received samples including matrix, impact melts, and clasts. Our report deals only with the characterization of the bulk meteorite. In the following paragraph the procedures and facilities at the different laboratories are described.

(1) Vienna. Institute of Geochemistry, University of Vienna, Austria. Two subsamples (Y-86032,84 and, 85), totalling about 0.7 g, were received for chemical and petrological studies (the latter in cooperation with the Naturhistorisches Museum in Vienna). The samples have been subdivided into several matrix and clast samples, and prepared for INAA (instrumental neutron activation analysis) and RNAA (radiochemical neutron activation analysis). Two separate sets of irradiations (for short-lived and long-lived isotopes) for INAA have been performed, using the Triga Mark II reactor of the Austrian Universities at a neutron flux of about $2\times10^{12}$ n $cm^{-2}$ $s^{-1}$. The long irradiation (8 h) was followed by four counting cycles over a period of three months (see also KOEBERL, 1988a). The data given in Table 1 are for a 70 mg bulk of Y-86032,84.

(2) UCLA. Institute of Geophysics and Planetary Physics, University of California, Los Angeles, U.S.A. The samples have been subdivided for INAA studies (trace elements) and fused bead electron microprobe analysis (major elements). A bulk sample (Y-86032,78) and two clasts (Y-86032,104 and ,105) have been studied. The data given in Table 1 are for a 244 mg bulk of Y-86032,78. For details on the procedures see KALLEMEYN and WARREN (1983).

(3) Houston. SN21, NASA Johnson Space Center, Houston, Texas, U.S.A. A 1.2 g split of the meteorite (Y-86032,71) was received for distribution to other U.S. investigators. Among the samples allocated to the JSC laboratory were two matrix splits (Y-86032,75 and ,76; 128.6 and 100.7 mg, respectively). The samples were studied for trace elements (and Fe, Ca, and Na) by INAA, and for major elements by fused bead electron microprobe analysis. For INAA the samples were irradiated

for 20 h at a flux of about $5\times10^{13}$ n $cm^{-2}$ $s^{-1}$ and counted three times between 5 and 35 days after the irradiation (see also LINDSTROM *et al.*, 1986, 1988).

(4) Mainz. Max-Planck-Institut fuer Chemie, Mainz, F.R.G. Studies made at this laboratory include noble gases and multi-element chemistry. For the bulk chemical analysis that is reported in Table 1 a 122 mg chip of the matrix of Y-86032 was irradiated for about 6 h in the TRIGA reactor of the Institut fuer Kernchemie (University of Mainz) at a neutron flux of about $7\times10^{11}$ n $cm^{-2}$ $s^{-1}$. After the irradiation the sample was counted several times over a period of several weeks (see also OSTERTAG *et al.*, 1986; BISCHOFF *et al.*, 1987).

(5) Tokyo. Department of Chemistry, Gakushuin University, Mejiro, Tokyo. Samples analyzed for elemental composition include parts of the matrix and clasts (Y-86032,64; -,106 and ,109). For short lived isotopes, the samples have been irradiated for 4 minutes in the TRIGA reactor of the Musashi Institute of Technology at a flux of $1\times10^{12}$ n $cm^{-2}$ $s^{-1}$. For long-lived isotopes, the samples were irradiated for 6 h in the JRR-4 reactor of the Japan Atomic Energy Research Institute at a neutron flux of $5.5\times10^{13}$ n $cm^{-2}$ $s^{-1}$. The data reported in Table 1 are the weighted mean of three bulk matrix samples from Y-86032,64 and ,109.

(6) Bern. Anorganisch Chemisches Institut, University of Bern, Switzerland. Chips of sample Y-86032,86 have been analyzed by INAA and RNAA. For details see EUGSTER *et al.* (1989).

(7) Tokyo. Geological Institute, University of Tokyo, Japan. A wet chemical major element analysis was performed by H. HARAMURA and I. KUSHIRO (H. TAKEDA, pers. commun., 1988) and is included in Table 1.

## 3. Results and Discussion

The results of the bulk analyses of samples of Y-86032 that have been obtained by the seven laboratories described above are given in Table 1. Some preliminary results have been published by KOEBERL (1988b, c), WARREN and KALLEMEYN (1988), and LINDSTROM *et al.* (1988).

