15386

KREEP Basalt

7.5 grams


Figure 1: Photos of front and back of 15386. Rock is 2 cm across. NASA #s S76-24073 and 24072.

Introduction

15386 is the largest sample of pristine KREEP basalt in the collection (figure 1). By pristine we mean that it is lacking in meteoritical siderophiles (Ir, Re, Au etc), and hence not contaminated by meteorite debris. Thus it is thought to represent an indogenous lunar volcanic melt derived from the lunar interior (see discussion in 15382).

Petrography

Steele et al. (1972) and Takeda et al. (1978) give very brief descriptions of 15386. Plagioclase laths are surrounded by interstitial pyroxene (figure 2). The mesostasis has significant cristobalite (10%), ilmenite plates (3%), and minor phosphate, iron and sulfide.

Mineralogy

Pyroxene: The cores of pyroxene crystals are Mg-rich orthopyroxene (Takeda et al. 1978). They are surrounded (overgrown) by pigeonite with patches or rims of subcalcic augite (figure 3).

Plagioclase: Steele et al. (1972) report that plagioclase in 15386 is An_{85-70} and contains minor amounts of FeO (0.2 wt %).

Cristobalite: Steele et al. (1972) report a significant amount of cristobalite (10%).

Opaques: Not studied.

Mineralogical Mode for 15386

	Steele et al. 1972	Simonds et al. 1975	Taylor et al. 1991
Pyroxene	50 %	50	43
Plagioclase	35		43
Cristobalite	10		8
Ilmenite	3		3
mesostasis			

