Asuka 881757

Gabbro

442 g

Figure 1: Asuka 881757 gabbro with 1 cm cube.

Introduction

Asuka 881757 (also nicknamed Asuka 31; Fig. 1) was collected from the Nansen Icefield, near Asuka Station, by the JARE-20 meteorite search party December 20, 1989 (Fig. 2). One half of this 8.0 x 8.0 x 5.8 cm stone has a broken face without fusion crust and the other half is rounded with black shiny fusion crust (Fig. 1). It was recognized as an unbrecciated gabbro (Yanai and Kojima, 1991).

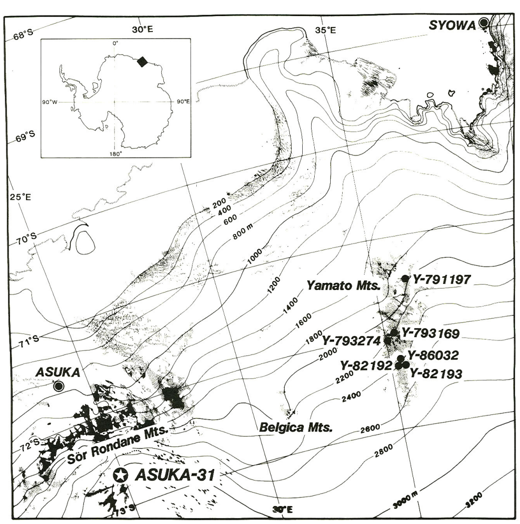


Figure 2: Location map for Asuka Station, Sør Rondane Mountains. Inset also shows locations for some of the lunar meteorites found by the ANSMET search teams.

Petrography and Mineralogy

Asuka 881757 exhibits a subhedral granular texture of coarse-grained pyroxene (59%) and plagioclase (30%), ilmenite (6%), and minor chromite, troilite, olivine (Fo_5 to Fo_{13}), apatite, FeNi metal, and fayalite-hedenbergite-silica symplectitites (Fig. 3; Yanai and Kojima, 1993).

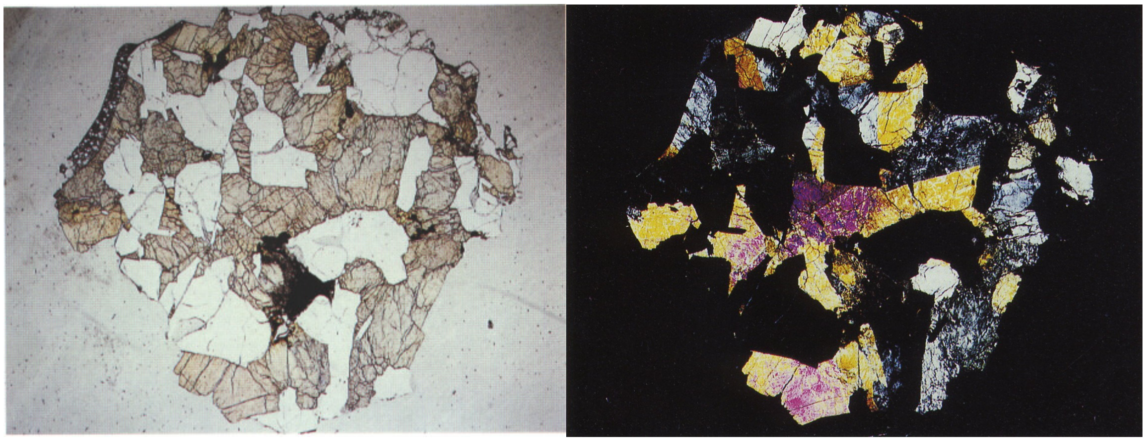
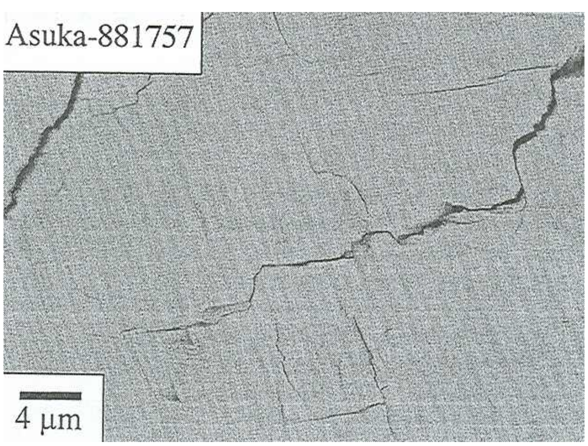