First of all, the data leave no doubt that Y-86032 is a rock from the lunar highlands. Most major and trace element abundances are in accordance with a lunar origin. Figure 1 shows a plot of Fe *vs.* Mn for Y-86032 and the other known lunar meteorites. The Fe/Mn ratio of lunar samples (70 for lunar highland samples) is significantly different from differentiated and undifferentiated meteorites and terrestrial rocks (see *e.g.* LAUL *et al.*, 1983; FUKUOKA *et al.*, 1986b). All lunar meteorites, including Y-86032, plot on or near the lunar correlation line (for references on the construction of the lunar highlands correlation line, see LAUL *et al.*, 1983; FUKUOKA *et al.*, 1986b). Normal meteorites (chondrites as well as achondrites) plot far from the lunar correlation line (outside of the field given in Fig. 1). This plot is just one example of several demonstrating the lunar origin of the sample.

Petrological data (TAKEDA *et al.*, 1988, 1989) have already indicated that Y-86032 is more heterogeneous than the previous lunar meteorites. The chemical data obtained by different laboratories that is given in Table 1 (as well as data that has

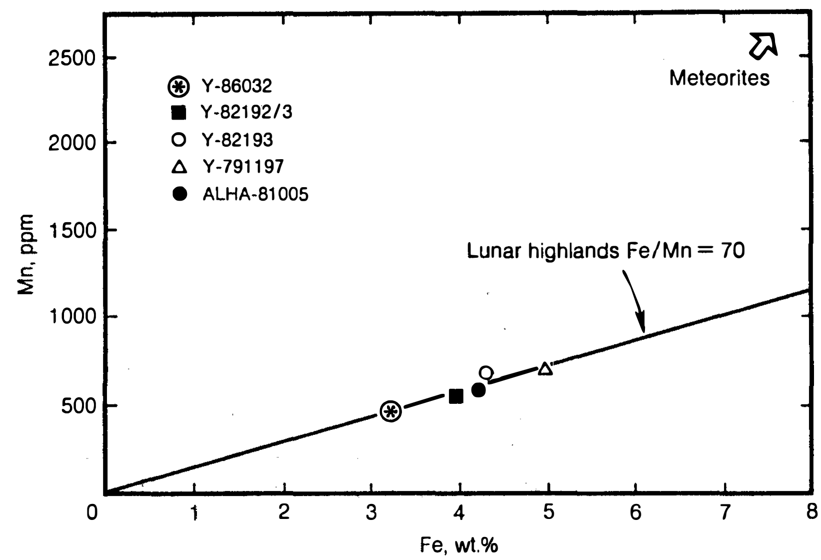


*Fig. 1. The Fe/Mn correlation is characteristic for different bodies in the solar system. It is easy to distinguish lunar rocks from meteorites (chondrites and achondrites have quite different ratios) or terrestrial rocks (see e.g. LAUL et al., 1983: and FUKUOKA et al., 1986 b). All lunar meteorites, including Yamato-86032, have ratios that are indistinguishable from the average ratio for lunar highland rocks (see also Table 2).*

been obtained on different splits of the sample in our laboratories and will be published in the final reports) show that the sample is indeed heterogeneous. So far it is not clear if this is simply due to the larger size of the sample.

In most cases the agreement between the individual analyses is very good. For some elements the discrepancies between individual analyses may be due to sample heterogeneity. Other variations are due to low abundances and higher errors. For example, Ba contents vary between 23 and 30 ppm, but analytical errors are typically about 20%. The Zr abundances given in Table 1 vary between <10 (Mainz laboratory) and 29 ppm (UCLA), with errors of about 40%. The <10 ppm limit for Zr may be too low, since the other results give an average of about 24 ppm, which is comparable to other lunar meteorites. Lithophile and incompatible element abundances show good agreement between individual analyses. An exception are some data from the Bern laboratory, *e.g.*, for Ti and Hf (which are different by a factor of about 2) and Fe (which is also rather low), and K and U data from the Tokyo laboratory (which also seem to be low). The wet chemical data of the Geological Institute, University of Tokyo laboratory agrees well with other major element analyses, with the exception of Fe (3.91 wt%) which is considerably higher than all other determinations. This laboratory also reports $H_2O$ (−) contents of <0.05 wt% and $H_2O$ (+) contents of <0.1 wt%. Their Mn value (230 ppm) is considerably smaller than other numbers, but this probably reflects the analytical uncertainty of wet chemical analyses at such low levels.

