15597

Vitrophyric Pigeonite Basalt

145.7 grams

Figure 1: Exposed surface of 15597 showing numerous micrometeorite craters. Sample is 7 cm across. NASA S71-44457.

Introduction

Lunar sample 15597 was collected from the soil near the edge of Hadley Rille in an area called The Terrace (see transcript). It has a texture similar to the boulder sampled nearby (see 15595). The "plagioclase clusters" that the CDR (Scott) described on the surface, are, in fact, large pigeonite phenocrysts. The surfaces of 15597 are covered with zap pits (figure 1).

15597 is thought to be an important lunar sample, because it was quenched from high temperature giving important insight to the crystallization history and cooling rate of lunar basalts. Its bulk composition has also been interpreted as that of primary undifferentiated liquid formed by partial melting at depth and giving information of the lunar interior. Ryder (1985) presents an excellent review of the petrology of 15597.

Petrography

Weigand and Hollister (1973) described "sample 15597 as a pyroxene vitrophyre (figures 2 and 3) consisting mainly of acicular pyroxene phenocrysts, typically with a glass core, set in a matrix of brown glass which shows incipient crystallization in only a few places. The texture is locally variolitic. The pyroxene crystals are composed of a pigeonite center epitaxially rimmed by

TRANSCRIPT

CDR . . Let's go down and get a chunk of the bedrock here.
LMP Oh, you're getting the bedrock here, huh?
CDR Yes
LMP Okay. I thought you were going to press on to the north.
CDR Well, he said go get the bedrock, and I think we ought to try and get it if we can. Because this sure looks like bedrock to me. I looked at the rille and down the rille to the south, and it's just one great big massive layer of the same type of fragmental debris on the order of meters. Quite well-rounded.
LMP Yes, but the thing that bothers me, Dave, is look to the north there, it looks like int might be the top of the bedrock. And those blocks are – seem to be slightly different.
CDR Darker. - - - A little darker.
LMP - - - almost have columnar jointing. Look to the north there.
CDR Yes, I see what you are talking about. Come on down here and let's get a frag off of one of these boulders and then we'll head on back to the rover. - - That's a good one - - -Hey, Joe, these rounded fragments down here are on the order of meters in

Mineralogical Mode of 15597

	Catalog Butler 1971	Papike et al. 1976	Weigand and Hollister 1973
Olivine			
Pyroxene	59 %	50.1	59
Plagioclase			
Opaque	0.3	<0.1	1
Groundmass	41	49.9	
Glass			35