Figure 3: plane polarized light (left) and crossed polars (right) photomicrographs of Asuka 881757. Field of view is 2 mm (from Yanai and Kojima, 1991).

Plagioclase is lath shaped from 1 to 3 mm, completely maskelynitized (Fig. 3), and ranges from An_{96} to An_{75} (Ab_{4-23}; Or $_{0.1-2.3}$) (Yanai and Kojima, 1993). Pyroxene is the coarsest phase, with 2 to 4 mm crystals (Fig. 3), some of which contain fine exsolution lamellae (Fig. 4) and is zoned from low Ca and Mg#=50 cores to Ca- and Fe-rich rims. The symplectites (Fig. 5) have been attributed to the breakdown of pyroxferrite, at shallow levels in the lunar crust (Oba and Kobayashi, 2001; Mikouchi, 2001), which is reasonable given the ferroan nature of the pyroxenes (Fig. 6). This, together with the fine grained exsolution, suggests that the rock cooled slowly in the shallow crust. Spinels have chromian cores and more TiO_2-rich rims (Fig. 7).



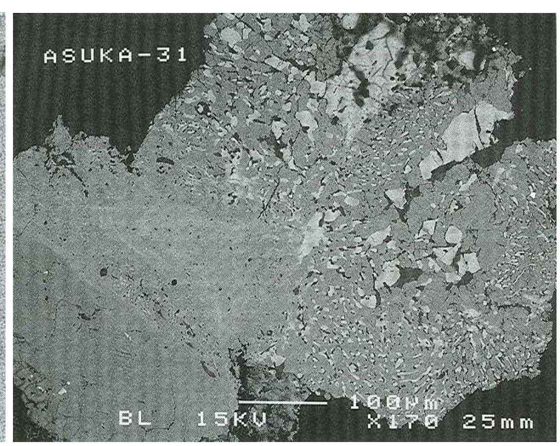
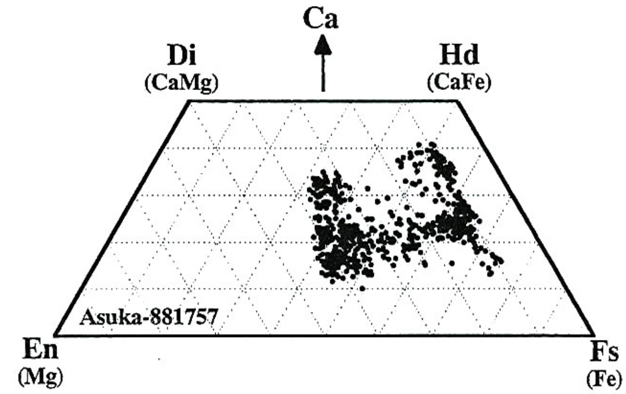


Figure 4 (left): fine exsolution lamellae in Asuka 881757 pyroxene (Mikouchi et al., 1999)
Figure 5 (right): symplectites of fayalite, silicate and hedenbergite in Asuka 881757 (Koeberl et al., 1993).



