thermore, the estimate of supply rate to Kilauea made by Stearns and Macdonald (*6*) may be low because several Mauna Loa eruptions took place during the same time interval, if Moore's (*7*) data are reliable. The rate estimates for Kilauea made in this report are for a period of no Mauna Loa eruptive activity, and seismic and geodetic data suggest no substantial deformation of Mauna Loa during this time (*8*).

From an analysis of tide gauge records, Moore (*7*) concluded that the island of Hawaii is subsiding isostatically at a rate of 22.5×10^6 m^3/month because of the addition of magma (mass) to Mauna Loa and Kilauea. This subsidence rate is more than six times the magma supply rate that he used. Moore found from simplified isostatic models that the subsidence rate could be a maximum of only 2.6 times the supply rate, which leaves an apparent discrepancy between the observed subsidence and supply rates of a factor of 2.3. This discrepancy is virtually eliminated by using the magma supply rate calculated in this report. Possibly, therefore, magma has been supplied to the combined reservoir systems of Mauna Loa and Kilauea at a constant rate of about 9×10^6 m^3/month throughout at least historic time, but much of this supply has been intruded into the volcanic pile or extruded on the sea floor where observation is impossible, as suggested by Moore (*7*). Such hidden activity is implied by the numerous subsidence events, with little or no corresponding visible eruption, that have taken place at Kilauea during historic time (*9*) and by the substantial permanent uplift and dilation of the rift zones measured during the past 50 years (*10*).

These considerations suggest that the observed rate of magma supply may be that from the mantle, not simply from some holding reservoir within the volcanic edifice itself. In support of this, the chemical compositions of lava erupted throughout the 1967–68 and Mauna Ulu eruptions show very little variation (*11*), which suggests that an intermediate-depth storage chamber susceptible to magmatic differentiation is not being emptied. Kilauea Volcano could have been built in much less than 4×10^5 years at the magma supply rate presented here, but simultaneous Mauna Loa activity could have extended this period of growth substantially.

DONALD A. SWANSON
U.S. Geological Survey,
Menlo Park, California 94025

References and Notes

1. G. A. Macdonald, *U.S. Geol. Surv. Bull. 1021-B* (1955), pp. 53–104.
2. W. T. Kinoshita, R. Y. Koyanagi, T. L. Wright, R. S. Fiske, *Science* **166**, 459 (1969).
3. D. A. Swanson, D. B. Jackson, W. A. Duffield, D. W. Peterson, *Geotimes* **16**, 12 (1971).
4. Such estimates are considered reliable within 10 to 15 percent. All 11 rate estimates for this period were virtually identical, even when based on flows of quite different geometries.
5. The vesicularity adjustment factor is the average of 20 percent vesicularity for flows and 10 percent for solidified lava lakes.
6. H. T. Stearns and G. A. Macdonald, *Hawaii Div. Hydrogr. Bull. 9* (1946).
7. J. G. Moore, *Bull. Volcanol.* **34**, 562 (1970). Moore found an antithetic relationship between the supply rates of Kilauea and Mauna Loa; during periods of increased Mauna Loa activity, Kilauea's volume rate of erupted lava dwindles, and vice versa. This suggests that the two volcanoes are not totally isolated, independent systems.
8. Hawaiian Volcano Observatory, unpublished data.
9. *Bull. Hawaii. Vol. Observ. 12* (1924); R. M. Wilson, *Univ. Hawaii Res. Publ. 10* (1935); W. T. Kinoshita, *U.S. Geol. Surv. Prof. Pap. 575-C* (1967), p. C173; R. S. Fiske and R. Y. Koyanagi, *U.S. Geol. Surv. Prof. Pap. 607* (1968).
10. D. A. Swanson, W. A. Duffield, R. T. Okamura, *Amer. Geophys. Union Trans.* **52**, 372 (1971); paper presented at the 15th General Assembly of the International Union of Geodesy and Geophysics, Moscow, 1971.
11. T. L. Wright and R. S. Fiske, *J. Petrology* **12**, 1 (1971); Hawaiian Volcano Observatory, unpublished data. There is only one chemical analysis for the 1952 eruption.
12. I thank W. A. Duffield and D. W. Peterson for discussion and help in fieldwork and J. G. Moore and T. L. Wright for manuscript review. Publication has been authorized by the director, U.S. Geological Survey.

