UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

LEACHABILITY OF URANIUM AND OTHER ELEMENTS FROM FRESHLY ERUPTED VOLCANIC ASH

By David B. Smith[1], Robert A. Zielinski[1]
and W. I. Rose, Jr.[2]

Open-File Report 81-118
1981

[1]U.S. Geological Survey, Denver, CO 80225
[2]Michigan Technological University, Houghton, MI 49931

CONTENTS

	Page
Abstract	1
Introduction	1
Soluble uranium on freshly erupted ash?	2
Sample description	3
Experimental methods	12
Analytical methods for unleached volcanic material	14
Analytical methods for leachates	17
Results and discussion	19
Environmental implications	36
Economic implications	36
Conclusions	42
Acknowledgments	42
References	43

ILLUSTRATIONS

Figure 1.	4
Figure 2.	9
Figure 3.	21

TABLES

Table 1.	5
Table 2.	8
Table 3.	13
Table 4.	16
Table 5.	18
Table 6.	28
Table 7.	29
Table 8.	34
Table 9.	35
Table 10.	37
Table 11.	38
Table 12.	40

FIGURE CAPTIONS

Fig. 1. Location map of Fuego (F), Pacaya (P), and Santiaguito (S) volcanoes.	4
Fig. 2. Scanning electron microscope images of unleached ash particles.	9
A. Basaltic vitric ash from Pacaya volcano (110 x 150 μm).	9
B. Vesicular basaltic ash from Fuego volcano (500 x 700 μm).	9
C. Dacitic ash from Santiaguito volcano (240 x 300 μm).	10

FIGURE CAPTIONS--continued

Page

D. Surface of Santiaguito ash. Energy dispersive X-ray analysis showed the elongate crystal is a nonsilicate rich in Ca and S, probably calcium sulfate (25 x 36 μm).------------------- 10
E. Surface of Santiaguito ash. Hummocky area in center of photo is rich in Na and Cl and may be a poorly formed (or partially dissolved) NaCl crystal (250 x 360 μm).-------------------- 11
F. Closeup of NaCl-rich area shown in Fig. 2-E. Smaller grains clinging to NaCl are silicate ash fragments (85 x 110 μm).-------------------- 11

Fig. 3. Leachability of the measured elements as a function of leach type.-- 21
A. Fuego volcano.-- 21
B. Pacaya volcano.--- 22
C. Santiaguito volcano.------------------------------------ 23
D. Bomb fragments.--- 24
E. Historic "rhyolites".----------------------------------- 25

APPENDICES

Appendix I.-- 48
Table 1. Fuego volcano: Chemical composition of samples studied.-- 48
Table 2. Pacaya volcano: Chemical composition of samples studied.-- 50
Table 3. Santiaguito volcano: Chemical composition of samples studied.-- 51
Table 4. Freshly erupted bomb fragments: Chemical composition of samples studied.-------------------------------------- 52
Table 5. Historic "rhyolites": Chemical composition of samples studied.-- 53

Appendix II.--- 55
Table 1A. Fuego volcano: Concentration (mg/L) of analyzed elements in water leachates.------------------------ 55
Table 1B. Pacaya volcano: Concentration (mg/L) of analyzed elements in water leachates.------------------------ 57
Table 1C. Santiaguito volcano: Concentration (mg/L) of analyzed elements in water leachates.------------------------ 58
Table 2A. Fuego volcano: Concentration (mg/L) of analyzed elements in acid leachates.------------------------- 59
Table 2B. Pacaya volcano: Concentration (mg/L) of analyzed elements in acid leachates.------------------------- 61
Table 2C. Santiaguito volcano: Concentration (mg/L) of analyzed elements in acid leachates.------------------------- 62
Table 3A. Fuego volcano: Concentration (mg/L) of analyzed elements in carbonate-bicarbonate leachates.---------- 63

CONTENTS--continued

APPENDICES--continued

		Page
Table 3B.	Pacaya volcano: Concentration (mg/L) of analyzed elements in carbonate-bicarbonate leachates.----------	65
Table 3C.	Santiaguito volcano: Concentration (mg/L) of analyzed elements in carbonate-bicarbonate leachates.----------	66
Table 4A.	Freshly erupted bomb fragments: Concentration (mg/L) of analyzed elements in water leachates.-------------	67
Table 4B.	Freshly erupted bomb fragments: Concentration (mg/L) of analyzed elements in acid leachates.--------------	68
Table 4C.	Freshly erupted bomb fragments: Concentration (mg/L) of analyzed elements in carbonate-bicarbonate leachates.---	69
Table 5A.	Historic "rhyolite" samples: Concentration (mg/L) of analyzed elements in water leachates.----------------	70
Table 5B.	Historic "rhyolite" samples: Concentration (mg/L) of analyzed elements in acid leachates.-----------------	71
Table 5C.	Historic "rhyolite" samples: Concentration (mg/L) of analyzed elements in carbonate-bicarbonate leachates.---	72
Appendix III.--		73
Table 1A.	Percent of element removed by water leach of Fuego ash.---	73
Table 1B.	Percent of element removed by water leach of Pacaya ash.--	75
Table 1C.	Percent of element removed by water leach of Santiaguito ash.-------------------------------------	76
Table 2A.	Percent of element removed by acid leach of Fuego ash.---	77
Table 2B.	Percent of element removed by acid leach of Pacaya ash.--	79
Table 2C.	Percent of element removed by acid leach of Santiaguito ash.-------------------------------------	80
TABLE 3A.	Percent of element removed by carbonate-bicarbonate leach of Fuego ash.--------------------------------	81
Table 3B.	Percent of element removed by carbonate-bicarbonate leach of Pacaya ash.-------------------------------	83
Table 3C.	Percent of element removed by carbonate-bicarbonate leach of Santiaguito ash.--------------------------	84
Table 4A.	Percent of element removed by water leach of freshly erupted bomb fragments.-----------------------------	85
Table 4B.	Percent of element removed by acid leach of freshly erupted bomb fragments.-----------------------------	86
Table 4C.	Percent of element removed by carbonate-bicarbonate leach of freshly erupted bomb fragments.-------------	87
Table 5A.	Percent of element removed by water leach of historic "rhyolite" samples.-------------------------	88
Table 5B.	Percent of element removed by acid leach of historic "rhylolite" samples.------------------------	89
Table 5C.	Percent of element removed by carbonate-bicarbonate leach of historic "rhyolite" samples.----------------	90

ABSTRACT

A study of leaching of freshly erupted basaltic and dacitic air-fall ash and bomb fragment samples, unaffected by rain, shows that glass dissolution is the dominant process by which uranium is initially mobilized from air-fall volcanic ash. Si, Li, and V are also preferentially mobilized by glass dissolution. Gaseous transfer followed by fixation of soluble uranium species on volcanic-ash particles is not an important process affecting uranium mobility. Gaseous transfer, however, may be important in forming water-soluble phases, adsorbed to ash surfaces, enriched in the economically and environmentally important elements Zn, Cu, Cd, Pb, B, F, and Ba. Quick removal of these adsorbed elements by the first exposure of freshly erupted ash to rain and surface water may pose short-term hazards to certain forms of aquatic and terrestrial life. Such rapid release of material may also represent the first step in transportation of economically important elements to environments favorable for precipitation into deposits of commercial interest.

Ash samples collected from the active Guatemalan volcanoes Fuego and Pacaya (high-Al basalts) and Santiaguito (hornblende-hypersthene dacite); bomb fragments from Augustine volcano (andesite-dacite), Alaska, and Heimaey (basalt), Vestmann Islands, Iceland; and fragments of "rhyolitic" pumice from various historic eruptions were subjected to three successive leaches with a constant water-to-ash weight ratio of 4:1. The volcanic material was successively leached by (1) distilled-deionized water (pH = 5.0-5.5) at room temperature for 24 hours, which removes water-soluble gases and salts adsorbed on ash surfaces during eruption; (2) dilute HCl solution (pH = 3.5-4.0) at room temperature for 24 hours, which continues the attack initiated by the water and also attacks acid-soluble sulfides and oxides; (3) a solution 0.05 M in both Na_2CO_3 and $NaHCO_3$ (pH = 9.9) at 80°C for one week, which preferentially dissolves volcanic glass. The first two leaches mimic interaction of ash with rain produced in the vicinity of an active eruption. The third leach accelerates the effect of prolonged contact of volcanic ash with alkaline ground water present during ash diagenesis.

INTRODUCTION

Freshly erupted air-fall volcanic ash is washed by rains which frequently occur during or shortly after eruption (Finch, 1930; Wilcox, 1959). This initial washing may release readily soluble ash components into the local ground- and surface-water system and cause potentially short-term, but significant, changes in the local water chemistry. Transient elevated concentrations of some dissolved species may pose health hazards or represent the first step in transporting economically important elements to environments where they can be precipitated into deposits of commercial interest. After the initial washing, prolonged exposure of the ash to a weathering environment may cause slow release of elements within the structure of constituent minerals or in solid solution in glass. This process may be of equal or greater importance than the initial washing in transporting elements of economic interest.

The existence of readily soluble material on freshly erupted volcanic ash has been documented by many researchers (Lacroix, 1907; Basharina, 1958; Tovarova, 1958; Murata et al., 1966; Taylor and Stoiber, 1973; Rose et al., 1973, 1978; Rose, 1977). These authors found that the dominant constituents in distilled-water rinses of fresh ash were Cl, SO_4, Na, Ca, K, Mg, and F. Other elements reported in smaller concentrations in the leachates were Mn, Zn, Cu, Ba, Se, Br, B, Al, Si, and Fe.

The formation of this water-soluble material on volcanic ash is probably the result of a complex interaction between the ash particles and volatile constituents of the volcanic plume. Volatile halides of elements such as Na, K, Zn, and Cu may condense on ash particles during eruption and subsequent fallout, as temperature and pressure decrease (Taylor and Stoiber, 1973). Another possibility is that droplets of dilute acid (primarily H_2SO_4 formed by reaction of SO_2 and H_2O in the volcanic plume) attach to ash particles, and leach soluble elements from the constituent minerals and glass (Rose, 1977). The resulting coatings of acid and leached elements are then available for subsequent mobilization by rain.

Oskarsson (1978) proposed three temperature-dependent processes within an eruption cloud which affect the type and amount of soluble material on ash particles. At high temperatures in the eruption vent and the core of the eruption cloud, microscopic salt particles crystallize (primarily chlorides, fluorides, and sulfates of the alkali metals and calcium). An upper limit for the temperature of salt crystallization is set by the melting point of the salt being formed. For example, the melting point of NaCl is 801°C and of $CaSO_4$ is 1,450°C. At temperatures below 340°C, H_2SO_4 is stable and may condense as an aerosol. At temperatures between those for salt crystallization and H_2SO_4 formation, Oskarsson (1978) believed that adsorption of HCl and HF gas onto the surface of solidified silicate material may be common.

Soluble uranium on freshly erupted ash?

None of the previous studies of soluble material on freshly erupted volcanic ash cite data for U. The primary reason is the difficulty of measuring very low (less than 1 μg/l) levels of dissolved uranium when only a small volume of sample and resulting leachate are available. A knowledge of the amount of readily soluble uranium on ash is important because silicic volcanic ash has been postulated as the primary source of uranium for sandstone-type sedimentary uranium deposits (Waters and Granger, 1953; Densen et al., 1959; Kittel, 1963; Love, 1970; Harshman, 1972; Adams et al., 1978). Henry and Tyner (1978) speculated on the obvious economic implications of rapid removal of uranium from the surfaces of freshly erupted ash particles.

In this study, freshly erupted volcanic ash, unaffected by rain, was exposed to various experimental leaching conditions in order to model the behavior of uranium and a number of other elements during initial ash-water interactions and subsequent weathering. This is the first time that uranium has been monitored during initial water rinse of fresh ash, and also the first time that element leachability from such ash has been studied during successive leaches. The specific objectives of the investigation are:

(1) Through an initial water rinse, to determine the fraction of a given element which is present in a readily soluble form on the surface of freshly erupted ash, and evaluate the potential environmental and economic implications of element transport by this process.

(2) Through a series of successive leaches, to determine the mineralogic hosts which must be attacked in order to mobilize a given element during diagenesis of ash.

(3) To compare and contrast the mobility of a number of elements during initial washing and subsequent diagenesis of ash.

SAMPLE DESCRIPTION

Thirty samples of volcanic ash, fresh and unaffected by rain, were chosen for study. Thirteen of the fresh ash samples are from the four major pulses of the large 1974 eruption of Fuego volcano (Fig. 1) (Rose et al., 1978; Buell and Stoiber, 1976). Five samples are from a small 1973 eruption of Fuego, which was described by Bonis and Salazar (1974). Seven samples were collected from Pacaya volcano (Fig. 1) during February, March, and April, 1974. This volcano has been almost continuously active since 1965, alternating between mild strombolian activity and explosive vulcanian activity (Rose, 1978). Five samples are from Santiaguito volcano (Fig. 1). Santiaguito is a Pelean dome which has been continuously active since 1922 (Rose, 1978). One of the samples (1123) was collected in 1967 and has large amounts of soluble material (Taylor, 1969). The remaining four samples were collected in 1975 and 1976.

In recent years, both Fuego and Pacaya erupted olivine-bearing high-Al basalts (Rose et al., 1973, 1978; Eggers,1971). All of Santiaguito's lavas are hornblende-hypersthene dacites (Rose, 1972). The fresh ash in this study was previously analyzed for major elements and some trace elements (Table 1 and Appendix I) and for mineralogic components (Table 2).

The particle-size distribution of the fresh ash was determined by automatic image analysis of 300 grains. The suite of ashes showed two different size distributions. Some samples had a unimodal distribution with a mean diameter of approximately 5 Phi (31 μm) and a range from 250 μm to submicron dust particles. The other samples had a bimodal distribution, with the mean of the coarser mode near 1 Phi (500 μm) and the mean of the finer mode near 5.5 Phi (23 μm). The bimodal samples ranged in size from about 1 mm diameter to submicron dust. Three ashes with a bimodal size distribution were sieved through wire mesh with an opening of 106 μm. An average of 98.5%, by weight, of the ash was greater than 106 μm in diameter.

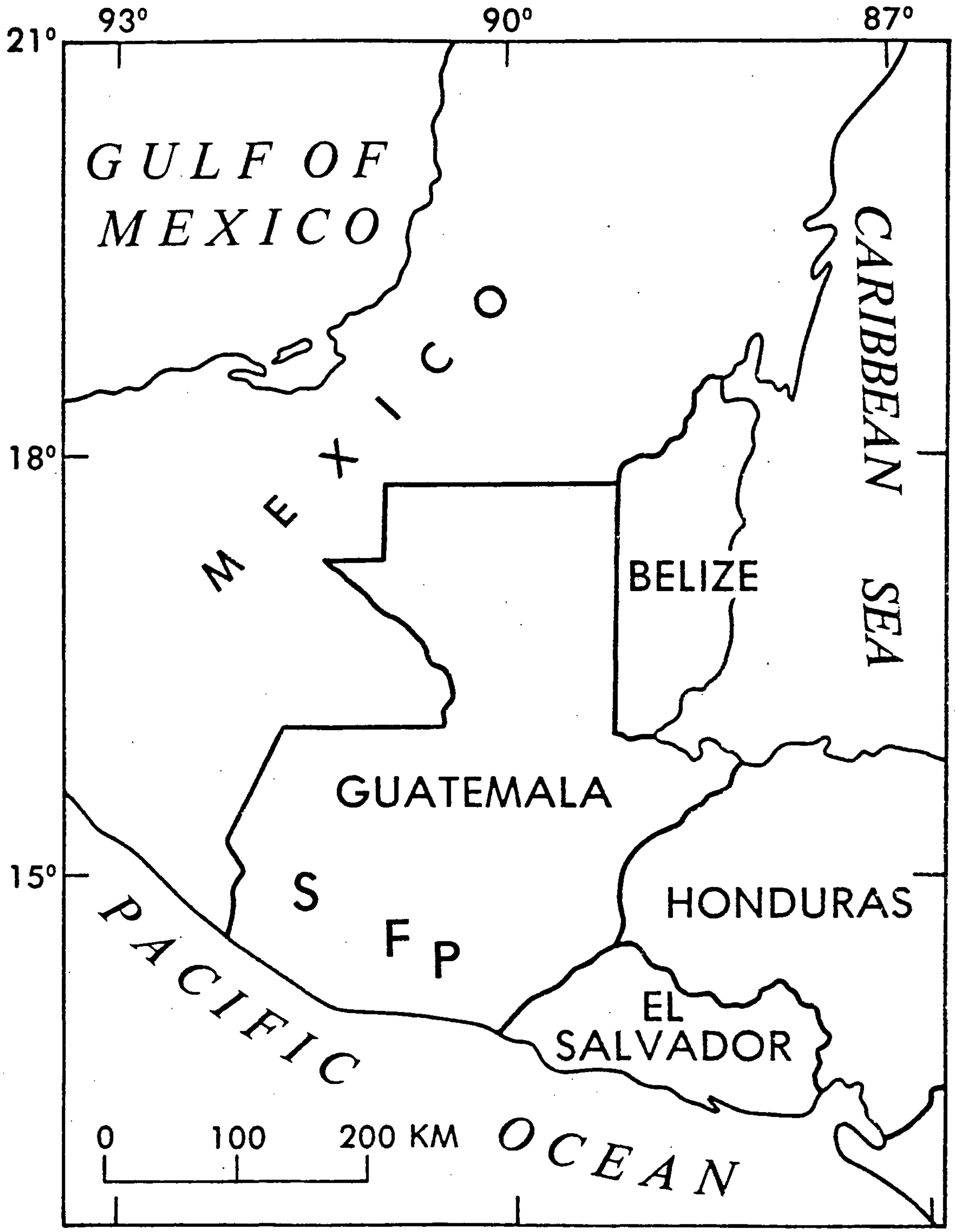


Figure 1. Location map of Fuego (F), Pacaya (P), and Santiaguito (S) volcanoes

TABLE 1. AVERAGE CHEMICAL COMPOSITION OF ASH SAMPLES FROM GUATEMALAN VOLCANOES

FUEGO VOLCANO--1974 ERUPTION

	OCT. 14 PULSE		OCT. 17 PULSE		OCT. 19 PULSE		OCT. 23 PULSE	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
MAJOR ELEMENT OXIDES (WT.%)								
SIO2	50.60	48.40-52.30	51.80	50.80-52.60	50.30	47.80-51.70	48.30	47.00-49.90
AL2O3	20.50	19.60-21.20	19.40	18.90-20.20	18.60	17.70-18.80	18.40	17.60-19.50
FE2O3	9.20	8.50-10.10	9.40	8.70-10.40	10.80	9.70-12.30	11.80	10.60-13.70
MGO	3.92	3.31-4.43	4.36	3.75-5.19	5.53	4.80-7.93	7.70	5.79-9.67
CAO	9.60	9.70-10.10	8.80	8.10-9.50	8.70	8.40-9.40	8.80	8.50-9.20
NA2O	3.50	3.20-3.80	3.60	3.50-4.10	3.40	2.80-3.70	2.90	2.60-3.39
K2O	0.74	0.62-0.95	0.86	0.81-1.00	0.75	0.60-0.83	0.61	0.50-0.71
TIO2	0.90	0.88-0.95	0.82	0.78-0.98	0.98	0.95-1.03	0.89	0.75-0.98
	-----		-----		-----		-----	
TOTAL	98.96		98.98		99.46		99.40	
TRACE ELEMENTS (PPM)								
BA	425.	350.-546.	509.	435.-598.	511.	496.- 525.	300.	260.-345
CL	600.	*	425.	300.-500.	650.	600.-700.	350.	300.-400.
CO	28.20	23.60-32.80	30.10	*	34.30	*	63.10	*
CU	109.	80.-140.	123.	115.-130.	106.	80.-130.	99.	90.-120.
MN	977.	930.-1000.	989.	950.-1060.	1124.	1075.-1250.	1300.	*
SR	559.	540.-581.	542.	530.-571.	511.	496.-525.	524.	482.-557.
U	0.35	0.25-0.49	0.40	0.32-0.49	0.36	0.33-0.38	0.24	0.19-0.29
V	213.	178.-235.	190.	154.-223.	236.	223.-249.	230.	217.-242.
ZN	84.30	60.-105.	65.50	57.50-102.50	86.60	65.-95.	90.	62.50-105.

* = ONLY ONE SAMPLE ANALYZED

TABLE 1 (CONT'D).
AVERAGE CHEMICAL COMPOSITION OF ASH SAMPLES FROM GUATEMALAN VOLCANOES

	FUEGO 1973		PACAYA 1974		SANTIAGUITO	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
MAJOR ELEMENT OXIDES (WT.%)						
SIO2	52.40	51.10-54.70	50.60	48.50-54.80	63.45	61.80-65.00
AL2O3	19.50	18.90-20.10	19.20	18.80-20.50	16.94	16.40-17.50
FE2O3	9.10	8.00-10.00	10.60	10.00-11.10	2.27	1.60-3.30
FEO	**		**		2.56	1.80-2.90
MGO	3.85	3.46-4.47	4.11	3.60-4.56	1.87	1.48-2.03
CAO	9.00	8.40-9.50	8.90	8.50-9.50	5.03	4.20-5.70
NA2O	3.40	2.90-3.90	3.70	3.60-3.90	4.91	4.70-5.10
K2O	0.82	0.74-0.95	0.86	0.81-0.93	1.59	1.48-1.70
TIO2	0.84	0.73-0.95	1.13	1.00-1.35	0.47	0.36-0.55
TOTAL	98.91		99.10		99.73	
TRACE ELEMENTS (PPM)						
BA	520.	*	490.	*	860.	*
CL	520.	400.-600.	730.	600.-1300.	510.	400.-840.
CO	19.	*	24.	*	6.	*
CU	100.	*	90.	*	14.	13.-15.
MN	1074.	1020.-1140.	1400.	1320.-1440.	1210.	1060.-1560.
SR	560.	*	530.	*	495.	476.-550.
U	0.38	0.27-0.49	0.59	0.45-0.65	0.93	0.90-1.0
V	160.	121.-209.	245.	214.-265.	120.	93.-160.

* = ONLY ONE SAMPLE ANALYZED
** = TOTAL FE EXPRESSED AS FE2O3

TABLE 1 (Continued)

Fuego volcano (1974 samples): Data for major elements, Sr, Ba, Cu, Mn, Co, and Zn from Rose et al. (1978). Cl analyzed by U.S.G.S. analytical labs; U analyzed by delayed neutron technique by H. T. Millard, Jr.; V analyzed by I.N.A.A. by David B. Smith.

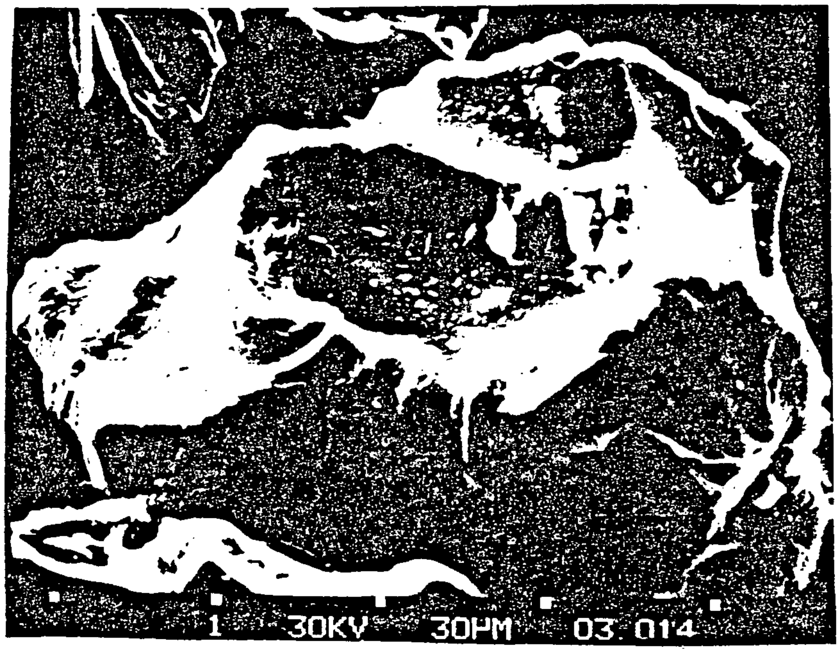
Fuego volcano (1973 samples) and Pacaya volcano; Major element data from W. I. Rose, Jr., unpublished results. Ba, Co. Cu, and Sr analyzed by emission spectrometry by U.S.G.S. analytical labs. Ci, U, and V analyzed as for 1974 Fuego samples.

Santiaguito volcano: Major element and Sr data from Rose et al. (1977). Other elements analyzed as above.