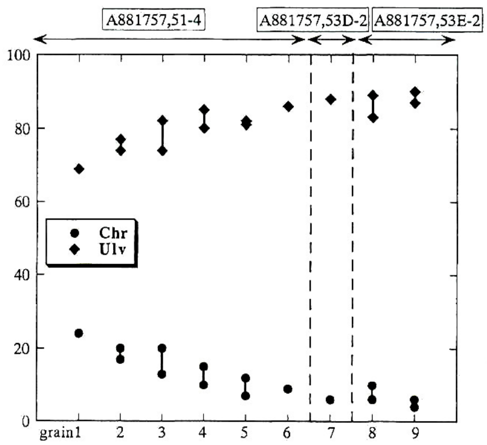
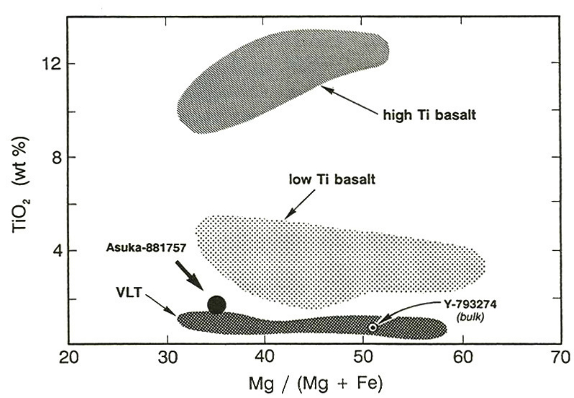


Figure 6 (left): Pyroxene compositional range found in Asuka 881757 (from Mikouchi, 1999).
Figure 7 (right): range of ülvospinel and chromite found within Asuka 881757 (from Arai et al., 1996).

Chemistry

Asuka 881757 has several distinctive compositional features (Table 1), including its low Mg# and Ti content giving it affinities with low Ti and VLT Apollo samples (Fig. 8). In addition, the high Sc contents (Fig. 9) are only observed in another basaltic lunar meteorite – Yamato 793169. The low V contents are consistent with an evolved nature, since V is mildly compatible in fractionation sequences. Rare earth element patterns determined in two different splits of this sample yield a flat pattern, with no slope and no Eu anomaly (Fig. 10). Siderophile contents are also low as exemplified by Ge (Warren and Kallemeyn, 1993). The low concentrations of highly siderophile elements Ir and Au suggest that meteoritic contamination of this sample is very low. In addition, the very low noble gas contents indicate Asuka 881757 did not reside very long (or at all) in the regolith before being ejected from the lunar surface (Nagao and Miura, 1993).



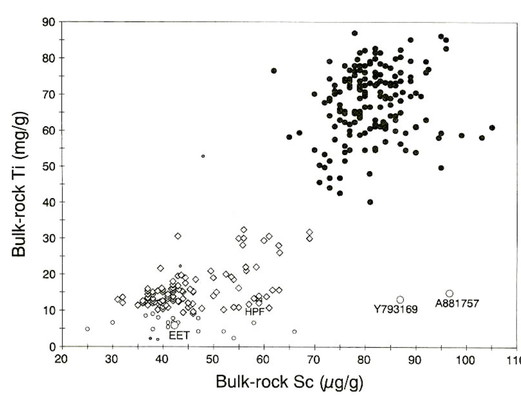


Figure 8: Mg/(Mg+Fe) vs TiO_2 for Asuka 881757 compared to very low TiO_2 (VLT), low TiO_2 and high TiO_2 basalt (from Koeberl et al., 1993).
Figure 9: Sc vs. Ti for Asuka 881757 illustrating the high Sc contents relative to Apollo basalt suites (from Warren and Kallemeyn, 1993).

