15426 GREEN GLASS CLODS ST. 7 223.6 g

INTRODUCTION: 15426 is an extremely friable greenish clod (Fig. 1) in which the green material is the common Apollo 15 volcanic (pyroclastic) green glass. The sample is really a regolith clod with green glass concentrations varying considerably from place to place. Volcanic yellow and red glasses and yellow impact glasses and some other mineral and lithic debris are present. Green glasses from this sample and 15427 have been dated as ~3.4 b.y. old, yellow volcanic glasses as ~3.6 b.y. old, and yellow impact glasses as ~3.35 b.y. old. Rare gas exposure ages are about 300 m.y.

Figure 1. Macroscopic view of 3 pieces of 15426 as removed from the sample bag. ,1 is to right; ,26 is at rear. S-71-43586

The clod is light grayish yellow-green, and is blocky, rounded, and very friable. It was removed from the sample bag and processed as three pieces. It is not entirely homogeneous as some pieces contain more than 90% spherules and are very green, while others contain a smaller proportion of spherules and are grayer. For instance, ,2, from which several thin sections were made, is a spherule-rich polymict regolith breccia, whereas ,29 from which several other thin sections were made consists predominantly of green volcanic glass and yellow impact glass to the general exclusion of other debris. ,26 is a large piece which consists almost entirely of green glass spheres (Fig. 2). The surfaces of pieces of 15426 are too friable to have retained any patina or zap pits. Because of its purity and extreme friability, 15426,26 is a restricted access sample.

15426 was collected with clods 15425 and 15427 and fines from the north rim of Spur Crater (see cataloging of 15425 for numbering and site characteristics). Many studies

have produced observations and conclusions without discriminating to which particular of the three samples specific data refer. Hence data from all three samples are most usefully considered together.

PETROLOGY: Macroscopically 15426 is fine-grained and is striking in its abundance and visibility of green glass spherules. Ovoids and broken glasses are much less abundant. As noted above, the sample is not homogeneous, with considerable green glass concentration variations from place to place. Plagioclase, mafic silicates, and small rock clasts are also visible in small amounts. Morris (1976) found that ,97 had an I_s/FeO of 0.3, and McKay et al. (1984) found an I_s/FeO of 0 to 1 for ,126. These are extremely low maturities; it is not clear how much these samples were typical 15426 or purer green 15426. Nagle (1981) observed 15426,26 macroscopically, and drew comparisons with 15425, 15427, and core 15007 green clods. 15426 contained more particles with quench crystallites, whereas 15425 and 15427 had numerous crystallized particles and 15007 had more glassy particles (the observations are probably more subsample specific than sample specific).

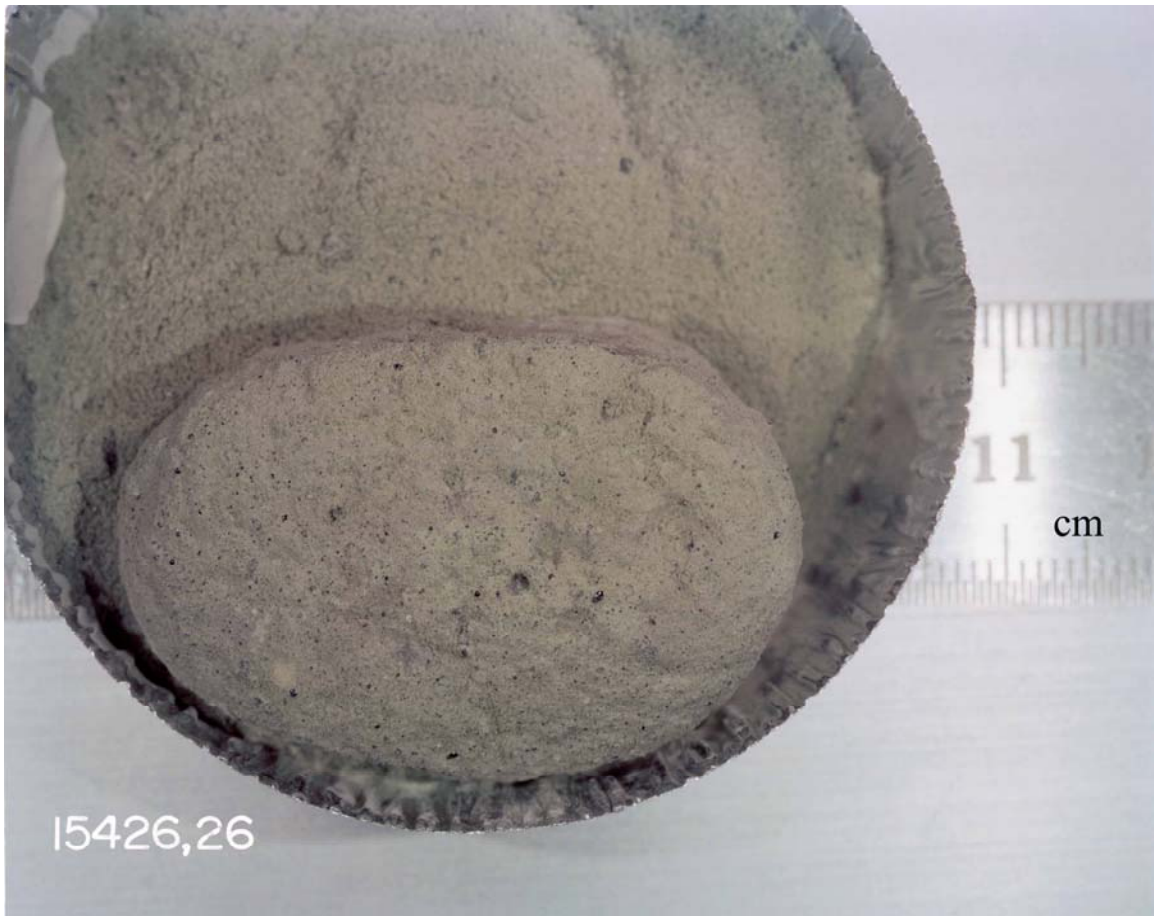

Fig. 2a

Fig. 2b

Figure 2. a) 15426,26. S-80-42656
b) Particles of green glass from 15426,6.

No comprehensive descriptions of 15426 petrography have ever been published, as most studies have concentrated on the glasses themselves. Thin sections from piece ,2 are of a polymict regolith breccia, not a pure green clod (Fig. 3a). The breccia is porous, contains agglutinitic glass, and not only green but also red and yellow glass spheres, as well as heterogeneous yellow glasses. Lithic clasts are present, including feldspathic crystalline fragments and possibly mare (or KREEP?) basalts, as well as coarse plagioclase and mafic mineral fragments. Thin sections from ,29 are less polymict, and are dominated by a mixture of green volcanic glasses and yellow impact glasses (Fig. 3b). Rare lithic (smalls plutonic?) and plagioclase fragments are scattered. Wood and Ryder (1977) found thin section ,19 to be a more mature regolith breccia than a 15427 sample, containing rock, mineral, and glass clasts, with 68% of the sample being a "matrix" of less than 25 micron grain size. Both mare and highland mineral fragments were identified. Desmarais et al. (1973) found 5% agglutinates in the greater-than-105 micron fraction of a split from a green-enriched clod.