7 July 1971; revised 15 September 1971

Chemical Composition of Sawdust from Lunar Rock 12013 and Comparison of a Java Tektite with the Rock

Abstract. *Abundances of 11 major and minor elements and 11 trace elements have been determined by instrumental neutron activation analysis of two Apollo 12013 rock fragments, a sample of rock 12013,17 sawdust, and a Java tektite (J2). Although the abundances of major elements in tektite J2 are similar to those of rock 12013, comparison of the minor and trace elements shows that no fragment or sawdust of rock 12013 that has been analyzed to date is chemically similar to tektite glass. Rock sawdust is representative of "whole rock" composition only if the amount of contamination from the sawing process is known. After appropriate correction for saw wire contamination, analyses of sawdust yield fairly accurate averaged elemental compositions of complex clastic lunar and other rocks.*

Lunar rock 12013 is undoubtedly the most extensively studied lunar rock to date. It is the oldest metamorphosed or recrystallized heterogeneous rock known [4.0×10^9 years (*1, 2*)]. Since this rock has a very high SiO_2 content (*3*), it is of special interest to the proponents of a lunar origin for tektites. In previous reports (*3, 4*), abundances of 22 major, minor, and trace elements were determined for seven fragments of rock 12013. In addition to aliquants from two previously analyzed 12013 fragments and a 12013 sawdust sample, a fragment of the tektite J2 was also analyzed by instrumental neutron activation. Abundances of 13 major and minor and 4 trace elements in this particular javanite (J2) are very similar to those found in tektites J86 and J87 (*5*). O'Keefe (*6*) observed that the major and some minor elemental abundances are indeed very similar in the J86 and J87 tektites and in the "glassy portion" of rock 12013. From this he concluded that tektites originated from explosive volcanic activity on the moon. There has been no mention of a "glassy portion" thus far in the published petrological descriptions of this complex microbreccia.

Analytical results are listed in Table 1. For the majority of the elements, the results of this work for 12013,10 are in good agreement with the abundances reported (*4*) for analyses of different aliquants of the same fragment powders. However, in case of disagreements, the recent data are considered more reliable. Because longer counting periods and adequate decay measurements were done in this work, the Eu, Th, and U abundances of this work are superior to those of the previous report.

The sawdust sample 12013,17 was collected from the remains of the rock sawing process. The saw wire was fabricated from diamonds impregnated into a copper sheath over an iron core. Comparison of the elemental abundances for sawdust #17 with the average abundances for seven fragments from rock 12013 (Table 1) indicates that abundances in the sawdust are lower by a relatively constant decrement of about 0.3. Assuming 4 percent Mg in the rock (*4*), a dilution decrement of about 0.27 is calculated, which agrees with a previous calculated value of 0.25 to 0.30 (*3*). Therefore, all absolute abundances except C and Cu in the sawdust may be calculated by dividing all abundances by the total fractional summation of all major and minor elements. In our particular sawdust analysis this factor is 0.73.

The chondritic normalized rare earth element (REE) patterns for #17 and #18 aliquants for 12013 sawdust are very similar and are displaced by a constant factor within experimental error (Fig. 1). These findings are consistent with the observation that rare earths are very highly abundant in accessory phosphate minerals (*7*) heterogeneously mixed in the powder. The ratios of the average REE abundances in #17 and #18 powders to the corresponding REE abundances in the average of seven 12013 fragments are about the same as the ratios of the major and minor elements in #17 and #18 to the corresponding elements in the average of seven fragments. Similar ratios are observed for Sc, V, Co, and Hf in #17 sawdust to the average in seven fragments. The average whole rock composition of U in 12013 sawdust was found to be 10.6 ppm (7.7 ppm divided by the dilution factor of 0.73); this value agrees well with the value of 10.3 ± 0.5 ppm determined by O'Kelley *et al.* (*8*) for the whole rock. Such agreement supports the suggestion by Hubbard *et al.* (*9*) that analyses of sawdust from very complex heterogeneous rocks yield the average whole rock composition.