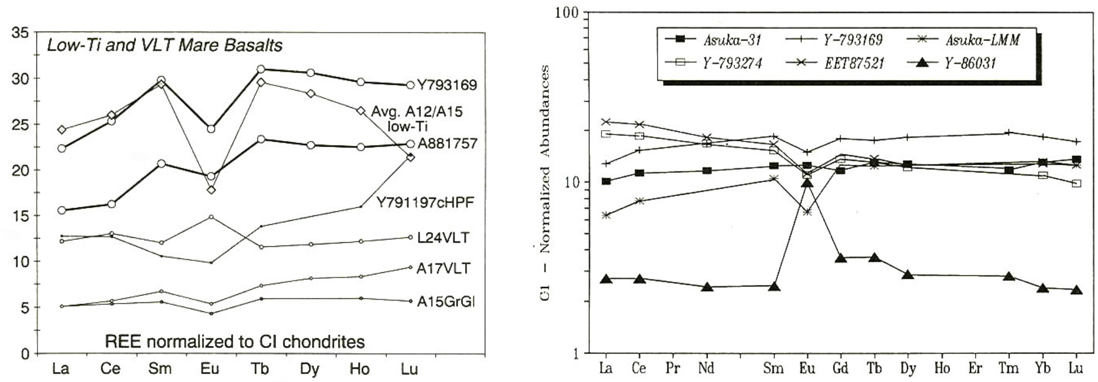


Figure 10: Chondrite normalized REE for Asuka 881757 from two different studies (Koeberl et al., 1993; Warren and Kallemeyn, 1993). Also shown for comparison are lunar samples from Apollo missions and other lunar meteorites.

Radiogenic age dating

First indication of an old age for this basalt came from K-Ar determination of 3.75 (±0.35) Ga (Nagao and Miura, 1993). Two compelling plateau ages on a glass fragment and a plagioclase crystal by Misawa et al. (1993) are 3.790 (±0.016) Ga and 3.808 (±0.018) Ga, respectively (Fig. 11). And more recent Ar-Ar age determinations by Fernandes et al. (2009) yield a plateau age of 3.699 Ga. Age determination by mineral and whole rock isochrons by both the Rb-Sr and Sm-Nd systems also yield consistent results of 3.840 (±0.032) Ga, and 3.871 (±0.057) Ga, respectively (Misawa et al., 1993; Fig. 12). Finally, U-Th-Pb isochrons result in a slightly older age for this sample, such as a 3.940 (±0.028) Ga, ^{206}Pb-^{238}Pb age of Misawa et al. (1992, 1993; Figure 13). The close correspondence between the ages of A-881757, and the Imbrium and Orientale basins have prompted the suggestion of a link (Misawa et al., 1993; Figure 14). The low U/Pb, Rb/Sr, and high Sm/Nd of the source of Asuka 881757 required by the isotopic work indicate derivation from melting a depleted olivine- and orthopyroxene-bearing mantle.

Furthermore, the combination of similar ages, mineralogy, bulk composition, and derived source region characteristics have led Arai et al. (2009) to conclude that Asuka 881757 is launch paired with Yamato 793169, MIL 05035, and MET 01210.

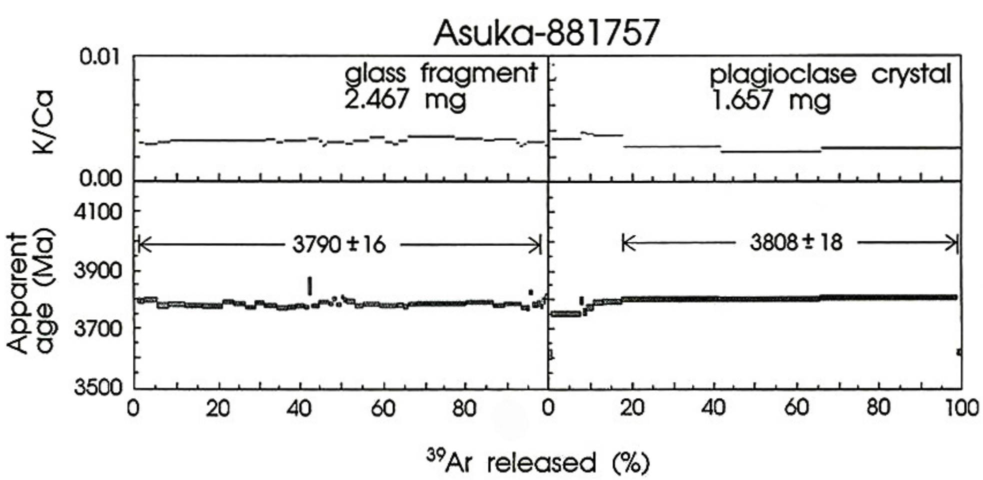


Figure 11: Ar-Ar ages and K/Ca ratios of glass fragment and a plagioclase crystal from Asuka 881757 (from Misawa et al., 1993b).