Volatile elements show more variation. The three different Zn values vary by a factor of 2, between 6.4 and 14 ppm, and Ga and Se vary by a factor of about 1.4. These elements are usually afflicted with higher analytical errors, and contaminations are more likely than for refractory elements. Of the siderophile elements, Co and

*Table 1. Chemical composition of different bulk samples of the lunar meteorite Y-86032, and comparison data for other meteorites.*

| | Y-86032 ,84 [V] | Y-86032 ,78 [L] | Y-86032 ,75/6 [H] | Y-86032 [M] | Y-86032 ,64 [T] | Y-86032 ,86 [B] | Y-86032 [TG] | Y-86032 wgt. ave. |
|---|---|---|---|---|---|---|---|---|
| Major elements (wt%) | | | | | | | | |
| Si | — | 21.1 | 20.1 | — | — | — | 20.41 | 20.62 |
| Ti | — | 0.15 | 0.113 | 0.12 | 0.12 | 0.06 | 0.018 | 0.12 |
| Al | — | 14.7 | 15.55 | 14.6 | 14.9 | — | 15.39 | 15.48 |
| Fe | 3.20 | 3.28 | 3.26 | 3.39 | 3.33 | 2.9 | 3.91 | 3.27 |
| Mg | — | 3.35 | 3.06 | 3.58 | 2.9 | — | 3.03 | 3.16 |
| Ca | — | 11.2 | 11.9 | 11.5 | 11.6 | — | 11.88 | 11.6 |
| Na | 0.32 | 0.331 | 0.31 | 0.30 | 0.31 | 0.29 | 0.33 | 0.32 |
| Trace elements (ppm) | | | | | | | | |
| P | — | — | 113 | — | — | — | 260 | 113 |
| Cl | <30 | — | — | <50 | — | — | — | <30 |
| K | 135 | 209 | <400 | 150 | 108 | 141 | <160 | 165 |
| Sc | 7.26 | 8.1 | 8.46 | 8.84 | 8.69 | 7.3 | — | 8.27 |
| V | — | 30 | — | 28 | 25 | — | — | 29 |
| Cr | 660 | 660 | 693 | 724 | 527 | 710 | — | 666 |
| Mn | 390 | 470 | 434 | 483 | 503 | — | 232 | 458 |
| Co | 13.2 | 14.4 | 14.4 | 14.8 | 14.9 | 13.1 | — | 14.4 |
| Ni | 150 | 115 | 132 | 130 | 155 | — | — | 131 |
| Zn | 10 | 6.4 | — | 14.0 | — | — | — | 9.1 |
| Ga | 4.8 | 3.4 | — | 3.54 | — | — | — | 3.66 |
| As | 0.27 | — | — | <0.1 | — | — | — | 0.27 |
| Se | 0.3 | — | 0.44 | <0.5 | — | — | — | 0.40 |
| Br | <0.2 | 0.12 | — | <0.1 | — | — | — | 0.12 |
| Rb | <10 | — | — | <1 | — | — | — | <1 |
| Sr | 118 | 160 | 169 | 174 | — | — | — | 161 |
| Y | — | — | — | — | — | 4.6 | — | 4.6 |
| Zr | 25 | 29 | — | 23 | — | 17 | — | 27 |
| Ag | — | — | — | <0.08 | — | — | — | <0.08 |
| Sb | <0.05 | — | — | <0.015 | — | — | — | <0.015 |
| Cs | 0.05 | <0.14 | 0.046 | <0.05 | — | — | — | 0.05 |
| Ba | 30 | 26 | 30 | 23 | 24 | — | — | 27 |
| La | 1.0 | 1.56 | 1.25 | 1.35 | 1.25 | 1.1 | — | 1.33 |
| Ce | 2.6 | 4.0 | 3.42 | 3.36 | 3.3 | — | — | 3.51 |
| Nd | 1.73 | 2.0 | 1.9 | 1.70 | 1.9 | — | — | 1.88 |
| Sm | 0.57 | 0.66 | 0.62 | 0.655 | 0.61 | 0.63 | — | 0.63 |
| Eu | 0.87 | 1.03 | 0.926 | 0.858 | 0.80 | 1.00 | — | 0.93 |
| Gd | 1.1 | — | — | — | — | — | — | 1.1 |
| Tb | 0.21 | 0.144 | 0.132 | 0.145 | — | — | — | 0.147 |
| Dy | 1.1 | 1.21 | — | 0.99 | 0.7 | — | — | 1.05 |
| Ho | — | — | — | 0.23 | — | — | — | 0.23 |
| Tm | — | — | — | 0.12 | — | — | — | 0.12 |
| Yb | 0.595 | 0.61 | 0.562 | 0.647 | 0.59 | — | — | 0.60 |
| Lu | 0.089 | 0.086 | 0.084 | 0.094 | 0.089 | — | — | 0.087 |
| Hf | 0.54 | 0.47 | 0.46 | 0.47 | 0.39 | 0.24 | — | 0.47 |
| Ta | 0.07 | 0.061 | 0.057 | 0.055 | — | 0.10 | — | 0.06 |
| W | 0.3 | — | — | <0.08 | — | 0.47 | — | 0.36 |
| Ir | 0.0085 | 0.0057 | 0.0039 | 0.0059 | 0.0043 | — | — | 0.0053 |
| Au | 0.006 | 0.0018 | 0.003 | 0.0013 | 0.0014 | — | — | 0.0024 |
| Hg | <0.07 | — | — | <0.1 | — | — | — | <0.07 |
| Th | 0.22 | 0.25 | 0.22 | 0.21 | 0.20 | — | — | 0.22 |
| U | 0.07 | 0.062 | 0.043 | 0.050 | 0.032 | — | — | 0.051 |