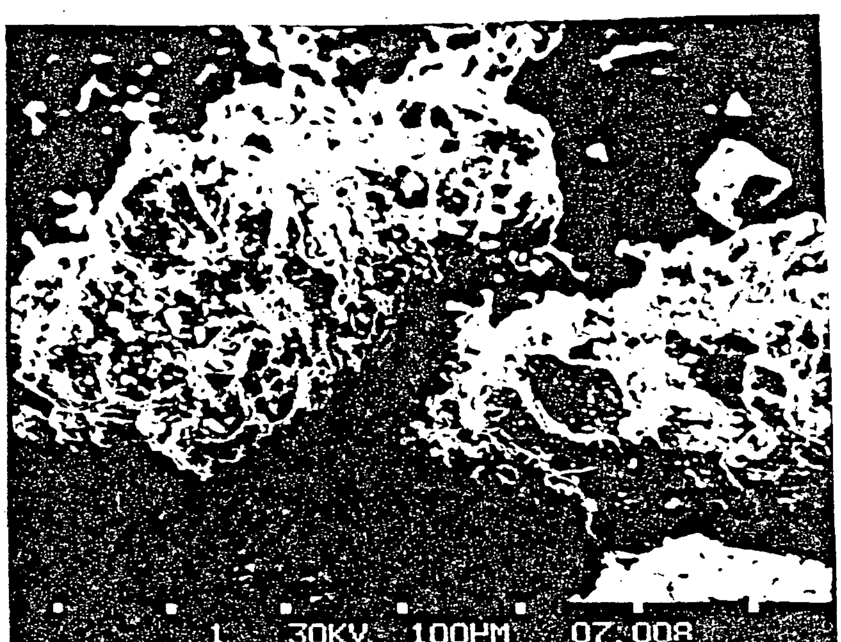
TABLE 2. Mean modal mineralogy of eruptives from Pacaya, Santiaguito, and the four pulses of the 1974 Fuego eruption

	Fuego[1]				Pacaya[2]	Santiaguito[3]
	Oct. 14	Oct. 17	Oct. 19	Oct. 23		
Groundmass*	62	68	66	55	55	69
Plagioclase	31	22	21	27	37	26
Olivine	3.6	6.0	9.4	12.6	5	
Clinopyroxene	0.8	1.6	0.9	1.5	2	Tr
Orthopyroxene						2
Oxyhornblende						1
Tridymite						Tr
Opaques	2.6	2.6	2.6	3.9	1	2

[1]Data from Rose et al. (1978).
[2]Data from Eggers (1971).
[3]Data from Rose et al. (1977).
*Groundmass = Glass + fine grained mixutre of phenocryst minerals.

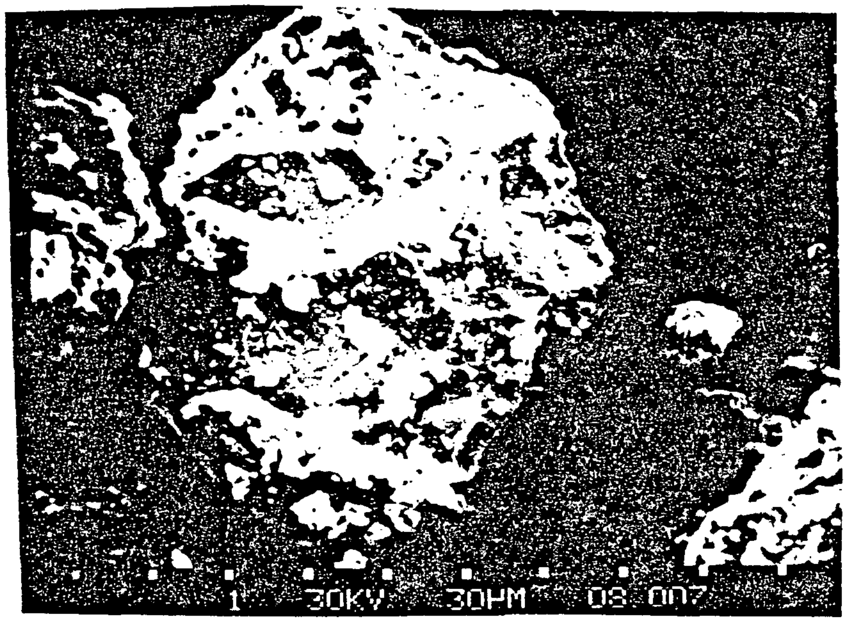


A. Basaltic vitric ash from Pacaya volcano
(110 x 150 μm).

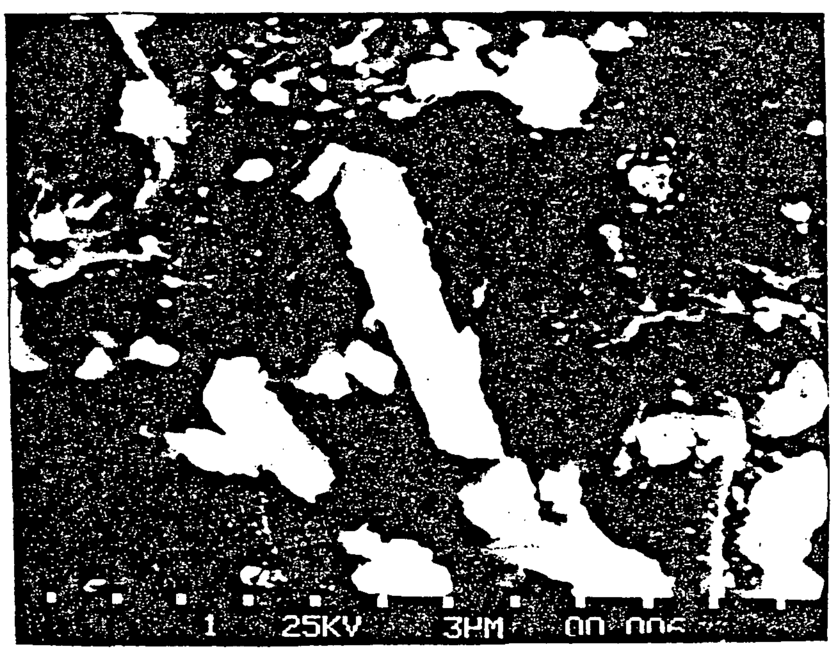


B. Vesicular basaltic ash from Fuego volcano
(500 x 700 μm).

Figure 2. Scanning electron microscope images of unleached ash particles.

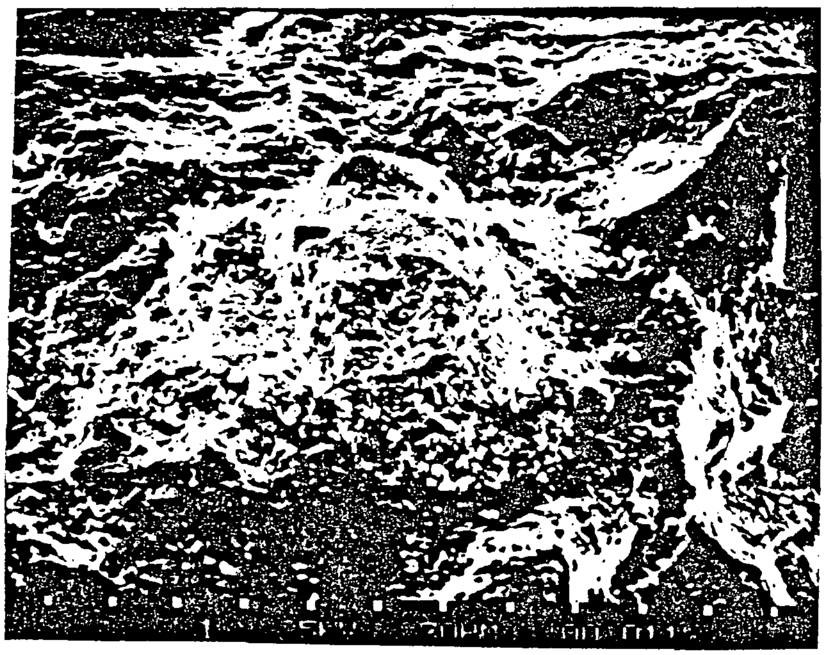


C. Dacitic ash from Santiaguito volcano (240 x 300 μm).

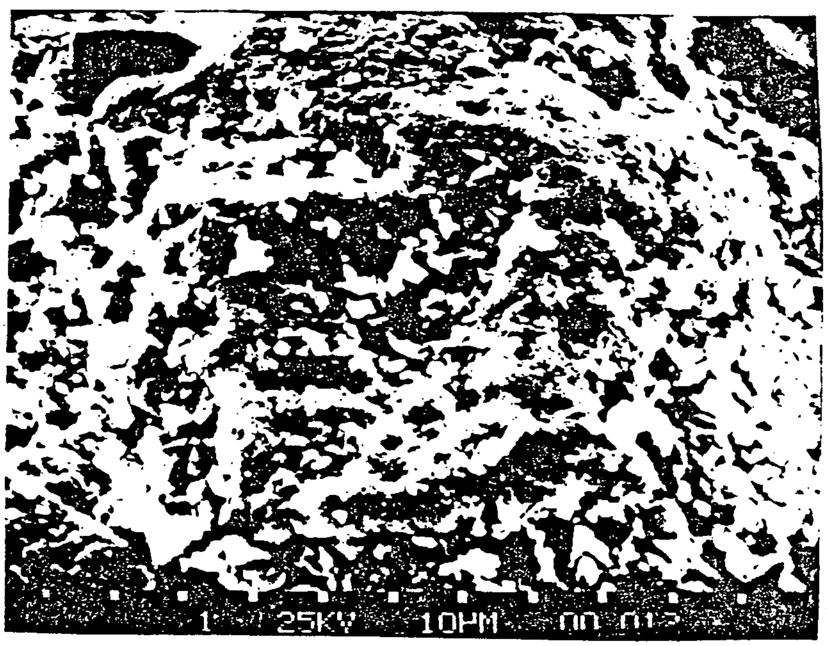


D. Surface of Santiaguito ash. Energy dispersive X-ray analysis showed the elongate crystal is a nonsilicate rich in Ca and S, probably calcium sulfate (25 x 36 μm).

Figure 2. Scanning electron microscope images of unleached ash particles.



E. Surface of Santiaguito ash. Hummocky area in center of photo is rich in Na and Cl and may be a poorly formed (or partially dissolved) NaCl crystal (250 x 360 μm).



F. Closeup of NaCl-rich area shown in Figure 2-E. Smaller grains clinging to NaCl are silicate ash fragments (85 x 110 μm).

Figure 2. Scanning electron microscope images of unleached ash particles.

The morphology and composition of individual ash particles were studied by scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDXRA). The following observations were made: (1) the surface area of particles varies greatly depending upon the degree of vesiculation (Fig. 2-A, B, C); (2) there are a large number of small (less than 10 m in diameter) particles; most of the small particles are similar in composition to their hosts and are interpreted as surface dustings of very fine ash fragments (Fig. 2-A, B, C); (3) some samples have well-formed tabular and cubic crystals, and EDXRA shows that the tabular crystals are rich in Ca and S and the cubic crystals are rich in Na and Cl (Fig. 2-D, E, F). These are believed to be calcium sulfate and sodium chloride, respectively.

Three fresh bomb fragments were also studied. Two of the three bomb fragments were ejected during the 1976 eruption of Augustine volcano in lower Cook Inlet about 290 km southwest of Anchorage, Alaska. The eruption was discussed by Johnston (1976), Johnston and Schmincke (1977). and Schmincke and Johnston (1977). The fragments are andesitic to dacitic in character (Appendix I). The third bomb fragment studied was a piece of basaltic tephra collected on June 5, 1970, on Heimaey, Vestmann Islands, Iceland (Appendix I).

Five samples of historically erupted pumice, ranging in composition from rhyolite to rhyodacite, were studied to contrast their leaching characteristics with freshly erupted ash. The sample suite consists of pumice from Katmai volcano in Alaska, Mount St. Helens volcano in southern Washington, Glass Mountain on the Medicine Lake Highland in northern California, and Mono Craters in east-central California (Table 3 and Appendix I). All the rhyolitic samples are dominantly glass (greater than 90%).

EXPERIMENTAL METHODS

Untreated splits of freshly erupted ash were taken directly from the collected material and subjected to the various leaching experiments. The bomb fragments and "rhyolite" pumice fragments were crushed with an agate mortar and pestle and sieved through silk bolting cloth. The 20-150 (850-106 m diameter) fraction and the <150 mesh (<106 m) fraction of each crushed sample were retained for use in the leaching experiments.

Each sample of volcanic material was subjected to three successive leach experiments of increasing severity. For the first leach, based on the method of Taylor and Stoiber (1973), five grams of sample were placed in a Teflon container and 20 ml of distilled-deionized water (pH = 5.0-5.5) were pipetted onto the sample. The pH was measured approximately one minute after contact of ash and leach solution. The container was covered with a Teflon cap and the contents were agitated for one hour at room temperature and pressure by a rocker-arm shaker. The pH was again determined and the sample was allowed to sit overnight. After a final pH measurement, the sample was filtered through a Millipore filter with a nominal pore size of 0.1 m and the filtrate was acidified to a pH of 2 or less with sub-boiling distilled nitric acid. The leachate and ash or pumice samples were then stored in polyethylene vials.

TABLE 3. Pertinent data on historic "rhyolitic" samples.

Sample Locality	Sample Furnished by	Rock Type	Age	References
Katmai	R. B. Forbes	Phyolitic Scoria	Erupted June 1912	Allen and Zies (1923), Fenner (1923), Zies (1924, 1929)
Mt. St. Helens Tephra Set T	D. R. Mullineaux	Rhyodacite	150 yrs	Mullineaux et al. (1975), Lawrence (1954)
Mt. St. Helens Tephra set W	D. R. Mullineaux	Rhyodacite	450-1150 yrs	Mullineaux et al. (1975), Crandell (1971)
Medicine Lake	I. Friedman	Rhyodacite Pumice	200-300 yrs	Condie and Hayslip (1975), Ives et al. (1964), Friedman (1968a, 1968b)
Mono Craters	I. Friedman	Rhyolite Pumice	2000 Hrs	Anderson (1933), Loney (1968), Gilbert et al. (1968)

The procedure for the second leach experiment was the same as for the first, but the leach solution was a very mild hydrochloric acid solution (pH = 3.5-4.0).

The third and most severe leach was with 20 ml of a solution that was 0.05 M in both sodium carbonate and sodium bicarbonate. These two reagents form a buffer solution at a pH of approximately 9.9. The sample was sealed in a Teflon container and agitated inside an oven at 80°C for one week. The sample was weighed and, if weight loss by evaporation was less than 5%, filtered, acidified, and stored as described above.

The liquid-to-solid ratio of 4:1 by weight was optimum for assuring that there was enough leachate to perform the necessary chemical analyses and at the same time assuring that most of the elements analyzed were present in detectable concentrations. A ratio of this magnitude was estimated to be realistic for Central America during the rainy season (Taylor and Stoiber, 1973). In a later section, this ratio is used as a model for calculations regarding likely concentration levels of contaminants of volcanic origin in ground and surface water near an erupting volcano.

The first two leaching episodes are intended to mimic the interaction of ash with rain produced in the vicinity of an active eruption. The rain undoubtedly is slightly acidic because of its interaction with acidic gases (SO_2, HCl, etc.) emitted during an eruption. Analogous production of acid precipitation has been documented for highly industrialized areas where, for example, smelters and coal-burning power plants may emit SO_2 and other gases into the atmoshpere (Hutchinson and Whitby, 1977; Li and Landsberg, 1975). The annual pH value for rain in the northeastern United States averages about 4, but values as low as 2.1 have been recorded (Likens and Bormann, 1974).

The third leach experiment is intended to accelerate and accentuate the effect of prolonged contact of a pile of volcanic ash with alkaline ground water present during ash diagenesis (Schoff and Moore, 1964; Harshman, 1972). Table 4 summarizes the chemistry of ground and surface water in weathering environments and shows how these compare with the carbonate-bicarbonate leach solution.

Analytical methods for unleached volcanic material

Much chemical data on the samples used in this study were available in the literature and in unpublished reports (Table 1 and Appendix I). In general, most major-element data were determined by X-ray fluorescence and trace elements by a combination of atomic absorption and instrumental neutron-activation analysis. Some elements analyzed in the leachate, however, had not been previously determined in the volcanic material. Thus, part of the present study involved such measurements.

The U content of the volcanic material was determined by a delayed-neutron technique (Millard, 1976). The coefficient of variation for the measurements ranges from 30-2% as the U content of the sample increases from 0.1 to 300 ppm. Checks on previously reported concentration values (Table 1 and Appendix I), as well as original measurements of additional elements, were performed on selected samples of the volcanic material as follows: 30 samples by instrumental neutron-activation analysis (V, Al, Mn, Na), 14 samples by emission spectrometry (B, Ba, Be, Cd, Cu, Li, Mn, Mo, Pb, Sr, V, Zn), and 38 samples by specific-ion-electrode methods (Cl and F). Where analytical values were not available for a particular ash sample, they were assumed to be equal to the average for measured samples of the same rock type. A few elements (B, Cd, Li, Pb) were detected in the leachates but were below detectability in analyzed unleached material. For these elements, values were assumed to be equal to reported literature averages for the appropriate rock types (Krauskopf, 1967).

TABLE 4 Comparison of experimental alkaline leach solution and pertinent analyogues. (From Zielinski, 1977.)

Source	Typical concentration of major components	Typical pH
Ground water draining rhyolite tuff	0.001-.005M HCO_3 (Na+K)	7- 8.5
Ground water draining carbonates	.001-.01M HCO_3 (Ca+Mg+Na)	7- 8.5
Experimental solution	.05M Na_2CO_3+.05M $NaHCO_3$	9.9
Sea water	.5M NaCl	8.15
Alkaline lakes, brines	.5-5M NaCl+Na_2CO_3+$NaHCO_3$	8-10

Analytical methods for leachates

Each leachate was analyzed for the following elements: U, F, Cl, B, Ba, Be, Ca, Cd, Co, Cu, Fe, Li, Mg, Mn, Mo, Na, Pb, Si, Sr, V, and Zn. In addition, some of the leachates were analyzed for Al. In order to maximize the amount of data for each leachate, analytical methods were chosen which provided high sensitivity and accuracy but required minimal sample volumes. The methods used for each element and estimated precision and sensitivity of the analyses are given in Table 5. Reagent blanks were determined by each analytical method.

Two slightly different fission-track techniques were used to arrive at a final U value for the leachates. In the first method, approximately 0.5 ml of leachate was placed in a 2/5 dram, acid-washed, polyethylene vial containing a 0.5 cm^2 piece of highly polished, acid-washed, pure silica glass. The samples, and similarly prepared vials with a standard U solution and blank, were then irradiated at a neutron flux of 2.5 x 10^{12} neutrons/cm^2-sec for four hours in the research reactor facility of the U.S. Geological Survey in Denver, Colorado. After about one day, the glass was recovered and etched for two minutes with 48% reagent-grade hydrofluoric acid. Resultant fission tracks were viewed with a microscope at 400x. The track density was compared to the density produced by submersion of glass in a 0.1 ppm U standard solution. The blank averaged approximately 0.0006 mg/L uranium.

TABLE 5. Analytical methods and precision estimates for leachate analyses.

Element	Analytical Techniquel	C.V.(%)*	Detection limit (g/L unless noted)
Al	I.N.A.A.	2	0.2 mg/l
B	ICP-PES	8	3
Ba	ICP-OES	2	1
Be	ICP-OES	-	0.5
Ca	ICP-OES	1	10
Cd	ICP-OES	5	0.5
Cl	SIE	3	1 mg/L
Co	ICP-OES	10	2
Cu	ICP-OES	1	5
F	SIE	7	10
Fe	ICP-OES	1	2
Li	ICP-OES	3	2
Mg	ICP-OES	1	2
Mn	ICP-OES	1	0.5
Mo	ICP-OES	-	10
Na	ICP-OES	1	100
Pb	ICP-OES	50	5
Si	C	3	0.5 mg/L
Sr	ICP-OES	1	0.3
U	FT	7**	0.2
V	ICP-OES	8	3
Zn	ICP-OES	1	2

I.N.A.A. = Instrumental Neutron Activation Analysis, ICP-OES = Inductively Coupled Plasma-Optical Emission Spectroscopy, SIE = Specific Ion Electrode, C = Colorimetry, FT = Fission Track, - = element not found in leachates,
* = estimated coefficient of variation (%) near middle of concentration range,
** = coefficient of variation at 0.1 ppm U.

The above technique proved to be quite adequate for the carbonate-bicarbonate leachates. However, several of the water and acid leachates had U concentrations at or below the blank level. A more sensitive method of fission-track analysis based upon the analysis of single drops was used to measure selected low-U samples (Fleischer and Lovett, 1968; Reimer, 1976). The blank for this second technique averaged about 0.0001 mg/L. Several samples showed U concentrations at or below this level.

The concentrations of B, Ba, Be, Ca, Cd, Co, Cu, Fe, Li, Mg, Mn, Mo, Na, Pb, Si, Sr, V, and Zn were determined by inductively coupled plasma-optical emission spectroscopy. The high-Na samples (carbonate-bicarbonate leachates) were diluted with distilled-deionized water by a factor of 2.5 to bring the specific conductance of the sample below 2,000 mho/cm. Separate high-Na blanks and standards were run for these samples.

Silica was determined by a standard colorimetric method using silicomolybdate blue (Brown et al., 1970). Fluoride and chloride concentrations in the leachates were determined by specific-ion-electrode methods. Some of the leachates were analyzed for Al, Mn, V, Cl, and Na by instrumental neutron-activation analysis (INAA). INAA was abandoned when the inductively coupled plasma-optical emission spectrometer became available. The ultimate value of the INAA data was the Al determinations and a check for the inductively coupled plasma and chloride electrode data. The values determined by INAA were generally within 10% of the values measured by inductively coupled plasma-optical emission spectroscopy.

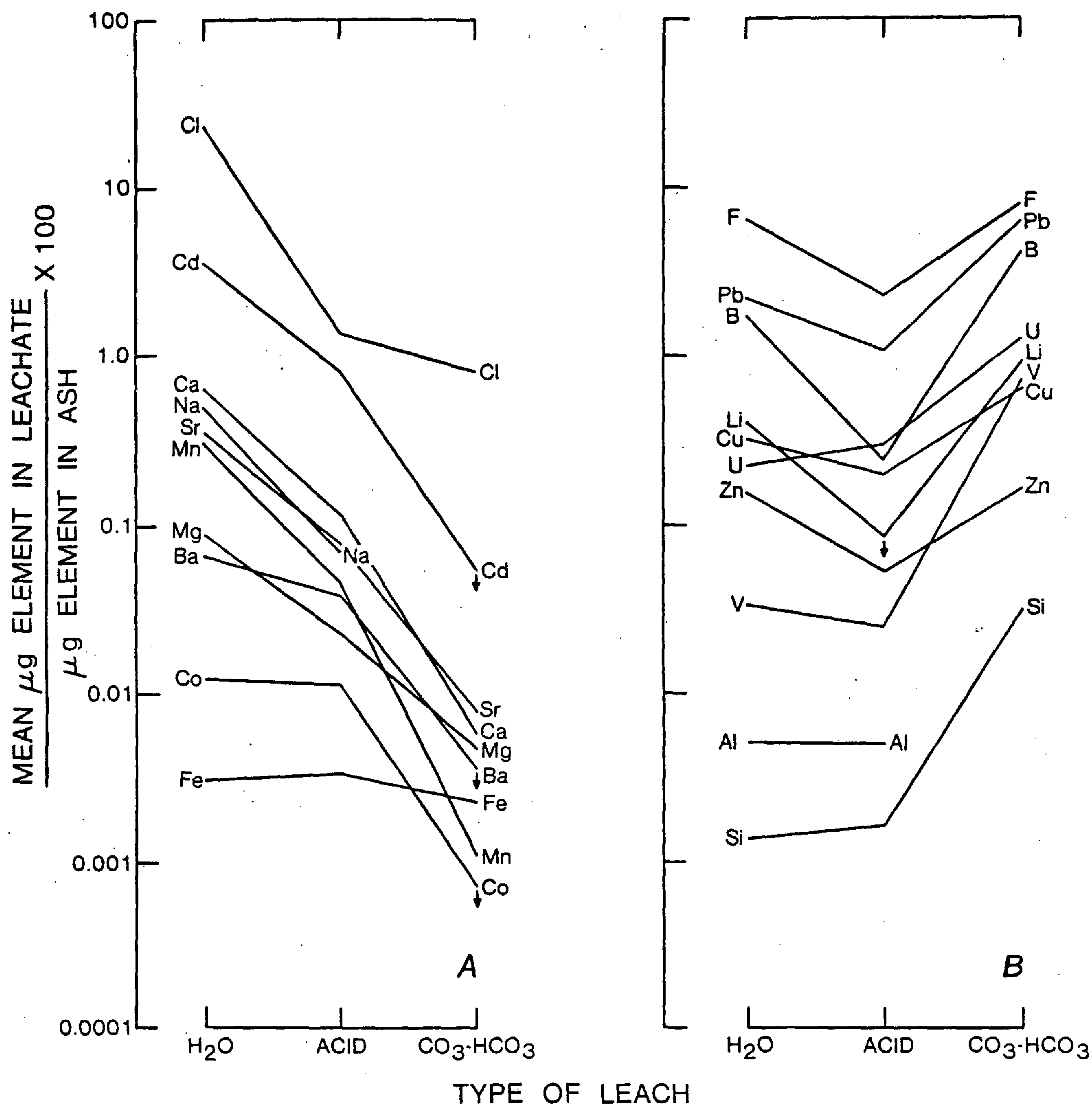
RESULTS AND DISCUSSION

The predominant elements present in the water leachates of the freshly erupted ash and bomb fragment samples are Ca, Cl, Na, Mg, and F (Appendix II). A similar group of elements predominate in the acid leachates, in addition to Si and Al. Si and F consistently occur in the highest concentration in the carbonate-bicarbonate leachate, followed by Ca, Cl, and Fe. Be and Mo were below blank concentrations in all three leachates.