Fig. 3a

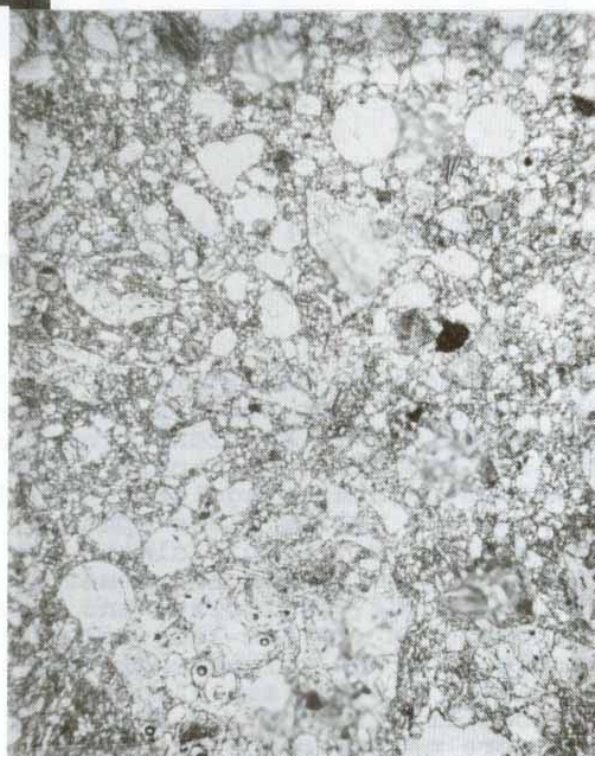

Fig. 3b

Figure 3. Photomicrographs of 15426. Transmitted light. Widths about 2 mm.
a) 15426,17, showing regolith-like nature;
b) 15426,70, showing mix of green glass spheres and yellow impact glasses.

Butler et al. (1972) noted that "chondrules" (= partly crystallized green glass) are abundant in thin sections from ,2 (they list thin section ,19 erroneously as from 15436), and depicted a "plag-px-glass" chondrule with a diameter of 0.35 mm. Agrell et al. (1972) described glasses from 15425, 15426, and 15427, with SEM observations of spheres and composite aggregates indicating a multiplicity of collisions and adhesions. They ascribed to the green glasses an impact origin, in which the final stage produced low velocity microcraters and minor abrasions. An absence of high velocity micrometeorite impacts indicates that the glasses, unlike many other types, were not exposed at the surface.

Green glasses have received the most intensive study, following early recognition of this glass type at the Apollo 15 site as common and significant (e.g., Ridley et al., 1973b). Desmarais et al. (1974) determined a mean grain size of $\Phi = 3.2$ for green glasses, and Morgan and Wandless (1974) found $\Phi = 3.25$, coarser than Apollo 17 yellow glass. Butler (1978) listed a microprobe analysis of a green glass droplet, recognizing its volcanic nature, and Delano (1979) precisely analyzed green glasses in 15425, 15426, and 15427 for major elements and Ni with the microprobe. These glasses defined two main arrays and five individual groups. Data from 15426 was not specified. Delano and Lindsley (1982) analyzed glasses from groups B and C in 15426 for P, Mn, Ti, and Cr to provide additional petrogenetic constraints, and suggested that the fractionation trends are difficult to understand in terms of any silicate and oxide assemblage, and speculated that igneous processes other than crystal-liquid fractionation might have occurred. Wood and Ryder (1977) discussed the enigma of the green glass compositional variation, which caused problems for both igneous and impact origin concepts. Basu et al. (1979) studied green glass vitrophyres in 15426 and 15427 (and other regoliths) providing microprobe data on glass and olivine compositions. Grove (1981) discussed data for 15426 green glasses, incorrectly attributing the Hlava et al. (1973) data to 15426, and assuming that all of the Delano (1979) analyses were from 15426. His discussion related the observed chemical trends to sulfide fractionation as part of the petrogenesis of green glasses. Grisoom et al. (1973, 1975) and Friebele et al. (1974) conducted ESR/FMR studies on separated green glass balls, finding a spectrum interpreted as arising entirely from "magnetite-like" phases (total ~0.01 wt %) (Fig. 4). Cusps and discontinuities in the spectrum show a behaviour typical of many titanomagnetites but unknown for Fe-iron. The "magnetite-like" phase is probably a ferric iron spinel. Burns and Dyar (1982) made a Mossbauer spectral study of handpicked green spherules, and found no Fe^{3+} in either it or a synthetic glass made at fO_2 of 10^{-14} atmospheres. Earlier work on a synthetic glass made at fO_2 of 10^{-11} atmospheres had shown significant Fe^{3+}. The spectrum showed olivine crystallites to be present; significant changes of coordination about Fe^{3+} ions occur in the glass during olivine crystallization.

Delano (1980b) analyzed red volcanic glasses (TiO_2 ~13.8%) in 15426,72 as well as in samples from 15318, 15425, and 15427, for major elements and Ni using the microprobe. Data for 15426 were not specified. Ni was always less than the detection limit of 50 ppm. Three subgroups were identified, related to each other by a prominent chemical trend. Experiments on this composition indicates that trend to originate from shallow (less than 5 kb) fractionation, and the most primitive glass to have originated at about 480 km depth.

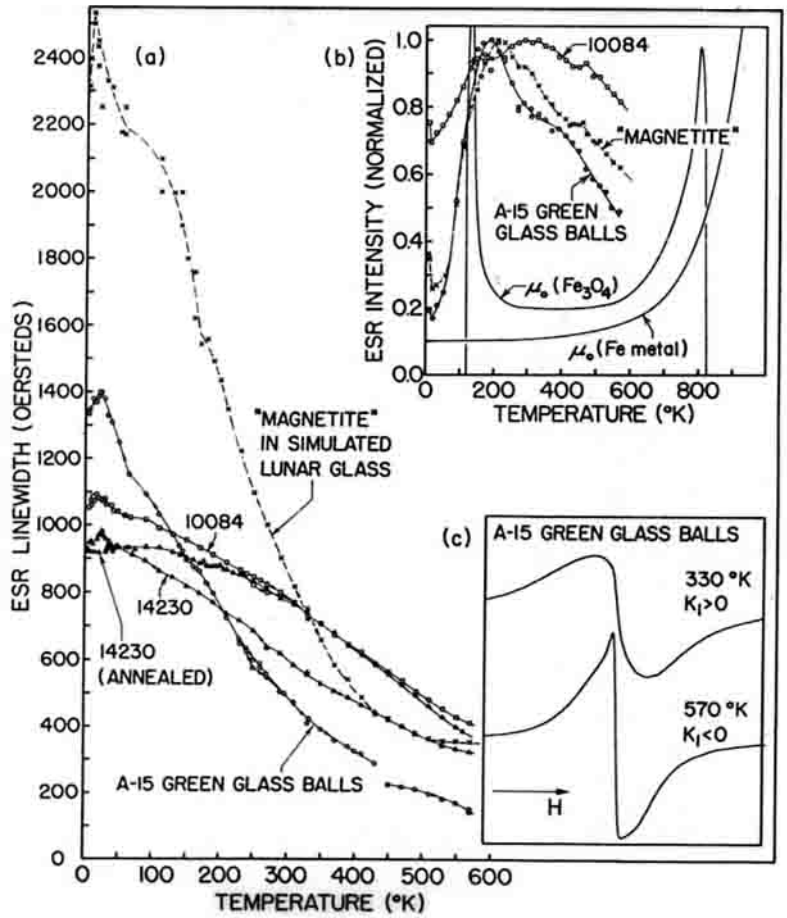

Figure 4. Temperature dependence of ESR (a) line width and (b) intensity for 15426 glass balls and other materials (Griscom et al., 1973).