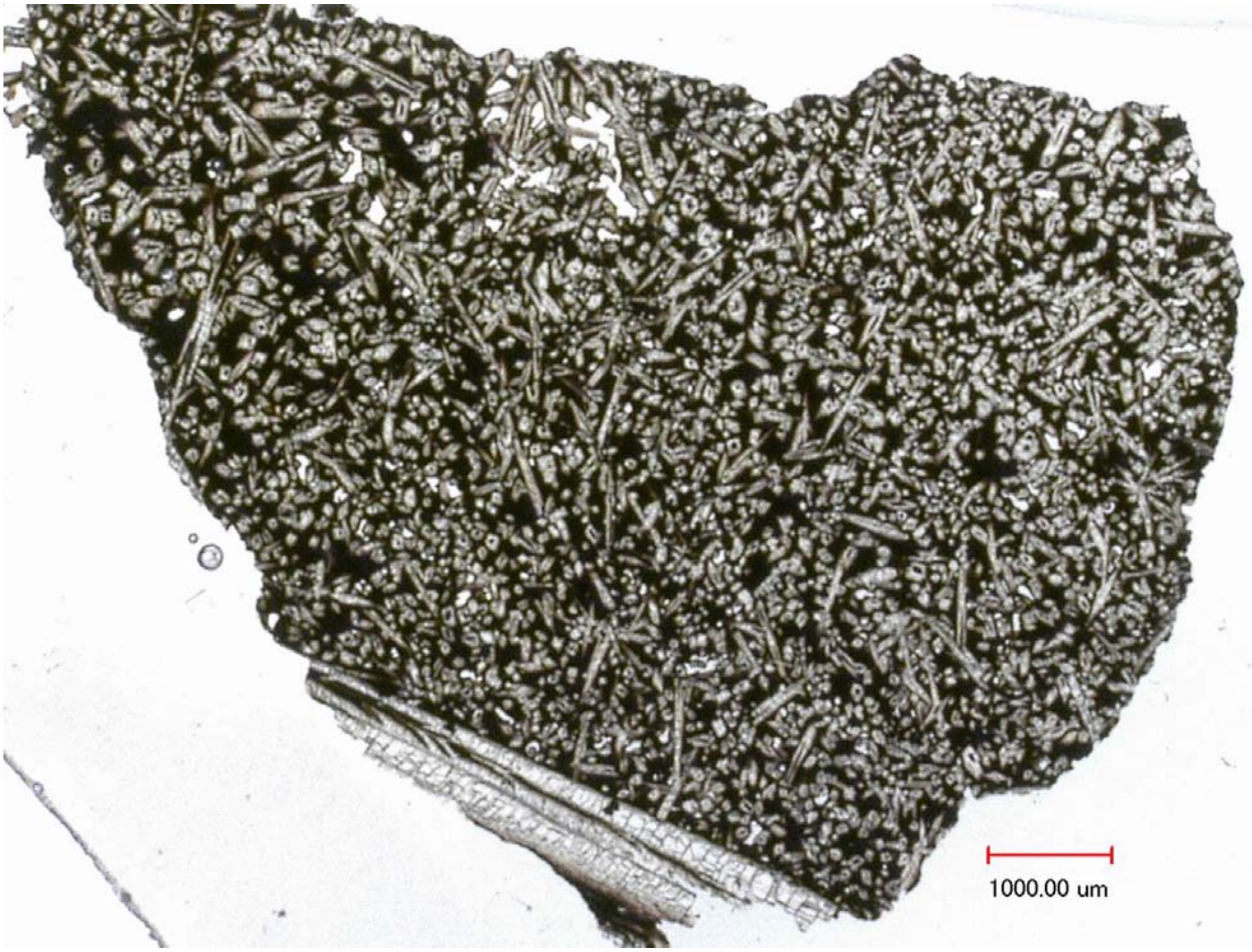


Figure 2: Photomicrograph of thin section 15597,12 by C Meyer @ 30x.

augite. Scattered chromium spinel euhedral and native iron globules also occur. Vesicles range in size from a few tens to ~ 500 microns." Drever et al. (1973) and Donaldson et al. (1977) described and explained the importance of radiate texture of pyroxene showing that they are not accumulations, but the result of rapid cooling. Other vitrophyres found at Apollo 15 include 15595, 15596, 15485, 15486 and 15499.

The bulk composition of 15597 was used for numerous experimental studies (Grove and Bence 1977; Grove and Raudsapp 1978; Grove and Lindsley 1979).

Residual glass has very high Fe/Mg ratio.

The cooling rate of 15597 has been much discussed (Lofgren et al. 1974, 1975 and 1979; Grove and Walker 1977; Donaldson et al. 1977; Grove 1982)

size; expose some very large – oh, – 3 cm vesicles – rather than the finer stuff that Jim saw back there before.

CDR And I believe, when I take a chip out of this, we're going to find it's the same kind of crystalline basalt. And they're all – well, they're subangular – looks like they've been weathered. Fairly clean on the surface and all buried. And I can look down to the south, and it's just a whole mass of great big boulders along the terrace here. And there's another breakoff down into the rille. And I'm – I guess, we're just about at the lip. - - - Beautiful stuff. Okay: I got them all loaded in the bag (15595, 15596?).

CDR Okay. This is a - looks like a darker, fine-grained, black, vesicular basalt, with vesicles on the order of mm. (15597?) Nonuniformly distributed. There are a mass of plagioclases about 3 mm long, and it may be a half a mm wide, randomly oriented throughout. And that's about the only mineral I see. And that – did you get the number on that, Jim,?