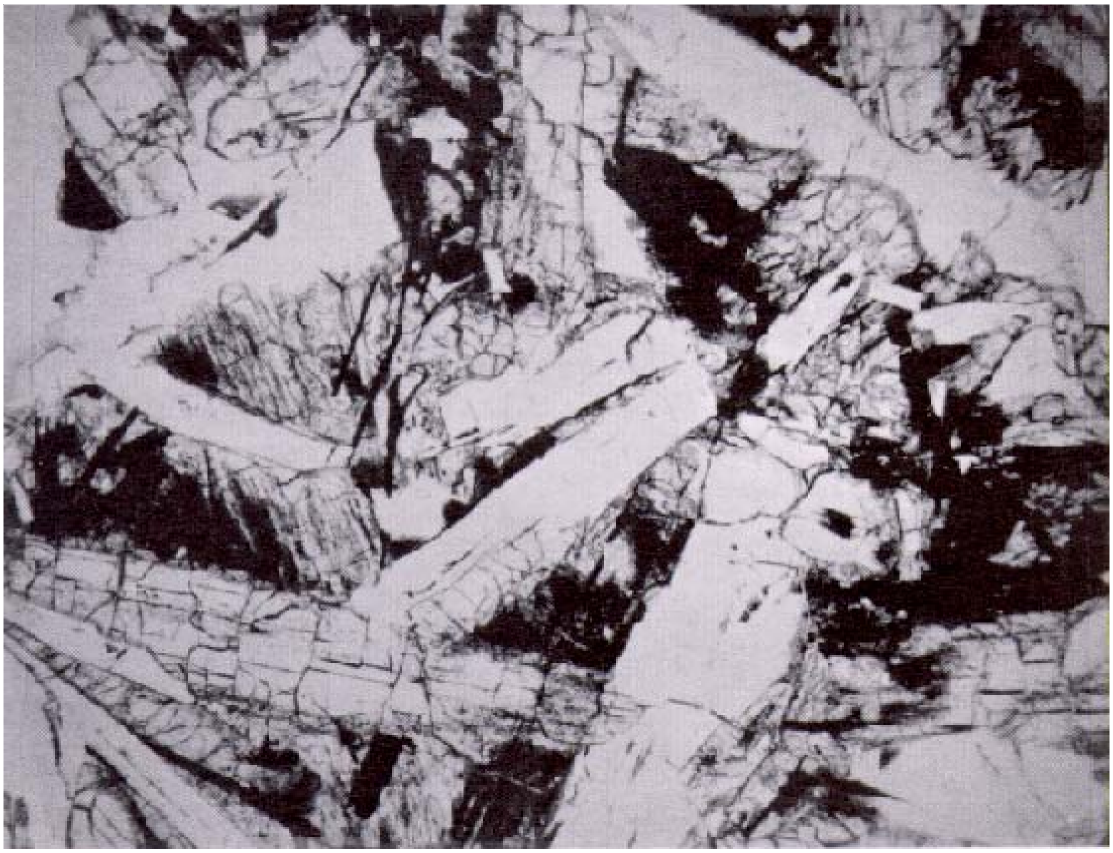


Figure 2: Photomicrograph of thin section of 15386. Field of view 2 mm.

Mesostasis: The mesostasis in 15386 was studied by Takeda et al. (1984) who found that the REE were located in whitlockite.

Chemistry

The chemical composition of 15386 is tabulated in table 1. The rare-earth-element pattern is parallel to that of "KREEP" (figure 4). When the major element composition is plotted on the Si-Ol-An pseudoternary phase diagram (figure 7), 15386 is found to be on the liquidus between plagioclase and pyroxene. Meteoritical siderophiles are low and, thus, this sample of KREEP is judged to be pristine (Ebihara et al. 1992, Warren and Wasson 1978).

Radiogenic age dating

Nyquist et al. (1975) and Carlson and Lugmair (1979) determined the age of 15386 by Rb/Sr and Sm/Nd internal mineral isochrons (figures 5 and 6).

Carlson and Lugmair (1979) determined the whole rock Sm and Nd isotopic composition and calculated the "whole rock" age at ~ 4.36 b.y. which is interpreted by them as the closure age of the initial global scale lunar differentiation.

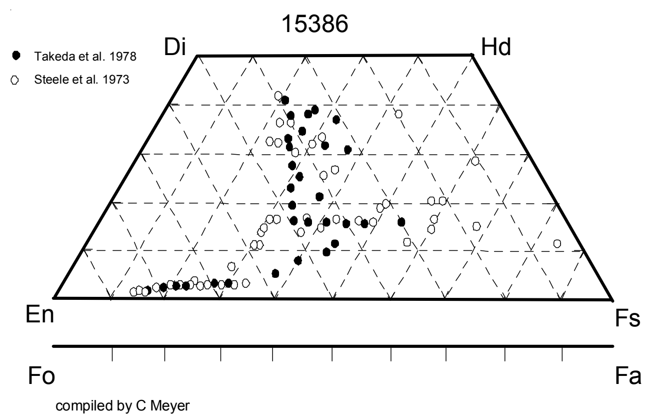


Figure 3: Pyroxene diagram for 15386 with data replotted from Steele et al. (1972) and Takeda et al. (1978). There is no olivine.

Unruh and Tatsumoto (1983) reported Lu and Hf isotopes and Lee et al. (1997) determined the W isotopes in 15386.

The age of Apollo 15 KREEP basalts (~3.9 b.y.) is indistinguishable from the age of the Imbrium basin.

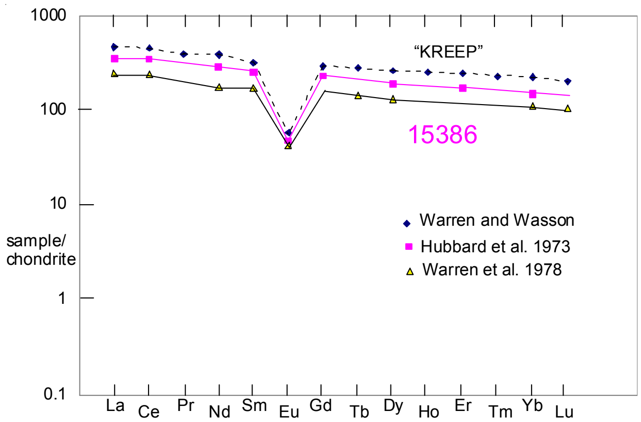


Figure 4: Normalized rare-earth-element diagram for 15386 with data from Hubbard et al. (1973) and Warren et al. (1978). Data for "KREEP" is included for comparison.