The composition of the water and acid leachates of the historic "rhyolites" differs from equivalent leachates of fresh basaltic and dacitic ash, in that Al, Na, Ca, Si, and Fe are their major constituents. Relatively more Al, less Na, and Ca, and roughly equivalent Si and Fe were released from the "rhyolites," as compared to the fresh ash. F and Cl are considerably depleted in the "rhyolite" leachates. This depletion may be because F and Cl are removed very early on exposure of the rock to ground and surface water (Ellis and Mahon, 1964; Zielinski, 1977). Si, F, Ca, Cl, and Fe predominate in the carbonate-bicarbonate leachate of the "rhyolites" as they do in the equivalent leachate of fresh ash.

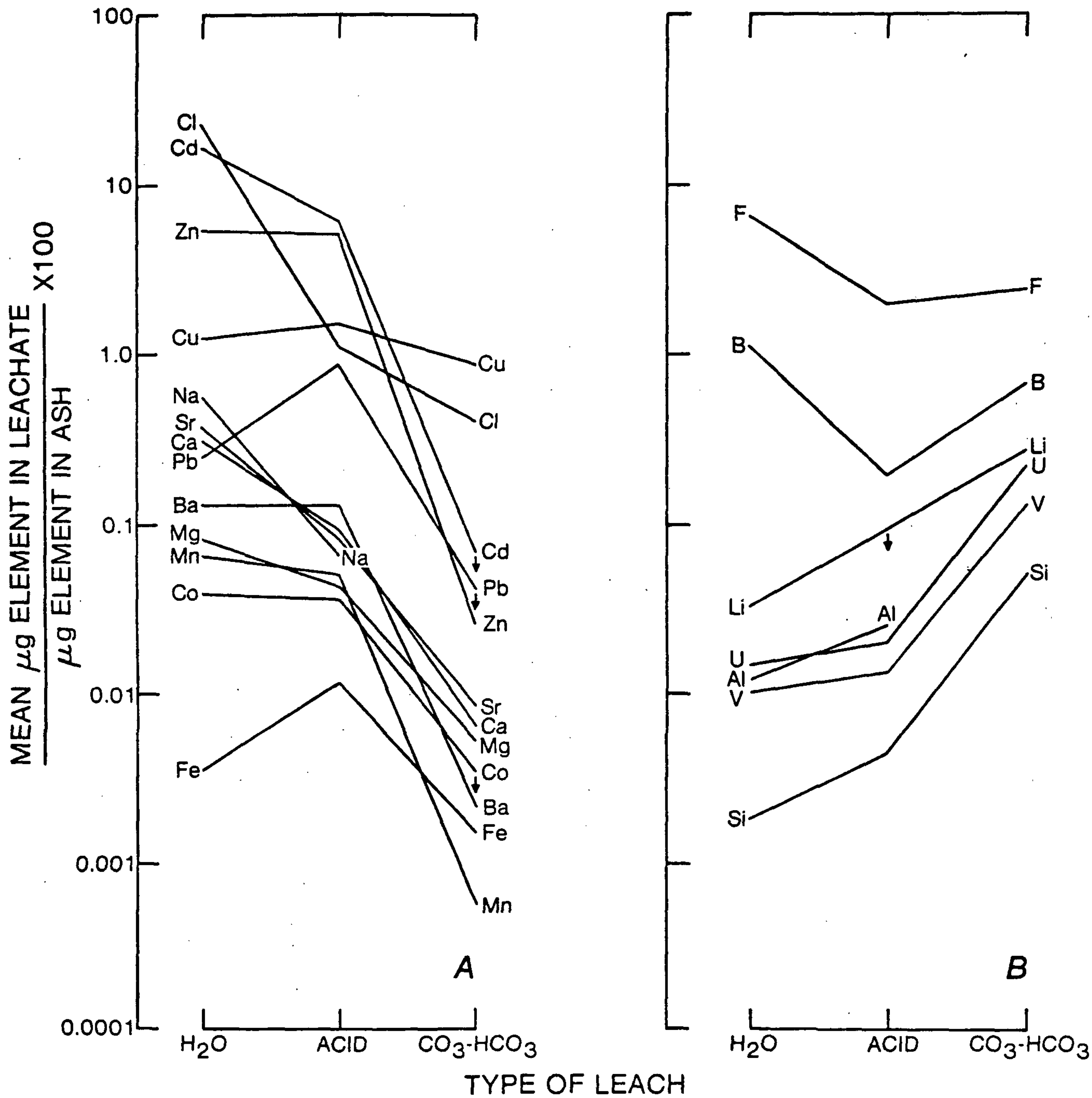
Both the basaltic (Fuego and Pacaya) and dacitic (Santiaguito) ash show release of similar suites of elements in similar amounts. There are anomalous samples from each volcano, but ash from a given center does not show consistently greater overall leachability.

The pH of the water and acid-leach solutions increased by 0.1 to 2 pH units upon contact with most fresh ash samples (Table 6). The increase in pH is probably caused by rapid exchange of dissolved hydrogen (as H_3O^+ ions) for alkali of alkaline earth ions at the surface of ash particles (Garrels and Howard, 1959; Luce et al., 1972; Petrovic et al., 1976). The decrease in pH caused by some ash samples is more difficult to explain. Perhaps ash particles in these samples had relatively longer residence times in the condensation zone (Oskarsson, 1978) of the eruption column where sulfuric and halogen acid-water azeotropes condense as aerosols and may then be scavenged by ash particles (Rose, 1977).



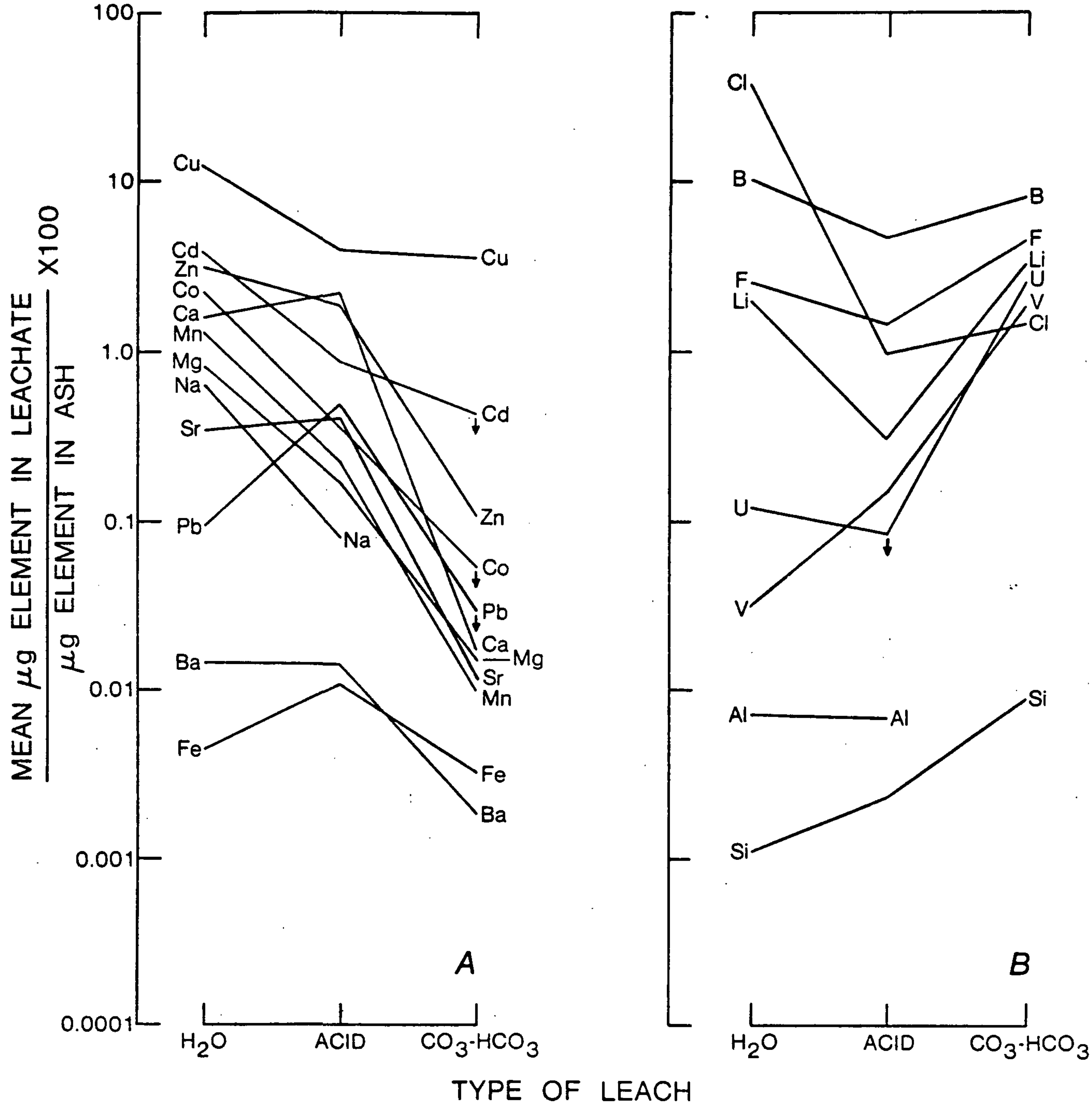
A. Fuego volcano

Figure 3. Leachability of the measured elements as a function of leach type.



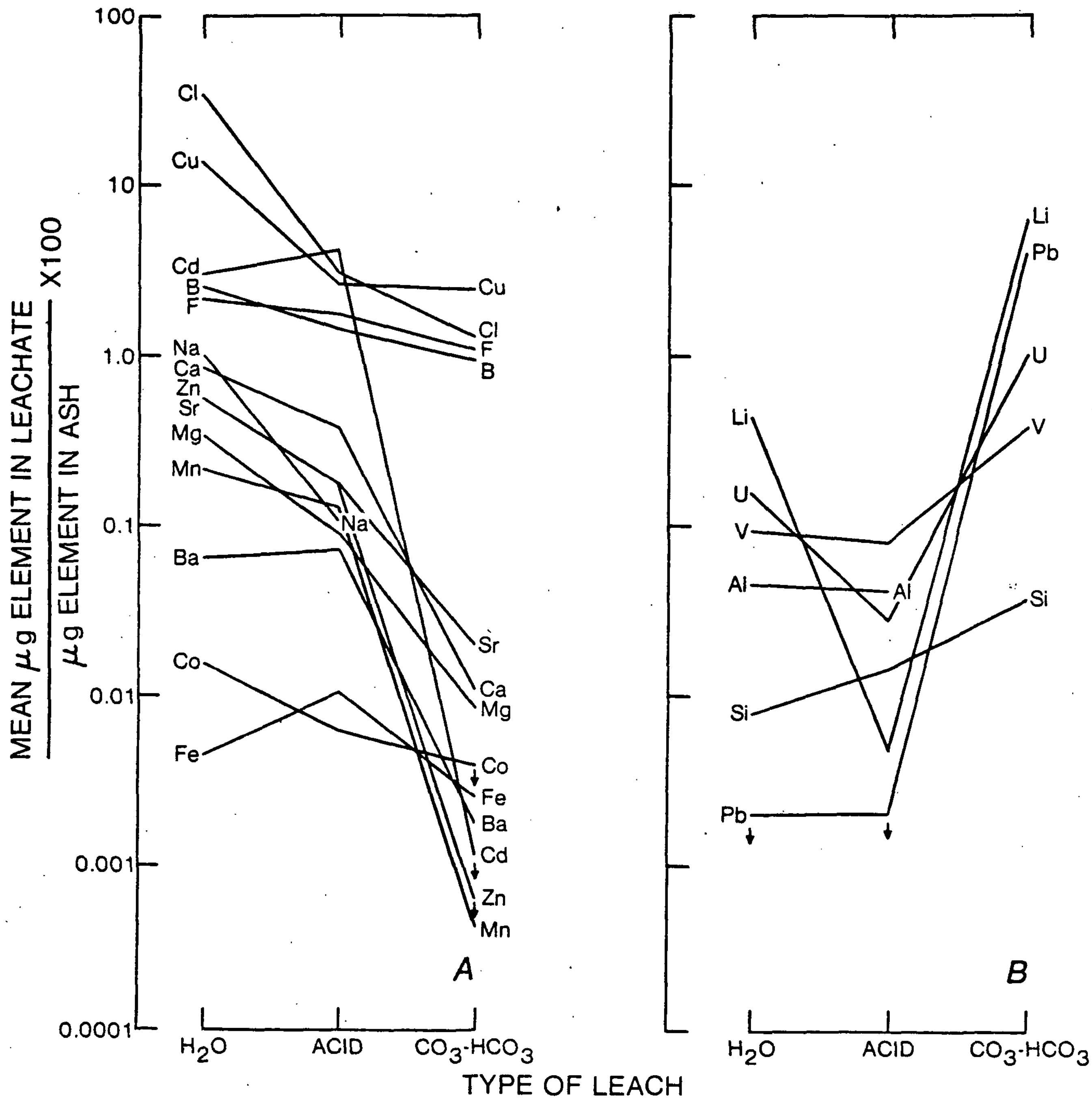
B. Pacaya volcano

Figure 3. Leachability of the measured elements as a function of leach type.



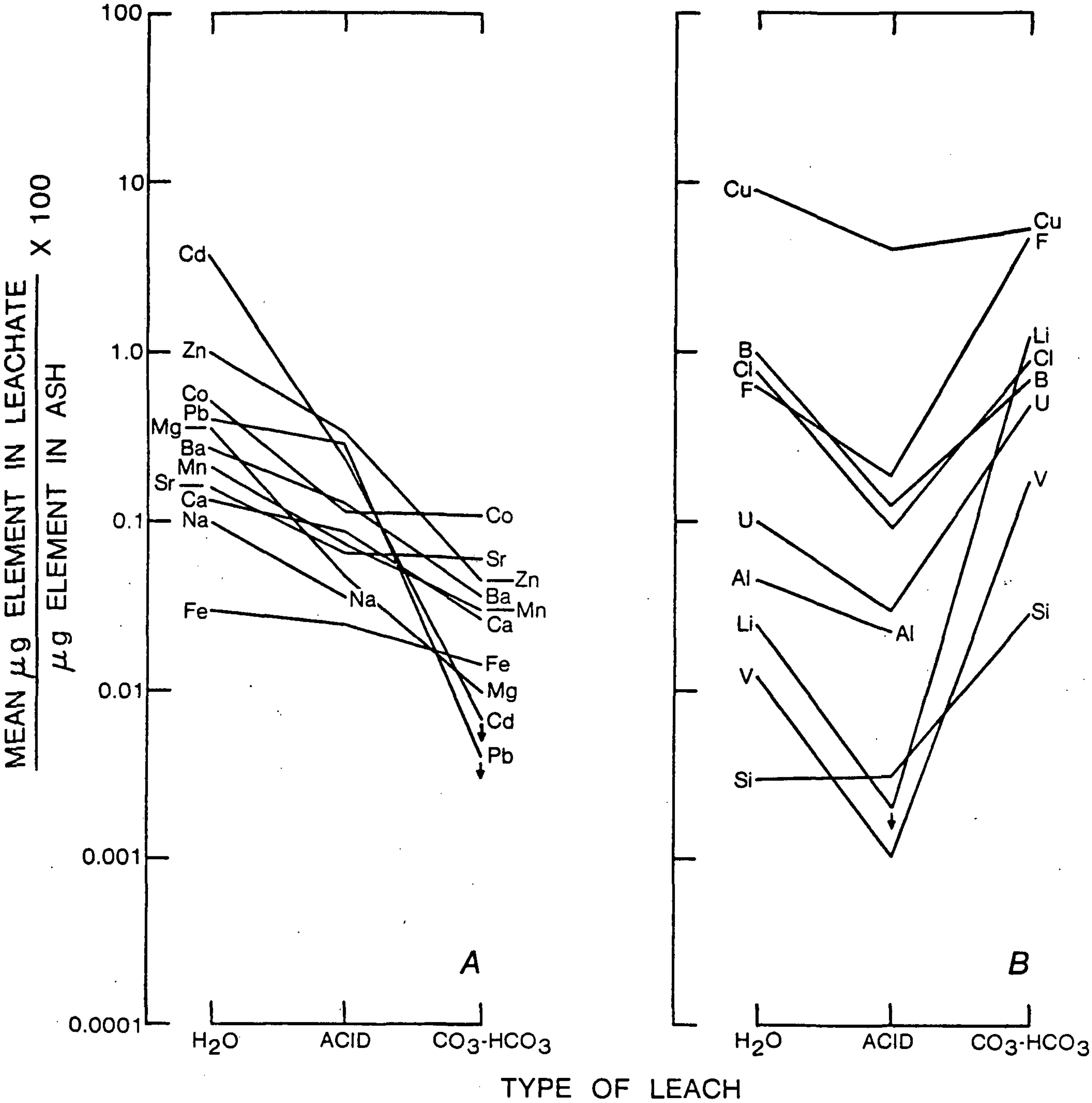
C. Santiaguito volcano

Figure 3. Leachability of the measured elements as a function of leach type.



D. Bomb fragments

Figure 3. Leachability of the measured elements as a function of leach type.



E. Historic "rhyolites"

Figure 3. Leachability of the measured elements as a function of leach type.

It is of interest that none of the samples which caused a pH decrease in water leachates showed greater overall leachability than the samples which caused a pH increase. This leachability result implies that acid leaching of ash particles by adsorbed acid aerosols does not contribute significantly to the total amount of soluble material on the ash. Apparently, most of the water-soluble salts are present as condensates (Oskarsson, 1978) and are not generated by in-situ attack of adsorbed acid on host ash particles.

The percentage of a given element removed from ash during each leach operation was calculated according to the following equation:

$$\% \text{ Element Removed} = \frac{\text{g element in leachate}}{\text{g element in unleached ash}} \times 100$$

The results of the calculations are given in Appendix III and shown graphically in Figure 3 (A-E). The elements in section A of the graphs all show a smaller percentage removed by the carbonate-bicarbonate leach than by the water or acid leach. Those in section B all show larger percentages removed by the carbonate-bicarbonate leach than by the acid leach and most show a larger percentage removed by the alkaline leach than by the water leach. U, V, Li, and Si are unique in that they consistently fall into section B, no matter which type of volcanic material is leached.

Of note is the order of magnitude or larger variation for the concentrations of leachable material on the ash (Table 7 A-E). As noted earlier by Rose (1977), this variation may even occur for successive ashes from the same volcano collected during short periods from localities in close proximity. The variable chemistry of the water-soluble material reflects the variable trajectories of ash particles within a thermally and chemically zoned volcanic plume (Rose, 1977; Oskarsson, 1978).

Examination of the predominant elements present in the leachates suggests that each of the three leach solutions preferentially attacked different phases in the solids. The water leach primarily attacked water-soluble salts and gas-phase material adsorbed on the surfaces of the ash. Scanning electron microscope study (Fig. 2) showed that water-soluble salts such as $CaSO_4$ and NaCl do exist on ash surfaces, and the constituent ions dominate in water leachates (Taylor and Stoiber, 1973; Rose et al., 1973; Rose, 1977). The acid leach continued the process of the water leach as evidenced by the similar suite of ions predominant in the leachate. The acid leach may also have attacked acid-soluble sulfides and/or oxides, as evidenced by increased Fe concentration in some samples.

The carbonate-bicarbonate leach was assumed to preferentially attack volcanic glass because of the reported high solubility of amorphous silica at the measured pH (9.9) of the solution (Alexander et al., 1954; Krauskopf, (1956) and the elevated concentrations of dissolved silica, a major constituent of glass. The glass appeared not to dissolve congruently, however, as shown by comparison of elemental ratios in the leachate with the same ratios obtained by electron microprobe measurement of residual glass (Table 8). Trace-element analyses were not available for pure glass separates, but in all likelihood these too would show incongruent dissolution. A comparison of similar ratios for studied "rhyolites" (Table 9) suggests that the trace elements U, V, and Mn also dissolve incongruently in the carbonate-bicarbonate solution. Cation exchange of Na ions in the alkaline leach solution for other alakli or alkaline earth ions in the volcanic material also probably occurred, contributing, for example, to the increased leaching efficiency of lithium (Fig 3; Zielinski et al., 1977).

It should be emphasized that the carbonate-bicarbonate leach models incipient dissolution of glassy components of volcanic ash caused by initial exposure of the glass to alkaline ground water. The results of this leach give no indication what effect secondary minerals such as clays and zeolites, with large adsorptive potential, would have on the mobility of dissolved ash components.

TABLE 6. pH values of water and acid leachates of Guatemalan ash samples.

Sample Number	pH after approximately 24 hours Water Leachate	 Acid Leachate
(Fuego, 1973)		
6	5.6	4.6
44	6.1	5.7
B-5	5.8	5.3
Z-2	5.8	5.2
Z-4	4.2	4.1
(Fuego, 1974)		
28	6.2	5.3
32	5.6	4.8
33	4.3	3.8
34	6.2	5.7
40	5.9	5.3
100	6.8	6.4
101	7.0	6.5
102	5.8	5.5
104	5.5	5.1
128	7.0	6.9
139	6.8	6.9
167	4.8	4.9
169	5.1	5.3
306	5.8	5.5
314	5.9	5.3
(Pacaya)		
2	3.5	3.2
3	6.6	4.7
4	3.6	3.2
5	3.6	2.8
VP5	4.0	3.8
7	3.5	3.1
9	6.2	5.1
(Santiaguito)		
1	6.4	6.9
2	4.1	3.7
3	4.3	4.0
4	3.7	3.4
1123	4.0	3.0

TABLE 7-A. AVERAGE CHEMICAL COMPOSITION (MG/L)
OF LEACHATES OF FUEGO ASH

	WATER LEACHATE		ACID LEACHATE		CARBONATE-BICARBONATE LEACHATE	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
AL	1.3	0.0-6.7	1.3	0.0-5.6	N.D.	N.D.
B	0.022	0.0030-0.11	0.0029	0.0010-0.022	0.049	0.0040-0.11
BA	0.074	0.020-0.25	0.043	0.0049-0.26	0.00040	0.0-0.0080
CA	100.	18.-260.	20.	3.3-53.	0.85	0.25-1.6
CD	0.0020	0.0-0.010	0.00040	0.0-0.0020	-	-
CL	31.	8.0-58.	2.0	0.20-5.0	0.93	0.10-1.7
CO	0.00090	0.0-0.0082	0.00090	0.0-0.011	-	-
CU	0.081	0.011-0.63	0.047	0.0030-0.22	0.16	0.020-0.52
F	5.3	1.1-22.	2.3	0.66-7.1	7.9	0.68-36.
FE	0.52	0.028-5.6	0.57	0.010-6.4	0.43	0.18-1.0
LI	0.011	0.0010-0.029	-	-	0.023	0.0020-0.066
MG	5.5	1.4-11.	1.5	0.31-12.	0.34	0.0-2.4
MN	0.37	0.060-0.78	0.12	0.023-0.79	0.0029	0.0015-0.0092
NA	32.	11.-46.	4.7	1.3-9.0	N.D.	N.D.
PB	0.026	0.0040-0.24	0.014	0.0060-0.18	0.075	0.0060-0.80
SI	1.8	0.75-3.1	2.5	1.3-5.4	19.	7.5-28.
SR	0.50	0.097-1.3	0.096	0.011-0.25	0.011	0.0018-0.027
U	0.00027	0.0-0.00070	0.00027	0.0-0.0018	0.0012	0.0-0.0044
V	0.015	0.0-0.032	0.012	0.0-0.046	0.34	0.082-0.66
ZN	0.036	0.0030-0.14	0.018	0.0040-0.049	0.037	0.0020-0.35

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
0.0 = ELEMENT NOT FOUND IN ABOVE-BLANK CONCENTRATION FOR AT LEAST ONE SAMPLE OF A GIVEN LEACH TYPE

TABLE 7-B. AVERAGE CHEMICAL COMPOSITION (MG/L) OF LEACHATES OF PACAYA ASH

	WATER LEACHATE		ACID LEACHATE		CARBONATE-BICARBONATE LEACHATE	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
AL	3.2	0.15-5.3	7.0	0.17-13.	N.D.	N.D.
B	0.015	0.0010-0.027	0.0026	0.0-0.0080	0.0081	0.0-0.019
BA	0.17	0.089-0.28	0.19	0.037-0.40	0.0029	0.0-0.015
CA	49.	32.-76.	15.	8.0-27.	1.1	0.65-2.0
CD	0.0089	0.0010-0.032	0.0030	0.0-0.012	-	-
CL	51.	13.-210.	3.2	0.0-15.	0.85	0.30-2.6
CO	0.0018	0.0-0.0060	0.0018	0.0-0.0056	-	-
CU	0.31	0.035-0.59	0.41	0.029-1.1	0.20	0.082-0.44
F	7.2	4.3-11.	2.6	0.58-7.8	3.1	0.77-11.
FE	0.70	0.0-2.3	2.2	0.068-4.5	0.34	0.26-0.42
LI	0.00090	0.0-0.016	-	-	0.0066	0.0020-0.010
MG	4.9	2.4-13.	2.5	0.80-4.6	0.33	0.13-0.52
MN	0.25	0.10-0.72	0.17	0.079-0.28	0.0015	0.0-0.0040
NA	39.	20.-110.	5.9	2.1-9.3	N.D.	N.D.
PB	0.0035	0.0-0.011	0.012	0.0-0.070	-	-
SI	2.3	0.70-3.8	6.1	1.3-11.	24.	20.-30.
SR	0.41	0.27-0.65	0.12	0.058-0.21	0.011	0.0032-0.024
U	0.00002	0.0-0.00012	0.00003	0.0-0.00014	0.00038	0.00017-0.00070
V	0.0062	0.0-0.017	0.0093	0.0-0.025	0.082	0.027-0.12
ZN	1.4	0.17-4.7	1.4	0.13-3.4	0.0071	0.0-0.028