LMP I gave it to them.

CDR There's one other frag down there that fell. About like that. Let me get a couple of rounded ones, too, that are just on the surface. I can't tell what that is, but we'll put it in anyway, as representative of surface material – at least the fragmental surface. (15598?)

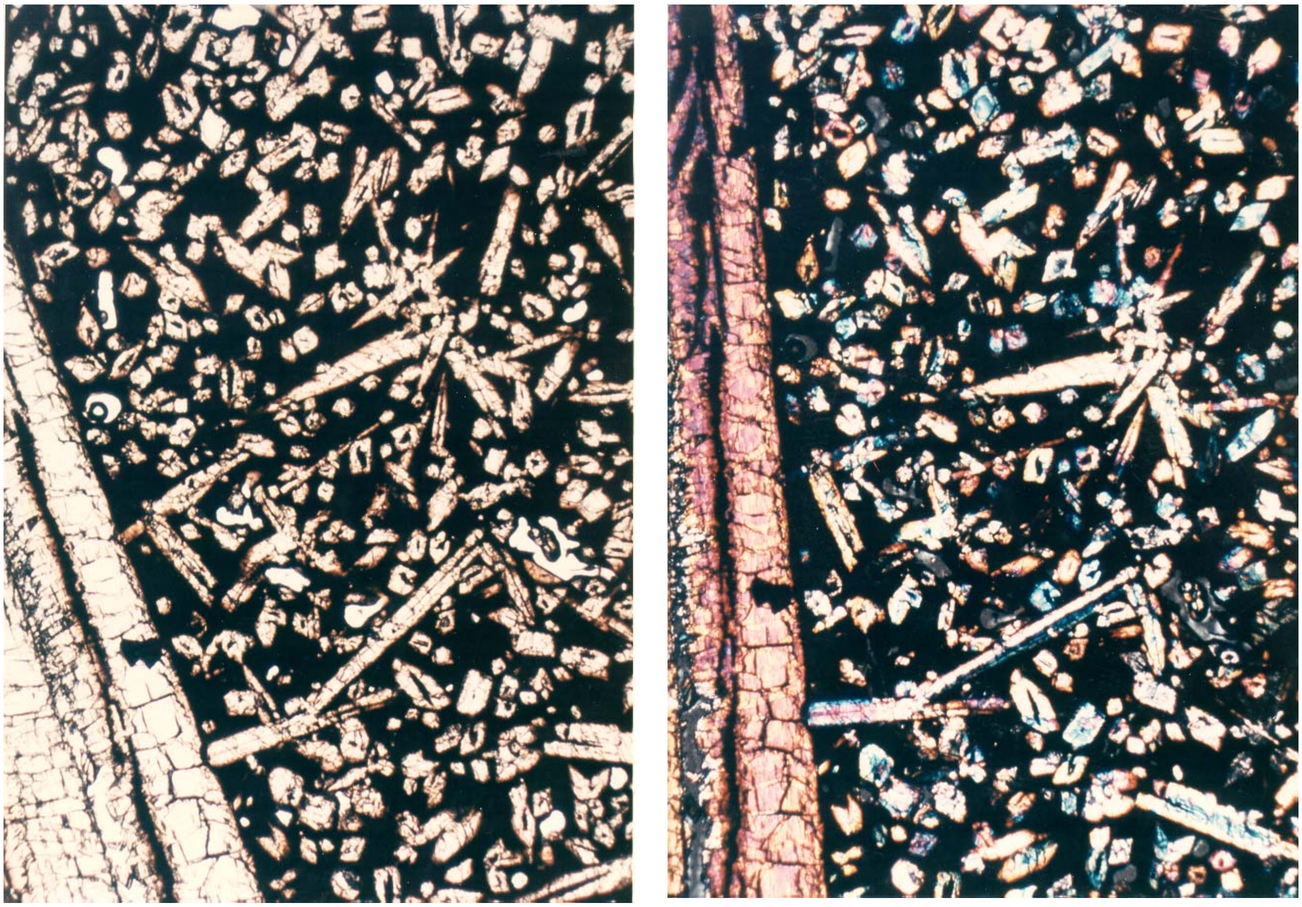


Figure 3: Photomicrographs of thin section of 15597. a) plane polarized, b) crossed polarized. NASA S 71-51793 and 51794. Scale about 1 x 2 mm.