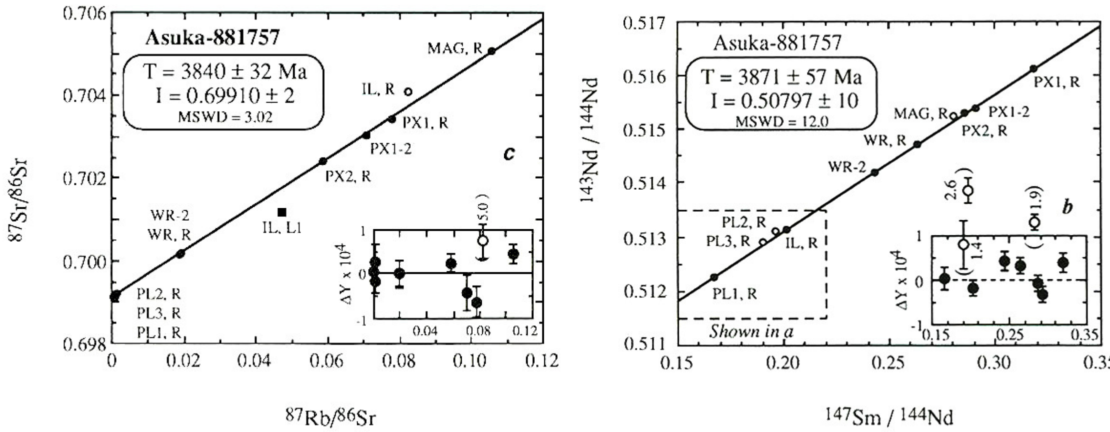


Figure 12: Rb-Sr isochron (left) and Sm-Nd isochron (right) for Asuka 881757 based on pyroxene, plagioclase, ilmenite, magnetic and whole rock fractions (Misawa et al., 1993b).