Wood and Ryder (1977) reported an average composition for five homogeneous yellow glasses in 15426,19; these glasses are the volcanic yellow glasses of Delano and Livi (1981). Delano (1980a), Delano et al. (1981) and Spangler and Delano (1984) analyzed yellow impact glasses (TiO_2 ~4.8%) in 15426 as well as 15425, 15427 and 15318; chemical data for 15426 were not distinguished. The glasses form a compositional cluster, unlike other impact glasses, and are distinct from the volcanic yellow glass. About 90% are angular fragments, with schlieren and lithic clasts, not spherules. Delano et al. (1981) considered that the glasses were exotic to the Apollo 15 site and were derived from Eratosthenian-age lavas in Mare Imbrium. However, such yellow impact glasses from 15426 (and 15427) were dated as 3.35 b.y. old by Spangler and Delano (1984). Delano et al. (1982) depicted yellow impact glass in 15426,72, containing three large single crystal clasts (olivine and pyroxene) and smaller inclusions of volcanic green glass, orthopyroxene, and olivine. All clast-glass contacts are sharp.

Ridley et al. (1973) quoted 15426 erroneously at the start of their paragraph 4; all their data and observations are for 15427.

CHEMISTRY: Chemical analyses are tabulated separately as bulk clods (Table 1); sized fractions of bulk clods (Table 2); green glass composites (Table 3); and brown (= yellow volcanic) glass composites (Table 4). Rare earth data for a very green bulk clod sample and for green glass composites and brown (yellow volcanic) glass are shown in Figure 5.

Only one clod analyses, that of Keith et al. (1972), represents bulk rock and that is for only K, U, and Th; all the other clods were selectively green-enriched portions of the rock. The data of Keith et al. (1972) is similar in U and Th to that of Taylor et al. (1973) for fines 15421, the less-than-l-mm bag residue from 15425, 15426, and 15427, and probably represents bulk rock. All other analyses are variously lower in U. Most of the analyses listed were reported without significant discussion. The "bulk" analyses labeled ,118 are all from the very green-glass rich sample ,26; most others from another green-glass rich sample ,27, and that of Korotev (1984 unpublished) is from a split of ,1. The iron in the bulk clod analyzed magnetically by Pearce et al. (1973) also suggests it was almost pure green glass. Th, Rb, Pb, and S are also lower in these "bulk" clods than in the Taylor et al. (1973) analysis of 15421 fines. These "bulk" analyses are enriched over the green glass composites in U and Th, and other incompatibles, but not by very much, nor are the refractory siderophiles greatly enriched compared with pure green glass, and Ni is not enriched at all. The major elements of Korotev (1984, unpublished) are a little higher in Al and Ti and a little lower in Mg than pure green glass. Morgan and Wandless (1984) found that the abundances of refractory siderophile elements Os, Re, and Ir are uniform, averaging 7.8×10^{-4} x Cl chondrites. Volatile siderophile elements and chalcogens are much more abundant. With appropriate corrections for an indigenous lunar contribution, the siderophile abundances resemble the Group IL meteoritic component ascribed to Imbrium (Hertogen et al., 1976), but may also reflect direct derivation from a "primitive" lunar mantle.

Desmarais et al. (1973) reported carbon as its contribution from CH_4 (0.4 ppm C), CO (15.0) and CO_2 (8), with the total C of 23 ppm, similar to other soils, and to the green glass itself. A similar C abundance was found by Modzeleski et al. (1972) and Wszolek et al. (1972) using methods criticized by Desmarais et al. (1973) (also separate CO, CO_2, CH_4 determinations) as less efficient in releasing all C than is combustion. Desmarais et al. (1974) also analyzed for hydrogen, finding 12 ± 0.5 micromoles/g, which is lower than most mature cores and fines (40-70). Two-thirds of the hydrogen is released between 450 and 1050°C. The surface correlated H is 42 ± 14 micromoles H/cm^2, the volume correlated only 2 ± 5 micromoles H/g (cf. total H of 12 micromoles/g). Wszolek et al. (1972) measured gases released by dissolution (DF dissolution) finding very small quantities of CD_4, CH_4, and C_3D_6 with total deuterocarbons only 1 or 2 % their abundances in other soils. They find their data for C and N (little surface implanted) to be consistent with an origin from 20 m within Spur Crater. Simoneit et al. (1973) used the same green-glass enriched clod to study release of other gases by pyrolysis, showing diagrams for H_2O, N_2, CO, NO, and H_2S release. They found very low amounts of these products; H_2O, NO, and CO_2 were released at low temperatures (<400°C), whereas H_2S, N_2, and CO were released at 1200-1300°C, probably on melting of the sample.

TABLE 15426-1. Analyses of bulk clod samples

		,0	,36	,31	,118	,118	,35	,33	,32	,30	,97	,126
Wt %	SiO2											
	TiO2											0.50
	Al2O3											9.75
	FeO										19.4	17.9
	MgO											15.1
	CaO											8.5
	Na2O											0.22
	K2O	0.11										
	P2O5											
(ppm)	Sc											33.5
	V											124
	Cr											3360
	Mn											1805
	Co											69.6
	Ni				116	163						210
	Rb		0.584									
	Sr		40.59									60
	Y											
	Zr											70
	Nb											
	Hf											2.0
	Ba											59
	Th	1.89	0.4203									0.9
	U	0.41	0.1134		0.061	0.081	0.125					0.23
	Pb		1.248									
	La											4.99
	Ce											13
	Pr											
	Nd											8
	Sm											2.43
	Eu											0.478
	Gd											
	Tb											0.51
	Dy											
	Ho											
	Er											
	Tm											
	Yb											2.10
	Lu											0.304
	Li											
	Be											
	B											
	C			23				2.5	21	7		
	N								42	29		
	S								340			
	F											
	Cl											
	Br											
	Cu											
	Zn				26	24	51					
(ppb)	I											
	At											
	Ga											
	Ge											
	As											
	Se				109	106	125					
	Mo											
	Tc											
	Ru											
	Rh											
	Pd				<1.5							
	Ag				21	14	25					
	Cd				110	89	118					
	In						5.6					
	Sn											
	Sb				2.9	0.9	0.89					
	Te											
	Cs											60
	Ta											270
	W											
	Re				0.031	0.032	0.034					
	Os				0.42	0.41						
	Ir				0.32	0.28	0.32					<2
	Pt											
	Au				0.52	0.34						<2
	Hg											
	Tl				3.0	2.0	4.2					
	Bi				2.7		1.7					
		(1)	(2)	(3)	(4)	(4)	(4)	(5)	(6)	(7)	(8)	(9)