Mineralogy

Olivine: Any early formed olivine (it is on the liquidus) has apparently reacted out.

Pyroxene: Weigand and Hollister (1973) and Grove and Bence (1977) studied major and trace element zoning in pyroxene (figure 4). It is unusual, because plagioclase and ilmenite did not have time to nucleate. Rim augite has high Al and Ti. Brown and Weschler (1973), Brown et al. (1973) and Grove (1982) studied the crystallography of pyroxenes in 15597 and synthetic experiments with controlled cooling history.

The first pigeonite to crystallize was Wo4En70Fs26 which zones outward to Wo15En52Fs33, where it jumps to Wo30En40Fs30 and continues to zone to Wo32En10Fs58.

Large crystals of pigeonite were seen in hand specimen (Butler 1972; Tanscript) and one is present in some of the thin section (figure 2 and 3). It has a wide core with constant composition, but since it is not as Mg rich as some, it probably wasn't the first crystal to form (see Weigand and Hossister).

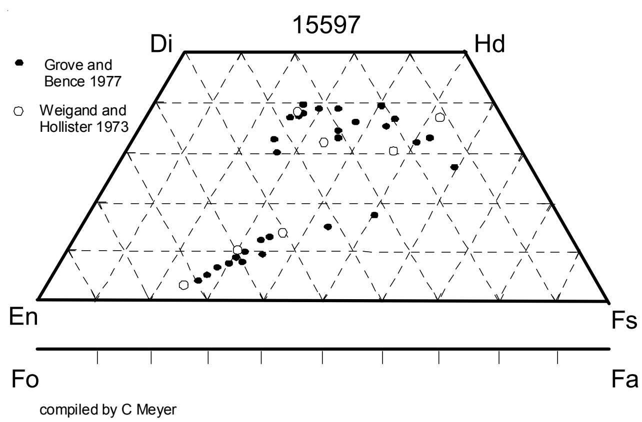


Figure 4: Pyroxene composition of 15597 (no olivine).

Plagioclase: none

Ilmenite: none

Chromite: Weigand and Hollister (1973) found that chromite grains had a "bimodal size distribution". The

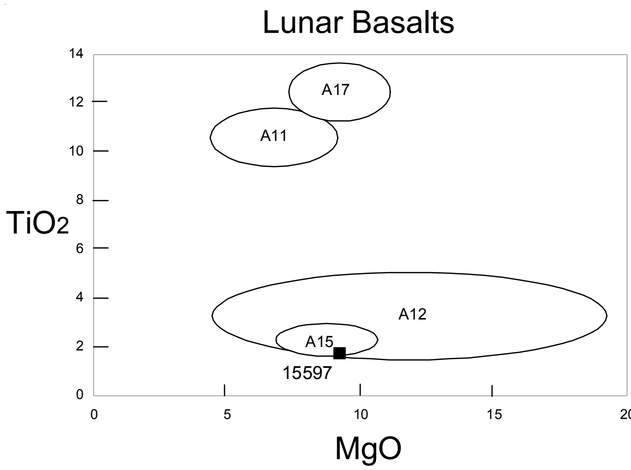


Figure 5: Chemical composition of 15597 compared with that of other lunar basalts.