The major and a few minor elemental abundances of the J2 tektite are well within the range of abundances exhibited by the various individual fragments and the average of seven fragments of rock 12013 (Table 1). However, when comparing minor and trace element concentrations, large differences are observed. Abundances in Australasian microtektites (*10, 11*) are in almost every case in excellent agreement with the abundances found for the javanites

Table 1. Elemental abundances of major, minor, and trace elements in aliquants of two 12013 fragment powders, in 12013 sawdust, and in a Java tektite determined by instrumental neutron activation analysis. The estimated errors are: Si and O, ± 1 to 2 percent; Na and Mn, ± 2 percent; Al and Cr, ± 3 percent; Fe, Ca, La, Sm, Yb, Sc, Co, and Lu, ± 5 percent; K, ± 7 percent; Ti, V, Hf, Ba, and Eu, ± 10 percent; Th and U, ± 10 to 20 percent. The values for U and Th given in parentheses are considered unreliable because of the short time allotted for analysis. The abundances for U and Th in this work are considered more accurate than those given in previous work because the decay of ^{239}Np (228 kev) was followed through three half-lives and the decay of ^{233}Pa (312 kev) was followed through two half-lives.

Element	Fragment powders				Sawdust from 12013		Mass weighted average of seven 12013 fragments (*4*)	Tektite J2, this work (61.1 mg)	Javanites, other work (range includes eight) (*5*)	Australasian microtektites (composite of five) (*10*)
	12013-10, #37 + 24		12013-10, #35							
	This and other work (17.1 mg)	Other work (*4*)	This and other work (19.8 mg)	Other work (*4*)	#17, This and other work (31.7 mg)	#18, Other work (*9*)				
Si (%)	28.4 (*3*)		24.9 (*3*)		18.2 (*3*)		27.9 ± 2.9	32.7*	30–36	32 (*11*)
O (%)	44.0 (*3*)		40.4 (*3*)		33.7 (*3*)		44.5 ± 2.3	49.1*		
Ti (%)	0.5	0.8	0.6	0.9	0.7		0.9 ± 0.5	0.4	0.4–0.5	0.5 (*11*)
Al (%)	6.3	6.0	6.9	6.7	5.0, 4.9 (*3*)		6.8 ± 0.7	7.2, 7.5*	5.7–7.1	7.9 (*11*)
Fe (%)	10.0	9.4	11.7	10.1	6.7		8.3 ± 1.1	6.2, 6.4*	3.0–6.1	3.3
Ca (%)	4.2	3.7	5.7	6.0	3.3	2.8	5.1 ± 1.3	2.3	1.3–2.6	2.2 (*11*)
Ca (%)				5.5 (*2*)						
Na (%)	0.87	0.86	0.80	0.78	0.67	0.57	0.93 ± 0.09	0.60	0.46–1.0	0.45
Na (%)				0.80 (*9*)						
K (%)	1.62	1.65	0.87	0.93	0.91	0.98	1.37 ± 0.87	1.16	1.2–2.1	1.42
K (%)		1.71 (*2*)		0.57 (*9*)						
Cr (ppm)	2170	1770	2430	2300	1190		1410 ± 480	420	110–390	81
Mn (ppm)	1200	1230	1540	1550	750		1200 ± 190	1000	660–1080	820
Ba (ppm)	2610	2720	1650	1810	1490	1660	2310 ± 910	330	370–410	530
Ba (ppm)		2770 (*2*)		1850 (*2*)						
Sum, less Mg (%)	96.5		92.5		69.5		96.3	99.8		
Sc (ppm)	28	28	41	38	17		27 ± 6	13	11 (*17*)	12
V (ppm)	100	80	100	100	50		78 ± 18	80	54–76	
Co (ppm)	36	35	31	25	18		26 ± 7	49	14–53	10
Hf (ppm)	15	18	17	20	15		23 ± 6	6	7 (*17*)	6
La (ppm)	54	50	42	37	60	45	66 ± 27	44	33 (*17*)	40
La (ppm)				38 (*9*)						
Sm (ppm)	18.6	17.9	14.7	14.0	21	18	25 ± 13	6.5		7.1
Sm (ppm)		16.5 (*2*)		13.9 (*9*)						
Eu (ppm)	2.3	1.7	2.4	1.4	1.7	1.6	2.0 ± 0.8	1.3	1.1 (*17*)	1.4
Eu (ppm)		2.2 (*2*)		2.2 (*9*)						
Yb (ppm)	29	29	20	19	23	21	30 ± 7	2.8		2.2
Yb (ppm)		27 (*2*)		20 (*9*)						
Lu (ppm)	4.4	4.0	3.1	2.7	3.6	2.9	4.1 ± 1.0	0.45		0.45
Lu (ppm)		4.3 (*2*)		2.8 (*9*)						
Th (ppm)	38	(25)	23	(12)	25		(22 ± 8)	16	13 (*17*)	15
U (ppm)	10.9	(9.7)	8.0	(4.6)	7.7		(7.9 ± 2.7)	2.8		
Th/U	3.5		2.9		3.2			5.7		
Sm/Eu	8.1	(11)	6.1	(10)	12.5	11.2	(9–24)	5.0		5.2

* Neutron activation analyses (14 Mev) made at the University of Kentucky.