Laboratories: [V]: Vienna (C. Koeberl). [L]: UCLA (P. Warren/G. Kallemeyn). [H]: Houston JSC (M. Lindstrom). [M]: MPI Mainz (H. Palme/B. Spettel). [T]: Tokyo (T. Fukuoka). [B]: Bern (U. Krähenbühl). [TG]: Tokyo, Geol. Inst. (H. Haramura/I. Kushiro).
The weighted average column gives average data (excluding [TG]).

*Table 1 (continued).*

| | Y-82192 bulk [1] | Y-82192 bulk [2] | Y-82192 bulk [3] | Y-82192/3 mean [4] | Y-82193 bulk [5] | Y-791197 bulk [1] | Y-791197 bulk [6] | Y-791197 bulk [7] | ALHA81005 mean [10] |
|---|---|---|---|---|---|---|---|---|---|
| Major elements (wt%) | | | | | | | | | |
| Si | — | — | — | 21.1 | — | — | — | — | 21.4 |
| Ti | — | 0.21 | 0.25 | 0.16 | 0.16 | — | 0.17 | 0.22 | 0.16 |
| Al | — | 13.4 | 13.53 | 14.1 | 13.65 | — | 14.1 | 13.3 | 13.6 |
| Fe | 4.85 | 4.47 | 4.74 | 4.03 | 4.38 | 4.99 | 4.43 | 5.05 | 4.27 |
| Mg | — | 3.2 | 3.47 | 3.30 | 3.08 | — | 3.6 | 4.25 | 4.94 |
| Ca | — | 10.2 | 10.6 | 11.0 | 11.9 | — | 10.8 | 11.4 | 10.7 |
| Na | 0.29 | 0.273 | 0.265 | 0.306 | 0.30 | 0.25 | 0.234 | 0.24 | 0.224 |
| Trace elements (ppm) | | | | | | | | | |
| P | — | — | — | — | — | — | — | 100 | 90 |
| Cl | — | — | — | 19 [8] | — | — | — | — | — |
| K | 170 | 173 | 150 | 182 | 307 | 238 | 232 | 290 | 194 |
| Sc | 13.8 | 13.5 | 14.5 | 11.0 | 12.2 | 12.1 | 12.5 | 16.5 | 9.1 |
| V | — | 36 | 41 | 34.3 | 31 | — | 30 | 39 | 24.6 |
| Cr | 1156 | 1010 | 1020 | 879 | 1053 | 889 | 880 | 1034 | 890 |
| Mn | 746 | 600 | 657 | 563 | 627 | 674 | 660 | 734 | 580 |
| Co | 18.6 | 16.7 | 19.9 | 16.6 | 19.2 | 24.6 | 18.4 | 16.9 | 21.0 |
| Ni | 159 | 122 | 120 | 130 | 148 | 218 | 154 | 100 | 198 |
| Zn | — | 7.3 | 30 | 3.8 [9] | — | — | 21 | 50 | 8.7 |
| Ga | 10.4 | 2.8 | 3.78 | 3.7 | — | 3.3 | 3.2 | 9.9 | 2.7 |
| As | 0.028 | — | <0.2 | — | — | 0.3 | — | — | — |
| Se | 0.3 | — | <0.2 | 0.33 [9] | — | 0.56 | — | — | 0.6 |