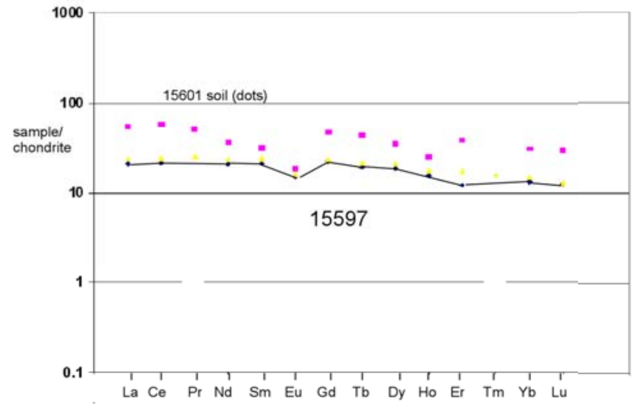


Figure 6: Normalized rare-earth-element diagram for 15597 (data by Helmke et al. 1973).

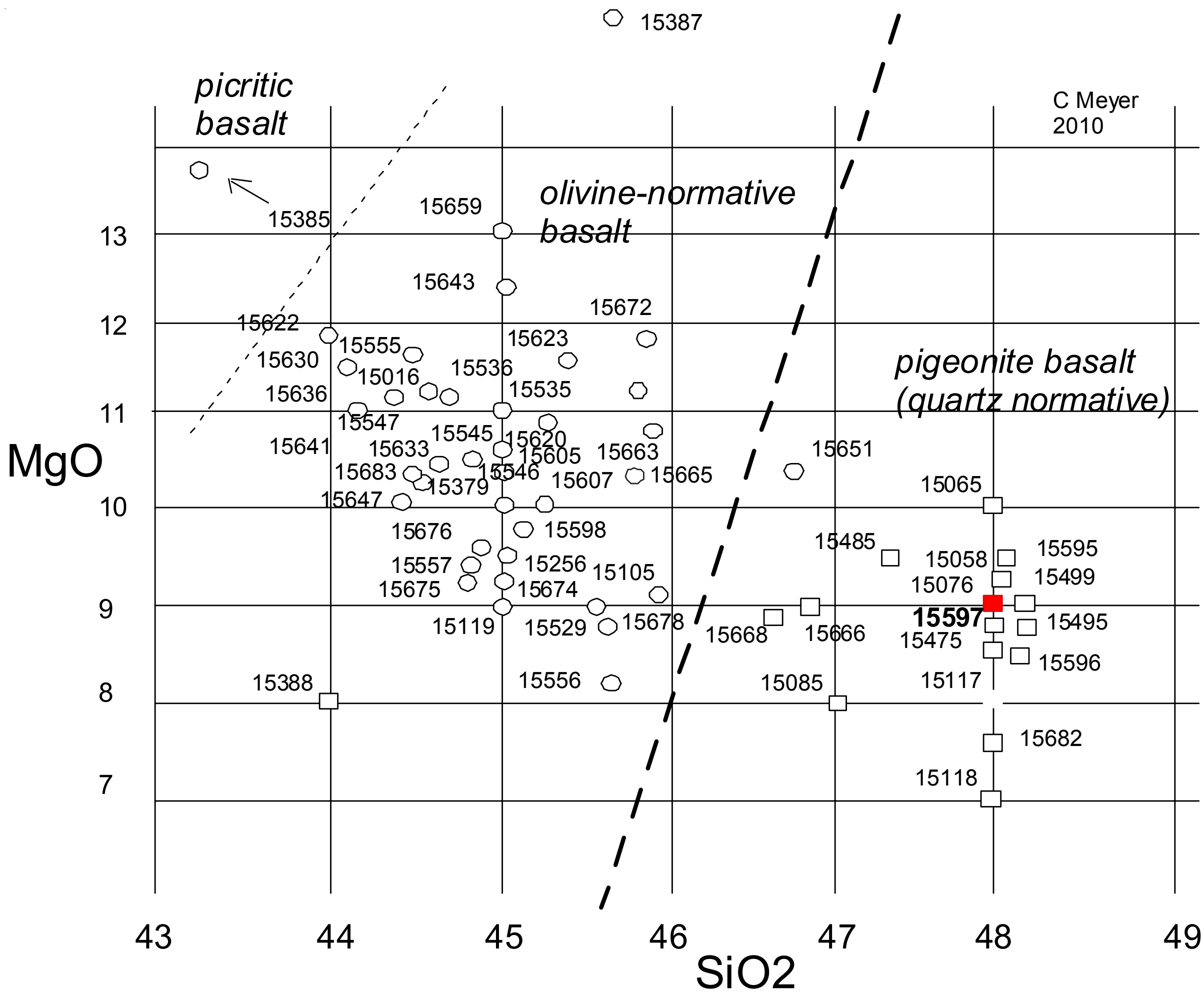
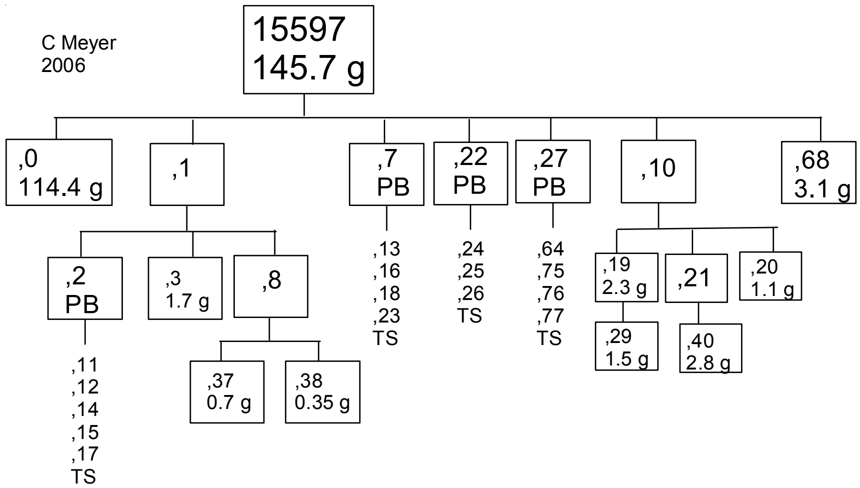