References and methods:

(1) Keith et al. (1972); gamma ray spectroscopy
(2) Barnes et al. (1973); isotope dilution, mass spectrometry, and some variations
(3) Desmarais et al. (1973); pyrolysis, gas chromatography
(4) Morgan and Wandless (1984); RNAA
(5) Modzeleski et al. (1972); vacuum pyrolysis, mass spectrometry
(6) Moore and Lewis (1972, 1976), Moore et al. (1973), Cripe and Moore (1974); combustion, gas chromatography
(7) Wszolek et al. (1972); pyrolysis, mass spectrometry
(8) Pearce et al. (1973); magnetic
(9) Korotev (1984 unpublished); INAA

TABLE 15426-2. Analyses of sized fractions of bulk green-rich clods

		.35(A)	.35(B)	.35(C)	.35(D)	.35(E)
Wt %	SiO2					
	TiO2					
	Al2O3					
	FeO					
	MgO					
	CaO					
	Na2O					
	K2O					
	P2O5					
(ppm)	Sc					
	V					
	Cr					
	Mn					
	Co	48				
	Ni		160	183	146	96
	Rb	0.47				
	Sr					
	Y					
	Zr					
	Nb					
	Hf					
	Ba					
	Th					
	U	0.095	0.112	0.075	0.065	0.066
	Pb					
	La					
	Ce					
	Pr					
	Nd					
	Sm					
	Eu					
	Gd					
	Tb					
	Dy					
	Ho					
	Er					
	Tm					
	Yb					
	Lu					
	Li					
	Be					
	B					
	C					
	N					
	S					
	F					
	Cl					
	Br	0.136				
	Cu					
	Zn	80	10.4	11.4	20	80
(ppb)	I					
	At					
	Ga					
	Ge	196				
	As					
	Se	174	43	61	85	334
	Mo					
	Tc					
	Ru					
	Rh					
	Pd		<2.5	<0.8	1.69	<2.5
	Ag	39	5.6	7.9	13.8	53
	Cd	183	34	49	72	283
	In	9.3				
	Sn					
	Sb	1.58	0.21	1.00	1.16	0.83
	Te	16				
	Cs	27				
	Ta					
	W					
	Re	0.047	0.014	0.0421	0.0130	0.048
	Os		0.28	0.42	0.26	0.68
	Ir	0.41	0.190	0.30	0.166	0.43
	Pt					
	Au		0.141	0.144	0.21	1.23
	Hg					
	Tl	6.9	1.41	0.90	1.75	8.0
	Bi	2.4	<0.7	26	8.9	64
		(1)	(2)	(2)	(2)	(2)

TABLE 15426-3. Analyses of bulk separated green glass spherules

		,38	,35	,31	,74	?(A)	?	?	(c)	?	,48(D)
Wt %	SiO2	45.6									
	TiO2	0.29				0.38	0.33				
	Al2O3	7.67				7.5	7.7				
	FeO	19.7				20.0	20.1				
	MgO	16.6				17.5	18				
	CaO	8.72				8.5	8.1			8.4	
	Na2O	0.12				0.133	0.144			0.014	
	K2O	<0.06					0.018				
	P2O5										
(ppm)	Sc	43				37.5	39				
	V	150				165	170				
	Cr	2800				3660	3860				
	Mn	1600				2020	1960				
	Co	72	77			74.8	80				
	Ni	170				153		154			
	Rb	0.34	0.46								
	Sr										
	Y	7.2									
	Zr	22.0									
	Nb	1.5									
	Hf	0.42				0.57	0.7				
	Ba	17.0									
	Th	0.08									
	U	0.02	0.120		0.050			0.0218	0.049		
	Pb	0.53									
	La	1.4				1.2	1.25				
	Ce	3.8									
	Pr	0.53									
	Nd	2.2									2.2
	Sm	0.76				0.83	0.78				0.73
	Eu	0.21				0.24	0.24				
	Gd	0.91									
	Tb	0.15				0.21	0.18				
	Dy	1.1									
	Ho	0.27									
	Er	0.8									
	Tm	0.15									
	Yb	0.93				0.97	0.92				
	Lu	0.14				0.14	0.16				
	Li										
	Be										
	B										
	C			25							
	N										
	S										
	F										
	Cl										
	Br		0.040								
	Cu	3.5									
	Zn		19								
ppb)	I										
	At										
	Ga	4700									
	Ge		37					9.0			
	As										
	Se		69								
	Mo										
	Tc										
	Ru										
	Rh										
	Pd										
	Ag		8.9								
	Cd		46								
	In		1.3								
	Sn	120									
	Sb		0.12								
	Te		3.3								
	Cs		24								
	Ta										
	W	140									
	Re		0.020					0.0058			
	Os										
	Ir		0.22					0.117			
	Pt										
	Au		0.188								
	Hg										
	Tl		1.13								
	Bi		0.38								
		(1)	(2)	(3)	(4)	(5)	(5)	(6)	(7)	(8)	(9)

TABLE 15426-4. Analyses of brown glass composites

		,35	,33?	,33?(c)
Wt %	SiO2			
	TiO2		3.7	
	Al2O3		8.5	
	FeO		23.2	
	MgO		12.5	
	CaO		9.0	
	Na2O		0.40	
	K2O		0.09	
	P2O5			
(ppm)	Sc		43.5	
	V		116	
	Cr		3780	
	Mn		2120	
	Co	60	65.2	
	Ni			
	Rb	2.0		
	Sr			
	Y			
	Zr			
	Nb			
	Hf		5.1	
	Ba			
	Th			
	U	0.915		0.72
	Pb			
	La		9.6	
	Ce			
	Pr			
	Nd			
	Sm		6.8	
	Eu		1.51	
	Gd			
	Tb		1.4	
	Dy			
	Ho			
	Er			
	Tm			
	Yb		4.5	
	Lu		0.62	
	Li			
	Be			
	B			
	C			
	N			
	S			
	F			
	Cl			
	Br	0.045		
	Cu			
	Zn	18		
(ppb)	I			
	At			
	Ga			
	Ge	64		12
	As			
	Se	101		
	Mo			
	Tc			
	Ru			
	Rh			
	Pd			
	Ag	8		
	Cd	<48		
	In	1.2		
	Sn			
	Sb	0.3(a)		9.2(b)
	Te	12		
	Cs	174		
	Ta		700	
	W			
	Re	0.029		0.0166
	Os			
	Ir	0.38		0.143
	Pt			
	Au	0.195		0.66(b)
	Hg			
	Tl	1.77		
	Bi	<2.8		
		(1)	(2)	(3)

References for Table 15426-2

References and methods:

(1) Ganapathy et al. (1973); RNAA
(2) Morgan and Wandless (1984); RNAA

Notes:

(A) finest portion "matrix", mainly green glass spheres
(B) sieved >240 microns from bulk
(C) sieved 270-72 microns from bulk
(D) sieved 72-37 microns from bulk
(E) sieved <37 microns from bulk

References for Table 15426-3

References and methods:

(1) S.R. Taylor et al. (1972, 1973), S.R. Taylor (1972); spark source mass spectrography; emission spectrography; microprobe
(2) Ganapathy et al. (1973); RNAA
(3) Desmarais et al. (1973); pyrolysis, gas chromatography
(4) Fleischer and Hart (1974); tracks of neutron-induced ^{235}U fissions
(5) Ma et al. (1981); INAA
(6) Morgan and Wandless (1984); RNAA
(7) Simoneit et al. (1973); fission tracks
(8) Podosek and Huneke (1973); argon isotopes
(9) Lugmair and Marti (1977, 1978); isotope dilution, mass spectrometry

Notes:

(A) weighted mean of 55 green glasses analysed individually
(B) combined from analyses of several green glass groups
(C) average of 100 green glass spheres
(D) combined leached, whole sphere, and broken sphere fractions with unleached yellow-green devitrified fractions, all of which show no significant difference.

References for Table 15426-4

References and methods:

(1) Ganapathy et al. (1973); RNAA
(2) Ma et al. (1981); INAA
(3) Morgan and Wandless (1984); RNAA

Notes:

(a) low precision, ±0.2
(b) high from contamination, according to authors.
(c) etched

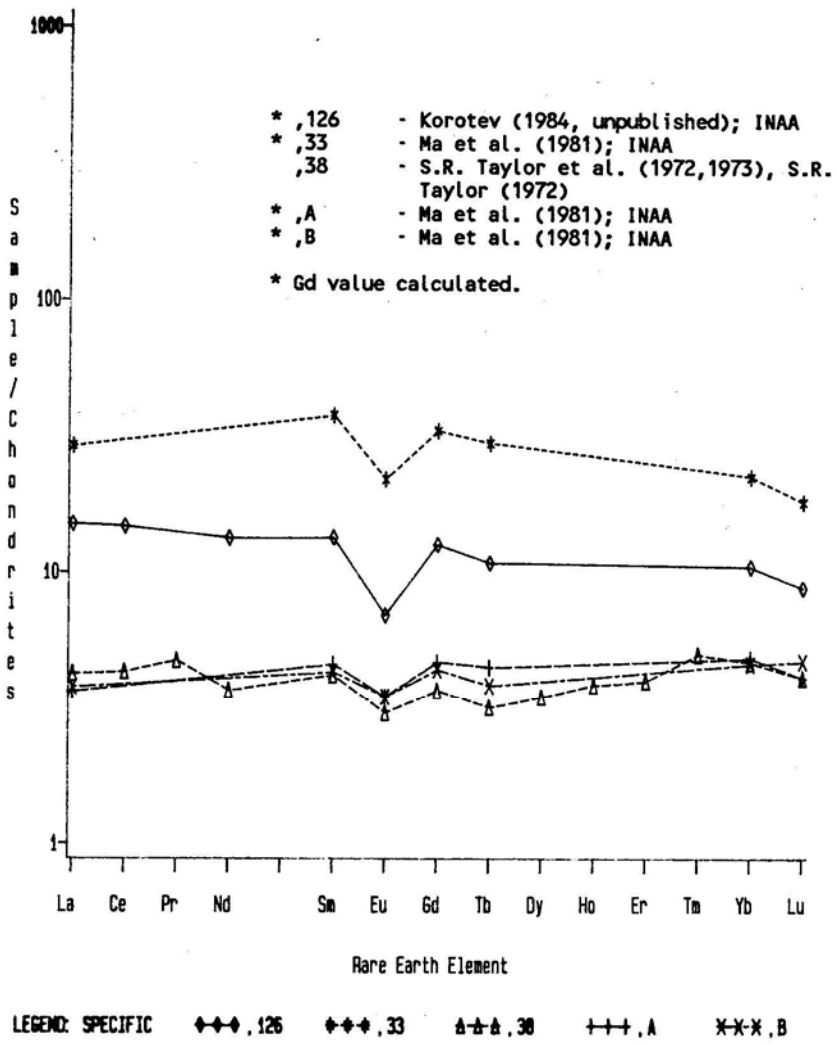

Figure 5. Rare earths in 15426 green glass and yellow glass.

Sieved fractions (Table 2) indicate that the log abundance of volatile elements is correlated with surface area (Morgan and Wandless, 1984). The correlation lines are parallel (Fig. 6) in spite of differences in volatility, indicating control by a single major phase, e.g., ZnS. The refractory siderophiles Os, Re, and Ir have a complex distribution versus surface area and appear to have two components. The distributions indicate that similar volatile species were involved, possibly carbonyl or carbonyl halides. The "finer matrix" of Ganapathy et al. (1973) is similar to an average of the Morgan and Wandless (1984) fractions for most elements, but its size is unknown as it was handpicked, not sieved. From it, Ganapathy et al. (1973) inferred that the matrix was enriched in volatiles, and that the volatiles and siderophiles are of lunar origin, perhaps condensed on the spheres in the impact [sic] which produced them.

Analyses of green glass composites of materials separated from the clods are generally consistent with each other (Table 3). The major element chemistry is basaltic but more magnesian than any other mare basalts, and the rare earths are primitive and barely fractionated, with a small Eu anomaly. Refractory siderophiles are low and similar to those of Apollo 15 low-Ti mare basalts. Fleischer and Hart (1972, 1973) originally determined a U abundance of 5.1 ± 1.5 ppb for three green glass spherules, but later revised their data to about 50 ppb (Fleischer and Hart, 1974). Desmarais et al. (1978)

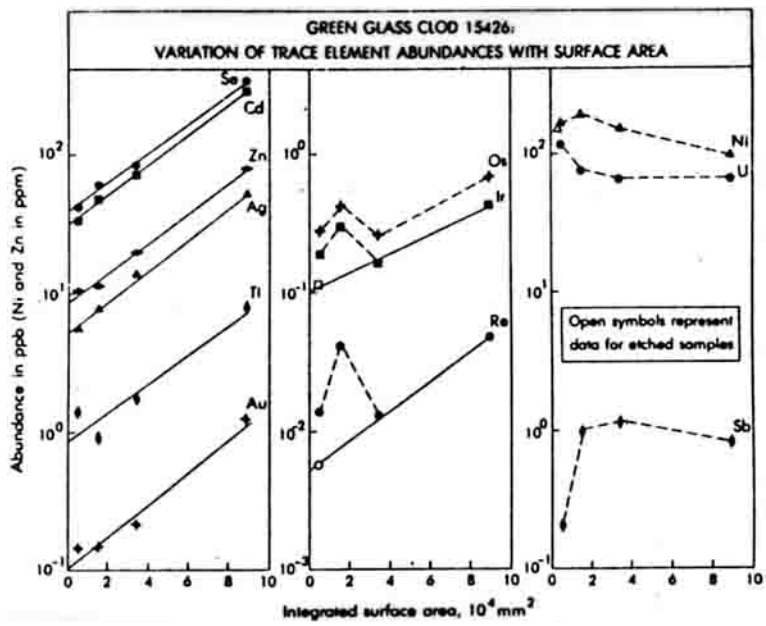

Figure 6. Trace elements and surface area for green glass (Morgan and Wandless, 1984).

analyzed for carbon contributions from different compounds, finding 0.14 ppm C from CH_4, 18.0 from CO, and 6.7 from CO_2, similar to the bulk clod (which was rather green glass rich). They claim that this demonstrates that molten material can retain some C. Desmarais et al. (1974) made hydrogen measurements, finding 10 ± 2.5 micromoles/g for the 149-1000 micron fraction of glass, similar to the bulk clod also analyzed.