- = BELOW BLANK LEVEL
N.D. = NOT DETERMINED
0.0 = ELEMENT NOT FOUND IN ABOVE-BLANK CONCENTRATION FOR AT LEAST ONE SAMPLE OF A GIVEN LEACH TYPE

TABLE 7-C. AVERAGE CHEMICAL COMPOSITION (MG/L) OF LEACHATES OF SANTIAGUITO ASH

	WATER LEACHATE		ACID LEACHATE		CARBONATE-BICARBONATE LEACHATE	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
AL	1.3	0.0-4.9	1.3	0.0-4.7	N.D.	N.D.
B	0.27	0.051-0.98	0.12	0.0090-0.50	0.20	0.055-0.46
BA	0.033	0.0045-0.087	0.037	0.0038-0.14	0.0040	0.0-0.0060
CA	150.	47.-560.	190.	5.9-880.	0.99	0.74-2.6
CD	0.014	0.0-0.064	0.00040	0.0-0.0010	-	-
CL	110.	20.-350.	7.3	0.20-32.	2.9	1.0-7.0
CO	0.033	0.0-0.15	0.0054	0.0-0.022	-	-
CU	0.39	0.055-0.70	0.14	0.010-0.40	0.12	0.029-0.24
F	3.6	1.8-5.8	1.8	1.0-3.0	5.3	1.2-13.
FE	0.39	0.10-0.90	1.2	0.054-3.6	0.19	0.20-0.48
LI	0.10	0.0050-0.47	0.019	0.0-1.9	0.16	0.12-0.18
MG	24.	3.7-100.	5.1	0.37-21.	0.45	0.50-0.59
MN	4.9	0.14-23.	0.87	0.090-3.7	0.028	0.0035-0.053
NA	100.	14.-440.	14.	6.0-53.	N.D.	N.D.
PB	0.0024	0.0-0.012	0.012	0.0-0.038	-	-
SI	1.9	0.75-2.8	4.1	2.3-5.6	16.	7.5-24.
SR	0.37	0.086-1.1	0.46	0.033-2.0	0.013	0.0-0.014
U	0.00030	0.0-0.0015	-	-	0.0053	0.0-0.010
V	0.0091	0.0-0.020	0.018	0.0-0.052	0.097	0.045-0.20
ZN	0.51	0.052-2.1	0.31	0.015-1.2	0.016	0.0040-0.026

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
0.0 = ELEMENT NOT FOUND IN ABOVE-BLANK CONCENTRATION FOR AT LEAST ONE SAMPLE OF A GIVEN LEACH TYPE

TABLE 7-D. AVERAGE CHEMICAL COMPOSITION (MG/L)
OF LEACHATES OF FRESHLY ERUPTED BOMB FRAGMENTS

	WATER LEACHATE		ACID LEACHATE		CARBONATE-BICARBONATE LEACHATE	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
AL	0.88	*	0.85	*	N.D.	N.D.
B	0.050	0.025-0.079	0.030	0.012-0.0560	0.017	0.006-0.025
BA	0.062	0.010-0.12	0.076	0.019-0.14	0.0018	0.0-0.0070
CA	110.	23.-250.	51.	22.-87.	1.4	1.0-2.1
CD	0.0014	0.0-0.0024	0.0020	0.0-0.0080	-	-
CL	62.	19.-110.	15.	10.-21.	2.1	1.7-3.1
CU	0.0028	0.0-0.0061	0.0011	0.0-0.0044	-	-
CU	0.51	0.022-1.0	0.18	0.0020-0.54	0.099	0.045-0.15
F	6.0	1.1-19.	4.3	0.66-14.	3.7	0.34-13.
FE	0.72	0.080-1.7	1.6	0.37-4.1	0.32	0.15-0.52
LI	0.019	0.0-0.029	0.00020	0.0-0.0010	0.083	0.0070-0.21
MG	20.	3.8-44.	5.5	2.5-9.8	0.55	0.21-1.3
MN	0.56	0.16-0.99	0.54	0.16-1.4	0.0010	0.0-0.0020
NA	68.	16.-130.	14.	4.9-25.	N.D.	N.D.
PB	-	-	-	-	0.038	0.0-0.12
SI	5.2	2.3-6.5	10.	4.4-15.	26.	13.-43.
SR	0.36	0.081-0.83	0.16	0.074-0.30	0.015	0.0055-0.031
U	0.00046	0.00002-0.0013	0.00010	0.0-0.00040	0.0023	0.00090-0.0034
V	0.031	0.0-0.065	0.028	0.0-0.052	0.098	0.0-0.24
ZN	0.089	0.021-0.19	0.036	0.0060-0.083	-	-

* = ONLY ONE SAMPLE ANALYZED
- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
0.0 = ELEMENT NOT FOUND IN ABOVE-BLANK CONCENTRATION FOR AT LEAST ONE SAMPLE OF A GIVEN LEACH TYPE

TABLE 7-E. AVERAGE CHEMICAL COMPOSITION (MG/L) OF LEACHATES OF HISTORIC "RHYOLITES"

	WATER LEACHATE		ACID LEACHATE		CARBONATE-BICARBONATE LEACHATE	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
AL	9.3	6.1-14.	4.7	2.1-7.9	N.D.	N.D.
B	0.032	0.0-0.22	0.0067	0.0-0.034	0.023	0.0080-0.050
BA	0.17	0.026-0.91	0.045	0.014-0.090	0.0031	0.0-0.024
CA	4.9	0.90-11.	4.5	0.35-15.	0.84	0.26-1.6
CD	0.0019	0.0-0.0085	0.00012	0.0-0.0012	-	-
CL	1.1	0.0-2.4	0.14	0.0-0.40	1.4	0.60-2.8
CO	0.0050	0.0-0.021	0.0013	0.0-0.0097	0.0012	0.0-0.012
CU	0.11	0.017-0.33	0.046	0.012-0.11	0.074	0.029-0.17
F	0.94	0.023-4.8	0.23	0.0-0.91	1.6	0.16-10.
FE	1.4	0.37-4.7	1.1	0.28-4.2	0.83	0.11-6.0
LI	0.0019	0.0-0.0060	-	-	0.096	0.040-0.28
MG	1.3	0.030-3.9	0.21	0.0-0.52	0.067	0.0-0.25
MN	0.22	0.020-0.62	0.085	0.0044-0.22	0.027	0.0-0.21
NA	9.3	4.2-17.	3.7	1.8-5.4	N.D.	N.D.
PB	0.023	0.0-0.14	0.020	0.0-0.056	-	-
SI	2.5	0.79-5.1	2.6	0.79-5.6	24.	7.9-61.
SR	0.035	0.0073-0.077	0.018	0.0021-0.060	0.0079	0.0025-0.016
U	0.00038	0.0-0.0017	0.00031	0.0-0.0012	0.0028	0.00020-0.010
V	0.0015	0.0-0.015	-	-	0.020	0.0-0.084
ZN	0.11	0.027-0.35	0.032	0.0-0.092	0.0058	0.0-0.018

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
0.0 = ELEMENT NOT FOUND IN ABOVE-BLANK CONCENTRATION FOR AT LEAST ONE SAMPLE OF A GIVEN LEACH TYPE

TABLE 8 Ratios of elements relative to Si in carbonate-bicarbonate leachates of five Fuego ash samples compared to the same ratio in residual glass in Fuego ash. A value of 1 indicates congruent dissolution.

Sample number	Mg	Fe	Ca
32	0.33	0.091	0.23
34	0.13	0.10	0.27
101	0.16	0.15	0.56
167	0.24	0.19	0.39
314	0.33	0.059	0.23

Explanation of columns: All columns show values of the following ratio:

$$\frac{(X/Si)_{\text{carbonate-bicarbonate leach}}}{(X/Si)_{\text{glass}}}$$

where X = Mg, Fe, or Ca. Glass compositions taken from Rose et al. (1978).

TABLE 9 Ratios of elements relative to Si in carbonate-bicarbonate leachates of historic "rhyolites" compared to the same ratio in the "rhyolites" themselves. A value of 1 indicates congruent dissolution.

	Mg	Ca	Fe	U	V	Mn
Katmai	<0.19	0.43	0.41	2.0	<0.27	<0.0052
Mt. St. Helens--T	0.37	0.49	0.058	32.	16.	<0.022
Mt. St. Helens--W	0.44	2.2	8.8	66.	62.	2.1
Medicine Lake	<0.013	1.3	0.19	0.63	<2.1	0.068
Mono Craters	<0.019	0.76	0.73	0.39	1.8	<0.0082

Explanation of columns: All columns show values of the following ratio:

$$\frac{(X/Si)_{\text{carbonate-bicarbonate leach}}}{(X/Si)_{\text{pumice}}}$$

where X = Mg, Ca, Fe, U, V, or Mn. Some elements in the leachates were below blank level. For these cases, the numbers in the table were calculated using the detection limit (Table 5) as the maximum concentration of the element of interest. These numbers are preceded by a "less than" symbol (<) in the above table.

Environmental implications

Some of the elements removed during the first washing of a freshly erupted volcanic ash may have short-term detrimental effects on the water quality of small streams in the vicinity of the volcano. Such effects were caused by the 1970 eruption of Hekla in Iceland, where consuming contaminated water and vegetation caused lethal fluoride poisoning in sheep and other livestock (Thorarinsson, 1970). Of all the elements found above blank in water leachates, only seven (Cd, Pb, Cu, Zn, Ba, B, F) are sufficiently harmful to have "safe" levels empirically established for various life forms. A comparison of these "safe" levels with concentrations of the same elements in water leachates of fresh ash shows that the "safe" levels are exceeded in some instances (Table 10). Any inference that streams near a fresh ash deposit might carry a harmful concentration of a certain element must be made with the understanding that the water-leachate data in Table 10 are based upon the experimental water/ash weight ratio of 4:1. The concentrations reported here are meant as semiquantitative estimates of likely contaminant levels for comparison with accepted standards of water quality.

Economic implications

The amounts of soluble material released during initial washing of the freshly erupted ash of this study were calculated (Table 11). It was assumed that the majority of water-soluble constituents contained on the ash surfaces were dissolved during the first experimental leach. The calculations also assumed a hypothetical, near-source ash fall similar in size to that estimated for the 1974 Fuego eruption (0.2 km^3) by Rose et al. (1978). Table 10 shows that there were some economically valuable metals released from the ash on its first exposure to water. The fate of these dissolved metals after their liberation from the ash can vary considerably, depending upon local hydrologic flow regimes, the solubility of possible precipitates, and the presence of adsorbents, reductants, etc., which act as traps for dissolved material.

TABLE 10 Comparison of elemental concentrations in water leachates with reported "safe" levels for natural waters

Element	Reported "safe" levels (mg/1)[1] Drinking water	Livestock	Aquatic Life	Plants	Maximum average concentration (mg/1) in water leachates[2]
Cd	0.01	0.05	0.003		0.014
Pb	0.05	0.1	0.03		0.026
Cu	1.0		0.011		0.39
Zn	5.0		0.18		1.4
Ba	1.0				0.17
B				0.75	0.27
F	0.8	5.0			7.2

[1]From Water Quality Criteria, 1972, and Gough et al., 1979.
[2]From Table 7.

TABLE 11. Estimated metric tons of element released by first water rinse of 0.2 km^3 of freshly erupted air-fall ash with similar composition and leaching characteristics of Fuego, Pacaya, and Santiaguito ash

Element	Estimated metric tons released		
	Fuego	Pacaya	Santiaguito
Al	1,200	2,700	1,400
B	20	13	240
Ba	65	150	28
Ca	90,000	43,600	134,000
Cd	1.7	7.9	1.5
Cl	25,000	35,300	43,400
Co	0.77	1.6	29
Cu	72	280	340
F	4,600	6,300	3,100
Fe	450	600	350
Li	8.4	0.75	88
Mg	5,500	4,400	20,600
Mn	330	220	3,400
Na	28,000	34,900	64,800
Pb	23	3.1	2.1
Si	740	990	7,800
Sr	440	360	310
U*	0.22	0.017	0.27
V	15	5.3	8.7
Zn	33	1,200	450

*The amount of U released from Fuego, Pacaya, and Santiaguito approximately equals deposits containing 570, 44, and 700 pounds U_3O_8, respectively

Only a small percentage (generally less than 0.1%) of the total U in the ash was released by the water and acid rinses. The largest percentage (approximately 1%) of U was removed during the carbonate-bicarbonate leach designed to produce dissolution of volcanic glass. Thus, in evaluating U source rocks, a volcanic ash showing evidence of extensive dissolution and/or alteration of glass shards should be considered a better source than volcanics with abundant unaltered glass.

Other elements which are preferentially removed during the carbonate-bicarbonate leach of volcanic ash include Si, Li, and V. Association of these elements with sedimentary U enrichment in or near tuffaceous rocks argues for a volcanic source.

Si and U have been found associated as uraniferous opal and chalcedony in tuffaceous sedimentary rocks (Davis and Hetland, 1956; Staatz and Bauer, 1951; Love, 1970; Lindsey, 1978). Zielinski (1977) noted that during experimental open-system leaching of rhyolitic glass shards by alkaline solution, U was released by a mechanism of glass dissolution. According to a proposed model, U and silica dissolved from volcanic glass are coprecipitated as a uraniferous silica gel in areas where ground water becomes supersaturated with silica (Zielinski, 1980).

U deposits associated with possible volcanic sources may also be associated with Li-rich clays (Lindsey et al., 1973; Lindsey, 1975; Glanzman et al., 1978). Experimental leaching studies of rhyolite glass showed tha Li was released at a greater rate than either silica or U (Zielinski, 1977). Release of Li during glass hydration and dissolution may explain the common occurrence of Li deposits in closed basins surrounded by volcanic highlands (Heinrich, 1974; Vine, 1975) and the abnormally low Li content (<20 ppm) of some rhyolite glass shards from tuffaceous sediments (Zielinski, 1977).

V is commonly associated with U as various uranyl vanadate minerals in the sedimentary U-V ores of the Colorado Plateau (Finch, 1967; Motica, 1968). In this region, there are important deposits in tuffaceous sandstones and in sandstones which are closely associated with volcanic ash or its alteration products (Finch, 1967). The U-V ratio from U deposits in the Jurassic Morrison Formation of the Colorado Plateau range from 0.025 to 2 (Dodd, 1956). The average U-V concentration ratio in the carbonate-bicarbonate leachate of the studied basaltic ash (Fuego and Pacaya) is 0.0053. Apparently, glass of basaltic composition cannot be the only source of the U in such deposits, or significant fractionation of U and V took place during transport and deposition. In contrast, the ratio of U to V in carbonate-bicarbonate leachates of dacitic ash (Santiaguito), 0.040-0.071, and the historic "rhyolites", 0.010->1.6 (Table 12), indicate that glass in these samples releases U and V in ratios similar to those found in Colorado Plateau U ore.

TABLE 12 Uranium/vanadium ratios in carbonate-bicarbonate leachates of historic "rhyolites"

"Rhyolite"	Uranium/Vanadium ratio
Katmai	>0.067
Mt. St. Helens--W	0.019
Mt. St. Helens--T	0.024
Medicine Lake	>0.10
Mono Craters	>1.6

Vanadium concentration in Katmai, Medicine Lake, and Mono Craters samples was below blank level. For these samples, the detection limit (Table 5) of vanadium was used to calculate the above ratios. These numbers are preceded by a "greater than" (>) symbol.

The freshly erupted volcanics of this study have a low U content (0.19-1.5 ppm) compared to rhyolites and granites which average approximately 5 ppm U (Rogers and Adams, 1967). Unfortunately no freshly erupted rhyolites were available for study. Data from leaching of historically erupted rhyolites indicate that present removal of U is accentuated by processes which promote glass dissolution, as evidenced by the very small amounts of most constituents removed in the water and acid rinses and by the high amounts of silica and U mobilized by the carbonate-bicarbonate leach. The minimum amount of U removed during initial washing of freshly erupted rhyolite may be estimated using the carbonate-bicarbonate leach data for historic "rhyolites". The estimate is calculated by assuming that the relative amounts of U lost during initial washing and subsequent carbonate-bicarbonate leach are the same as for the basaltic and dacitic ashes studied. By this reasoning, about ten times more U would be released from a freshly erupted rhyolite than from a freshly erupted basaltic ash. Calculated percentages of U leached during initial water rinsing (approximately 0.1%) are not very different from the values for more mafic material because rhyolite contains about ten times as much U as basalt or dacite.

Undoubtedly, the above estimate for rhyolites is an oversimplification in that it is an average of a highly variable population. Rhyolites represent highly evolved magmas, and it is reasonable to expect that they will be quite variable in their trace-element chemistry. The fact that trace-element fingerprinting of obsidian and ash is such a successful technique shows this well (Cann and Renfrew, 1964; Borchardt et al., 1971; Howorth and Rankin, 1975; Hahn, 1976). Given the reported range of U content of rhyolites (<1-30 ppm) (Coats, 1956), tenfold variations in the amount of U removed during initial water rinsing of ash seems reasonable, even if the percent leached remains constant. The percent leached during initial water rinsing of rhyolitic ashes may also exceed the maximum value of 0.6% observed in the studied basaltic and dacitic ashes. The high volatile content of rhyolite magmas compared to more basic magmas is evidenced by the abundance and extent of pyroclastic eruptives of rhyolitic composition. High volatile/ash ratios during explosive rhyolitic volcanism may promote more extensive condensation and adsorption of salts and acid gases.

If one assumes that as much as 1% of the total U contained in a typical rhyolite ash (5 ppm U) is lost during initial water rinsing and that all of this liberated U is precipitated, a deposit containing 10 tons U_3O_8 could be formed by rinsing approximately 2 x 10^8 tons of ash. The estimated volume for this weight (assuming 50% porosity) is 0.1 km^3 which is of similar magnitude to the 1974 Fuego eruption. Obviously it is unrealistic to expect all dissolved U to be concentrated into one deposit, so the estimate of the required ash volume is a minimum which may be orders of magnitude too low.

CONCLUSIONS

An experimental leaching study of freshly erupted basaltic and dacitic volanic ash, unaffected by rain, and "rhyolitic" pumice from historic eruptions has led to the following conclusions:

(1) Only about 0.1% of the total U contained in freshly erupted ash is mobilized by initial water rinsing versus approximately 1% released during a relatively short subsequent leach with alkline solution. This result indicates that gaseous transfer followed by fixation of soluble U species on volcanic ash is not an important process affecting U mobility. U is preferentially mobilized during dissolution and/or alteration of volcanic glass.

(2) Calculations based upon the amount of U released during water and carbonate-bicarbonate leaches of fresh basaltic ashes and carbonate-bicarbonate leaches of historic "rhyolite" pumices indicate that the amount of uranium released from a fresh rhyolite ash by the first water rinse may be about ten times larger than that released by a basaltic-dacitic ash. The percent of U released remains about 0.1%, however, because rhyolites contain about ten times more U than basalts.

(3) Leaching of ash in warm alkaline solutions chosen to preferentially attack volcanic glass indicates that of the analyzed elements, Si, U, Li, and V show the greatest increase in dissolved concentrations. Apparently these four elements are preferentially released by the dissolution of glass. This process may be responsible for the association of V, Si, and Li with certain U concentrations in nature.

(4) In agreement with previous work, Na, Cl, F, Ca, and Mg are the predominant elements present in water leachates of freshly erupted ash. In addition, this study has identified small but measurable quantities of Zn, Cu, Cd, Pb, B, V. Li, U, Ba, Fe, Mn, Si, and Sr in these same leachates. The water-soluble fraction of these elements probably exists as soluble salts (primarily halides and sulfates) which result from the interaction of ash particles with volcanic gas and acidic aerosols found in the eruption cloud.

(5) If the water/ash weight ratio during the first washing of the ash is 4:1 or lower, basaltic and dacitic ash can release sufficient quantities of Cd, Cu, F, and Zn to cause short-term, ecologically harmful concentrations in local ground and/or surface water.

(6) Likewise, the total amounts of Zn, Pb, V, Li, Cu, and U released during initial washing of ash could be of potential economic importance if the ash is deposited in a closed basin containing highly efficient traps for dissolved elements.

ACKNOWLEDGMENTS

Support for the collection of the Central American ashes studied came from the National Science Foundation, through grants GA-26026 and DES-74-01190. Dr. Howard E. Taylor of the U.S. Geological Survey supervised leachate analysis by inductively coupled plasma-optical emission spectroscopy.

REFERENCES

Adams, S. S., Curtis, H. S., Hafen, P. L., and Salek-Nejad, H., 1978, Interpretation of postdepositional processes related to the formation and destruction of the Jackpile-Paguate uranium deposit, northwest New Mexico: Economic Geology, v. 73, p. 1635-1654.

Alexander, G. B., Heston, W. M., and Iler, R. K., 1954, The solubility of amorphous silica in water: Journal of Physical Chemistry, v. 58, p. 453-455.

Allen, E. T., and Zies, E. G., 1923, A chemical study of fumaroles of the Katmai region: National Geographical Society Technical Paper, Katmai Series, v. 1(2), p. 75-155.

Anderson, C. A., 1933, Volcanic history of Glass Mountain, northern California: American Journal of Science, v. 26(155), p. 485-506.

_______, 1968, Metamorphosed Precambrian silicic volcanic rocks in central Arizona, <u>in</u> Coats, R. R., Hay, R. L., and Anderson, C. A., eds., Studies in volcanology: Geological Society of America Memoir 116, p. 9-44.

Basharina, L. A., 1958, Water extracts of the ashes and the ash-cloud gases of the Bezymyannyi volcano: Akad. Nauk SSSR, Lab. Vulkanol. Stantsii Biull., v. 27, p. 38-42.

Bonis, S. B., and Salazar, O. D., 1974, the 1971 and 1973 eruption of Volcan Fuego and some socio-economic considerations for the volcanologist: Bulletin Volcanologique, v. 37, p. 394-400.

Borchardt, G. H., Harward, M. E., and Schmitt, R. A., 1971, Correlation of volcanic ash deposits by activation analyses of glass separates: Quat. Res., v. p. 247-260.

Brown, E., Skougstad, M. W., and Fishman, M. J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: Techniques of Water-Resources Investigations of the U.S Geological Survey, Book 5, Chapter A1: 160 p.

Buell, W. C., and Stoiber, R. E., 1976, Eruption of Volcan Fuego, October 14, 1974: Bulletin Volcanologique v. 38, p. 861-870.

Cann, R. J., and Renfrew, C., 1964, The characterization of obsidian and its application to the Mediterranean region: Proceedings, Prehistoric Society, v. 30, p. 111-131.

Coats , R. R., 1956, Uranium and certain other trace elements in felsic volcanic rocks of Cenozoic age in Western United States: U.S. Geological Survey Professional Paper 300, p. 75-78.

Condie, K. C., and Hayslip, D. L., 1975, Young bimodal volcanism at Medicine Lake volcanic center, northern California: Geochimica Cosmochimica Acta, v. 39, p. 1165-1178.

Crandell, D. R., 1971, Postglacial lahars from Mount Rainier volcano, Washington: U.S. Geological Survey Professional Paper 677, 75 p.

Davis, D. L., and Hetland, D. L., 1956, Uranium in clastic rocks of the basin and range province: U.S. Geological Survey Professional Paper 300, p. 351-360.

Denson, N. M., Bachman, G. O., and Zeller, H. D., 1959, Uranium-bearing lignite in northwestern South Dakota and adjacent states: U.S. Geological Survey Bulletin 1055-B p. 11-57.

Dodd, P. H., 1956, Examples of uranium deposits in the upper Jurassic Morrison formation of the Colorado Plateau: U.S. Geological Survey Professional Paper 300, p. 243-262.

Eggers, A. A., 1971, The geology and petrology of the Amatitlan Quadrangle, Guatemala: Unpublished Ph.D. dissertation, Dartmouth College, Hanover, New Hampshire, 221 p.

Ellis, A. J., and Mahon, W. A. J., 1964, Natural hydrothermal systems and experimental hot-water/rock interactions: Geochimica Cosmochimica Acta, v. 28, p. 1323-1357.

Fenner, C. N., 1923, The origin and mode of emplacement of the great tuff deposit of the Valley of Ten Thousand Smokes: National Geographical Society Technical Paper, Katmai Series, v. 1(1), 74 p.

Finch, R. H., 1930, Rainfall accompanying explosive eruptions of volcanoes: American Journal of Science, 5th Series, v. 19, 147-150 p.

Finch, W. I., 1967, Geology of epigenetic uranium deposits in sandstone in the United States: U.S. Geological Survey Professional Paper 538, 121 p.

Fleischer, R. L., and Lovett, D. B., 1968, Uranium and boron content of water by particle track etching: Geochimica Cosmochimica Acta, v. 32, p. 1126-1128.

Friedman, I., 1968a, Hydration rind dates of rhyolite flows: Science, v. 159, p. 878-880.

_______, 1968b, Hydration rind dating of volcanic glass: Science, v. 162, p. 813-814.

Garrels, R. M., and Howard, P., 1959, Reactions of feldspar and mica with water at low temperature and pressure: Clays Clay Minerals v. 6, p. 68-88.

Gilbert, C. M., Christensen, M. N., and Yehya Al-Rawi, Lajoie, 1968, Structural and volcanic history of Mono Basin, California-Nevada, in Coats, R. R., Hay, R. L., and Anderson, C. A., eds., Studies in Volcanology: Geological Society of America Memoir 116, p. 275-331.

Glanzman, R. K., McCarthy, J. H., Jr., and Rytuba, J. J., 1978, Lithium in the McDermitt caldera, Nevada and Oregon: Energy, v. 3, p. 347-353.