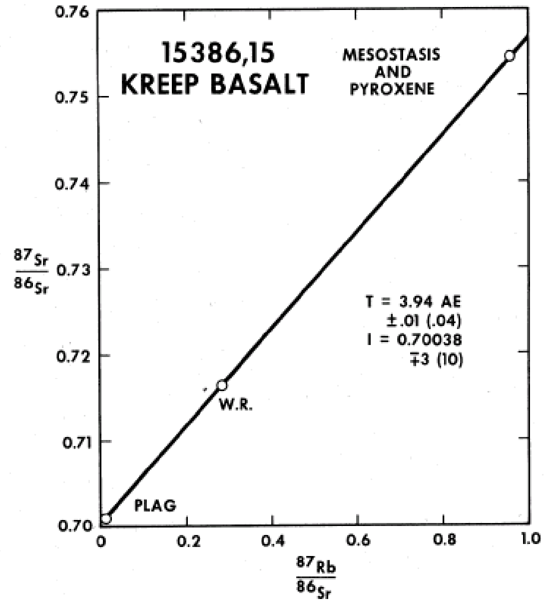


Figure 5: Rb-Sr internal mineral isochron for 15386 from Nyquist et al. (1975).

Cosmogenic isotopes and exposure ages

O'Kelley et al. (1976) determined ^{26}Al as 94 ± 9 dpm/kg.

Other Studies

Walker et al. (1973) first determined the phase diagram for nonmare lunar basalts (figure 7). The composition of 15386 lies near the cotectic between plagioclase and pyroxene.

Crystallization experiments on KREEP-like liquids have been reported by Irving (1977), Rutherford et al. (1980), and Dickinson and Hess (1982).

There are 5 thin sections.

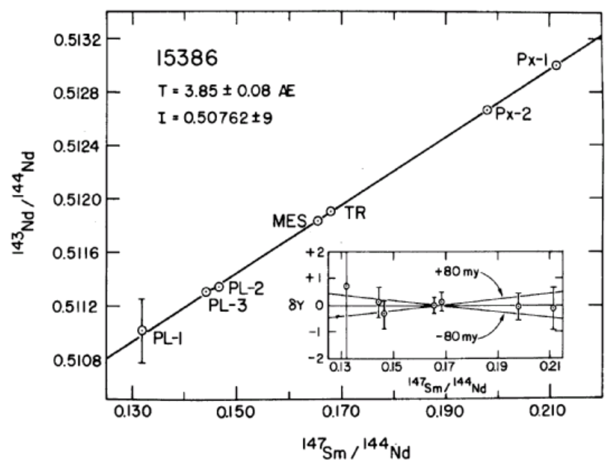


Figure 6: Sm-Nd internal mineral isochron for 15386 from Carlson and Lugmair (1979).

Summary of Age Data for 15386

	Rb/Sr	Ar/Ar	Sm/Nd
Nyquist et al. 1975	3.94 ± 0.01		
Carlson and Lugmair 1979			3.85 ± 0.08

Caution: These ages have not been corrected for new decay constants.

Table 1. Chemical composition of 15386.