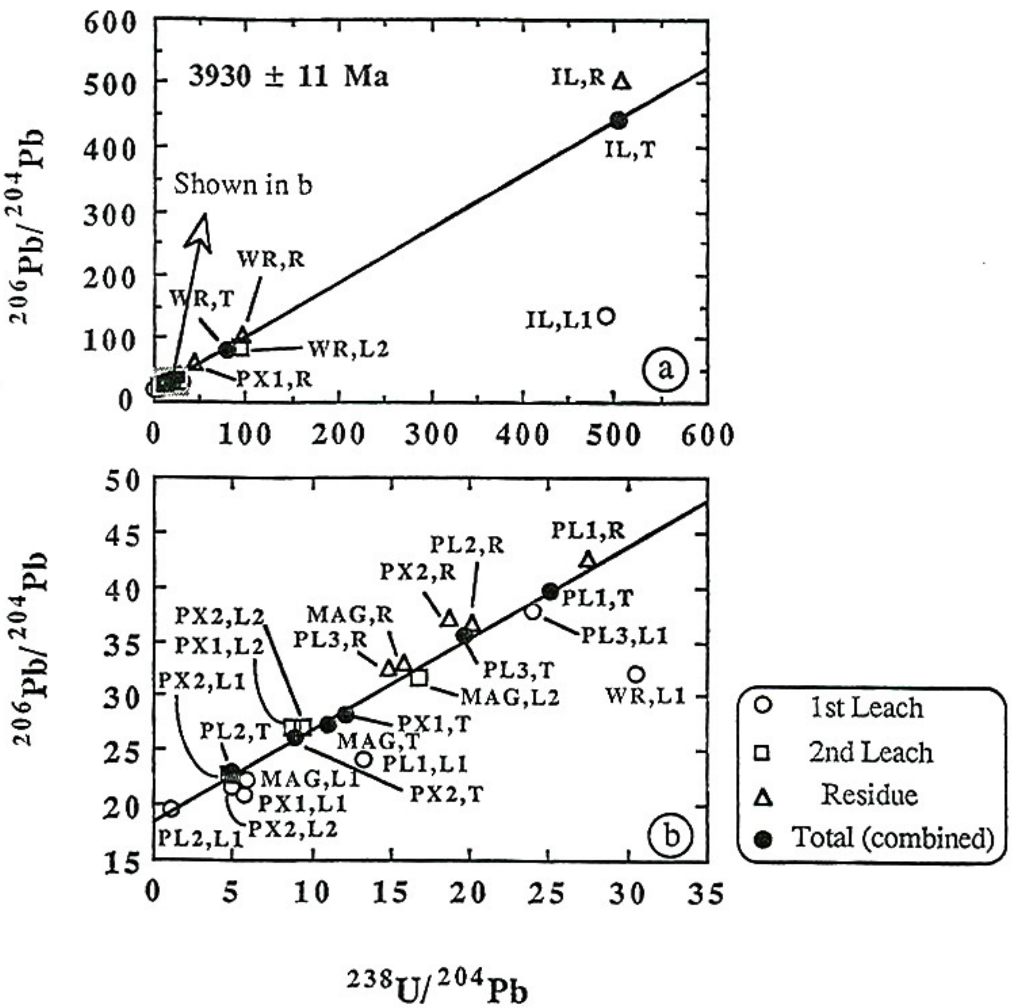


Figure 13: Pb isochron based on ^{206}Pb and ^{238}Pb for pyroxene, plagioclase, ilmenite, magnetic, and whole rock fractions from Asuka 881757 (from Misawa et al., 1993a).

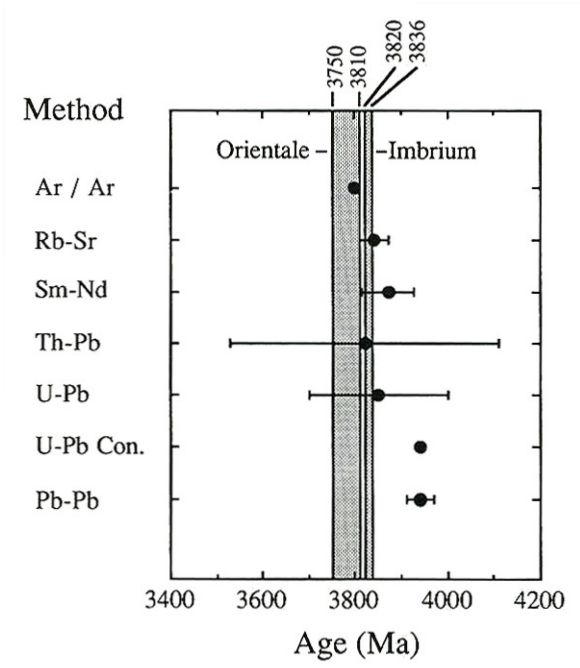


Figure 14: Summary of ages determined for Asuka 881757, illustrating that some may have been reset during the Imbrium or Orientale events (from Misawa et al., 1993a).

Cosmogenic isotopes and exposure ages

Asuka 881757 contains very little or no solar noble gases, indicating that it resided in the top layer of the lunar regolith for only a brief time, if at all (< 1 Ma based on ^{21}Ne, ^{38}Ar, ^{78}Kr, ^{83}Kr, and ^{126}Xe; Thalmann et al., 1996). The transit age (0.9 ±0.1 Ma) and terrestrial ages (< 0.05 Ma) were determined by Nishiizumi et al. (1992) using ^{10}Be, ^{26}Al, and ^{36}Cl (Fig. 15).