Gough, L. P., Shacklette, H. T., and Case, A. A., 1979, Element concentrations toxic to plants, animals, and man: U.S. Geological Survey Bulletin 1466, 80 p.

Hahn, G. A., 1976, Interbasin geochemical correlation of genetically related rhyolitic ash-flow and air-fall tuffs, central and western Guatemala: Unpublished M.S. thesis, Michigan Tecnological University, Houghton, Michigan: 68 p.

Harshman, E. N., 1972, Geology and uranium deposits, Shirley Basin area, Wyoming: U.S. Geological Survey Professional Paper 745, 82 p.

Heinrich, E. W., 1974, Lithium deposits: Their location and economic potential throughout the world: Mining Engineering, v. 26(9), p. 52-54.

Henry, C. D., and Tyner, G. N., 1978, Geology and uranium potential, Virgin Valley, Nevada, in Henry, C. D., and Walton, A. W., principal investigators, Formation of uranium ores by diagenesis of volcanic sediments: Bureau of Economic Geology, University of Texas at Austin: 8-1-8-52.

Howorth, R., and Rankin, P. C., 1975, Multielement characterization of glass shards from stratigraphically correlated rhyolitic tephra units: Chemical Geology, v. 15, p. 239-250.

Hutchinson, T. C., and Whitby, L. M., 1977, The effects of acid rainfall and heavy metal particulates on a boreal forest ecosystem near the Sudbury smelting region of Canada: Water, Air, Soil Pollution, v. 7(4), p. 421-438.

Ives, P. C., Levin, B., Robinson, R. D., and Rubin, M., 1964, U.S. Geological Survey radiocarbon dates VII: American Journal of Science, Radiocarbon Supplement, v. 6, p. 37-76.

Johnston, D. A., 1976, Evidence for a zoned magma chamber 6 to 10 km beneath Augustine volcano, Alaska [abs.]: Geological Society of America Abstract Program, v. 8(6), p. 942-943.

Johnston, D. A., and Schmincke, H., 1977, Triggering of explosive volcanic eruptions by mixing of basaltic and silicic magmas [abs.]; Geological Society of America Abstract Program, v. 9(7), p. 1041.

Kittel, D. F., 1963, Geology of the Jackpile mine area, in Geology and technology of the Grants uranium region: New Mexico Bureau of Mines and Mineral Resources Memoir, v. 15, p. 167-176.

Krauskopf, K. B., 1956, Dissolution and precipitation of silica at low temperatures: Geochimica Cosmochimica Acta, v. 10, p. 1-26.

_______, 1967, Introduction to geochemistry: New York, McGraw-Hill, 721 p.

Lacroix, A., 1907, Les mineraux des fumerolles de l'eruption du Vesuve en avril 1906: Bull. Soc. Min., France, v. 30, 219 p.

Lawrence, D. B., 1954, Diagrammatic history of the northeast slope of Mount St. Helens, Washington: Mazama, v. 36(13), p. 41-44.

Li, Ta-Yung, and Landsberg, H. E., 1975, Rain water pH close to a major power plant: Atmospheric Environment, v. 9(1), p. 81-88.

Likens, G. E., and Bormann, F. H., 1974, Acid rain. A serious regional environmental problem: Science, v. 184, p. 1176-1179.

Lindsey, D. A., 1975, Mineralization halos and diagenesis in water-laid tuff of the Thomas Range, Utah: U.S. Gelogical Survey Professional Paper 818-B, 59 p.

_______, 1978, Geology of volcanic rocks and mineral deposits in the southern Thomas Range, Utah: A brief summary: Brigham Young University Geological Studies, 25, pt. 1, 25-31 p.

Lindsey D. A., Ganow, H., and Mountjoy, W., 1973, Hydrothermal alteration associated with beryllium deposits at Spor Mountain, Utah: U.S. Geological Survey Professional Paper 818-A, 20 p.

Loney, R. A., 1968, Flow structure and composition of the Southern Coulee, Mono Craters, California--A pumice rhyolite flow, in Coats, R. R., Hay, R. L., and Anderson, C. A., eds., Studies in volcanology: Geological Society of America Memoir 116, p. 415-440.

Love, J. D., 1970, Cenozoic geology of the Granite Mountains area, central Wyoming: U.S. Geological Survey Professional Paper 495-C, 154 p.

Luce, R. W., Bartlett, R. W., and Parks, G. A., 1972, Dissolution kinetics of magnesium silicates: Geochimica Cosmochimica Acta, v. 36, p. 35-50.

Millard, H. T., Jr., 1976, Determinations of uranium and thorium in the U.S. Geological Survey standard rocks by the delayed neutron technique: U.S. Geological Survey Professional Paper 840, p. 61-65.

Motica, J. E., 1968, Geology and uranium-vanadium deposits in the Uravan mineral belt, southwestern Colorado, in Ridge, J. D., eds.: Ore deposits of the United States, 1933-1967, v. 1, p. 805-814.

Mullineaux, D. R., Hyde, J. H., and Rubin, M., 1975, Widespread late glacial and postglacial tephra deposits from Mount St. Helens volcano, Washington: U.S. Geological Survey Journal of Research, v. 3(3): p. 329-335.

Murata, K. J., Dondoli, C., and Saenz, R., 1966, The eruption of Irazu volcano, Costa Rica (the period of March 1963 to October 1964): Bulletin Volcanologique v. 29, p. 765-796.

Oskarsson, N., 1978, The interaction between volcanic gases and solid tepra--Notes on fluorine adhering to tephra of the 1970 Hekla eruption: Nordic Volcanologic Institute, University of Iceland, Report 7804, 39 p.

Petrovic, R., Berner, R. A., and Goldhaber, M. B., 1976, Rate control in dissolution of alkali feldspars--I. Study of residual feldspar grains by X-ray photoelectron spectroscopy: Geochimica Cosmochimica Acta, v. 40, p. 537-548.

Reimer, G. M., 1976, Fission track uranium analysis of single drops of natural waters: U.S. Geological Survey Open-File Report 76-239.
Rogers, J. J. W., and Adams, J. A. S., 1967, Uranium, in Wedepohl, K. H., ed., Handbook of geochemistry: New York, Springer-Verlag, 2, pt. 1, Chapter 92, 50 p.
Rose, W. I., Jr., 1972, Santiaguito volcanic dome, Guatemala: Geological Society of America Bulletin 83, p. 1413-1434.
_______, 1977, Scavenging of volcanic aerosols by ash: Atmospheric and volcanologic implications: Geology, 5, p. 621-624.
Rose, W. L., Jr., 1978, Activity of Guatemalan volcanoes, February 1978 [abs.]: EOS (Am. Geophys. Union Trans.), v. 59, p. 1221-1222.
Rose, W. I., Jr., Anderson, A. T., Jr., Woodruff, L. G., and Bonis, S. B., 1978, The October 1974 basaltic tephra from Fuego volcano: Description and history of the magma body: Journal of Volcanology, Geotherm. Res., v. 4, p. 3-53.
Rose, W. I., Jr., Bonis, S., Stoiber, R. E., Keller, M., and Bickford, T., 1973, Studies of volcanic ash from two recent Central American eruptions: Bulletin of Volcanologique v. 37, p. 338-364.
Rose, W. I., Jr., Grant, N. K., Hahn, G. A., Lange, I. M., Powell, J. L., Easter, J., and Degraff, J. M., 1977, The evolution of Santa Maria volcano, Guatemala: Journal of Geology, v. 85, p. 63-87.
Schmincke, H., and Johnston, D. A., 1977, Contrasting pyroclastic flow deposits of the 1976 eruption of Augustine volcano, Alaska [abs.]: Geology Society of America Abstract Program 9(7), p. 1161.
Schoff, S. L., and Moore, J. E., 1964, Chemistry and movement of ground water, Nevada Test Site: U.S. Geological Survey TEI-838, 75 p.
Staatz, M. H., and Bauer, H. L., 1951, Virgin Valley opal district, Humboldt County, Nevada: U.S. Geological Survey Circular 142, 7 p.
Taylor, P. S., 1969, Soluble material on volcanic ash: Unpublished M. A. thesis, Dartmouth College, Hanover, New Hampshire: 77 p.
Taylor, P. S., and Stoiber, R. E., 1973, Soluble material on ash from active Central American volcanoes: Geologic Society of America Bulletin 84, p. 1031-1042.
Thorarinsson, S., 1970, The "Hekla Fires"--A preliminary report of the 1970 Mt. Hekla volcanic eruption: Washington, Smithsonian Institute Center Short-Lived Phenomena: 2 p.
Thorarinsson, S., Steinthorsson, S., Einarsson, T., Kristmannsdottir, H., and Oskarsson, N., 1973, The eruption on Heimaey, Iceland: Nature, v. 241, p. 372-375.
Tovarova, I. I., 1958, Removal of water-soluble matter from the pyroclastic material of the Bezymyannyi volcano: Geokhimiya 1958: p. 686-688.
Vine, J. D., 1975, Lithium in sediments and brines--How, why, and where to search: U.S. Geological Survey Journal of Research, v. 3(4), p. 479-485.
Water Quality Criteria, 1972, A report of the Committee of Water Quality Criteria, Environmental Studies Board, National Academy of Sciences, National Academy of Engineering, Washington, D.C.: 594 p.
Waters, A. O., and Granger, H. C., 1953, Volcanic debris in uraniferous sandstones, and its possible bearing on the origin and precipitation of uranium: U.S. Geological Survey Circular 224, 26 p.
Wilcox, R. E., 1959, Some effects of recent volcanic ash falls with especial reference to Alaska: U.S. Geological Survey Bulletin 1028-N, p. 409-476.
Zielinski, R. A., 1977, Uranium mobility during interaction of rhyolitic glass with alkaline solutions: Dissolution of glass: U.S. Geological Survey Open-File Report 77-774, 36 p.

Zielinski, R. A., 1980, Uranium in secondary silica: A possible exploration guide: Economic Geology 75, p. 592-602.

Zielinski, R. A., Lipman, P. W., and Millard, H. T., Jr., 1977, Minor-element abundances in obsidian, perlite, and felsite of calc-alkalic rhyolites: American Mineralogist 62, p. 426-437.

Zies, E. G., 1924, The fumarolic incrustations in the Valley of Ten Thousand Smokes: National Geographical Society Technical Paper, Katmai Series, v. 1(3), p. 157-179.

_______, 1929, The Valley of Ten Thousand Smokes: National Geographical Society Technical Paper, Katmai Series, v. 1(4), 79 p.

APPENDIX I--TABLE 1

FUEGO VOLCANO: CHEMICAL COMPOSITION OF SAMPLES STUDIED

	28	32	33	34	40	100	101	102	104
MAJOR ELEMENT OXIDES (WT.%)									
SIO2	51.5	50.5	52.2	50.3	52.3	52.6	52.8	51.4	50.8
AL2O3	20.1	20.4	19.4	20.9	20.1	19.3	20.2	19.3	18.9
FE2O3	8.6	10.1	9.4	9.5	8.7	8.7	8.8	9.2	10.4
MGO	3.65	3.9	4.55	4.41	3.31	3.81	3.75	4.23	5.19
CAO	9.1	9.9	8.7	10.1	8.7	9.5	9.2	9.1	8.7
NA2O	3.5	3.5	3.4	3.5	3.8	4.1	3.7	3.6	3.5
K2O	0.94	0.67	0.87	0.68	0.83	1.08	0.93	0.87	0.81
TIO2	0.93	0.98	0.7	0.95	0.95	0.83	0.8	0.78	0.98
TOTAL	98.22	99.85	99.22	100.34	98.69	99.92	100.18	98.48	99.28
TRACE ELEMENTS (PPM)									
BA	430.	430.	430.	360.	430.	540.	430.	430.	430.
CL	600.	600.	600.	600.	600.	300.	400.	500.	500.
CO	27.	27.	27.	23.	27.	19.	27.	27.	27.
CU	96.	96.	96.	90.	96.	120.	96.	96.	96.
F	400.	400.	500.	400.	400.	400.	400.	400.	400.
MN	1190.	1100.	1070.	1080.	1170.	1090.	1120.	1230.	1260.
SR	540.	540.	540.	540.	540.	530.	540.	540.	540.
U	0.48	0.25	0.40	0.28	0.36	0.49	0.44	0.33	0.32
V	234.	178.	213.	204.	235.	154.	177.	209.	223.
ZN	105.	87.50	88.	75.00	92.50	87.50	85.00	57.50	95.00

SAMPLES 28-40 FROM 10/14/74 PULSE
SAMPLES 100-101 FROM 10/17/74 PULSE

APPENDIX I--TABLE 1 (CONT'D)

FUEGO VOLCANO: CHEMICAL COMPOSITION OF SAMPLES STUDIED

	306	314	167	169	6	Z-2	44	Z-4	B-5
MAJOR ELEMENT OXIDES (WT.%)									
SIO2	50.90	49.90	47.00	49.20	51.10	52.20	54.70	51.60	52.20
AL2O3	18.80	18.80	17.60	18.80	20.10	19.60	19.90	19.20	18.90
FE2O3	9.70	10.60	12.00	10.60	8.90	9.70	8.00	10.00	8.90
MGO	4.93	5.32	9.67	5.79	3.57	4.39	3.37	4.47	3.46
CAO	9.40	9.00	8.50	9.20	9.50	9.10	8.80	9.10	8.40
NA2O	3.50	3.40	2.60	3.00	3.50	3.40	3.90	3.40	2.90
K2O	0.82	0.72	0.50	0.63	0.78	0.74	0.95	0.77	0.87
TIO2	0.98	0.93	0.75	0.93	0.83	0.85	0.73	0.95	0.85
TOTAL	99.03	98.67	98.62	98.15	98.28	99.98	100.35	99.49	96.48
TRACE ELEMENTS (PPM)									
BA	430.	430.	290.	430.	430.	430.	430.	430.	520.
CL	700.	600.	300.	400.	500.	500.	600.	600.	400.
CO	27.	27.	48.	27.	27.	27.	27.	27.	19.
CU	96.	90.	80.	96.	96.	96.	96.	96.	100.
F	400.	400.	400.	400.	400.	400.	400.	400.	400.
MN	1240.	1290.	1390.	1210.	1020.	1070.	1120.	1140.	1020.
SR	540.	620.	460.	540.	540.	540.	540.	540.	560.
U	0.38	0.33	0.19	0.29	0.27	0.36	0.40	0.40	0.49
V	223.	249.	242.	217.	146.	209.	121.	180.	139.
ZN	87.5	85.	105.	92.5	88.	88.	89.	88.	88.

SAMPLES 306-314 COLLECTED FROM 10/18-19/74 PULSE; SAMPLES 167-169 COLLECTED FROM 10/23/74 PULSE; SAMPLE 6 COLLECTED 2/24/73; SAMPLE Z-2 COLLECTED 2/28/73-3/1/73; SAMPLE 44 COLLECTED 3/1/73; SAMPLE Z-4 COLLECTED 3/1-2/73; SAMPLE B-5 COLLECTED 3/23/73.

APPENDIX 1--TABLE 2

PACAYA VOLCANO: CHEMICAL COMPOSITION OF SAMPLES STUDIED

	2	3	4	5	VP5	7	9
MAJOR ELEMENT OXIDES (WT.%)							
SIO2	50.3	48.5	49.6	48.6	50.8	54.8	51.6
AL2O3	20.5	18.8	18.9	18.9	18.8	19.1	19.3
FE2O3	10.9	10.9	10.6	10.6	10.0	11.1	10.0
MGO	3.96	4.1	4.01	4.56	3.68	4.3	4.19
CAO	8.9	8.5	9.1	8.8	9.5	9.0	8.8
NA2O	3.8	3.7	3.9	3.7	3.6	3.7	3.7
K2O	0.93	0.92	0.81	0.87	0.87	0.81	0.83
TIO2	1.03	1.16	1.1	1.2	1.0	1.35	1.05
TOTAL	100.32	96.6	98.02	97.23	98.25	104.16	99.47
TRACE ELEMENTS (PPM)							
BA	490.	490.	490.	490.	490.	490.	490.
CL	600.	700.	700.	600.	1300.	600.	600.
CO	24.	24.	24.	24.	24.	24.	24.
CU	90.	90.	90.	90.	90.	90.	90.
F	400.	500.	400.	400.	500.	400.	500.
MN	1430.	1440.	1360.	1410.	1320.	1420.	1410.
SR	530.	530.	530.	530.	530.	530.	530.
U	0.65	0.65	0.45	0.54	0.62	0.64	0.55
V	265.	254.	224.	244.	214.	253.	259.
ZN	100.	100.	100.	100.	100.	100.	100.

SAMPLE 2 COLLECTED 2/14/74, SAMPLE 3 COLLECTED 2/20/74, SAMPLE 4 COLLECTED 2/21/74, SAMPLE 5 COLLECTED 3/18/74, SAMPLE VP5 COLLECTED 3/18/74, SAMPLE 7 COLLECTED 4/3/74, SAMPLE 9 COLLECTED 4/7/74.

APPENDIX I--TABLE 3

SANTIAGUITO VOLCANO:
CHEMICAL COMPOSITION OF SAMPLES STUDIED

	1	2	3	4	1123
MAJOR ELEMENT OXIDES (WT.%)					
SIO2	63.45	63.45	63.45	63.45	63.45
AL2O3	16.94	16.94	16.94	16.94	16.94
FE2O3	2.27	2.27	2.27	2.27	2.27
FEO	2.56	2.56	2.56	2.56	2.56
MGO	1.87	1.87	1.87	1.87	1.87
CAO	5.03	5.03	5.03	5.03	5.03
NA2O	4.91	4.91	4.91	4.91	4.91
K2O	1.59	1.59	1.59	1.59	1.59
TIO2	0.47	0.47	0.47	0.47	0.47
TOTAL	99.09	99.09	99.09	99.09	99.09
TRACE ELEMENTS (PPM)					
BA	860.	860.	860.	860.	860.
CL	400.	400.	500.	400.	340.
CO	6.	6.	6.	6.	6.
CU	15.	15.	13.	13.	15.
F	400.	400.	400.	400.	700.
MN	1200.	1060.	1110.	1120.	1560.
SR	400.	400.	470.	470.	470.
U	0.92	1.0	0.93	0.90	0.91
V	93.	110.	162.	124.	150.
ZN	60.	60.	60.	60.	60.

SAMPLE 1 COLLECTED 2/75, SAMPLE 2 COLLECTED 3/75,
SAMPLE 3 COLLECTED 1/76, SAMPLE 4 COLLECTED 2/76,
SAMPLE 1123 COLLECTED 7/21/67

APPENDIX I--TABLE 4

FRESHLY ERUPTED BOMB FRAGMENTS:
CHEMICAL COMPOSITION OF SAMPLES STUDIED

	1	2	3
MAJOR ELEMENT OXIDES (WT.%)			
SIO2	63.80	64.20	49.10
AL2O3	15.90	15.70	16.53
FE2O3	1.80	2.10	1.85
FEO	3.30	3.30	10.80
MGO	3.30	3.10	4.66
CAO	6.40	6.00	8.15
NA2O	3.60	3.60	4.35
K2O	1.00	1.00	1.08
TIO2	0.58	0.50	2.44
TOTAL	99.68	99.50	98.96
TRACE ELEMENTS (PPM)			
BA	400.	400.	360.
CL	800.	1100.	300.
CO	16.	16.	17.
CU	20.	20.	10.
F	400.	400.	1600.
MN	970.	970.	2050.
SR	300.	300.	330.
U	0.74	0.86	1.5
V	140.	140.	80.
ZN	60.	60.	100.

1 = AUGUSTINE VOLCANO, 1/26/76
2 = AUGUSTINE VOLCANO, 2/6/76
3 = HEIMAEY, 6/5/70

APPENDIX I--TABLE 5

HISTORIC "RHYOLITES":
CHEMICAL COMPOSITION OF SAMPLES STUDIED

	1	2	3	4	5
MAJOR ELEMENT OXIDES (WT.%)					
SIO2	76.56	63.60	67.50	73.16	75.41
AL2O3	12.15	17.00	16.20	13.91	12.73
FE2O3	0.49	1.80	1.30	0.48	0.37
FEO	0.92	3.20	2.10	1.94	0.56
MGO	0.02	2.20	0.99	0.36	0.10
CAO	0.97	4.80	3.60	1.64	0.55
NA2O	4.32	4.50	4.80	4.02	3.90
K2O	3.11	1.30	1.60	4.08	5.00
TIO2	0.18	0.68	0.44	0.00	0.00
TOTAL	98.72	99.08	98.53	99.59	98.62
TRACE ELEMENTS (PPM)					
BA	540.	490.	490.	980.	30.
CL	900.	800.	500.	500.	700.
CO	14.	15.	4.	2.	2.
CU	5.	50.	9.	6.	1.
F	400.	400.	400.	400.	700.
MN	1100.	440.	440.	300.	370.
SR	280.	370.	370.	130.	10.
U	1.18	0.61	0.91	6.37	6.91
V	130.	50.	50.	20.	10.
ZN	60.	40.	40.	40.	40.

1 = KATMAI
2 = MT. ST. HELENS--TEPHRA SET T
3 = MT. ST. HELENS--TEPHRA SET W
4 = MEDICINE LAKE
5 = MONO CRATERS

APPENDIX I (Continued)

Major element data obtained as follows:

Fuego and Pacaya: from W. I. Rose, Jr., written communication.

Santiaguito: average of 19 analyses of Santiaguito dacite from Rose et al. (1977).

Augustine: from D. A. Johnston, written communication.

Heimaey: estimated from analyses of 1973 eruptives by Thorarinsson et al. (1973).

Katmai: average of four analyses from Zies (1929).

Mt. St. Helens: from D. R. Mullineaux, written communication.

Medicine Lake: from Anderson (1968).

Trace element data obtained as follows:

Mn, V, Ba, Co, Cu, and Sr analyzed by emission spectrometry on 14 samples (Fuego: 34, 100, 167, 314, B-5; Pacaya: 5; Santiaguito: 1, 3; Augustine: 1/26/76; Heimaey; Katmai, Mt. St. Helens--W; Medicine Lake; and Mono Craters. For the remaining samples (except as noted), values listed for these six elements are averages of similar rock types from the 14 analyzed samples.

Mn and V values for all Fuego, Pacaya, and Santiaguito samples determined by I.N.A.A. by D. B. Smith.

Cl and F analyzed by U.S.G.S. Analytical Labs.

U analyzed by delayed neutron technique by H. T. Millard, Jr.

Zn values for 1974 Fuego samples from W. I. Rose, Jr., written communication. Values for 1973 Fuego material represent average of 1974 values. Zn concentrations for remaining samples estimated from tables giving average composition of appropriate rock types (Krauskopf, 1967).

APPENDIX II -- TABLE 1A

FUEGO VOLCANO:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN WATER LEACHATES

	28	32	33	34	40	100	101	102	104
AL	0.34	1.4	4.1	0.45	1.1	0.12	0.15	0.71	0.35
B	0.033	0.027	0.013	0.017	0.014	0.021	0.033	0.0030	0.0040
BA	0.089	0.10	0.25	0.063	0.13	0.029	0.041	0.066	0.073
CA	150.	76.	62.	72.	260.	95.	140.	120.	150.
CD	0.010	0.0010	0.0014	0.0030	0.0040	-	-	0.0022	-
CL	49.	51.	34.	45.	55.	8.6	12.	16.	30.
CO	-	0.0082	-	0.0038	-	0.0044	-	-	-
CU	0.056	0.039	0.63	0.024	0.042	0.016	0.016	0.026	0.024
F	2.6	3.8	8.5	3.9	3.5	1.4	2.5	3.1	3.4
FE	0.036	3.0	5.6	0.12	0.070	0.028	0.043	0.050	0.033
LI	0.015	0.0010	0.018	0.0030	0.016	0.0050	0.013	0.0080	0.0090
MG	6.9	7.6	8.3	6.9	11.	6.0	8.3	4.5	6.1
MN	0.53	0.53	0.78	0.36	0.63	0.15	0.18	0.27	0.19
NA	46.	37.	29.	35.	45.	28.	43.	28.	37.
PB	0.019	0.039	-	0.24	0.090	-	-	0.0040	0.090
SI	1.8	1.3	2.0	1.1	2.4	3.1	2.9	1.9	1.8
SR	0.79	0.43	0.36	0.39	1.3	0.39	0.67	0.60	0.67
U	0.00070	0.00024	-	-	-	-	0.00025	-	-
V	0.0094	0.023	-	-	-	0.032	0.026	0.017	0.016
ZN	0.12	0.056	0.14	0.085	0.041	0.0030	0.0060	0.060	0.0040

- = BELOW BLANK LEVEL
SAMPLES 28-40 FROM 10/14/74 PULSE
SAMPLES 100-104 FROM 10/17/74 PULSE

APPENDIX II -- TABLE 1A (CONT'D)

FUEGO VOLCANO:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN WATER LEACHATES

	306	314	167	169	6	Z-2	44	Z-4	B-5
AL	1.4	2.5	2.2	0.85	6.6	0.35	0.25	2.0	-
B	0.11	0.020	-	-	0.015	0.0060	0.017	0.012	0.014
BA	0.080	0.094	0.036	0.077	0.023	0.020	0.051	0.036	0.033
CA	210.	110.	22.	63.	18.	54.	120.	57.	64.
CD	0.0015	0.0021	-	0.0014	0.0033	0.0038	0.0022	0.0016	-
CL	58.	42.	9.4	7.8	14.	20.	32.	38.	29.
CU	-	-	-	-	-	-	-	-	-
CU	0.051	0.058	0.049	0.011	0.11	0.023	0.053	0.043	0.071
F	5.9	8.3	4.4	4.4	22.	6.0	3.1	7.0	1.1
FE	0.090	0.12	0.12	0.035	0.040	0.10	0.11	0.051	0.11
LI	0.016	0.0050	-	-	0.0020	0.0090	0.016	0.014	0.029
MG	4.7	3.7	1.4	1.9	1.8	2.5	9.8	2.2	5.5
MN	0.48	0.33	0.090	0.059	0.21	0.25	0.60	0.37	0.58
NA	41.	33.	14.	11.	19.	29.	37.	18.	30.
PB	-	-	-	-	-	-	-	-	0.015
SI	1.8	1.6	0.75	0.93	1.0	1.2	1.9	1.7	2.9
SR	0.85	0.56	0.11	0.30	0.097	0.24	0.59	0.29	0.43
U	-	-	-	-	0.00037	-	-	-	-
V	0.013	0.023	0.021	0.019	0.012	0.014	0.015	0.010	0.018
ZN	0.031	0.024	0.010	0.015	0.032	0.012	0.0030	0.019	0.0090

- = BELOW BLANK LEVEL
SAMPLES 306-314 FROM 10/19-19/74 PULSE; SAMPLES 167-169 FROM 10/23/74 PULSE; SAMPLE 6 COLLECTED 2/24/73; SAMPLE Z-2 COLLECTED 2/28/73-3/1/73; SAMPLE 44 COLLECTED 3/1/73; SAMPLE Z-4 COLLECTED 3/1/73-3/2/73; SAMPLE B-5 COLLECTED 3/23/73.