(5). The abundances of most major and minor elements of these two tektite groups generally agree with the corresponding abundances reported in the 12013 rock. However, large differences are noted for Cr, Ba, Sc, Hf, Sm, Yb, Lu, and U abundances between these tektites and 12013 rock.

The REE patterns (Fig. 1) exemplify even better the striking compositional differences between the javanite and Australasian microtektites and rock 12013. The chondritic normalized REE patterns for the tektites, J2 included, resemble the terrestrial REE distribution with insignificant, if any, Eu depletion. On the other hand, the REE patterns for 12013 (2, 4, 9) and for all Apollo 11 and 12 rocks and soil studied to date except the Apollo 11 gabbroic anorthositic rocks (12), all display a severe Eu depletion.

King *et al.* (13) observed no similarities between lunar and tektite glasses. Taylor and Epstein (14) found large differences between the $^{18}O/^{16}O$ ratios in lunar rocks and minerals and in tektites. We also note that large differences exist in the minor and trace elemental contents of the lunar rock 12013 and the tektite J2. Taylor (15), Chapman and Scheiber (5), and O'Keefe (16) have suggested that the final composition of tektite matter cannot be attributed to a simple fractional vaporization mechanism from terrestrial starting materials. Because of this difficulty, the tektite composition must closely resemble the composition of the parent preimpact rock. From these discussions and in conjunction with our observations, we must conclude that the lunar rocks and soils analyzed to date cannot in any way be related to the parent material that gave rise to tektites. Since no close correspondence exists between the chemical compositions of the J2 and other tektites and terrestrial rocks and sediments analyzed to date—that is, the individual elemental contents should agree within about ± 10 percent of one another—a terrestrial origin for J2 and other tektites may be more complex than is currently envisioned.

In summary, analyses of rock sawdust yield the overall "whole rock" composition after corrections are made for dilution by the saw wire debris. Such analyses should be quite valuable in studying complex rocks such as the Apollo 14 clastic rocks. A direct comparison of the elemental abundances of a javanite (J2) and Australasian microtektites with various fragments of rock 12013 and with the overall 12013 rock indicates that rock 12013 is not related to tektites.

D. L. Showalter, H. Wakita
R. H. Smith,* R. A. Schmitt
Department of Chemistry and
Radiation Center, Oregon State University, Corvallis 97331
D. E. Gillum, W. D. Ehmann
Department of Chemistry, University of Kentucky, Lexington 40506