| Br | 0.08 | <0.17 | <0.2 | 0.08 | — | <0.08 | 0.16 | — | 0.19 |
| Rb | 3 | — | <3 | 0.22 [9] | — | 8 | — | — | 1.5 |
| Sr | 150 | 143 | 136 | — | 180 | 158 | 140 | 118 | 135 |
| Y | — | — | — | — | — | — | — | — | — |
| Zr | 30 | 24 | — | — | — | 35 | 26 | — | 26.8 |
| Ag | — | — | — | 0.004 [9] | — | — | — | — | — |
| Sb | <0.1 | — | <0.1 | 0.004 [9] | — | <0.1 | — | — | — |
| Cs | 0.08 | <0.16 | <0.1 | 0.02 [9] | — | 0.08 | 0.06 | — | 0.024 |
| Ba | 20 | 22 | 21 | 22.9 | 28 | 30 | 29 | 34 | 28.4 |
| La | 1.11 | 1.54 | 1.13 | 1.21 | 1.27 | 2.45 | 2.16 | 3.24 | 1.98 |
| Ce | 2.77 | 3.78 | 2.98 | 3.1 | 3.0 | 4.53 | 5.0 | 8.76 | 5.2 |
| Nd | 2.1 | 2.32 | 1.97 | 1.91 | 2.0 | 3.58 | 3.0 | 5.24 | 3.2 |
| Sm | 0.627 | 0.68 | 0.631 | 0.58 | 0.65 | 1.17 | 0.96 | 1.56 | 0.95 |
| Eu | 0.779 | 0.87 | 0.754 | 0.82 | 0.82 | 0.717 | 0.72 | 0.723 | 0.69 |
| Gd | 1.0 | — | — | — | 0.57 | 1.60 | — | — | 1.4 |
| Tb | 0.21 | 0.174 | 0.17 | 0.155 | 0.14 | 0.23 | 0.216 | 0.33 | 0.214 |
| Dy | 1.08 | 1.28 | 1.13 | 0.94 | 1.0 | 1.67 | 1.40 | 2.22 | 1.33 |
| Ho | — | 0.243 | 0.26 | — | — | — | 0.28 | 0.48 | 0.31 |
| Tm | 0.1 | — | — | — | — | 0.16 | — | 0.23 | 0.18 |
| Yb | 0.71 | 0.79 | 0.76 | 0.62 | 0.73 | 1.11 | 0.95 | 1.34 | 0.84 |
| Lu | 0.10 | 0.121 | 0.115 | 0.096 | 0.117 | 0.142 | 0.135 | 0.19 | 0.124 |
| Hf | 0.92 | 0.73 | 0.44 | 0.46 | 0.45 | 1.2 | 0.73 | 1.11 | 0.73 |
| Ta | <0.1 | 0.038 | — | — | 0.034 | 0.1 | 0.078 | 0.16 | 0.093 |
| W | — | — | — | — | — | — | — | — | — |
| Ir | 0.010 | 0.0064 | 0.0056 | 0.0051 | 0.0057 | 0.0067 | 0.0064 | 0.0059 | 0.0068 |
| Au | 0.0031 | 0.0014 | 0.0011 | 0.0023 | 0.0013 | 0.0066 | <0.002 | 0.0013 | 0.0022 |
| Hg | <0.05 | — | — | — | — | <0.1 | — | — | — |
| Th | 0.23 | 0.188 | 0.2 | 0.18 | 0.20 | 0.34 | 0.28 | 0.43 | 0.29 |
| U | 0.066 | 0.058 | 0.05 | 0.051 | 0.040 | 0.10 | 0.079 | 0.14 | 0.098 |

