

TABLE 1. Composition of zircon in lunar sample 14161,7069

	A	B	C	D	E	EMP Avg*
Oxides (wt%) by EMP, except as noted						
SiO ₂	32.5 ± 0.18**	32.8 ± 0.18	32.8 ± 0.18	32.6 ± 0.18	32.7 ± 0.18	32.4(0.54)
ZrO ₂	66.2 ± 0.54	65.1 ± 0.54	66.5 ± 0.55	65.8 ± 0.55	66.3 ± 0.54	65.9(1.18)
HfO ₂	1.28 ± 0.08	1.37 ± 0.08	1.22 ± 0.08	1.28 ± 0.08	1.24 ± 0.08	1.18(0.06)
Al ₂ O ₃	<0.05	<0.05	<0.05	<0.05	<0.05	0.02(0.05)
Y ₂ O ₃	0.07 ± 0.03	0.16 ± 0.03	0.23 ± 0.03	0.28 ± 0.04	0.34 ± 0.05	0.19(0.09)
FeO	0.10 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.05 ± 0.01	0.06 ± 0.01	0.10(0.09)
P ₂ O ₅	0.05 ± 0.01	0.09 ± 0.01	0.13 ± 0.02	0.16 ± 0.02	0.18 ± 0.02	0.11(0.05)
Ln ₂ O ₃ †	0.05	0.08	0.13	0.16	0.16	0.12(0.08)
Sum	100.3	99.6	101.1	100.4	101.0	100.0
Trace elements (parts per million) by SIMS						
P	227 ± 13	380 ± 13	566 ± 13	715 ± 14	766 ± 16	
Ca	38 ± 8	24 ± 2	63 ± 10	125 ± 5	70 ± 5	
Sc	49 ± 10	58 ± 12	59 ± 12	69 ± 14	72 ± 14	
Ti	59 ± 2	66 ± 2	80 ± 4	79 ± 3	161 ± 5	
Y	776 ± 7	1250 ± 9	2136 ± 10	2519 ± 14	2660 ± 15	
Ba	1.8 ± 0.4	1.1 ± 0.3	1.8 ± 0.5	2.7 ± 0.5	7.5 ± 1.0	
La	0.2 ± 0.05	0.1 ± 0.05	0.4 ± 0.1	2.4 ± 0.2	0.4 ± 0.1	
Ce	0.7 ± 0.1	0.5 ± 0.1	1.7 ± 0.2	6.7 ± 0.6	2.3 ± 0.3	
Pr	0.1 ± 0.05	0.1 ± 0.05	0.3 ± 0.1	1.1 ± 0.1	0.6 ± 0.1	
Nd	0.9 ± 0.1	1.5 ± 0.1	4.9 ± 0.3	7.6 ± 0.5	7.3 ± 0.6	
Sm	2.0 ± 0.2	3.3 ± 0.3	8.3 ± 0.5	11 ± 1	10 ± 1	
Eu	0.05 ± 0.02	0.03 ± 0.02	0.12 ± 0.06	0.03 ± 0.06	0.03 ± 0.10	
Gd	14 ± 1	23 ± 1	49 ± 1	72 ± 1	68 ± 2	
Tb	3.3 ± 0.3	5.9 ± 0.4	11 ± 1	17 ± 1	14 ± 1	
Dy	58 ± 1	90 ± 2	167 ± 3	222 ± 3	213 ± 4	
Ho	22 ± 1	35 ± 1	60 ± 1	77 ± 1	78 ± 2	
Er	113 ± 2	171 ± 2	291 ± 4	344 ± 4	358 ± 4	
Tm	23 ± 1	36 ± 1	55 ± 1	68 ± 1	71 ± 2	
Yb	197 ± 3	286 ± 5	438 ± 6	499 ± 5	540 ± 9	
Lu	30 ± 2	8 ± 4	14 ± 5	76 ± 3	15 ± 7	
Th	6 ± 0.5	11 ± 0.5	21 ± 1	29 ± 2	31 ± 2	
U	21 ± 1	31 ± 2	44 ± 2	51 ± 2	55 ± 2	
Calculated Th and U concentrations (ppm) at 4.0 Ga						
Th	7.3	13	26	35	38	
U	46	69	98	113	122	
Calculated cumulative α-decay events per milligram of zircon						
Σ α-decay events	0.52 × 10 ¹⁵	0.77 × 10 ¹⁵	1.1 × 10 ¹⁵	1.3 × 10 ¹⁵	1.4 × 10 ¹⁵	

* Average of 58 electron microprobe analyses (not normalized). Parentheses contain one standard deviation values; these values reflect compositional zoning, so they exceed analytical uncertainty.

** Analytical uncertainty for data points A–E (± values) represents one standard deviation on the basis of counting statistics.

† Ln₂O₃, lanthanides, determined by SIMS; see individual elements for analytical uncertainty. Ln₂O₃ value was summed for all trivalent lanthanides and extrapolated for those not measured.

row-line fluorescence spectra to be recorded on a micrometer scale in zoned minerals. The mechanical configuration of the high-resolution monochromator in combination with an argon ion laser as excitation source makes it possible to monitor the fluorescence-emission spectra between the wavelength of excitation (488 or 514 nm) and 850 nm. In general, laser-induced fluorescence is an undesired phenomenon in Raman spectroscopy because it typically interferes with and overwhelms the desired Raman spectroscopic information to the extent that the Raman spectrum cannot be interpreted. However, there are certain transitions of trace element ions, e.g., certain trivalent REE ions, that do not overlap or interfere with the Raman peaks, and whose fluorescence emission spectrum can be monitored in addition to the Raman spectrum.

Six of the observed peaks in the Raman spectrum of pure zircon (Fig. 2a) were theoretically assigned by Dawson et al. (1971) according to a full crystal-field analysis

of the silicate tetrahedra in a crystalline structure with a D_{4h} point-group symmetry (Table 2). The four highest frequency modes are internal stretching and bending vibrations of the (SiO₄)⁴⁻ tetrahedra; whereas, the modes at 224 and 201 Δcm⁻¹ are lattice modes. The intensity of the bands with the E_g symmetry (see Table 2) depends on the orientation of the zircon crystal with respect to the polarization plane of the exciting laser light.

The optical spectrum of zircon obtained with a laser Raman microprobe consists not only of the Raman scattering from allowed vibrational modes but also of the structure- and site-specific fluorescence of trivalent REE ions (REE³⁺). Many terrestrial zircon samples yield Raman spectra that are substantially different from the one predicted from the crystalline structure and obtained for pure ZrSiO₄ (Jolliff et al. 1995; Nasdala et al. 1995). The Raman peaks are frequently shifted substantially downward or upward in position, the peaks are wider, and additional peaks (which are caused by laser-induced flu-