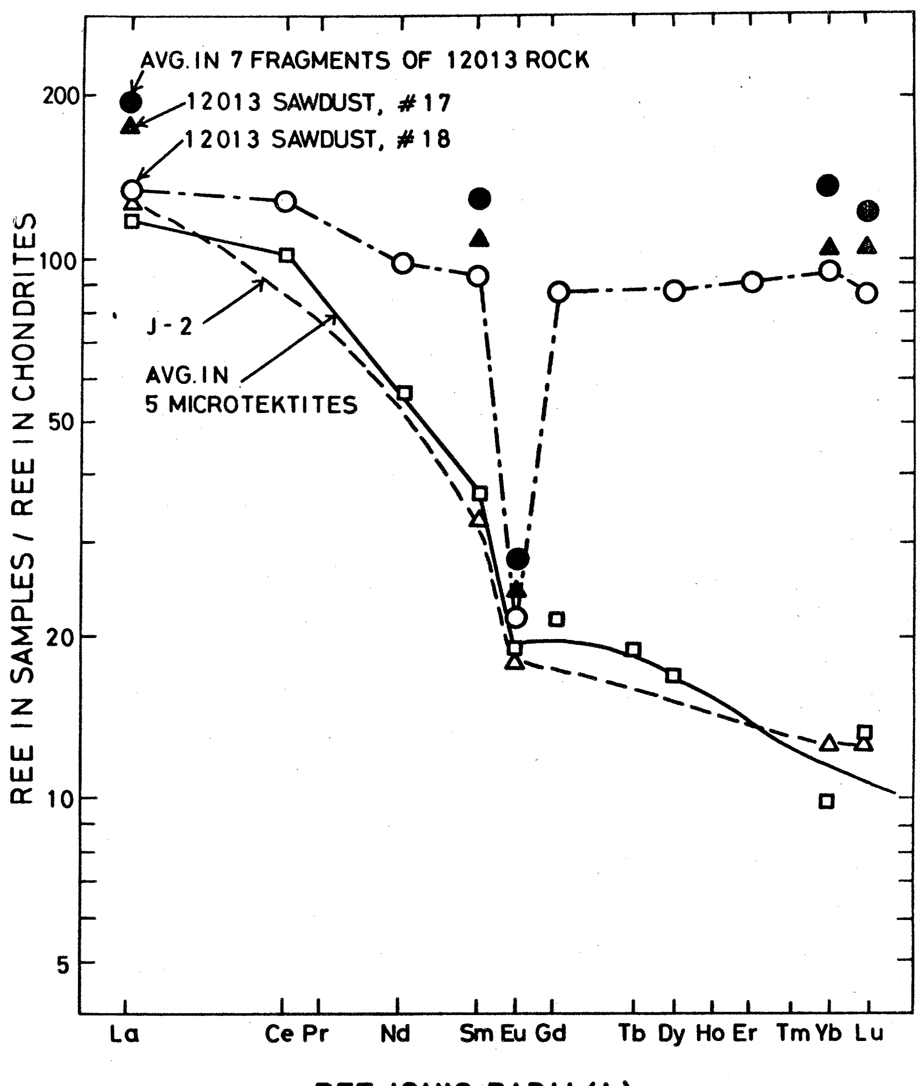

Fig. 1. Abundances of rare earth elements in seven fragments (average) of rock 12013 (4), sawdust 12013,17 (this work), sawdust 12013,18 (9), five microtektites (10), and in the J2 tektite (this work).

References and Notes

1. A. L. Albee, D. S. Burnett, A. A. Chodos, E. L. Haines, J. C. Huneke, D. A. Papanastassiou, F. A. Podosek, G. P. Russ III, G. J. Wasserburg, *Earth Planet. Sci. Lett.* **9**, 137 (1970).
2. C. C. Schnetzler, J. A. Philpotts, M. L. Bottino, *ibid.*, p. 185.
3. J. W. Morgan and W. D. Ehmann, *ibid.*, p. 164.
4. H. Wakita and R. A. Schmitt, *ibid.*, p. 169.
5. D. R. Chapman and L. C. Scheiber, *J. Geophys. Res.* **74**, 6737 (1969).
6. J. A. O'Keefe, *Science* **168**, 1209 (1970).
7. M. H. Drake, I. S. McCallum, G. A. McKay, D. F. Weill, *Earth Planet. Sci. Lett.* **9**, 103 (1970).
8. G. D. O'Kelley, J. S. Eldridge, E. Schonfeld, P. R. Bell, *Proceedings of the Second Lunar Science Conference*, A. A. Levinson, Ed. (M.I.T. Press, Cambridge, Mass., 1971), vol. 2, pp. 1159–1168.
9. N. J. Hubbard, P. W. Gast, H. Wiesman, *Earth Planet. Sci. Lett.* **9**, 181 (1970).
10. F. A. Frey, C. M. Spooner, P. A. Baedecker, *Science* **170**, 845 (1970).
11. W. A. Cassidy, B. P. Glass, B. C. Heezen, *J. Geophys. Res.* **74**, 1008 (1969).
12. H. Wakita and R. A. Schmitt, *Science* **170**, 969 (1970).
13. E. A. King, M. F. Carman, J. C. Butler, *ibid.* **167**, 650 (1970).
14. H. P. Taylor, Jr., and E. Epstein, *Proceedings of the Apollo 11 Lunar Science Conference*, A. A. Levinson, Ed. (Pergamon, New York, 1970), vol. 2, pp. 1613–1626.
15. S. R. Taylor, *Geochim. Cosmochim. Acta* **30**, 1121 (1966).
16. J. A. O'Keefe, *Science* **171**, 313 (1971).
17. D. L. Showalter, thesis, University of Kentucky (1970).
18. Supported by NASA contracts 9-8017 and 9-8097 and NASA grant 38-002-020. D. R. Chapman loaned the J2 sample to us. We thank E. Anders, G. G. Goles, and J. A. O'Keefe for criticisms of this manuscript, and we thank the TRIGA nuclear reactor group at Oregon State University for sample activations.
* Deceased.

26 August 1971