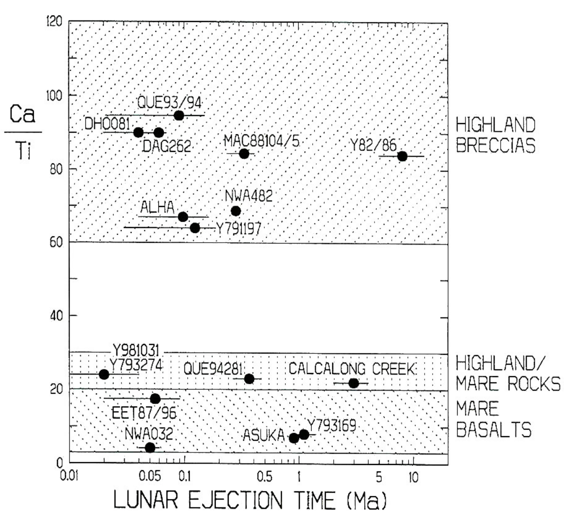


Figure 15: Ejection age of Asuka 881757 determined by Nishiizumi et al. (1992) at approximately 1 Ma (Figure from Eugster, 2003).

Table 1a. Chemical composition of Asuka 881757

reference	1	2	2	3	3	4
weight		108.3	126.25			246.3
method	d	c	c	c	c	c
SiO2 %	45.36			47.06	47.06	
TiO2	1.66			2.45	2.45	
Al2O3	11.49			9.95	10.01	
FeO	21.72	23.29	22.64	22.00	22.51	23
MnO	0.25			0.34	0.34	
MgO	6.41			6.20	6.30	
CaO	11.99			11.47	11.75	11.9
Na2O	0.50	0.30	0.28	0.25	0.25	0.254
K2O	0.04	0.04	0.04	0.04	0.04	
P2O5	0.05					
S %	0.19					
sum						
Sc ppm		101	98	97	96	93.9
V				88		
Cr	1163	1930	1850	2040	1980	2066
Co		27.9	27.9	24.9	24.3	24.1
Ni		60	45	13.2	<35	<150
Cu						
Zn		3	2	1.72	<16	
Ga		2.5	3	2.2	2.8	
Ge				3.9		
As		0.065	0.06			
Se		<.7	<0.5			
Rb		2.3	2.8			
Sr		110	120	128	112	140
Y						
Zr		40	50	97	<110	135
Nb						
Mo						
Ru						
Rh						
Pd ppb						
Ag ppb		<200	<200			
Cd ppb						
In ppb						
Sn ppb						
Sb ppb		<40	<30			
Te ppb						
Cs ppm		0.038	0.037			<0.7
Ba		30	25	65	50	60
La		3.75	3.64	3.7	3.3	3.31
Ce		11.5	10.3	10	8.7	9.1

Pr					
Nd	8.9	7.8	7.7	7.8	<35
Sm	2.96	2.81	3.08	2.96	3
Eu	1.07	1.12	1.08	1.03	1.02
Gd	3.86	3.35			
Tb	0.81	0.72	0.83	0.84	0.85
Dy	5.3	4.5	5.5	6	
Ho			1.24	1.39	
Er					
Tm	0.49	0.36			
Yb	3.64	2.94	3.8	3.48	3.57
Lu	0.56	0.49	0.56	0.54	0.534
Hf	2.37	2.05	2.26	2.18	2.53
Ta	0.23	0.22	0.31	0.28	0.32
W ppb	84	73			
Re ppb			0.016		
Os ppb			380		
Ir ppb	<1	0.3	310	<2000	<12
Pt ppb					
Au ppb	0.3	0.2	140	<3000	<9
Th ppm	0.43	0.42	0.48	0.44	0.45
U ppm	0.21	0.11			<0.75

technique (a) ICP-AES, (b) ICP-MS, (c) INAA (d) wet chemistry

Table 1b. Light and/or volatile elements for Asuka 881757

Li ppm		
Be		
C		
S		
F ppm		
Cl		
Br	0.1	0.12
I		
Pb ppm		
Hg ppb	<2000	<2000
Tl		
Bi		

1) Yanai and Kojima (1991); 2) Koeberl et al. (1993); 3) Warren and Kallemeyn (1993); 4) Korotev et al. (2003)