	O'Kelley76		Hubbard 74		Rhodes 73		Warren78		Ebihara92		Nyquist75	Unruh84	Lee 97		Neal2003	
reference											Carlson79					
weight																
SiO2 %					50.83	(c)										
TiO2			2.25	(b)	2.23	(c)	1.93	(d)								
Al2O3					14.77	(c)	15.3	(d)								
FeO					10.55	(c)	10.16	(d)								
MnO					0.16	(c)	0.148	(d)								
MgO					8.17	(c)	10.44	(d)								
CaO					9.71	(c)	9.51	(d)								
Na2O			0.82	(b)	0.73	(c)	0.82	(d)								
K2O	0.6	(a)	0.69	(b)	0.67	(c)	0.5	(d)								
P2O5					0.7	(c)										
S %					0.09	(c)										
sum					98.61											
Sc ppm							22	(d)							21.7	(c)
V							62	(d)							47.8	(c)
Cr							2430	(d)							1760	(c)
Co							23	(d)							24.1	(c)
Ni							12.5	(d)	6.42	(e)					13.9	(c)
Cu															14.6	(c)
Zn							3.5	(d)	2.56	(e)					25	(c)
Ga							6.2	(d)							6.8	(c)
Ge ppb							61	(d)	65.6	(e)						
As																
Se									67.6	(e)						
Rb			18.46	(b)			14	(d)	17	(e)	18.46			(b)	18.7	(c)
Sr			187	(b)							187.4			(b)	186.5	(c)
Y															241	(c)
Zr							970	(d)							916	(c)
Nb															72.4	(c)
Mo															0.21	(c)
Ru																
Rh																
Pd ppb									<0.8	(e)						
Ag ppb									0.592	(e)						
Cd ppb							10	(d)	8.56	(e)						
In ppb							1.8	(d)	2.38	(e)						
Sn ppb															0.06	(c)
Sb ppb									0.605	(e)					0.02	(c)
Te ppb									<1.8	(e)						
Cs ppm							0.8	(d)	0.746	(e)					0.76	(c)
Ba			837	(b)			650	(d)							852.6	(c)
La			83.5	(b)			58	(d)							84.1	(c)
Ce			211	(b)			147	(d)							213.1	(c)
Pr															30	(c)
Nd			131	(b)			80	(d)			129.6			(b)	125.6	(c)
Sm			37.5	(b)			25.5	(d)			36			(b)	36.5	(c)
Eu			2.72	(b)			2.4	(d)							2.78	(c)
Gd			45.4	(b)											43.9	(c)
Tb							5.3	(d)							7.51	(c)
Dy			46.3	(b)			32	(d)							45.7	(c)
Ho															10.3	(c)
Er			27.3	(b)											28.3	(c)
Tm															3.97	(c)
Yb			24.4	(b)			18.2	(d)							26.2	(c)
Lu							2.58	(d)				3.193		(b)	3.59	(c)
Hf							21	(d)				26.228	30.51	(b)	27.3	(c)
Ta							2.4	(d)							3.81	(c)
W ppb													1743	(b)	1.38	(c)
Re ppb									0.016	(e)						
Os ppb									<0.09	(e)						
Ir ppb							0.061	(d)	0.004	(e)						
Pt ppb																
Au ppb							0.22	(d)	0.012	(e)						
Th ppm	11.8	(a)	13.7	(b)			10	(d)							15.4	(c)
U ppm	3.3	(a)	3.98	(b)			2.8	(d)	3.75	(e)					4	(c)

technique (a) radiation counting, (b) IDMS, (c) XRF, (d) INAA, RNAA, (e) RNAA, (f) ICP-MS