Ma et al. (1981) made a chemical study of individual green glass spheres (<1 mg); 175 were analyzed for Na and Mn, and 55 for majors, transition metals, and rare earths. The data showed them to belong to several different groups (not equivalent to the Delano (1979) groups based on microprobe major element data), whose petrogenetic significance was discussed by Ma et al. (1981). Morgan and Wandless (1984) used the same samples to characterize the groups in refractory siderophiles and volatiles. They also found a correlation of Ni and U, counter to geological experience but in accord with the anticorrelation of Ni with Mg found by Delano (1979). The argon isotopic studies by both Huneke et al. (1973) and Podosek and Huneke (1973) and Spangler et al. (1984)

indicate that the K/Ca ratios of the exterior few microns of the green glasses are higher than the interiors, and this is almost certainly a result of higher K in the exteriors of the spheres.

Brown (=yellow volcanic) glasses are distinct from the green glasses and form a tight cluster (Delano and Livi, 1981). They are lower in MgO, and richer in TiO_2 (~3.8%) and incompatible elements. Their siderophile abundances demonstrate them to be uncontaminated with meteoritic material. Ma et al. (1981) analyzed five such glasses individually and inferred that despite their tight clustering they consist of groups related by mixing and fractionation lines. Brown glass data were presented but not discussed by Ganapathy et al. (1973) and by Morgan and Wandless (1984).

STABLE ISOTOPES: Clayton et al. (1972, 1973), and Clayton and Mayeda (1975) measured oxygen isotopic ratios in a subsplit of a green glass-enriched clod. The low δO^{18} (Table 5) is a result of the high pyroxene and olivine components of the melt. The δO^{18} and δO^{17} values show that the samples lie on an Earth-Moon mass fractionation line.

Barnes et al. (1973) determined K isotopic ratios: $^{39}K/^{41}K$ of 14.018 and 14.004, and $^{40}K/^{41}K$ of 0.001845 and 0.001830. These data do not show fractionation effects, whereas regoliths do, hence 15426 is not merely a compacted soil.

TABLE 15426-5. Oxygen isotopes in ,42, a green glass enriched portion

WR δO^{17}	WR δO^{18}	Spheres δO^{18}	Reference
	5.41	5.27	Clayton et al. (1972)
	5.46	5.32	Clayton et al. (1973)
2.60	5.27		Clayton and Mayeda (1975)

RADIOGENIC ISOTOPES/GEOCHRONOLOGY: Husain (1972) reported the first age determination for green glass spherules. Using the ^{40}Ar-^{39}Ar method he derived an age of 3.79 ± 0.08 b.y., consistent with an origin in the Imbrium impact. No details of the analysis have ever been published. The age is inconsistent with ^{40}Ar-^{39}Ar studies by Huneke et al. (1973) and Podosek and Huneke (1973) and by Spangler et al. (1984), in which ages similar to other Apollo 15 mare basalts were determined. The former study provided an age of 3.38 ± 0.06 b.y. for a composite of green glasses. The age was determined from the three higher temperature releases in which most of the ^{39}Ar was released, and in which corrections for trapped ^{40}Ar are small (Fig. 7). At the lowest temperature releases trapped ^{40}Ar is significant. The data are considered very reliable and irreconcilable with the age by Husain (1972). Spangler et al. (1984) used the laser microprobe for argon releases and dated six glasses from green glass group A (Delano, 1979) as an average 3.41 ± 0.12 b.y. old and three from group D as an average 3.35 ± 0.18 b.y. old. The samples include examples from both 15426 and 15427. There is no significant difference among these ages or with the age determined by Huneke et al. (1973) and Podosek and Huneke (1973). The method produced low amounts of argon,

but the low blanks and internal checks give confidence in the data. Lakatos et al. (1973) also studied Ar in 15426, but mainly for exposure purposes. However, from ^{40}Ar, ^{39}Ar data intercepts, they determined that the spherules were constrained to be older than 2.5 b.y., younger than 4.4 b.y., hence were not formed in the Spur Crater impact.

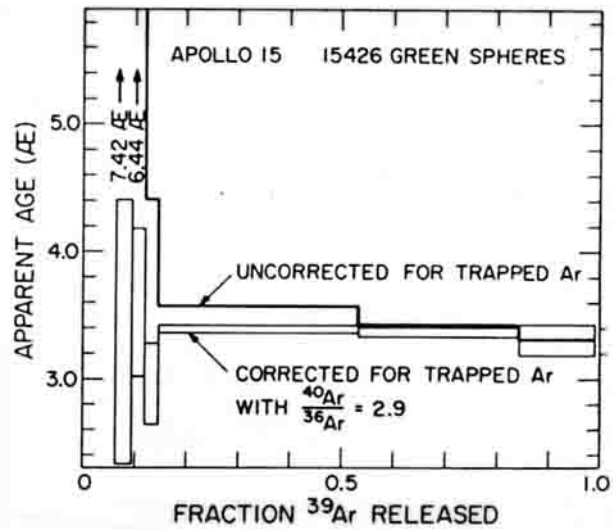

Figure 7. Ar-release and age (Huneke et al.,1973).

Barnes et al. (1973) analyzed a bulk green glass-enriched sample for $^{87}Sr/^{86}Sr$ and for Pb isotopes. The $^{87}Sr/^{86}Sr$ is 0.70301, giving a model age (I = 0.6990) of 6.642 m.y. (λ ^{87}Rb = 1.39 x 10^{-11}), indicating complexities for the isotopic system. Pb isotopes also give very old model ages (Table 6) presumably because the Pb is unsupported surficial material (see Meyer et al., 1974).