Figure 7: The big picture showing the composition of 155597 compared with other Apollo 15 basalts.

Table 1. Chemical composition of 15597.

reference	Chappel73		Helmke73		Nava75			Ganapathy73		O'Kelley72	
weight					3.8 g	*matrix*		Wolf79			
SiO2 %	47.98	(a)	48	(d)	48.1	*47.9*	(b)				
TiO2	1.8	(a)	1.84	(d)	1.87	*2.3*	(b)				
Al2O3	9.44	(a)	9.55	(d)	9.27	*15.13*	(b)				
FeO	20.23	(a)	20.6	(d)	20.17	*22.24*	(b)				
MnO	0.3	(a)	0.28	(d)	0.254	*0.224*	(b)				
MgO	8.74	(a)	9.06	(d)	9.18	*1.4*	(b)				
CaO	10.43	(a)	10.4	(d)	9.69	*9.62*	(b)				
Na2O	0.32	(a)	0.317	(d)	0.32	*0.66*	(b)				
K2O	0.06	(a)	0.078	(d)	0.056	*0.111*	(b)			0.053	(e)
P2O5	0.07	(a)			0.107	*0.151*	(b)				
S %	0.06	(a)									
sum											
Sc ppm											
V											
Cr	3284	(a)			3353		(b)				
Co								40	(c)		
Ni			30	(d)							
Cu											
Zn								1.2	(c)		
Ga	2.6	(a)									
Ge ppb								6.5	(c)		
As											
Se								117	(c)		
Rb	0.9	(a)						0.72	(c)		
Sr	109.4	(a)	91	(d)							
Y	27	(a)									
Zr	101	(a)									
Nb	6	(a)									
Mo											
Ru											
Rh											
Pd ppb											
Ag ppb								0.9	(c)		
Cd ppb								1.7	(c)		
In ppb								0.59	(c)		
Sn ppb											
Sb ppb								1.49	(c)		
Te ppb								1.9	(c)		
Cs ppm								0.04	(c)		
Ba			52	(d)							
La			4.86	(d)							
Ce			13	(d)							
Pr											
Nd			9.3	(d)							
Sm			3.09	(d)							
Eu			0.84	(d)							
Gd			4.4	(d)							
Tb			0.69	(d)							
Dy			4.51	(d)							
Ho			0.86	(d)							
Er			1.9	(d)							
Tm											
Yb			2.13	(d)							
Lu			0.301	(d)							
Hf											
Ta											
W ppb											
Re ppb								0.0081	(c)		
Os ppb											
Ir ppb								0.0072	(c)		
Pt ppb											
Au ppb								0.045	(c)		
Th ppm										0.53	(e)
U ppm										0.14	(e)