APPENDIX II--TABLE 1B

PACAYA VOLCANO:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN WATER LEACHATES

	2	3	4	5	VP5	7	9
AL	4.0	0.33	4.3	4.1	4.4	5.3	0.15
B	0.017	0.016	0.017	0.0010	0.027	0.0080	0.017
BA	0.28	0.12	0.19	0.25	0.11	0.17	0.089
CA	53.	76.	58.	35.	55.	32.	36.
CD	0.032	0.0020	0.0070	0.0030	0.014	0.0033	0.0010
CL	13.	43.	34.	19.	210.	19.	22.
CO	-	-	0.0038	-	0.0060	-	0.0030
CU	0.25	0.10	0.59	0.35	0.47	0.39	0.035
F	4.3	11.	8.4	5.4	8.9	6.9	5.6
FE	2.3	0.057	0.67	1.1	0.090	0.76	-
LI	-	0.0020	-	-	0.0040	-	-
MG	2.8	5.1	5.0	2.5	13.	2.4	3.4
MN	0.18	0.14	0.27	0.17	0.72	0.17	0.10
NA	22.	41.	37.	23.	110.	21.	22.
PB	0.011	0.0070	0.0010	-	-	0.0020	N.D.
SI	3.6	0.93	3.8	2.7	2.0	2.7	0.70
SR	0.56	0.65	0.47	0.32	0.33	-	29.
U	-	-	-	0.00012	-	-	-
V	0.0097	-	0.0082	0.017	-	0.0092	-
ZN	4.7	0.16	2.0	0.36	0.20	0.67	1.6

- = BELOW BLANK LEVEL
N.D. = NOT DETERMINED
SAMPLE 2 COLLECTED 2/14/74, SAMPLE 3 COLLECTED 2/20/74, SAMPLE 4 COLLECTED 2/21/74,
SAMPLE 5 COLLECTED 3/18/74, SAMPLE VP5 COLLECTED 3/18/74, SAMPLE 7 COLLECTED 4/3/74,
SAMPLE 9 COLLECTED 4/7/74

APPENDIX II--TABLE 1C

SANTIAGUITO VOLCANO:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN WATER LEACHATES

	1	2	3	4	1123
AL	-	-	3.7	2.8	4.8
B	0.17	0.051	0.083	0.057	0.98
BA	0.0073	0.0083	0.057	0.087	0.0045
CA	56.	47.	64.	49.	560.
CD	0.0012	-	0.0033	0.0024	0.064
CL	66.	63.	68.	20.	350.
CO	0.0050	0.0053	0.0033	-	0.15
CU	0.13	0.055	0.70	0.49	0.55
F	2.2	1.8	5.6	2.7	5.6
FE	0.10	0.41	0.16	0.13	1.2
LI	0.0080	0.0050	0.015	0.010	0.47
MG	5.6	3.7	5.0	4.2	100.
MN	0.18	0.14	0.97	0.41	23.
NA	15.	13.	33.	14.	440.
PB	0.012	-	-	-	-
SI	2.5	2.3	0.75	0.98	2.3
SR	0.11	0.086	0.30	0.24	1.1
U	-	-	-	-	0.0015
V	0.013	0.020	0.0063	0.0061	-
ZN	0.17	0.15	0.081	0.052	2.1

- = BELOW BLANK LEVEL
SAMPLE 1 COLLECTED 2/75, SAMPLE 2 COLLECTED 3/75,
SAMPLE 3 COLLECTED 1/76, SAMPLE 4 COLLECTED 2/76,
SAMPLE 1123 COLLECTED 7/21/67

APPENDIX II--TABLE 2A

FUEGO VOLCANO:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN ACID LEACHATES

	28	32	33	34	40	100	101	102	104
AL	0.53	1.7	4.9	0.12	2.1	0.077	0.016	0.54	0.70
B	0.012	-	0.022	-	0.0050	0.0010	0.0010	-	-
BA	0.020	0.027	0.26	0.0078	0.090	0.0052	0.0074	0.024	0.029
CA	17.	6.6	39.	7.3	53.	13.	17.	37.	34.
CD	0.0018	-	-	-	-	0.0012	-	-	-
CL	4.3	2.7	3.3	3.0	3.0	1.0	1.5	0.80	1.5
CO	-	-	0.011	-	-	-	-	-	-
CU	0.014	0.080	0.22	-	0.027	0.0060	0.0080	0.011	0.0030
F	1.4	1.7	2.4	1.5	2.2	0.67	0.85	1.5	1.9
FE	0.030	0.10	6.4	0.011	0.13	0.070	1.4	0.023	0.025
LI	-	-	-	-	-	-	-	-	-
MG	0.90	0.90	12.	0.74	0.90	1.0	1.3	1.0	1.1
MN	0.12	0.11	0.79	0.050	0.11	0.024	0.064	0.11	0.059
NA	9.7	4.1	5.0	3.6	5.8	7.1	9.7	6.3	5.3
PB	0.011	-	-	-	0.040	0.019	-	-	-
SI	2.4	1.6	4.3	1.4	2.6	3.2	3.6	2.2	2.3
SR	0.098	0.048	0.25	0.036	0.22	0.051	0.078	0.16	0.15
U	-	0.00036	0.0018	0.00011	0.00032	0.00002	0.00031	-	-
V	-	-	-	-	-	0.045	0.046	0.014	0.012
ZN	0.020	0.047	0.049	-	0.015	0.0050	-	0.037	0.0040

- = BELOW BLANK LEVEL
SAMPLES 28-40 FROM 10/14/74 PULSE
SAMPLES 100-104 FROM 10/17/74 PULSE

60

APPENDIX II--TABLE 2A (CONT'D)

FUEGO VOLCANO: CONCENTRATION (MG/L) OF ANALYZED ELEMENTS IN ACID LEACHATES

	306	314	167	169	6	Z-2	44	Z-4	B-5
AL	0.78	0.88	1.0	1.1	3.0	0.33	0.050	5.7	-
B	0.015	-	-	-	-	-	-	-	-
BA	0.079	0.050	0.016	0.028	0.0091	0.0049	0.011	0.041	0.0061
CA	63.	19.	3.3	9.5	4.7	6.9	20.	13.	8.1
CD	-	-	-	-	0.0017	-	-	0.0020	-
CL	5.0	3.6	0.20	-	1.3	-	2.5	1.5	2.7
CU	-	-	-	-	-	0.0053	-	-	-
CU	0.012	0.0090	0.018	0.013	0.046	0.025	0.015	0.16	0.0090
F	3.2	3.0	1.1	1.9	6.3	2.9	1.8	7.1	0.66
FE	0.13	0.10	0.044	0.045	0.15	0.26	0.039	1.1	0.10
LI	-	-	-	-	-	-	-	-	-
MG	0.90	0.65	0.31	0.33	0.59	0.51	1.3	1.7	0.80
MN	0.10	0.057	0.024	0.023	0.059	0.074	0.13	0.26	0.12
NA	4.9	4.7	2.0	2.4	3.4	3.8	6.7	7.2	6.3
PB	-	0.18	0.012	-	-	0.0060	-	-	-
SI	2.2	1.6	1.3	1.3	2.0	1.9	2.3	5.4	3.2
SR	0.24	0.10	0.023	0.054	0.025	0.014	0.083	0.12	0.011
U	0.00050	-	0.00005	0.00005	-	-	-	-	-
V	0.012	0.014	0.0089	0.012	0.0066	0.015	0.012	0.010	0.012
ZN	0.015	-	0.0060	0.036	0.0040	0.040	0.0070	0.046	0.0090

- = BELOW BLANK LEVEL
SAMPLES 306-314 FROM 10/18-19/74 PULSE; SAMPLES 167-169 FROM 10/23/74 PULSE; SAMPLE 6 COLLECTED 2/24/73; SAMPLE Z-2 COLLECTED 2/28/73-3/1/73; SAMPLE 44 COLLECTED 3/1/73; SAMPLE Z-4 COLLECTED 3/1/73-3/2/73; SAMPLE B-5 COLLECTED 3/23/73.

APPENDIX II--TABLE 2B

PACAYA VOLCANO:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN ACID LEACHATES

	2	3	4	5	VP5	7	9
AL	6.5	1.7	13.	11.	7.6	9.1	0.17
B	-	0.0030	0.0070	-	0.0080	-	-
BA	0.22	0.10	0.40	0.27	0.046	0.25	0.037
CA	14.	25.	27.	14.	9.6	11.	8.0
CD	0.012	0.0030	0.0023	-	0.0040	-	-
CL	0.70	2.5	2.6	-	15.	0.40	1.5
CO	-	-	0.0056	-	0.0035	0.0035	-
CU	0.25	0.15	1.1	0.40	0.62	0.36	0.029
F	0.58	2.7	4.0	1.0	7.8	1.2	0.87
FE	4.5	0.19	4.5	3.5	0.23	2.8	0.068
LI	-	-	-	-	-	-	-
MG	3.1	2.0	4.6	2.9	2.1	2.3	0.80
MN	0.18	0.18	0.28	0.14	0.19	0.14	0.079
NA	5.3	5.0	9.3	5.9	9.3	4.6	2.1
PB	-	-	0.070	N.D.	-	-	N.D.
SI	8.4	3.0	11.	9.3	2.7	7.5	1.3
SR	0.12	0.21	0.21	0.11	0.071	0.095	0.058
U	-	-	0.00008	0.00014	-	-	-
V	0.013	-	0.011	0.025	-	0.016	-
ZN	2.1	1.0	3.4	0.12	0.13	0.18	2.7

\- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
SAMPLE 2 COLLECTED 2/14/74, SAMPLE 3 COLLECTED 2/20/74, SAMPLE 4 COLLECTED 2/21/74, SAMPLE 5 COLLECTED 3/18/74, SAMPLE VP5 COLLECTED 3/18/74, SAMPLE 7 COLLECTED 4/3/74, SAMPLE 9 COLLECTED 4/7/74

APPENDIX II--TABLE 2C

SANTIAGUITO VOLCANO:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN ACID LEACHATES

	1	2	3	4	1123
AL	-	0.12	1.4	4.7	3.0
B	0.045	0.017	0.0090	0.010	0.50
BA	0.0038	0.014	0.018	0.14	0.0068
CA	26.	42.	5.9	16.	890.
CD	0.0012	0.0010	-	-	-
CL	1.9	0.20	0.20	1.9	32.
CO	-	0.0052	-	-	0.022
CU	0.016	0.010	0.11	0.18	0.40
F	1.7	1.0	1.7	1.3	3.0
FE	0.054	3.6	0.065	0.24	2.0
LI	-	-	-	-	0.095
MG	1.6	1.9	0.37	0.67	21.
MN	0.11	0.34	0.094	0.13	3.7
NA	2.9	4.1	4.0	5.3	53.
PB	0.010	-	0.01	0.038	-
SI	3.3	5.5	2.3	5.3	4.0
SR	0.048	0.12	0.033	0.075	2.0
U	-	-	-	-	-
V	0.012	0.052	-	0.0066	0.022
ZN	0.033	1.2	0.015	0.025	0.26

- = BELOW BLANK LEVEL
SAMPLE 1 COLLECTED 2/75, SAMPLE 2 COLLECTED 3/75,
SAMPLE 3 COLLECTED 1/76, SAMPLE 4 COLLECTED 2/76,
SAMPLE 1123 COLLECTED 7/21/67

APPENDIX II--TABLE 3A

FUEGO VOLCANO:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN CARBONATE-BICARBONATE LEACHATES

	28	32	33	34	40	100	101	102	104
AL	N.D.	N.D.	4.4	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
B	0.016	0.050	0.0040	0.076	0.072	0.11	0.076	0.069	0.068
BA	-	-	-	-	-	-	-	0.0080	-
CA	0.25	0.57	0.35	0.64	0.95	1.6	1.0	1.0	1.0
CD	-	-	-	-	-	-	-	-	-
CL	1.2	0.90	0.60	0.80	1.0	1.7	1.4	1.1	1.3
CO	-	-	-	-	-	-	-	-	-
CU	0.090	0.063	0.020	0.065	0.16	0.52	0.40	0.30	0.20
F	4.7	9.1	3.5	8.4	7.5	2.5	3.1	6.7	9.4
FE	0.15	0.46	0.91	0.47	0.38	0.45	0.54	0.44	0.50
LI	0.010	0.018	0.0020	0.010	0.032	0.052	0.050	0.036	0.018
MG	-	0.34	2.4	0.13	0.070	-	0.12	0.31	0.48
MN	-	0.0032	0.0060	0.0025	0.0018	0.0080	0.0062	0.0040	0.0015
NA	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PB	-	-	0.0060	-	-	-	-	-	-
SI	19.	23.	22.	21.	18.	19.	16.	14.	21.
SR	0.0055	0.0032	0.0060	0.0052	0.014	0.027	0.020	0.016	0.017
U	0.0013	0.00090	0.0014	0.00090	0.0019	0.0044	0.0023	0.0021	0.0014
V	0.19	0.22	0.18	0.24	0.61	0.66	0.58	0.43	0.37
ZN	-	-	0.0020	-	0.0030	0.073	0.0020	0.015	0.018

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
SAMPLES 28-40 FROM 10/14/74 PULSE
SAMPLES 100-104 FROM 10/17/74 PULSE

APPENDIX II--TABLE 3A (CONT'D)

FUEGO VOLCANO:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN CARBONATE-BICARBONATE LEACHATES

	306	314	167	169	6	Z-2	44	Z-4	B-5
AL	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
B	0.051	0.016	0.11	0.062	0.010	0.030	0.020	0.019	0.014
BA	-	-	-	-	-	-	-	-	-
CA	0.47	0.54	1.0	0.51	0.66	1.0	0.75	1.0	1.4
CD	-	-	-	-	-	-	-	-	-
CL	1.2	0.90	0.90	0.70	0.10	1.0	1.2	0.50	1.2
CO	-	-	-	-	-	-	-	-	-
CU	0.074	0.066	0.079	0.042	0.037	0.16	0.26	0.12	0.34
F	36.	14.	1.5	2.0	1.4	14.	5.3	18.	2.8
FE	0.25	0.29	0.97	0.42	0.39	0.38	0.37	0.27	0.29
LI	0.020	0.011	0.029	0.011	0.0020	0.015	0.049	0.015	0.066
MG	0.26	0.34	0.26	0.050	0.22	0.29	0.24	0.51	0.13
MN	-	-	0.0082	0.0032	0.0035	0.0025	-	0.0015	0.0018
NA	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PB	-	-	0.61	0.80	-	-	-	-	-
SI	20.	22.	23.	21.	28.	16.	14.	15.	7.5
SR	0.013	0.010	0.0080	0.0018	0.0030	0.019	0.013	0.017	0.016
U	0.00035	0.00006	0.00050	0.00060	-	0.00050	0.0018	0.0010	0.0020
V	0.42	0.27	0.38	0.082	0.14	0.33	0.53	0.30	0.48
ZN	0.0020	-	0.23	0.35	-	-	-	-	-

- = BELOW BLANK LEVEL
N.D.= NOT DETERRMINED
SAMPLES 306-314 FROM 10/18-19/74 PULSE; SAMPLES 167-169 FROM 10/23/74 PULSE; SAMPLE 6 COLLECTED 2/24/73; SAMPLE Z-2 COLLECTED 2/28/73-3/1/73; SAMPLE 44 COLLECTED 3/1/73; SAMPLE Z-4 COLLECTED 3/1/73-3/2/73; SAMPLE B-5 COLLECTED 3/23/73.

APPENDIX II--TABLE 3B

PACAYA VOLCANO: CONCENTRATION (MG/L) OF ANALYZED ELEMENTS IN CARBONATE-BICARBONATE LEACHATES

	2	3	4	5	VP5	7	9
AL	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
B	0.019	0.010	0.0030	-	0.013	0.0040	0.0080
BA	-	0.015	-	-	-	-	0.0050
CA	2.0	1.2	1.4	0.73	0.65	0.75	0.85
CD	-	-	-	-	-	-	-
CL	0.70	0.60	0.70	0.70	2.6	0.36	0.30
CO	-	-	-	-	-	-	-
CU	0.18	0.44	0.30	0.12	0.082	0.088	0.21
F	0.21	5.3	1.3	0.77	11.	0.93	1.8
FE	0.35	0.27	0.38	0.27	0.41	0.42	0.26
LI	0.0020	0.010	0.0050	0.010	0.010	0.0070	0.0020
MG	0.13	0.33	0.26	0.46	0.52	0.43	0.16
MN	0.0015	0.0030	0.0040	-	0.0022	0.0025	-
NA	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PB	-	-	-	-	-	-	-
SI	22.	20.	26.	23.	30.	25.	20.
SR	0.014	0.024	0.012	0.0032	0.0052	0.0045	0.015
U	0.00035	0.00070	0.00020	0.00020	0.00032	0.00017	0.00070
V	0.074	0.11	0.078	0.074	0.12	0.090	0.027
ZN	0.015	-	0.028	-	-	-	0.0070

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
SAMPLE 2 COLLECTED 2/14/74, SAMPLE 3 COLLECTED 2/20/74, SAMPLE 4 COLLECTED 2/21/74, SAMPLE 5 COLLECTED 3/18/74, SAMPLE VP5 COLLECTED 3/18/74, SAMPLE 7 COLLECTED 4/3/74, SAMPLE 9 COLLECTED 4/7/74

APPENDIX II--TABLE 3C

SANTIAGUITO VOLCANO:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN CARBONATE-BICARBONATE LEACHATES

	1	2	3	4	1123
AL	N.D.	N.D.	N.D.	N.D.	31.
B	N.D.	N.D.	0.076	0.055	0.46
BA	N.D.	N.D.	0.0080	0.0040	-
CA	N.D.	N.D.	2.6	1.6	0.74
CD	N.D.	N.D.	-	-	-
CL	2.1	3.5	1.1	1.0	7.0
CO	N.D.	N.D.	-	-	-
CU	N.D.	N.D.	0.24	0.10	0.029
F	6.8	3.1	2.3	1.1	13.
FE	N.D.	N.D.	0.48	0.26	0.20
LI	N.D.	N.D.	0.18	0.12	0.17
MG	N.D.	N.D.	0.50	0.41	0.43
MN	N.D.	N.D.	0.053	0.027	0.0035
NA	N.D.	N.D.	N.D.	N.D.	N.D.
PB	N.D.	N.D.	-	-	-
SI	13.	13.	19.	24.	7.5
SR	N.D.	N.D.	0.024	0.014	-
U	0.010	0.0062	0.0021	0.0032	0.0079
V	N.D.	N.D.	0.046	0.045	0.20
ZN	N.D.	N.D.	0.026	0.019	0.0040

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
SAMPLE 1 COLLECTED 2/75, SAMPLE 2 COLLECTED 3/75,
SAMPLE 3 COLLECTED 1/76, SAMPLE 4 COLLECTED 2/76,
SAMPLE 1123 COLLECTED 7/21/67

APPENDIX II--TABLE 4A

FRESHLY ERUPTED BOMB FRAGMENTS:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN WATER LEACHATES

	1	2	3	4
AL	N.D.	N.D.	N.D.	0.88
B	0.050	0.079	0.025	0.046
BA	0.12	0.068	0.048	0.010
CA	110.	250.	49.	23.
CD	0.0014	0.0024	-	0.0018
CL	86.	110.	31.	19.
CO	0.0049	0.0061	-	-
CU	0.74	1.0	0.29	0.022
F	1.1	1.8	1.9	19.
FE	0.36	0.080	0.75	1.7
LI	0.022	0.029	-	0.025
MG	26.	44.	3.8	5.5
MN	0.68	0.39	0.16	0.39
NA	76.	130.	16.	50.
PB	-	-	-	-
SI	6.5	5.5	2.3	5.5
SR	0.37	0.33	0.16	0.081
U	0.00023	0.00030	0.00002	0.0013
V	0.065	0.046	0.013	-
ZN	0.080	0.19	0.021	0.065

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
1 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE 20-150
2 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE <150
3 = AUGUSTINE VOLCANO, 2/6/76, MESH SIZE 20-150
4 = HEIMAEY, 6/5/70, MESH SIZE <150

APPENDIX II--TABLE 4B

FRESHLY ERUPTED BOMB FRAGMENTS:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN ACID LEACHATES

	1	2	3	4
AL	N.D.	N.D.	N.D.	0.85
B	0.012	0.056	0.013	0.038
BA	0.14	0.12	0.023	0.019
CA	22.	87.	55.	40.
CD	-	-	-	0.0080
CL	14.	21.	14.	10.
CO	-	-	-	0.0044
CU	0.16	0.54	0.035	0.0020
F	0.66	1.1	1.4	14.
FE	0.37	0.52	1.5	4.1
LI	-	0.0010	-	-
MG	2.9	9.3	2.5	6.8
MN	0.13	0.43	0.16	1.4
NA	6.6	25.	4.9	21.
PB	-	-	-	-
SI	4.4	11.	11.	15.
SR	0.074	0.30	0.11	0.17
U	-	-	-	0.00040
V	0.051	0.052	0.0082	-
ZN	0.0080	0.049	0.0060	0.033

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
1 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE 20-150
2 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE <150
3 = AUGUSTINE VOLCANO, 2/6/76, MESH SIZE 20-150
4 = HEIMAEY, 6/5/70, MESH SIZE <150

APPENDIX II--TABLE 4C

FRESHLY ERUPTED BOMB FRAGMENTS:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS
IN CARBONATE-BICARBONATE LEACHATES

	1	2	3	4
AL	N.D.	N.D.	N.D.	N.D.
B	0.0060	0.022	0.016	0.025
BA	-	0.0070	-	-
CA	1.3	2.1	1.3	1.0
CD	-	-	-	-
CL	1.7	3.1	1.9	1.8
CO	-	-	-	-
CU	0.062	0.14	0.045	0.15
F	0.65	0.65	0.34	13.
FE	0.26	0.15	0.52	0.34
LI	0.060	0.21	0.0070	0.055
MG	0.21	0.44	0.23	1.3
MN	-	0.0020	0.0020	-
NA	N.D.	N.D.	N.D.	N.D.
PB	-	0.030	0.12	-
SI	20.	13.	26.	43.
SR	0.014	0.031	0.0080	0.0055
U	0.00080	0.0019	0.0034	0.0030
V	0.11	0.24	-	0.042
ZN	-	-	-	-

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
1 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE 20-150
2 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE <150
3 = AUGUSTINE VOLCANO, 2/6/76, MESH SIZE 20-150
4 = HEIMAEY, 6/5/70, MESH SIZE <150

APPENDIX II--TABLE 5A

HISTORIC "RHYOLITE" SAMPLES:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS IN WATER LEACHATES

	KATMAI		MT. ST. HELENS--W		MT. ST. HELENS--T		MEDICINE LAKE		MONO CRATERS	
	1	2	1	2	1	2	1	2	1	2
AL	6.1	6.8	14.	12.	N.D.	N.D.	7.4	N.D.	N.D.	N.D.
B	0.012	0.0040	0.0010	0.011	0.018	0.0010	0.048	0.22	-	0.0090
BA	0.042	0.048	0.094	0.91	0.15	0.094	0.12	0.092	0.088	0.026
CA	0.90	5.0	7.9	11.	2.4	7.7	4.9	6.2	1.2	1.9
CD	-	-	-	-	-	0.0013	0.0057	0.0065	0.0019	0.0020
CL	0.10	1.1	-	2.1	1.2	1.2	0.80	2.4	0.46	1.9
CO	-	-	0.013	0.021	0.012	0.0040	-	-	-	-
CU	0.078	0.068	0.11	0.13	0.33	0.24	0.025	0.017	0.046	0.061
F	1.2	0.75	0.43	0.29	0.42	0.23	0.43	0.46	0.36	4.8
FE	0.41	0.75	1.3	1.5	1.2	2.3	4.7	1.2	0.48	0.37
LI	-	-	-	0.0060	-	0.0020	-	0.0020	0.0030	0.0060
MG	0.030	0.90	2.7	3.9	0.33	1.2	1.6	2.5	0.080	0.090
MN	0.020	0.084	0.46	0.62	0.30	0.25	0.17	0.098	0.074	0.15
NA	6.8	7.5	10.	16.	10.	9.1	3.6	7.3	4.2	11.
PB	0.014	-	-	-	-	-	0.14	0.023	0.0060	-
SI	0.79	3.3	1.9	4.3	3.0	5.1	1.3	2.2	1.2	1.8
SR	0.0073	0.023	0.043	0.076	0.043	0.073	0.022	0.028	0.011	0.014
U	-	-	-	-	0.0010	0.00033	0.00013	0.00040	0.0017	0.00020
V	-	-	-	-	-	0.015	-	-	-	-
ZN	0.027	0.071	0.054	0.11	0.044	0.035	0.13	0.17	0.090	0.35