TABLE 15426-6. Pb-isotopic ratios and model ages
(Barnes et al., 1973)

Pb-ratios (after blank correction)				Model ages (b.y.)		
208/206	207/206	204/206	Pb207/Pb206	Pb206/U238	Pb202/U235	Pb208/Th232
1.1186	1.0683	0.01580	4.670	8.427	6.074	16.209

Lugmair and Marti (1977, 1978) analyzed three composites of green glass separates for Sm and Nd isotopes (Table 7). This system is not capable of supplying a direct crystallization age on glasses. The three composites have different physical characteristics (see Table 7); EG1 and EG2 were leached to remove volatile coatings. There is no real difference between the three subsamples. The data of Lugmair and Marti (1978) updates that of Lugmair and Marti (1977) in decreasing $^{147}Sm/^{144}Nd$ about 0.5%, changing T_{ICE} from 3.35 ± 0.27 b.y. to 3.8 ± 0.4 b.y. (hence not so close to the Ar gas

retention ages) (Fig. 8). Sm/Nd is only 4.6% higher than chondritic. Small changes in Sm/Nd produce large changes in T_{ICE}. If the age is 3.38 b.y., then ϵ_{JUV} is +0.4 ± 0.4, and if the age is 3.79 b.y., then ϵ_{JUV} is 0 ± 0.4. These are different (lower) than other mare basalts, and require an origin for green glass from nearly unfractionated reservoirs; an impact origin is unlikely. During melting of a "chondritic" source at 3.4 (or 3.8) b.y., the Sm/Nd was increased and a small Eu anomaly developed (Lugmair and Marti, 1977). Lugmair and Marti (1978) concluded that the lunar initial $^{144}Nd/^{143}Nd$ is consistent with an initially chondritic Moon.

A U fission track age (Storzer et el., 1973) for green spherules of 5.50 b.y. corresponds with an excess of 36.1%. If this results from Pu, and assuming a lunar $^{244}Pu/^{238}U$ of 0.013 at 4.58 b.y., a fission track age of 4.0 b.y. is calculated. In any case, whatever the source of excess tracks, the glass must be older than 3 b.y. (this is taken by Storzer et el., 1973, to suggest formation in a major, basin-forming impact).

TABLE 15426-7. Sm-Nd isotopic data
(Lugmair and Marti, 1978)

Sample	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	Sm x 10^{-9} moles/g	^{144}Nd x 10^{-9} moles/g
EG1	0.2016	0.512842 ± 34	4.735	3.523
EG2	0.2015	0.512831 ± 18	4.897	3.645
YG1	0.2011	0.512823 ± 24	4.890	3.646

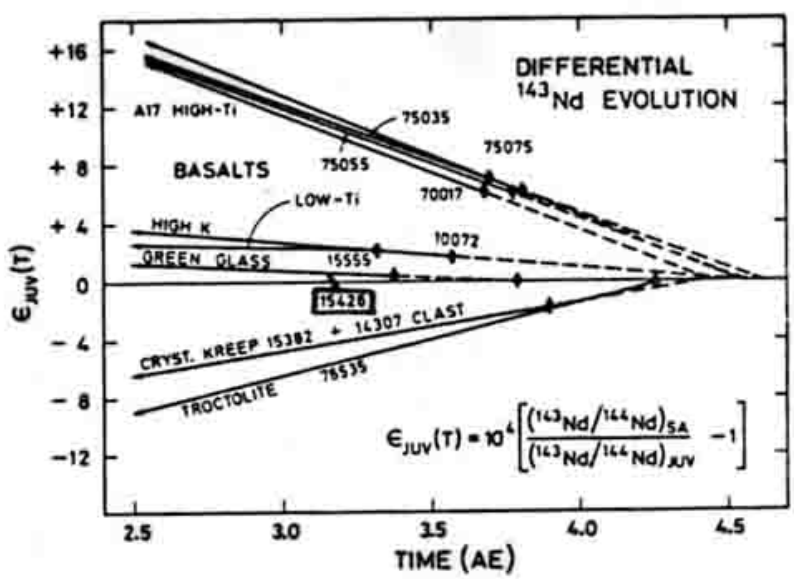

Figure 8. Differential ^{143}Nd evolution for 15426 green glass and other lunar materials (Lugmair and Marti, 1978).

Spangler et al. (1984) used the laser probe Ar method to determine ages of five fragments of yellow volcanic glass from 15426 and 15427, finding an average age of 3.62 ± 0.07 b.y. There was no significant correction for trapped argon in the yellow glasses. Spangler and Delano (1984) used the same technique to determine ages for five fragments of yellow impact glasses in 15426 and 15427. They determined an age of 3.35 + 0.05 b.y. for the impact; there was a significant correction for trapped ^{40}Ar but a similar age was derived for each glass and the ages are considered reliable. Hence the ages of their source basalts are not young (i.e., Eratosthenian), as had been predicted by Delano et el. (1981).

RARE GASES, TRACKS, AND EXPOSURE: Lakatos et el. (1973) tabulated He, Ne, and Ar isotopic data for single spherules and size separates from 15426 and other green glass materials. They found that spherules contain about 100x less trapped inert gas than do normal bulk Apollo 15 fines, and have never been directly exposed to the solar wind; spherules in other fines contain about 10x as much inert gas as those in 15426. The ^{21}Ne and ^{38}Ar exposure ages are 270-400 m.y.; ^{3}He exposure ages are always much less (less than 150 m.y.) because of ^{3}He losses. The trapped gases are not directly of solar wind origin and could be from solar-wind or an impacted precursor, or primordial lunar gas, which would then be similar to solar gas or the unfractionated component of gas-rich meteorites. The gas was trapped before formation of the clod. The ^{20}Ne/^{36}Ar ratio for spherules is very high. The ^{40}Ar-^{36}Ar systematics for materials from 15426 (and its residues, 15421) are different from green glasses in other fines.

Huneke et al. (1973) and Podosek and Huneke (1973) extensively discussed argon isotopic ratios which they determined and tabulated for 15426 green glasses. They found considerable trapped Ar in the near-surface regions, and it can be resolved into (at least) two components with separate origins--one shallow with ^{40}Ar/^{39}Ar >30; the other deeper (2 microns or so) with ^{40}Ar/^{39}Ar = 2.9. ^{40}Ar in both components is parentless. The ratio of trapped ^{40}Ar to ^{36}Ar is higher than in any lunar soil, and the trapped gas was implanted early. The derived exposure ages of ~ 300 m.y. differs from those of Lakatos et al. (1973) only in the choice of the production rate of ^{38}Ar. Spangler et al.(1984) determined Ar exposure ages of 275 to 300 m.y. for both green and yellow volcanic glasses in 15426 and 15427. Spangler and Delano (1984) determined Ar exposure ages of 274 ± 74 m.y. for yellow impact glasses from the same samples. Spangler and Delano (1984) noted two possibilities: either the clods formed more than 300 m.y. ago so have the same exposure, or 300 m.y. is an average for soils from St. 7.

Heymann (1975) plotted (^{40}Ar/^{36}Ar) trapped vs. ^{207}Pb/^{206}Pb (low temp. sites) for 15426 green glass in a discussion of records of ancient regolith, with the implication that 15426 is an ancient regolith from 3.5 to 4.0 b.y. ago.

Megrue (1972) and Megrue et al. (1973a,b) measured He, Ne, and Ar isotopes within individual green glass spheres from 15426 using a laser probe for gas release. Samples were sieved (<100 mesh and >60 mesh) and individual green (undevitrified) and black (devitrified) spherules picked from the coarser materials. They found differences in the proportions of cosmogenic and fractionated solar gases even within spherules and in the fine fractions. ^{20}Ne/^{36}Ar varies from 10 to 20 among spheres, and is higher than in soils.