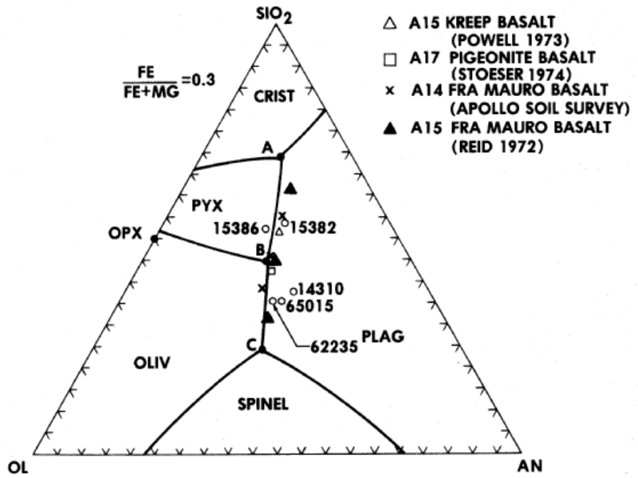
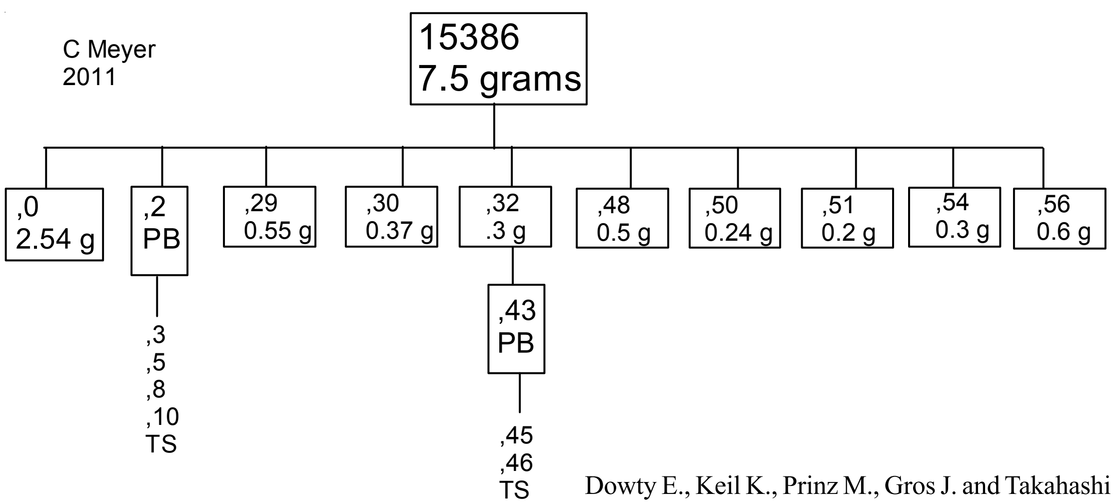


Figure 7: Projection of phase diagram for Fe/Fe+Mg = 0.3 as determined by Walker et al. (1973), showing that the composition of 15386 is near the cotectic between pyroxene and plagioclase (figure from Meyer 1977).



References for 15386

Basu A., Holmberg B.B. and Molinaroli E. (1992) Origin of yellow glasses associated with Apollo 15 KREEP basalt fragments. *Proc. 22nd Lunar Planet. Sci. Conf.* 365-372. Lunar Planetary Institute, Houston.

Butler P. (1971) Lunar Sample Catalog, Apollo 15. Curators' Office, MSC 03209

Carlson R.W. and Lugmair G.W. (1979b) Sm-Nd constraints on early lunar differentiation and the evolution of KREEP. *Earth Planet. Sci. Lett.* **45**, 123-132.

Crawford M.L. and Hollister L.S. (1974) KREEP basalt: a possible partial melt from the lunar interior. *Proc. 5th Lunar Sci. Conf.* 399-419.

Dowty E., Keil K., Prinz M., Gros J. and Takahashi H. (1976) Meteorite-free Apollo 15 crystalline KREEP. *Proc. 7th Lunar Sci. Conf.* 1833-1844.

Ebihara M., Wolf R., Warren P.H. and Anders E. (1992) Trace elements in 59 mostly highland moon rocks. *Proc. 22nd Lunar Planet. Sci. Conf.* 417-426. Lunar Planetary Institute, Houston

Gros J., Takahashi H., Hertogen J., Morgan J.W. and Anders E. (1976) Composition of the projectiles that bombarded the lunar highlands. *Proc. 7th Lunar Sci. Conf.* 2403-2425.

Haines E.L. and Weiss J.R. (1978) KREEP fission track ages from Hadley Delta (abs). *Lunar Sci.* **IX**,, 448-450.

Hess P.C., Rutherford M.J. and Campbell H.W. (1978) Ilmenite crystallization in nonmare basalt: Genesis of

KREEP and high-Ti mare basalt. *Proc. 9th Lunar Planet. Sci. Conf.* 705-724.