\- = BELOW BLANK LEVEL
N.D. = NOT DETERMINED
1 = 20-150 MESH
2 = 150-325 MESH

APPENDIX II--TABLE 5B

HISTORIC "RHYOLITE" SAMPLES:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS IN ACID LEACHATES

	KATMAI		MT. ST. HELENS--W		MT. ST. HELENS--T		MEDICINE LAKE		MONO CRATERS	
	1	2	1	2	1	2	1	2	1	2
AL	2.5	5.6	5.8	7.8	N.D.	N.D.	2.0	N.D.	N.D.	N.D.
B	-	-	-	-	-	-	-	0.034	0.0020	0.014
BA	0.014	0.026	0.029	0.044	0.058	0.061	0.044	0.090	0.027	0.056
CA	0.36	3.0	8.4	5.5	9.6	15.	1.1	1.5	0.35	0.67
CD	-	-	-	-	-	-	0.0012	-	-	-
CL	-	0.10	0.20	0.30	-	-	-	-	0.40	0.40
CO	-	-	-	0.0097	0.0033	-	-	-	-	-
CU	0.021	0.043	0.033	0.064	0.11	0.10	0.017	0.017	0.012	0.041
F	0.23	0.15	0.29	0.14	0.28	0.23	0.060	0.0010	-	0.91
FE	0.31	0.52	0.52	1.1	0.52	0.60	2.6	4.2	0.29	0.28
LI	-	-	-	-	-	-	-	-	-	-
MG	-	0.17	0.42	0.52	0.080	0.30	0.26	0.35	-	0.040
MN	0.0044	0.021	0.16	0.22	0.13	0.15	0.046	0.059	0.019	0.054
NA	1.1	2.5	1.8	4.7	3.7	4.2	3.9	2.4	1.1	4.4
PB	-	-	-	-	-	-	0.056	0.043	-	0.043
SI	0.79	3.4	1.7	3.0	5.1	5.6	0.79	2.1	1.1	2.0
SR	0.0021	0.015	0.019	0.025	0.032	0.059	0.0049	0.011	0.0026	0.0090
U	-	-	-	-	0.00020	-	0.00016	0.00050	0.00090	0.0012
V	-	-	-	-	-	-	-	-	-	-
ZN	0.0030	0.021	0.011	0.048	-	0.0018	0.082	0.042	0.016	0.092

- = BELOW BLANK LEVEL
N.D. = NOT DETERMINED
1 = 20-150 MESH
2 = 150-325 MESH

APPENDIX II--TABLE 5C

HISTORIC "RHYOLITE" SAMPLES:
CONCENTRATION (MG/L) OF ANALYZED ELEMENTS IN CARBONATE-BICARBONATE LEACHATES

	KATMAI 1	KATMAI 2	MT. ST. HELENS--W 1	MT. ST. HELENS--W 2	MT. ST. HELENS--T 1	MT. ST. HELENS--T 2	MEDICINE LAKE 1	MEDICINE LAKE 2	MONO CRATERS 1	MONO CRATERS 2
AL	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
B	0.025	0.0090	0.0080	0.029	0.033	0.014	0.038	0.050	0.026	N.D.
BA	-	-	-	-	-	-	-	0.0070	0.024	N.D.
CA	0.26	0.60	1.5	1.6	0.85	0.85	1.1	1.3	0.51	N.D.
CD	-	-	-	-	-	-	-	-	-	N.D.
CL	0.60	0.70	1.0	1.2	2.8	2.1	0.80	1.8	1.5	N.D.
CO	-	-	0.012	-	-	-	-	-	-	N.D.
CU	0.060	0.090	0.070	0.17	0.041	0.082	0.038	0.033	0.029	N.D.
F	0.51	10.	0.83	0.57	0.49	0.46	0.28	0.16	0.82	N.D.
FE	0.36	0.17	6.0	0.11	0.11	0.18	0.25	0.17	0.15	N.D.
LI	0.050	0.084	0.13	0.28	0.053	0.061	0.040	0.11	0.052	N.D.
MG	-	0.030	0.070	-	0.25	0.13	-	0.060	-	N.D.
MN	-	-	0.025	-	-	0.0032	0.0015	0.21	-	N.D.
NA	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PB	-	-	-	-	-	-	-	-	-	N.D.
SI	31.	18.	8.4	7.9	15.	19.	25.	34.	61.	N.D.
SR	0.0032	0.0025	0.0038	0.0090	0.0070	0.0070	0.0030	0.016	0.015	N.D.
U	0.00020	0.00037	0.0016	0.0019	0.0010	0.0016	0.00030	0.010	0.0047	0.0053
V	-	-	0.084	0.018	0.041	0.019	-	0.018	-	N.D.
ZN	0.010	0.018	-	-	0.0020	-	0.0070	0.0090	0.0060	N.D.

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
1 = 20-150 MESH
2 = 150-325 MESH

APPENDIX III--TABLE 1A

PER CENT OF ELEMENT REMOVED BY WATER LEACH OF FUEGO ASH

	28	32	33	34	40	100	101	102	104
AL	0.0010	0.0050	0.015	0.0014	0.0038	0.00020	0.00030	0.0025	0.0011
B	2.6	2.2	1.0	1.4	1.1	1.7	2.6	0.24	0.32
BA	0.083	0.093	0.23	0.070	0.12	0.021	0.038	0.061	0.068
CA	0.92	0.43	0.40	0.40	1.7	0.56	0.85	0.74	0.97
CD	20.	2.0	2.8	6.0	8.0	-	-	4.4	-
CL	32.	34.	22.	30.	36.	12.	12.	13.	24.
CO	-	0.12	-	-	0.065	-	-	-	-
CU	0.23	0.16	2.6	0.11	0.18	0.053	0.067	0.11	0.10
F	2.6	3.8	6.8	3.9	3.5	1.4	2.5	3.1	3.4
FE	0.00024	0.017	0.034	0.00072	0.00046	0.00018	0.00028	0.00031	0.00018
LI	0.60	0.040	0.72	0.12	0.64	0.20	0.52	0.32	0.36
MG	0.13	0.13	0.12	0.10	0.22	0.10	0.15	0.071	0.078
MN	0.18	0.19	0.29	0.13	0.22	0.055	0.064	0.087	0.060
NA	0.71	0.58	0.48	0.55	0.64	0.37	0.63	0.43	0.58
PB	1.5	3.1	-	19.	7.2	-	-	0.32	7.2
SI	0.0029	0.0022	0.0033	0.0019	0.0039	0.0050	0.0043	0.0031	0.0039
SR	0.59	0.32	0.27	0.29	0.36	0.29	0.50	0.44	0.50
U	0.58	0.38	-	-	-	-	0.23	-	-
V	0.016	0.052	-	-	-	0.083	0.059	0.033	0.029
ZN	0.46	0.26	0.65	0.45	0.18	0.014	0.028	0.42	0.017

- = BELOW BLANK LEVEL
SAMPLES 28-40 FROM 10/14/74 PULSE
SAMPLES 100-104 FROM 10/17/74 PULSE

APPENDIX III--TABLE 1A (CONT'D)

PER CENT OF ELEMENT REMOVED BY WATER LEACH OF FUEGO ASH

	306	314	167	169	6	Z-2	44	Z-4	B-5
AL	0.0049	0.0097	0.0091	0.0033	0.024	0.0014	0.00090	0.0077	-
B	9.0	1.6	-	-	1.2	0.48	1.4	0.96	1.1
BA	0.074	0.067	0.050	0.076	0.021	0.019	0.047	0.033	0.025
CA	1.3	0.68	0.14	0.41	0.11	0.33	0.76	0.35	0.43
CD	3.0	4.2	-	2.8	6.6	7.6	4.4	3.2	-
CL	33.	28.	12.	8.3	11.	16.	21.	25.	29.
CO	-	-	-	-	-	-	-	-	-
CU	0.21	0.26	0.24	0.049	0.46	0.096	0.22	0.18	0.28
F	5.9	8.3	4.4	4.4	22.	6.0	3.1	7.0	1.1
FE	0.00047	0.00065	0.00057	0.00020	0.00026	0.00059	0.00079	0.00029	0.00071
LI	0.64	0.20	-	-	0.090	0.36	0.64	0.56	1.2
MG	0.063	0.046	0.0096	0.023	0.033	0.038	0.19	0.033	0.11
MN	0.15	0.10	0.026	0.021	0.092	0.093	0.21	0.13	0.23
NA	0.57	0.55	0.30	0.22	0.29	0.28	0.48	0.45	0.44
PB	-	-	-	-	-	-	-	-	1.2
SI	0.0030	0.0027	0.0014	0.0017	0.0017	0.0020	0.0029	0.0028	0.0047
SR	0.63	0.36	0.096	0.24	0.072	0.18	0.44	0.21	0.31
U	-	-	-	-	0.55	-	-	-	-
V	0.023	0.037	0.035	0.037	0.033	0.027	0.050	0.022	0.052
ZN	0.14	0.11	0.038	0.069	0.11	0.055	0.014	0.086	0.041

- = BELOW BLANK LEVEL
SAMPLES 306-314 FROM 10/18-19/74 PULSE; SAMPLES 167-169 FROM 10/23/74 PULSE; SAMPLE 6 COLLECTED 2/24/73; SAMPLE Z-2 COLLECTED 2/28/73-3/1/73; SAMPLE 44 COLLECTED 3/1/73; SAMPLE Z-4 COLLECTED 3/1/73-3/2/73; SAMPLE B-5 COLLECTED 3/23/73.

APPENDIX III--TABLE 18

PER CENT OF ELEMENT REMOVED BY WATER LEACH OF PACAYA ASH

	2	3	4	5	VP5	7	9
AL	0.016	0.0011	0.016	0.016	0.017	0.020	0.00040
B	1.4	1.3	1.4	0.080	2.2	0.64	1.4
BA	0.23	0.098	0.16	0.20	0.090	0.14	0.073
CA	0.33	0.50	0.36	0.22	0.32	0.20	0.23
CD	64.	4.0	14.	6.0	28.	6.6	2.0
CL	8.5	24.	19.	12.	65.	12.	14.
CO	-	-	0.063	-	0.10	-	0.050
CU	1.1	0.44	2.6	1.6	2.1	1.7	0.16
F	4.3	8.8	8.4	5.4	7.1	6.9	4.5
FE	0.012	0.00029	0.0036	0.0059	0.00052	0.0039	-
LI	-	0.080	-	-	0.16	-	-
MG	0.047	0.083	0.083	0.036	0.23	0.037	0.054
MN	0.050	0.039	0.079	0.048	0.22	0.048	0.028
NA	0.31	0.58	0.53	0.34	1.6	0.30	0.29
PB	0.88	0.56	0.080	-	-	0.16	N.D.
SI	0.0061	0.0017	0.0065	0.0047	0.0033	0.0042	0.0012
SR	0.42	0.49	0.35	0.24	0.25	0.22	0.20
U	-	-	-	0.089	-	-	-
V	0.014	-	0.014	0.028	-	0.014	-
ZN	19.	0.65	8.0	1.4	0.81	2.7	6.4

\- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
SAMPLE 2 COLLECTED 2/14/74, SAMPLE 3 COLLECTED 2/20/74, SAMPLE 4 COLLECTED 2/21/74, SAMPLE 5 COLLECTED 3/18/74, SAMPLE VP5 COLLECTED 3/18/74, SAMPLE 7 COLLECTED 4/3/74, SAMPLE 9 COLLECTED 4/7/74.

APPENDIX III--TABLE 1C

PER CENT OF ELEMENT REMOVED BY WATER LEACH OF SANTIAGUITO ASH

	1	2	3	4	1123
AL	-	-	0.016	0.012	0.22
B	6.9	2.0	3.4	2.3	39.
BA	0.0036	0.0039	0.027	0.040	0.0021
CA	0.62	0.52	0.73	0.55	6.2
CD	2.4	-	6.8	4.8	128.
CL	68.	63.	56.	20.	167.
CO	0.33	0.35	0.23	-	10.
CU	3.5	1.5	22.	15.	15.
F	2.2	1.8	5.7	2.7	3.3
FE	0.0011	0.0046	0.0018	0.0015	0.013
LI	0.16	0.10	0.31	0.20	9.4
MG	0.21	0.13	0.18	0.15	3.5
MN	0.060	0.052	0.36	0.15	5.9
NA	0.17	0.15	0.36	0.15	4.7
PB	0.48	-	-	-	-
SI	0.0034	0.0037	0.0010	0.0013	0.0032
SR	0.11	0.086	0.26	0.20	0.94
U	-	-	-	-	0.66
V	0.056	0.073	0.016	0.019	-
ZN	1.1	1.0	0.56	0.35	14.

- = BELOW BLANK LEVEL
SAMPLE 1 COLLECTED 2/75, SAMPLE 2 COLLECTED 3/75,
SAMPLE 3 COLLECTED 1/76, SAMPLE 4 COLLECTED 2/76,
SAMPLE 1123 COLLECTED 7/21/67.

APPENDIX III--TABLE 2A

PER CENT OF ELEMENT REMOVED BY ACID LEACH OF FUEGO ASH

	28	32	33	34	40	100	101	102	104
AL	0.0021	0.0063	0.019	0.00050	0.0090	0.00040	0.00010	0.0022	0.0029
B	0.96	-	1.8	-	0.40	0.080	0.060	-	-
BA	0.019	0.025	0.24	0.0087	0.084	0.0039	0.0069	0.022	0.027
CA	0.10	0.037	0.25	0.039	0.34	0.077	0.10	0.23	0.22
CD	3.6	-	-	-	-	2.4	-	-	-
CL	2.9	1.3	2.2	2.0	2.0	1.3	1.5	0.64	1.2
CO	-	-	0.16	-	-	-	-	-	-
CU	0.058	0.33	0.92	-	0.11	0.020	0.033	0.046	0.012
F	1.4	1.7	1.9	1.5	2.2	0.67	0.85	1.5	1.9
FE	0.00020	0.00057	0.039	0.00007	0.00079	0.00046	0.0089	0.00014	0.00014
LI	-	-	-	-	-	-	-	-	-
MG	0.016	0.015	0.17	0.011	0.018	0.017	0.023	0.016	0.014
MN	0.039	0.039	0.29	0.019	0.036	0.0088	0.023	0.034	0.019
NA	0.14	0.052	0.070	0.045	0.072	0.084	0.13	0.084	0.071
PB	0.88	-	-	-	3.2	1.5	-	-	-
SI	0.0040	0.0028	0.0070	0.0023	0.0042	0.0052	0.0059	0.0036	0.0039
SR	0.073	0.036	0.19	0.027	0.16	0.038	0.058	0.12	0.11
U	-	0.58	1.8	0.16	0.36	0.016	0.28	-	-
V	-	-	-	-	-	0.12	0.10	0.027	0.022
ZN	0.076	0.21	0.22	-	0.065	0.023	-	0.26	0.017

- = BELOW BLANK LEVEL
SAMPLES 28-40 FROM 10/14/74 PULSE
SAMPLES 100-104 FROM 10/17/74 PULSE

APPENDIX III--TABLE 2A (CONT'D)

PER CENT OF ELEMENT REMOVED BY ACID LEACH OF FUEGO ASH

	306	314	167	169	6	Z-2	44	Z-4	B-5
AL	0.0030	0.0036	0.0045	0.0047	0.011	0.0013	0.00020	0.022	-
B	1.2	-	-	-	-	-	-	-	-
BA	0.073	0.047	0.022	0.028	0.0085	0.0046	0.010	0.038	0.0047
CA	0.38	0.12	0.022	0.062	0.028	0.042	0.13	0.080	0.054
CD	-	-	-	-	3.4	-	-	4.0	-
CL	2.9	2.4	0.27	-	1.0	-	1.7	1.0	2.7
CO	-	-	-	-	-	0.079	-	-	-
CU	0.050	0.040	0.090	0.058	0.19	0.10	0.062	0.67	0.036
F	3.2	3.0	1.1	1.9	6.3	2.9	1.8	7.1	0.66
FE	0.00077	0.00054	0.00021	0.00026	0.00096	0.0015	0.00028	0.0061	0.00064
LI	-	-	-	-	-	-	-	-	-
MG	0.012	0.0081	0.0021	0.0040	0.011	0.0077	0.026	0.025	0.015
MN	0.031	0.018	0.0069	0.0081	0.023	0.028	0.045	0.090	0.045
NA	0.058	0.066	0.027	0.033	0.041	0.047	0.076	0.097	0.081
PB	-	14.	0.96	-	-	0.48	-	-	-
SI	0.0036	0.0028	0.0024	0.0024	0.0034	0.0031	0.0036	0.0090	0.0052
SR	0.18	0.065	0.020	0.043	0.019	0.010	0.061	0.089	0.0079
U	0.53	-	0.11	0.74	-	-	-	-	-
V	0.022	0.022	0.015	0.024	0.018	0.029	0.040	0.022	0.035
ZN	0.068	-	0.023	0.17	0.018	0.18	0.032	0.21	0.041

- = BELOW BLANK LEVEL
SAMPLES 306-314 FROM 10/18-19/74 PULSE; SAMPLES 167-169 FROM 10/23/74 PULSE; SAMPLE 6 COLLECTED 2/24/73; SAMPLE Z-2 COLLECTED 2/28/73-3/1/73; SAMPLE 44 COLLECTED 3/1/73; SAMPLE Z-4 COLLECTED 3/1/73-3/2/73; SAMPLE B-5 COLLECTED 3/23/73.

APPENDIX III--TABLE 2B

PER CENT OF ELEMENT REMOVED BY ACID LEACH OF PACAYA ASH

	2	3	4	5	VP5	7	9
AL	0.025	0.0069	0.049	0.043	0.029	0.035	0.00070
B	-	0.24	0.56	-	0.64	-	-
BA	0.18	0.082	0.33	0.22	0.038	0.20	0.030
CA	0.087	0.16	0.17	0.088	0.057	0.067	0.051
CD	24.	6.0	4.6	-	8.0	-	-
CL	0.47	1.4	1.5	-	4.5	0.27	1.0
CO	-	-	0.093	-	0.058	0.058	-
CU	1.1	0.67	4.8	1.8	2.8	1.6	0.13
F	0.58	2.2	4.0	1.0	6.2	1.2	0.70
FE	0.023	0.0010	0.024	0.019	0.0013	0.014	0.00040
LI	-	-	-	-	-	-	-
MG	0.052	0.032	0.076	0.042	0.038	0.035	0.013
MN	0.049	0.049	0.081	0.040	0.056	0.038	0.021
NA	0.073	0.070	0.13	0.085	0.13	0.064	0.030
PB	-	-	5.6	N.D.	-	-	N.D.
SI	0.014	0.0054	0.019	0.016	0.0045	0.012	0.0022
SR	0.091	0.16	0.16	0.083	0.054	0.072	0.044
U	-	-	0.071	0.10	-	-	-
V	0.020	-	0.020	0.041	-	0.025	-
ZN	8.4	4.0	14.	0.49	0.53	0.73	11.

\- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
SAMPLE 2 COLLECTED 2/14/74, SAMPLE 3 COLLECTED 2/20/74, SAMPLE 4 COLLECTED 2/21/74, SAMPLE 5 COLLECTED 3/18/74, SAMPLE VP5 COLLECTED 3/18/74, SAMPLE COLLECTED 4/3/74, SAMPLE 9 COLLECTED 4/7/74

APPENDIX III--TABLE 2C

PER CENT OF ELEMENT REMOVED BY ACID LEACH OF SANTIAGUITO ASH

	1	2	3	4	1123
AL	-	0.00050	0.0062	0.020	0.14
B	1.8	0.68	0.37	0.40	20.
BA	0.0018	0.0065	0.0086	0.065	0.0032
CA	0.29	0.47	0.067	0.18	9.3
CD	2.4	2.0	-	-	-
CL	1.9	0.20	0.16	1.9	15.
CO	-	0.35	-	-	1.5
CU	0.43	0.27	3.5	5.5	11.
F	1.7	1.0	1.8	1.3	1.7
FE	0.00061	0.040	0.00075	0.0027	0.022
LI	-	-	-	-	1.9
MG	0.057	0.067	0.013	0.024	0.74
MN	0.035	0.13	0.033	0.045	0.95
NA	0.032	0.044	0.044	0.056	0.61
PB	0.40	-	0.41	1.5	-
SI	0.0045	0.0074	0.0031	0.0071	0.0027
SR	0.048	0.12	0.029	0.064	1.7
U	-	-	-	-	-
V	0.052	0.18	-	0.021	-
ZN	0.22	7.9	0.10	0.17	1.7

- = BELOW BLANK LEVEL
SAMPLE 1 COLLECTED 2/75, SAMPLE 2 COLLECTED 3/75,
SAMPLE 3 COLLECTED 1/76, SAMPLE 4 COLLECTED 2/76,
SAMPLE 1123 COLLECTED 7/21/67

APPENDIX III--TABLE 3A

PER CENT OF ELEMENT REMOVED BY CARBONATE-BICARBONATE LEACH OF FUEGO ASH

	28	32	33	34	40	100	101	102	104
AL	N.D.	N.D.	0.17	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
B	1.3	4.0	0.32	6.1	5.8	9.0	6.1	5.5	5.4
BA	-	-	-	-	-	-	-	0.0074	-
CA	0.0015	0.0032	0.0023	0.0036	0.0061	0.0091	0.0064	0.0065	0.0068
CD	-	-	-	-	-	-	-	-	-
CL	0.80	0.60	0.40	0.53	0.67	2.3	1.4	0.80	1.0
CO	-	-	-	-	-	-	-	-	-
CU	0.38	0.26	0.083	0.29	0.67	1.7	1.7	1.2	0.83
F	4.7	9.2	2.9	8.4	7.6	2.5	3.1	6.8	9.4
FE	0.0010	0.0026	0.0055	0.0028	0.0025	0.0030	0.0035	0.0027	0.0028
LI	0.40	0.72	0.080	0.40	1.3	2.1	2.0	1.4	0.72
MG	-	0.0058	0.035	0.0020	0.0014	-	0.0021	0.0049	0.0061
MN	-	0.0012	0.0022	0.00090	0.00060	0.0029	0.0018	0.0010	0.00050
NA	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PB	-	-	0.48	-	-	-	-	-	-
SI	0.032	0.039	0.031	0.036	0.030	0.030	0.026	0.023	0.035
SR	0.0041	0.0024	0.0044	0.0039	0.010	0.020	0.015	0.012	0.013
U	1.1	1.4	1.4	1.3	2.1	3.6	2.1	2.5	1.6
V	0.32	0.49	0.34	0.47	1.0	1.7	1.3	0.82	0.66
ZN	-	-	0.0091	-	0.013	0.33	0.0094	0.10	0.078

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
SAMPLES 28-40 FROM 10/14/74 PULSE
SAMPLES 100-104 FROM 10/17/74 PULSE

APPENDIX III--TABLE 3A (CONT'D)

PER CENT OF ELEMENT REMOVED BY CARBONATE-BICARBONATE LEACH OF FUEGO ASH

	306	314	167	169	6	Z-2	44	Z-4	B-5
AL	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
B	4.1	1.3	9.0	5.3	0.80	2.4	1.6	1.5	1.1
BA	-	-	-	-	-	-	-	-	-
CA	0.0028	0.0034	0.0069	0.0033	0.0039	0.0065	0.0048	0.0065	0.0090
CD	-	-	-	-	-	-	-	-	-
CL	0.69	0.60	1.2	0.75	0.080	0.80	0.80	0.33	1.2
CO	-	-	-	-	-	-	-	-	-
CU	0.31	0.29	0.40	0.19	0.150	0.67	1.1	0.5	1.4
F	36.	14.	1.5	2.0	1.4	14.	5.4	18.	2.8
FE	0.0015	0.0016	0.0046	0.0024	0.0025	0.0022	0.0026	0.0015	0.0019
LI	0.80	0.44	1.2	0.47	0.080	0.60	2.0	0.60	2.6
MG	0.0035	0.0042	0.0026	0.00060	0.0041	0.0044	0.0047	0.0076	0.0025
MN	-	-	0.0023	0.0011	0.0014	0.00090	-	0.00050	0.00070
NA	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PB	-	-	49.	64.	-	-	-	-	-
SI	0.033	0.038	0.042	0.039	0.046	0.027	0.022	0.025	0.012
SR	0.0096	0.0065	0.0070	0.0014	0.0022	0.014	0.0096	0.013	0.011
U	0.37	0.073	1.1	0.88	-	0.56	1.8	1.0	1.6
V	0.75	0.43	0.63	0.16	0.39	0.63	1.8	0.67	1.4
ZN	0.0091	-	0.88	1.6	-	-	-	-	-

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
SAMPLES 306-314 FROM 10/18-19/74 PULSE; SAMPLES 167-169 FROM 10/23/74 PULSE; SAMPLE 6 COLLECTED 2/24/73; SAMPLE Z-2 COLLECTED 2/28/73-3/1/73; SAMPLE 44 COLLECTED 3/1/73; SAMPLE Z-4 COLLECTED 3/1/73-3/2/73; SAMPLE B-5 COLLECTED 3/23/73.