Devitrified spherules have only 1/2 to 1/4 the ^{4}He of non-devitrified spherules, and cosmogenic ^{21}Ne is 5x as much in devitrified as in non-devitrified spherules. Both devitrified and non-devitrified spherules contain solar gases at depths greater than 5 microns. Megrue et al. (1973a) note that the $^{4}He(total)/^{36}Ar$ solar might result from different concentrations of radiogenic ^{4}He in spherules, or to selective fractionation of the gas when the original solids of the lunar surface were melted to produce the spherules (i.e., they assume an impact origin).

Lugmair and Marti (1978) noted an unusually large neutron fluence for $^{150}Sm/^{149}Sm$ for green glass spherules, consistent with a long near-surface residence time with a lower limit of 300 m.y.

Keith et al. (1972) provided cosmogenic nuclide disintegration count data for ^{26}Al, ^{22}Na, ^{54}Mn, ^{66}Co, and ^{46}Sc. They and Yokoyama et al. (1974) noted that the sample appears to be unsaturated in ^{26}Al, indicating an erosion rate high enough that ^{26}Al could not build up to saturation levels.

Fleischer and Hart (1972, 1973, 1974) measured particle tracks densities in green glass spherules, amber glass, and feldspar in 15426 (Fig. 9). The very abrupt cutoff of track densities shows that the clod has been "solid", i.e., unstirred, during its exposure to heavy cosmic rays, and contrasts with soils. The amber glass has a median track density l0x that of the green glass in 15426 and is either older, added separately, or contains tracks from different particles (according to its track-determined U content, this amber glass is probably yellow impact glass). The cosmic ray tracks indicate that 15426 was brought to the surface 0.5 m.y. ago (and the rare gas spallation ages of 50-300 m.y. are subsurface exposures). The clod itself is older.

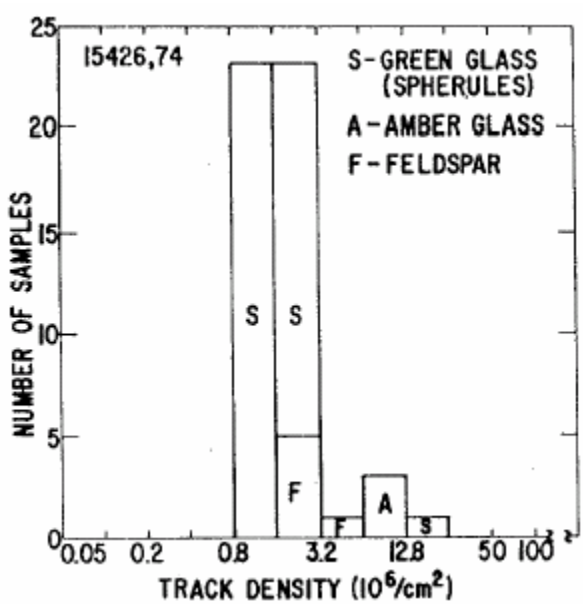

Figure 9. Track densities
(Fleischer and Hart, 1972).

Bhandari et al. (1972, 1973) reported cosmic ray track data, finding a peak track density in glasses of 7 x 10^6 cm^{-2} for an interior chip. Track density frequencies are shown in Figure 10, which shows that track densities are lower than for regolith 15302 collected nearby. MacDougall et al. (1973) found etchable solar flare tracks in glass and feldspars, indicating a maximum of 300°C or a very short heating event since formation of the tracks. They apparently assume an impact origin, suggest that the glasses may not have completely outgassed at formation, and hence may be younger than the ^{40}Ar-^{39}Ar ages (this scenario is according to a fission track age of <0.7 b.y. for a green glass in 15086). This scenario is incompatible with both our understanding of impact melting and subsequent isotopic data for 15426.

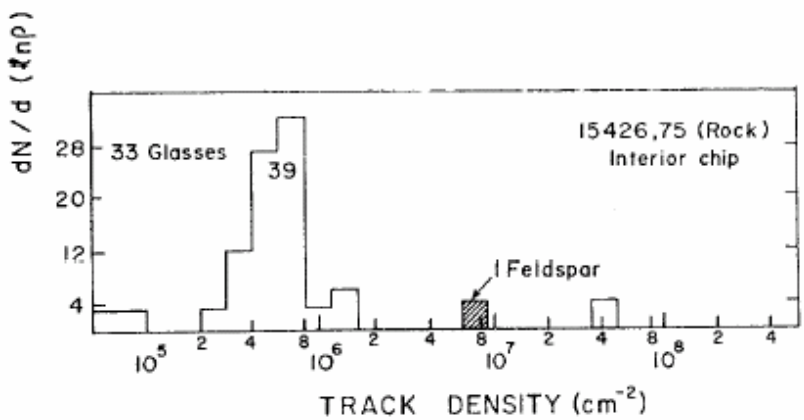

Figure 10. Track densities (Bhandari et al., 1973).

Storzer et al. (1973) studied cosmic ray and fission tracks (Table 8). Green spherules have a very low abundance of solar flare tracks compared with regoliths, and the 1.6% of solar flare-bearing particles observed might be soil contaminant. Solar flare tracks in the brown glasses and feldspars are higher (20%) and result from pre-clod irradiation. Combined 15426, 15421, and 15301 data give 4.5-5.5 x 10^5 tracks cm^{-2} on average. Assuming an average 5 cm burial gives a surface residence time of ~2 m.y. In 100 green spherules, 8.5 x 10^4 fission tracks cm^{-2} were found, with an average U of 0.049 ppm.

TABLE 15426-8. Track data of Storzer et al., 1973.

	% solar flare irradiated	Density of cosmic ray tracks	Apparent exposure age (m.y.)
Green Glass	1.6	0.1 - 70	~2
Brown Glass	20	0.3 - 10	--
Feldspar	20	2 - 8	--

PHYSICAL PROPERTIES: Pearce et al. (1973) tabulated room temperature magnetic measurements for a green clod sample: J_s of 0.05 emu/g; X_8 of 32.8 emu/g Oe; and J_{rs}/J_s of 0.08. They found a very low Fe content, suggesting a process more oxidizing than most lunar processes; in fact the Fe^0 content is very similar to most mare basalts.

Perry and Lowndes (1972) and Perry et al. (1972) measured infrared reflectance spectra on 15426, finding it spectroscopically different from soils and "also obviously richer in pyroxene than the Fra Mauro breccias". They calculated the real and imaginary parts of the dielectric constant. Perry et al. (1972) also produced a Raman spectrum for a green glass sphere, finding a doublet at 850 cm^{-1} from partial devitrification into olivine.

PROCESSING AND SUBDIVISIONS: Of the original three pieces ,1 is now 110.3 g and ,26 is 53.3 g. The latter is very pure green glass and is a restricted access sample. No other split is as large as 4 g. Most samples have been allocated from ,27, which is also a generally green glass-rich sample. A series of thin sections was made from ,2: ,4 is essentially a grain mount; and ,17 to ,25 are porous regolith breccia samples. Thin sections ,69; ,70; and ,72 were from a split of ,27 and are much richer in green glass, but also contain other materials. Sample ,3 was made into sieved fractions from which grain mounts were made; these are dominated by green glass.