Hollister L.S. and Crawford M.L. (1977) Melt immiscibility in Apollo 15 KREEP: Origin of the Fe-rich mare basalts. *Proc. 8th Lunar Sci. Conf.* 2419-2432.

Hubbard N.J., Gast P.W., Rhodes J.M., Bansal B.M., Wiesmann H. and Church S.E. (1972a) Nonmare basalts: Part II. *Proc. 3rd Lunar Sci. Conf.* 1161-1179.

Hubbard N.J., Rhodes J.M., Gast P.W., Bansal B.M., Shih C.-Y., Wiesmann H. and Nyquist L.E. (1973b) Lunar rock types: The role of plagioclase in non-mare and highland rock types. *Proc. 4th Lunar Sci. Conf.* 1297-1312.

Lee D-C., Halliday A.N., Snyder G.A. and Taylor L.A. (1997) Age and origin of the Moon. *Science* **278**, 1098-1103.

LSPET (1972a) The Apollo 15 lunar samples: A preliminary description. *Science* **175**, 363-375.

LSPET (1972b) Preliminary examination of lunar samples. Apollo 15 Preliminary Science Report. NASA SP-289, 6-1—6-28.

Lugmair G.W. and Carlson R.W. (1978) The Sm-Nd history of KREEP. *Proc. 9th Lunar Planet. Sci. Conf.* 689-704.

McKay G.A. and Weill D. (1976) The petrogenesis of KREEP. *Proc. 7th Lunar Sci. Conf.* 2427-2447.

McKay G.A. and Weill D. (1977) KREEP petrogenesis revisited. *Proc. 8th Lunar Science Conf.* 2339-2355.

Meyer C. (1972) Mineral assemblages and the origin of non-mare lunar rock types (abs). *Lunar Sci*. **III,** 542-544. Lunar Planetary Institute, Houston.

Meyer C. (1977) Petrology, mineralogy and chemistry of KREEP basalt. *Physics and Chemistry of the Earth* **10**, 239-260. (Ahrens and Runcorn , eds)

Neal C.R. and Kramer G.Y. (2003) The composition of KREEP: A detailed study of KREEP basalt 15386 (abs#1665). *Lunar Planet. Sci*. **XXXIV,** Lunar Planetary Institute, Houston.

Nyquist L.E., Hubbard N.J., Gast P.W., Bansal B.M., Wiesmann H. and Jahn B-M. (1973) Rb-Sr systematics for chemically defined Apollo 15 and 16 materials. *Proc. 4th Lunar Sci. Conf.* 1823-1846.

Nyquist L.E., Bansal B.M. and Wiesmann H. (1975a) Rb-Sr ages and initial $^{87}Sr/^{86}Sr$ for Apollo 17 basalts and KREEP basalt 15386. *Proc. 6th Lunar Sci. Conf.* 1445-1465.

Nyquist L.E., Bansal B.M, and Wiesmann H. (1975b) Rb-Sr ages and initial $^{87}Sr/^{86}Sr$ for Apollo 17 basalts and KREEP basalt 15386 (abs). *Lunar Sci.* **VI**, 610-612. Lunar Planetary Institute, Houston.

O'Kelley G.D., Eldridge J.S., Northcutt K.J. and Schonfeld E. (1976) Radionuclide concentrations of KREEP basalt samples 15382 and 15386 (abs). *Lunar Sci.* **VII**, 651-652.

Papanastassiou D.A. and Wasserburg G.J. (1976b) Early lunar differentiates and lunar initial $^{87}Sr/^{86}Sr$ (abs). *Lunar Sci.* **VII**, 665-667. Lunar Planetary Institute, Houston.

Papanastassiou D.A., DePaolo D.J., Tera F. and Wasserburg G.J. (1976c) An isotopic triptych on mare basalts: Rb-Sr, Sm-Nd, U-Pb. *Lunar Science* **VIII**, 750-752. Lunar Planetary Institute, Houston.