technique: (a) XRF, (b) AA, (c) RNAA, (d) INAA, (e) radiation counting



larger grains (~100 microns) were euhedral and found in "clusters", generally within pyroxene. Where chromite grains are in contact with glass, they are rimmed with ulvospinel.

Metallic Iron: Weigand and Hollister (1973) reported that small Ni-Co-Fe grains nucleated early (Ni = 4 – 7%; Co 1 – 3%). Metallic iron is often found adjacent to chromite.

Chemistry
Chappell and Green (1973) determined the major element composition by XRF. O'Kelley et al. (1972), Helmke et al. (1973) and Ganapathy et al. (1973) determined trace elements (figure 6).

Radiogenic age dating
Kirsten et al. (1973) reported that 15597 had "large amounts" of excess Ar. Compston et al. (1972) determined the Sr isotopic composition.

Cosmogenic isotopes and exposure ages
Eldridge et al. (1972) determined the cosmic-ray-induced activity of ^{22}Na = 31 dpm/kg, ^{26}Al = 88 dpm/kg and ^{54}Mn = 30 dpm/kg, Kirsten et al. (1973) reported a cosmic ray exposure age of 210 m.y. by ^{38}Ar and Alexander et al. (1972) determined the isotopic composition of Kr (exposure age not calculated).

Other Studies
Clayton et al. (1972) reported oxygen isotopes.

Hargraves and Dorety (1972) and Fuller et al. (1979) determined the magnetic properties.

References for 15597
Alexander E.C., Davis P.K., Reynolds J.H. and Srinivasan B. (1972) Age, exposure history and trace element composition of some Apollo 14 and 15 rocks as determined from rare gas analysis (abs). *Lunar Sci.* **IV**, 27-29.

Arvidson R., Crozaz G., Drozd R.J., Hohenberg C.M. and Morgan C.J. (1975) Cosmic ray exposure ages of features and events at the Apollo landing sites. *The Moon* **13**, 259-276.

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

Brown G.M., Emeleus C.H., Holland G.J., Peckett A. and Phillips R. (1972) Mineral-chemical variations in Apollo 14 and Apollo 15 basalts and granitic fractions. *Proc. 3rd Lunar Sci. Conf.* 141-157.

Brown G.E. and Wechsler B.A. (1973) Crystallography of pigeonites from basaltic vitrophyre 15597. *Proc. 4th Lunar Sci. Conf.* 887-900.

Chappell B.W. and Green D.H. (1973) Chemical compositions and petrogenetic relationships in Apollo 15 mare basalts. *Earth Planet. Sci. Lett.* **18**, 237-246.

Cisowski S.M., Hale C. and Fuller M. (1977) On the intensity of ancient lunar fields. *Proc. 8th Lunar Sci. Conf.* 725-750.

Clayton R.N., Hurd J. and Mayeda T. K. (1972) Oxygen isotopic compositions and oxygen concentrations of Apollo 14 and Apollo 15 rocks and soils. *Proc. 3rd Lunar Sci. Conf.* 1455-1463.

Compston W., de Laeter J.R. and Vernon M.J. (1972) Strontium isotope geochemistry of Apollo 15 basalts. *In* **The Apollo 15 Lunar Samples**, 347-351.

Donaldson C.H., Drever H.I. and Johnston R. (1977) Supercooling on the lunar surface: a review of analogue information. *Phil. Trans. Roy. Soc. London* **A285**, 207-218.