References: [1]: KOEBERL (1988a). [2]: WARREN and KALLEMEYN (1987). [3]: BISCHOFF *et al.* (1987). [4]: weighted mean of literature data, from WARREN and KALLEMEYN (1988). [5]: FUKUOKA *et al.* (1986a). [6]: WARREN and KALLEMEYN (1986). [7]: OSTERTAG *et al.* (1986). [8]: KOEBERL and KIESL (1986). [9]: DENNISON *et al.* (1987). [10]: weighted mean of literature data, after PALME *et al.* (1983), WARREN and KALLEMEYN (1986), and WARREN and KALLEMEYN (1988).

Ni do not show much variation between the individual samples, but Ir and Au and their ratios differ to some extent. The lowest and highest Ir abundances are 3.9 and 8.5 ppb and have been measured in the Houston and Vienna laboratories, respectively. Gold shows similar variations, between 1.3 and 6 ppb. The Ir/Au ratios vary between 1.3 (Houston) and 4.5 (Mainz). It is quite possible that some of these variations are due to the incorporation of various amounts of meteoritic debris (in the lunar soil or impact melt), although analytical problems cannot be excluded.

For comparison, the second part of Table 1 contains data for the other known lunar meteorites that have been analyzed so far (no data are available for Y-793274 at this time). Major and trace element abundances in Y-86032 are comparable to the other samples, demonstrating that Y-86032 is also a sample from the lunar highlands. The Hf, Ta, Th, and rare earth element (REE) abundances in Y-86032 are very low, comparable to Y-82192/3. Like in Y-82192/3, a KREEP component is completely missing.

Table 2 gives several characteristic elemental ratios for Y-86032 and the other lunar meteorites, in comparison with lunar highlands data. Most ratios are in good agreement with average lunar highland ratios. Due to the lack of a KREEP component the K/La ratio is higher in the lunar meteorites than in the average highland sample. The low K/La ratio in the Tokyo sample is caused by the low K content. As was observed for the absolute abundances, there are similarities in elemental ratios between Y-86032 and Y-82192/3 (*e.g.*, Fe/Mn).

In spite of these similarities, there are, however, some interesting disparities between Y-86032 and Y-82192/3. The absolute abundances of Sc, Ti, Cr, Mn, Fe, and Co are significantly lower in Y-86032 than in Y-82192/3. Some of these elements are also less abundant in ALHA-81005, but most element ratios in Y-86032 are quite different from ALHA-81005. Due to these differences in elemental abundances there are also variations in some ratios, such as Fe/Sc, K/La, or Th/Sm.

A petrogenetically very important factor is the molar Mg/(Mg+Fe) (or *mg*) ratio. WARREN and KALLEMEYN (1986) have used the difference in the *mg* ratio between

*Table 2. Elemental ratios in Y-86032 as compared to other lunar meteorites and average lunar highland samples.*

| | Y-86032 [V] | Y-86032 [L] | Y-86032 [H] | Y-86032 [M] | Y-86032 [T] | Y-86032 [B] | Y-82192/3 ave. [1] | Y-791197 ave. [1] | ALHA 81005 ave. [1] | Ave. lunar highland rocks [2] |
|---|---|---|---|---|---|---|---|---|---|---|
| Fe*/Mn | 76.3 | 66.1 | 70.6 | 66.1 | 61.6 | — | 68.1 | 71.0 | 68.5 | 70 |
| Fe*/Sc | 4095 | 3835 | 3620 | 3615 | 3565 | 3700** | 3485 | 3525 | 4365 | 4000 |
| Al/Ga | — | 43200 | — | — | — | — | 38100 | 23400 | 50400 | 36000 |
| K/La | 135 | 134 | — | 111 | 86.4 | 128 | 150 | 105 | 98 | 70 |
| Na/Eu | 3680 | 3215 | 3350 | 3500 | 3900 | 2900 | 3730 | 3115 | 3245 | 3000 |
| Th/Sm | 0.39 | 0.38 | 0.35 | 0.32 | 0.33 | — | 0.31 | 0.31 | 0.31 | 0.34 |

* Fe corrected for meteoritic contribution (Fe* = Fe − 15 × Ni); see BISCHOFF *et al.* (1987).
** Ni averaged from other analyses and subtracted.
Laboratory identification see Table 1.
References: [1] weighted mean of literature data, see WARREN and KALLEMEYN (1987, 1988); [2] WÄNKE *et al.* (1975).