APPENDIX III--TABLE 3B

PER CENT OF ELEMENT REMOVED BY CARBONATE-BICARBONATE LEACH OF PACAYA ASH

	2	3	4	5	VP5	7	9
AL	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
B	1.5	0.60	0.24	-	1.0	0.32	0.64
BA	-	0.012	-	-	-	-	0.0041
CA	0.012	0.0076	0.0089	0.0046	0.0038	0.0047	0.0054
CD	-	-	-	-	-	-	-
CL	0.47	0.34	0.40	0.47	0.80	0.24	0.20
CO	-	-	-	-	-	-	-
CU	0.80	2.0	1.3	0.53	0.36	0.39	0.93
F	0.21	4.3	1.3	0.77	8.8	0.93	1.5
FE	0.0018	0.0014	0.0021	0.0015	0.0023	0.0022	0.0015
LI	0.080	0.40	0.20	0.40	0.40	0.28	0.080
MG	0.0022	0.0053	0.0043	0.0067	0.0094	0.0066	0.0025
MN	0.00040	0.00080	0.0012	-	0.00070	0.00070	-
NA	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PB	-	-	-	-	-	-	-
SI	0.037	0.036	0.045	0.040	0.051	0.039	0.033
SR	0.011	0.018	0.0091	0.0024	0.0039	0.0034	0.011
U	0.022	0.43	0.18	0.15	0.21	0.11	0.51
V	0.11	0.17	0.14	0.12	0.22	0.14	0.042
ZN	0.060	-	0.11	-	-	-	0.028

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
SAMPLE 2 COLLECTED 2/14/74, SAMPLE 3 COLLECTED 2/20/74, SAMPLE 4 COLLECTED 2/21/74, SAMPLE 5 COLLECTED 3/18/74, SAMPLE VP5 COLLECTED 3/18/74, SAMPLE 7 COLLECTED 4/3/74, SAMPLE 9 COLLECTED 4/7/74.

APPENDIX III--TABLE 3C

PER CENT OF ELEMENT REMOVED BY CARBONATE-BICARBONATE LEACH OF SANTIAGUITO ASH

	1	2	3	4	1123
AL	N.D.	N.D.	N.D.	N.D.	1.4
B	N.D.	N.D.	3.1	2.2	18.
BA	N.D.	N.D.	0.0038	0.0019	-
CA	N.D.	N.D.	0.029	0.018	0.0082
CD	N.D.	N.D.	-	-	-
CL	2.1	3.5	0.90	1.0	3.3
CO	N.D.	N.D.	-	-	-
CU	N.D.	N.D.	7.6	3.1	0.77
F	6.3	3.1	2.4	1.1	7.4
FE	N.D.	N.D.	0.0055	0.0029	0.0022
LI	N.D.	N.D.	3.7	2.4	3.4
MG	N.D.	N.D.	0.018	0.015	0.015
MN	N.D.	N.D.	0.020	0.0096	0.00090
NA	N.D.	N.D.	N.D.	N.D.	N.D.
PB	-	-	-	-	-
SI	0.025	0.017	0.026	0.032	0.010
SR	N.D.	N.D.	0.021	0.012	-
U	4.6	2.4	0.93	1.4	3.5
V	N.D.	N.D.	0.12	0.15	5.3
ZN	N.D.	N.D.	0.18	0.13	0.027

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
SAMPLE 1 COLLECTED 2/75, SAMPLE 2 COLLECTED 3/75,
SAMPLE 3 COLLECTED 1/76, SAMPLE 4 COLLECTED 2/76,
SAMPLE 1123 COLLECTED 7/21/67.

APPENDIX III--TABLE 4A

PER CENT OF ELEMENT REMOVED BY WATER LEACH OF FRESHLY ERUPTED BOMB FRAGMENTS

	1	2	3	4
AL	N.D.	N.D.	N.D.	0.045
B	2.0	3.2	1.0	3.7
BA	0.12	0.068	0.048	0.011
CA	0.87	2.0	0.46	0.11
CD	2.8	4.8	-	3.6
CL	43.	57.	11.	25.
CO	0.031	0.038	-	-
CU	15.	20.	5.3	0.88
F	1.1	1.8	1.9	4.8
FE	0.0032	0.00070	0.0074	0.0063
LI	0.54	0.63	-	0.50
MG	0.41	0.69	0.081	0.079
MN	0.23	0.41	0.066	0.076
NA	1.2	1.9	0.25	0.63
PB	-	-	-	-
SI	0.0087	0.0075	0.0031	0.011
SR	0.49	1.1	0.21	0.093
U	0.12	0.16	0.0093	0.35
V	0.19	0.13	0.037	-
ZN	0.53	1.3	0.14	0.26

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
1 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE 20-150
2 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE <150
3 = AUGUSTINE VOLCANO, 2/6/76, MESH SIZE 20-150
4 = HEIMAEY, 6/5/70, MESH SIZE <150

APPENDIX III--TABLE 4B

PER CENT OF ELEMENT REMOVED BY ACID LEACH
OF FRESHLY ERUPTED BOMB FRAGMENTS

	1	2	3	4
AL	N.D.	N.D.	N.D.	0.043
B	0.48	2.2	0.52	3.0
BA	0.14	0.12	0.023	0.021
CA	0.17	0.69	0.51	0.19
CD	-	-	-	16.
CL	3.2	6.7	2.3	3.2
CO	-	-	-	0.026
CU	3.2	11.	0.70	0.030
F	0.66	1.1	1.4	3.5
FE	0.0033	0.0046	0.015	0.017
LI	-	0.020	-	-
MG	0.046	0.15	0.054	0.097
MN	0.073	0.18	0.064	0.27
NA	0.099	0.38	0.073	0.013
PB	-	-	-	-
SI	0.0059	0.015	0.015	0.026
SR	0.10	0.40	0.15	0.21
U	-	-	-	0.11
V	0.14	0.14	0.023	-
ZN	0.053	0.33	0.040	0.33

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
1 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE 20-150
2 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE <150
3 = AUGUSTINE VOLCANO, 2/6/76, MESH SIZE 20-150
4 = HEIMAEY, 6/5/70, MESH SIZE <150

APPENDIX III--TABLE 4C

PER CENT OF ELEMENT REMOVED BY CARBONATE-BICARBONATE LEACH OF FRESHLY ERUPTED BOMB FRAGMENTS

	1	2	3	4
AL	N.D.	N.D.	N.D.	N.D.
B	0.24	0.83	0.64	2.0
BA	-	0.0070	-	-
CA	0.0099	0.016	0.012	0.0045
CD	-	-	-	-
CL	0.85	1.6	0.69	2.4
CO	-	-	-	-
CU	1.2	2.3	0.90	6.0
F	0.65	0.65	0.36	3.2
FE	0.0023	0.0013	0.0052	0.0014
LI	1.0	4.2	0.16	1.1
MG	0.0033	0.0069	0.0049	0.019
MN	-	0.00080	0.00080	-
NA	N.D.	N.D.	N.D.	N.D.
PB	-	1.2	4.8	-
SI	0.027	0.017	0.035	0.075
SR	0.019	0.041	0.013	0.0067
U	0.43	1.0	1.6	0.30
V	0.31	0.69	-	0.34
ZN	-	-	-	-

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
1 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE 20-150
2 = AUGUSTINE VOLCANO, 1/26/76, MESH SIZE <150
3 = AUGUSTINE VOLCANO, 2/6/76, MESH SIZE 20-150
4 = HEIMAEY, 6/5/70, MESH SIZE <150

APPENDIX III--TABLE 5A

PER CENT OF ELEMENT REMOVED BY WATER LEACH OF HISTORIC "RHYOLITE" SAMPLES

	KATMAI		MT. ST. HELENS--W		MT. ST. HELENS--T		MEDICINE LAKE		MONO CRATERS	
	1	2	1	2	1	2	1	2	1	2
AL	0.038	0.042	0.065	0.056	N.D.	N.D.	0.040	N.D.	N.D.	N.D.
B	0.32	0.11	0.027	0.29	0.48	0.027	1.3	5.9	-	0.24
BA	0.031	0.036	0.077	0.74	0.12	0.077	0.049	0.038	1.2	0.35
CA	0.052	0.29	0.12	0.17	0.028	0.030	0.17	0.21	0.12	0.19
CD	-	-	-	-	-	2.6	11.	17.	3.8	4.0
CL	0.040	0.49	-	1.7	0.60	0.60	0.64	1.9	0.26	1.1
CO	-	-	1.3	2.1	1.2	0.40	-	-	-	-
CU	5.2	4.5	4.9	5.8	15.	11.	1.7	1.1	18.	24.
F	1.2	0.75	0.43	0.29	0.42	0.23	0.43	0.46	0.21	2.7
FE	0.016	0.028	0.020	0.023	0.013	0.024	0.10	0.025	0.028	0.021
LI	-	-	-	0.080	-	0.027	-	0.027	0.040	0.080
MG	0.067	2.0	0.19	0.26	0.0099	0.036	0.29	0.46	0.053	0.060
MN	0.0073	0.031	0.42	0.56	0.27	0.23	0.23	0.13	0.089	0.16
NA	0.095	0.094	0.12	0.18	0.12	0.11	0.048	0.098	0.058	0.16
PB	0.29	-	-	-	-	-	2.8	0.46	0.12	-
SI	0.00090	0.0037	0.0024	0.0053	0.0041	0.0059	0.0015	0.0026	0.0013	0.0021
SR	0.010	0.040	0.046	0.082	0.046	0.079	0.068	0.086	0.44	0.56
U	-	-	-	-	0.66	0.22	0.0081	0.025	0.099	0.012
V	-	-	-	-	-	0.12	-	-	-	-
ZN	0.18	0.47	0.54	1.1	0.44	0.35	1.3	1.7	0.90	3.5

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
1 = 20-150 MESH
2 = 150-325 MESH

APPENDIX III--TABLE 5B

PER CENT OF ELEMENT REMOVED BY ACID LEACH OF HISTORIC "RHYOLITE" SAMPLES

	KATMAI		MT. ST. HELENS--W		MT. ST. HELENS--T		MEDICINE LAKE		MONO CRATERS	
	1	2	1	2	1	2	1	2	1	2
AL	0.016	0.035	0.027	0.036	N.D.	N.D.	0.011	N.D.	N.D.	N.D.
B	-	-	-	-	-	-	-	0.91	0.053	0.37
BA	0.010	0.019	0.024	0.036	0.047	0.050	0.018	0.037	0.36	0.75
CA	0.021	0.17	0.13	0.086	0.11	0.17	0.038	0.051	0.036	0.068
CD	-	-	-	-	-	-	2.4	-	-	-
CL	-	0.040	0.16	0.24	-	-	-	-	0.23	0.23
CO	-	-	-	0.97	0.33	-	-	-	-	-
CU	1.4	2.9	1.5	2.8	4.9	4.4	1.1	1.1	4.8	16.
F	0.23	0.15	0.29	0.14	0.28	0.23	0.060	0.010	-	0.52
FE	0.012	0.020	0.0082	0.017	0.0056	0.0064	0.056	0.091	0.017	0.016
LI	-	-	-	-	-	-	-	-	-	-
MG	-	0.38	0.028	0.035	0.0024	0.0090	0.048	0.065	-	0.027
MN	0.0016	0.0076	0.14	0.20	0.11	0.13	0.061	0.079	0.021	0.058
NA	0.014	0.031	0.020	0.053	0.044	0.050	0.052	0.032	0.015	0.061
PB	-	-	-	-	-	-	1.1	0.86	-	0.86
SI	0.00090	0.0039	0.0022	0.0038	0.0069	0.0075	0.00090	0.0024	0.0012	0.0023
SR	0.0030	0.021	0.021	0.027	0.035	0.065	0.015	0.034	0.10	0.36
U	-	-	-	-	0.13	-	0.010	0.038	0.052	0.070
V	-	-	-	-	-	-	-	-	-	-
ZN	0.020	0.14	0.11	0.48	-	0.018	0.82	0.42	0.16	0.92

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
1 = 20-150 MESH
2 = 150-325 MESH

APPENDIX III--TABLE 5C

PER CENT OF ELEMENT REMOVED BY CARBONATE-BICARBONATE LEACH OF HISTORIC "RHYOLITE" SAMPLES

	KATMAI		MT. ST. HELENS--W		MT. ST. HELENS--T		MEDICINE LAKE		MONO CRATERS	
	1	2	1	2	1	2	1	2	1	2
AL	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
B	0.67	0.24	0.21	0.77	0.88	0.37	1.0	1.3	0.69	N.D.
BA	-	-	-	-	-	-	-	0.0029	0.32	N.D.
CA	0.015	0.035	0.023	0.024	0.0099	0.0099	0.036	0.043	0.052	N.D.
CD	-	-	-	-	-	-	-	-	-	N.D.
CL	0.27	0.31	0.80	0.96	1.4	1.0	0.64	1.4	0.86	N.D.
CO	-	-	1.2	-	-	-	-	-	-	N.D.
CU	4.0	6.0	3.1	7.6	1.8	3.6	2.5	5.5	12.	N.D.
F	0.51	9.9	0.88	0.57	0.49	0.46	0.28	0.16	0.47	N.D.
FE	0.014	0.0064	0.094	0.0017	0.0012	0.0019	0.0054	0.0037	0.0086	N.D.
LI	0.67	1.1	1.7	3.7	0.71	0.81	0.53	1.5	0.69	N.D.
MG	-	0.067	0.0047	-	0.0075	0.0039	-	0.011	-	N.D.
MN	-	-	0.023	-	-	0.0029	0.0020	0.28	-	N.D.
NA	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PB	-	-	-	-	-	-	-	-	-	N.D.
SI	0.034	0.020	0.011	0.010	0.020	0.025	0.029	0.039	0.069	N.D.
SR	0.0046	0.0036	0.0041	0.0097	0.0076	0.0076	0.025	0.049	0.60	N.D.
U	0.067	0.12	0.70	0.84	0.66	1.0	0.019	0.66	0.27	0.32
V	-	-	0.68	0.14	0.33	0.15	-	0.36	-	N.D.
ZN	0.067	0.12	-	-	0.020	-	0.070	0.090	0.060	N.D.

\- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
1 = 20-150 MESH
2 = 150-325 MESH

APPENDIX IV--TABLE 1

AVERAGE PER CENT OF ELEMENT REMOVED BY LEACHES OF FUEGO ASH

	WATER LEACH		ACID LEACH		CARBONATE-BICARBONATE LEACH	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
AL	0.0051	0.0-0.024	0.0051	0.0-0.022	N.D.	N.D.
B	1.8	0.24-9.0	0.24	0.0-1.8	3.9	0.32-9.0
BA	0.069	0.019-0.23	0.040	0.0039-0.24	0.00039	0.0-0.0074
CA	0.63	0.11-1.7	0.12	0.022-0.38	0.0053	0.0015-0.0091
CD	3.9	0.0-20.	0.82	0.0-4.0	-	-
CL	23.	8.3-36.	1.4	0.0-2.9	0.79	0.0-2.3
CO	0.013	0.0-0.12	0.013	0.0-0.16	-	-
CU	0.34	0.049-2.6	0.20	0.0-0.92	0.64	0.083-1.7
F	5.2	1.1-22.	2.2	0.66-7.1	7.9	0.54-36.
FE	0.0031	0.00018-0.034	0.0035	0.00007-0.039	0.0026	0.0010-0.0055
LI	0.38	0.0-1.2	-	-	0.94	0.0-2.6
MG	0.091	0.0096-0.22	0.023	0.0021-0.17	0.0050	0.0-0.035
MN	0.13	0.021-0.29	0.045	0.0069-0.29	0.0010	0.0-0.0029
NA	0.48	0.22-0.71	0.071	0.027-0.14	N.D.	N.D.
PB	2.1	0.0-19.	1.1	0.0-14.	6.0	0.0-64.
SI	0.0029	0.0014-0.0050	0.0041	0.0023-0.0090	0.031	0.012-0.042
SR	0.37	0.072-0.96	0.072	0.0079-0.19	0.0084	0.00089-0.020
U	0.28	0.0-0.35	0.30	0.0-1.8	1.3	0.0-3.6
V	0.033	0.0-0.083	0.026	0.0-0.12	0.75	0.16-1.8
ZN	0.17	0.014-0.65	0.085	0.0-0.26	0.16	0.0-1.6

\- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
0.0 = ELEMENT NOT FOUND IN ABOVE-BLANK CONCENTRATION FOR AT LEAST ONE SAMPLE OF A GIVEN LEACH TYPE

APPENDIX IV--TABLE 2

AVERAGE PER CENT OF ELEMENT REMOVED BY LEACHES OF PACAYA ASH

	WATER LEACH		ACID LEACH		CARBONATE-BICARBONATE LEACH	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
AL	0.012	0.00040-0.020	0.027	0.00070-0.049	N.D.	N.D.
B	1.2	0.080-2.2	0.21	0.0-0.64	0.64	0.0-1.5
BA	0.14	0.073-0.23	0.15	0.030-0.33	0.0023	0.0-0.012
CA	0.31	0.20-0.50	0.097	0.051-0.17	0.0067	0.0036-0.012
CD	18.	2.0-64.	6.1	0.0-24.	-	-
CL	22.	8.5-65.	1.3	0.0-4.5	0.42	0.20-0.80
CU	0.030	0.0-0.10	0.030	0.0-0.093	-	-
CU	1.4	0.16-2.6	1.8	0.13-4.8	0.90	0.36-2.0
F	6.5	4.3-8.8	2.3	0.58-6.2	2.5	0.21-8.8
FE	0.0037	0.0-0.012	0.012	0.00040-0.024	0.0018	0.0014-0.0023
LI	0.034	0.0-0.16	-	-	0.26	0.080-0.40
MG	0.081	0.036-0.23	0.041	0.013-0.076	0.0053	0.0022-0.0094
MN	0.073	0.028-0.22	0.048	0.021-0.081	0.00054	0.0-0.0012
NA	0.56	0.29-1.6	0.083	0.030-0.13	N.D.	N.D.
PB	0.28	0.0-0.88	0.93	0.0-5.6	-	-
SI	0.0040	0.0012-0.0065	0.0098	0.0022-0.019	0.040	0.033-0.051
SR	0.31	0.20-0.49	0.095	0.044-0.16	0.0084	0.0024-0.018
U	0.013	0.0-0.089	0.024	0.0-0.10	0.23	0.022-0.51
V	0.010	0.0-0.028	0.015	0.0-0.041	0.13	0.042-0.22
ZN	5.5	0.65-19.	5.5	0.49-14.	0.028	0.0-0.11

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
0.0 = ELEMENT NOT FOUND IN ABOVE-BLANK CONCENTRATION FOR AT LEAST ONE SAMPLE OF A GIVEN LEACH TYPE

APPENDIX IV--TABLE 3

AVERAGE PER CENT OF ELEMENT REMOVED BY LEACHES OF SANTIAGUITO ASH

	WATER LEACH		ACID LEACH		CARBONATE-BICARBONATE LEACH	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
AL	0.0070	0.0-0.016	0.0067	0.0-0.020	N.D.	N.D.
B	11.	2.0-39.	4.6	0.37-20.	7.9	2.2-18.
BA	0.015	0.0021-0.040	0.017	0.0018-0.065	0.0019	0.0-0.0038
CA	1.7	0.52-6.2	2.2	0.067-9.8	0.018	0.0082-0.029
CD	3.5	0.0-6.8	0.88	0.0-2.0	-	-
CL	40.	20.-68.	1.0	0.16-1.9	1.9	0.90-3.5
CO	2.2	0.0-10.	0.37	0.0-1.5	-	-
CU	11.	1.5-22.	4.1	0.27-11.	3.8	0.77-7.6
F	3.1	1.8-5.7	1.5	1.0-1.8	4.2	1.1-7.4
FE	0.0044	0.0011-0.013	0.013	0.00061-0.040	0.0035	0.0022-0.0055
LI	2.0	0.10-9.4	0.38	0.0-1.9	3.2	2.4-3.7
MG	0.83	0.13-3.5	0.18	0.013-0.74	0.016	0.015-0.018
MN	1.3	0.052-5.9	0.24	0.033-0.95	0.010	0.00090-0.020
NA	0.79	0.15-3.1	0.085	0.032-0.25	N.D.	N.D.
PB	0.096	0.0-0.48	0.46	0.0-1.5	-	-
SI	0.0025	0.0010-0.0037	0.0055	0.0031-0.0074	0.022	0.010-0.032
SR	0.32	0.086-0.94	0.39	0.029-1.7	0.011	0.0-0.021
U	0.13	0.0-0.66	-	-	2.6	0.93-4.6
V	0.033	0.0-0.016	0.17	0.021-0.59	1.9	0.12-5.3
ZN	3.4	0.35-14.	2.0	0.10-7.9	0.11	0.027-0.18

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
0.0 = ELEMENT NOT FOUND IN ABOVE-BLANK CONCENTRATION FOR AT LEAST ONE SAMPLE OF A GIVEN LEACH TYPE

APPENDIX IV--TABLE 4

AVERAGE PER CENT OF ELEMENT REMOVED BY LEACHES OF BOMB FRAGMENTS

	WATER LEACH		ACID LEACH		CARBONATE-BICARBONATE LEACH	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
AL	0.045	*	0.043	*	N.D.	N.D.
B	2.5	1.0-3.7	1.6	0.48-3.0	0.94	0.24-2.0
BA	0.062	0.011-0.12	0.076	0.021-0.14	0.0018	0.0-0.0070
CA	1.9	0.11-2.0	0.39	0.17-0.69	0.011	0.0045-0.016
CD	2.8	0.0-4.8	4.0	0.0-16.	-	-
CL	34.	11.-57.	3.8	2.3-6.7	1.4	0.69-2.4
CO	0.017	0.0-0.038	0.0065	0.0-0.026	-	-
CU	10.	0.98-20.	3.7	0.080-11.	2.7	0.90-6.0
F	2.4	1.1-4.8	1.7	0.65-3.5	1.2	0.36-3.2
FE	0.0045	0.00070-0.0074	0.010	0.0033-0.017	0.0026	0.0013-0.0052
LI	0.43	0.0-0.68	0.0050	0.0-0.020	1.6	0.16-4.2
MG	0.32	0.079-0.69	0.087	0.046-0.15	0.0085	0.0033-0.019
MN	0.21	0.066-0.41	0.15	0.064-0.27	0.00040	0.0-0.00080
NA	1.0	0.63-1.9	0.14	0.013-0.38	N.D.	N.D.
PB	-	-	-	-	1.5	0.0-4.8
SI	0.0078	0.0031-0.0087	0.015	0.0059-0.026	0.038	0.017-0.075
SR	0.47	0.098-1.1	0.22	0.10-0.40	0.020	0.0067-0.041
U	0.16	0.0093-0.35	0.028	0.0-0.11	0.96	0.43-1.6
V	0.089	0.0-0.19	0.078	0.0-0.14	0.34	0.0-0.69
ZN	0.56	0.14-1.3	0.19	0.040-0.33	-	-

* = ONLY ONE SAMPLE ANALYZED
\- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
0.0 = ELEMENT NOT FOUND IN ABOVE-BLANK CONCENTRATION FOR AT LEAST ONE SAMPLE OF A GIVEN LEACH TYPE

APPENDIX IV--TABLE 5

AVERAGE PER CENT OF ELEMENT REMOVED BY LEACHES OF HISTORIC "RHYOLITES"

	WATER LEACH		ACID LEACH		CARBONATE-BICARBONATE LEACH	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
AL	0.049	0.038-0.065	0.025	0.011-0.036	N.D.	N.D.
B	0.97	0.0-5.9	0.13	0.0-0.91	0.68	0.21-1.3
BA	0.27	0.031-1.2	0.14	0.010-0.75	0.036	0.0-0.32
CA	0.14	0.029-0.29	0.088	0.021-0.17	0.028	0.0099-0.052
CD	3.8	0.0-17.	0.24	0.0-2.4	-	-
CL	0.73	0.0-1.9	0.090	0.0-0.24	0.85	0.27-1.4
CO	0.50	0.0-2.1	0.13	0.0-0.97	0.13	0.0-1.2
CU	9.1	1.1-24.	4.1	1.1-16.	5.1	1.8-12.
F	0.71	0.21-2.7	0.19	0.0-0.52	1.5	0.16-9.9
FE	0.030	0.013-0.10	0.025	0.0056-0.091	0.015	0.0012-0.094
LI	0.025	0.0-0.080	-	-	1.3	0.53-3.7
MG	0.34	0.0099-2.0	0.059	0.0-0.38	0.010	0.0-0.067
MN	0.21	0.0073-0.56	0.081	0.0016-0.20	0.034	0.0-0.28
NA	0.11	0.049-0.18	0.037	0.014-0.061	N.D.	N.D.
PB	0.37	0.0-2.8	0.28	0.0-1.1	-	-
SI	0.0031	0.00090-0.0069	0.0032	0.00090-0.0075	0.029	0.010-0.069
SR	0.15	0.010-0.56	0.068	0.0030-0.36	0.079	0.0036-0.60
U	0.10	0.0-0.66	0.030	0.0-0.13	0.47	0.019-0.84
V	0.012	0.0-0.12	-	-	0.19	0.0-0.68
ZN	1.0	0.18-3.5	0.31	0.0-0.92	0.047	0.0-0.12

- = BELOW BLANK LEVEL
N.D.= NOT DETERMINED
0.0 = ELEMENT NOT FOUND IN ABOVE-BLANK CONCENTRATION FOR AT LEAST ONE SAMPLE OF A GIVEN LEACH TYPE