Drever H.I., Johnston R. and Brebner G. (1973) Radiate texture in lunar igneous rocks and terrestrial analogs (abs). *Lunar Sci.* **IV**, 187-189.

Fuller M.D., Meshkov E., Ciscowski S.M. and Hale C.J. (1979) On the natural remanent magnetism of certain mare basalts. *Proc. 10th Lunar Planet. Sci. Conf.* 2211-2233.

Ganapathy R., Morgan J.W., Krahenbuhl U. and Anders E. (1973) Ancient meteoritic components in lunar highland rocks: Clues from trace elements in Apollo 15 and 16 samples. *Proc. 4th Lunar Sci. Conf.* 1239-1261.

Grove T.L. (1982) Use of exsolution lamellae in lunar clinopyroxenes as cooling rate speedometers: an experimental calibration. *Amer. Min.* **67**, 251-268.

Grove T.L. and Bence A.E. (1977) Experimental study of pyroxene-liquid interactions in quartz-normative basalt 15597. *Proc. 8th Lunar Sci. Conf.* 1549-1579.

Grove T.L. and Walker D. (1977) Cooling histories of Apollo 15 quartz-normative basalts. *Proc. 8th Lunar Sci. Conf.* 1501-1520.

Grove T.L. and Raudsepp M. (1978) Effects of kinetics on the crystallization of quartz normative basalt 15597: An experimental study. *Proc. 9th Lunar Planet. Sci. Conf.* 585-599.

Grove T.L. and Lindsley D.H. (1979) The partioning of Fe, Mg, and Ca between pigeonite and liquid in lunar basalts (abs). *Lunar Planet. Sci.* **X**, 473-475. Lunar Planetary Institute, Houston.

Helmke P.A., Blanchard D.P., Haskin L.A., Telander K., Weiss C. and Jacobs J.W. (1973) Major and trace elements in igneous rocks from Apollo 15. *The Moon* **8**, 129-148.

Kirsten T., Horn P. and Kiko J. (1973d) Ar40-Ar39 dating of Apollo 16 and Apollo 15 rocks and rare gas analysis of Apollo 16 soils (abs). *Lunar Sci.* **IV**, 438-440. The Lunar Sci. Institute, Houston.

Lofgren G.E., Donaldson C.H. and Usselman T.M. (1975) Geology, petrology and crystallization of Apollo 15 quartz-normative basalts. *Proc. 6th Lunar Sci. Conf.* 79-99.

Lofgren G.E., Grove T.L., Brown R.W. and Smith D.P. (1979) Comparison of dynamic crystallization techniques on Apollo 15 quartz normative basalts. *Proc. 10th Lunar Planet. Sci. Conf.* 423-438.

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.

Morgan J.W., Krahenbuhl U., Ganapathy R. and Anders E. (1972a) Trace elements in Apollo 15 samples: Implications for meteorite influx and volatile depletion on the moon. *Proc. 3rd Lunar Sci. Conf.* 1361-1376.

Nava D.F. (1974a) Chemical compositions of some soils and rock types from the Apollo 15, 16, and 17 lunar sites. *Proc. 5th Lunar Sci. Conf.* 1087-1096.

O'Kelley G.D., Eldridge J.S. and Northcutt K.J. (1972a) Abundances of primordial radioelements K, Th, and U in Apollo 15 samples, as determined by non-destructive gamma-ray spectrometry. *In* **The Apollo 15 Lunar Samples**, 244-246.

Papike J.J., Hodges F.N., Bence A.E., Cameron M. and Rhodes J.M. (1976) Mare basalts: Crystal chemistry, mineralogy and petrology. *Rev. Geophys. Space Phys.* **14**, 475-540.

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

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.

Weigand P.W. and Hollister L.S. (1973) Basaltic vitrophyre 15597: An undifferentiated melt sample. *Earth Planet. Sci. Lett.* **19**, 61-74.

Wolf R., Woodrow A. and Anders E. (1979) Lunar basalts and pristine highland rocks: Comparison of siderophile and volatile elements. *Proc. 10th Lunar Planet. Sci. Conf.* 2107-2130.