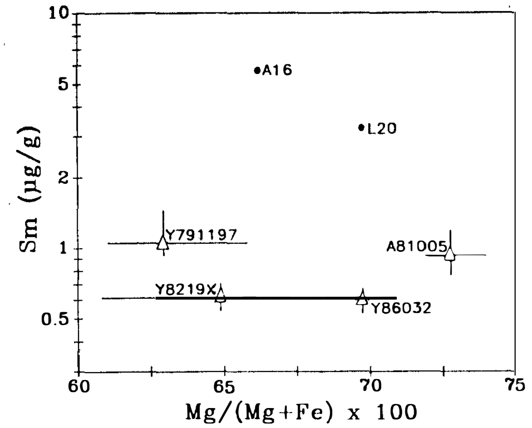


*Fig. 2. A plot of the molar Mg/(Mg+Fe) ratio (or mg ratio) vs. the incompatible element Sm reveals chemical differences between the individual lunar meteorites. Average Apollo 16 and Luna 20 highland soils are shown for comparison. It may be noted that there is a large difference between ALHA81005 and Y-791179, and also between Y-82192/3 and Y-86032. However, the significance of these differences is greater for the proven regolith breccias (ALHA81005 and Y-791197) than for Y-86032 (see text). The data have been averaged from the literature (see also Table 1: WARREN and KALLEMEYN, 1987, 1988).*

ALHA-81005 and Y-791197 to argue against an origin from the same target area. Figure 2 gives a plot of the *mg* ratio *vs.* Sm. It is clearly visible that the lunar meteorites are different from each other and from normal Apollo 16 regolith breccias and Luna 20 rocks. LINDSTROM *et al.* (1986, 1987) showed that the fragmental breccias ejected from a single lunar crater exhibit more variation in *mg* ratio (55-78) and REE concentration than do the lunar meteorites. However, the *mg* disparity is relatively insignificant in the case of Y-86032, which is not necessarily a regolith breccia (*i.e.*, it may be a generic fragmental breccia). Further discussions and analyses are necessary to evaluate the question if Y-86032 is significantly different from the other lunar meteorites (KOEBERL, 1988b) or paired with Y-82192/3, as indicated by studies of the cosmic ray exposure history (EUGSTER, 1988; EUGSTER *et al.*, 1989). Even if Y-86032 was ejected and launched by the same impact as Y-82192/3, there is no need that it is actually paired (*i.e.*, being part of the same rock).

## 4. Conclusion

Chemical data have been used to demonstrate that the Yamato-86032 sample, which was recovered from Antarctica in 1986, is indeed of lunar origin. Major and trace element abundances are in perfect agreement with a lunar source. Elemental ratios such as Fe/Mn, Th/Sm, K/La, and others, may be used to show that the sample is an anorthositic rock from the lunar highlands. This is the sixth lunar "meteorite" and the fifth that has been analyzed in detail. The elemental abundances in Y-86032 are generally in the same range as in other lunar meteorites. The abundances of incompatible and lithophile elements, such as Zr, Hf, Ta, Th, or the REE's, are very low (lower than in ALHA-81005 or Y-791197) and comparable to Y-82192/3.

Other elements, in particular Fe, Ti, Sc, Cr, Mn, and Co, have lower abundances in Y-86032 than in Y-82192/3. Elemental ratios such as Fe/Sc, K/La, or Th/Sm show similar differences. Variations between individual analyses demonstrate that the rock itself is heterogeneous. Especially volatile and siderophile element abundances and ratios vary between individual chips. Additional analyses of different parts of the whole rock sample are needed to clarify if these differences are real, or partly related to interlaboratory bias. The large size of Y-86032 allows the allocation of larger samples to address important problems related to the origin and history of lunar meteorites.

Although at present it is difficult to determine the exact source location of the lunar meteorites in general, and of Y-86032 in particular, Y-86032 is a valuable addition to our Apollo and Luna collection of moon rocks, and an interesting sample from the lunar highlands.

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