Rhodes J.M. and Hubbard N.J. (1973) Chemistry. classification, and petrogenesis of Apollo 15 mare basalts. *Proc. 4th Lunar Sci. Conf.* 1127-1148.

Ryder G. (1985) Catalog of Apollo 15 Rocks (three volumes). Curatoial Branch Pub. # 72, JSC#20787

Ryder G. (1987) Petrographic evidence for nonlinear cooling rates and a volcanic origin for Apollo 15 KREEP basalt. *Proc. 17th Lunar Planet. Sci. Conf.* in J. Geophys. Res. **92**, E331-E339.

Ryder G. (1988) Quenching and disruption of lunar KREEP lava flows by impacts. *Nature* **336**, 751-754.

Shih C.-Y. (1977) Origins of KREEP basalts. *Proc. 8th Lunar Sci. Conf.* 2375-2401.

Simonds C.H., Warner J.L. and Phinney W.C. (1975b) The petrology of the Apennine Front revisited. *Lunar Sci.* **VI**, 744-746.

Spudis P.D. (1978) Composition and origin of the Apennine Bench Formation. *Proc. 9th Lunar Planet. Sci. Conf.* 3379-3394.

Steele I.M., Smith J.V. and Grossman Larry (1972a) Mineralogy and petrology of Apollo 15 rake samples: I. Basalts. *In* **The Apollo 15 Lunar Samples** 158-160. Lunar Planetary Institute, Houston.

Steele I.M., Smith J.V. and Grossman L. (1972b) Mineralogy and petrology of Apollo 15 rake samples: II. Breccias. *In* **The Apollo 15 Lunar Samples** 161-164. Lunar Planetary Institute, Houston.

Swann G.A., Hait M.H., Schaber G.C., Freeman V.L., Ulrich G.E., Wolfe E.W., Reed V.S. and Sutton R.L. (1971b)

Preliminary description of Apollo 15 sample environments. U.S.G.S. Interagency report: 36. pp219 with maps

Swann G.A., Bailey N.G., Batson R.M., Freeman V.L., Hait M.H., Head J.W., Holt H.E., Howard K.A., Irwin J.B., Larson K.B., Muehlberger W.R., Reed V.S., Rennilson J.J., Schaber G.G., Scott D.R., Silver L.T., Sutton R.L., Ulrich G.E., Wilshire H.G. and Wolfe E.W. (1972) 5. Preliminary Geologic Investigation of the Apollo 15 landing site. In Apollo 15 Preliminary Science Rpt. NASA SP-289. pages 5-1-112.

Takeda H., Miyamoto M., Duke M. and Ishii T. (1978) Crystallization of pyroxenes in lunar KREEP basalt 15386 and meteoritic basalts. *Proc. 9th Lunar Planet. Sci. Conf.* 1157-1171.

Takeda H., Mori H., Ishii T. and Miyamoto M. (1984) Mesostasis-rich lunar and eucritic basalts with reference to REE-rich minerals (abs). *Lunar Planet. Sci.* **XV**, 842-843.

Unruh D.M., Stille P., Patchett P.J. and Tatsumoto M. (1984) Lu-Hf and Sm-Nd evolution in lunar mare basalts. *Proc. 14th Lunar Planet. Sci. Conf.* in J. Geophys. Res. **88**, B459-B477.

Walker D., Grove T.L., Longhi J., Stopler E.M. and Hays J.F. (1973a) Origin of lunar feldspathic rocks. *Earth Planet. Sci. Lett*. **20**, 325-336.

Warren P.H. and Wasson J.T. (1978) Compositional-petrographic investigation of pristine nonmare rocks. *Proc. 9th Lunar Planet. Sci. Conf.* 185-217.

Wiesmann H. and Hubbard N.J. (1975) A compilation of the Lunar Sample Data Generated by the Gast, Nyquist and Hubbard Lunar Sample PI-Ships. Unpublished. JSC