puts to lakes rather than processes within lakes. Inputs dominate because they are controlled by rates of mineral alteration, degradation of entrained organics, and regrowth of vegetation in deposit areas.

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References and Notes

1. C. L. Rosenfeld, *Am. Sci.* **68**, 494 (1980); N. P. Dion and S. S. Embrey, *U.S. Geol. Surv. Circ. 850-6* (1981), p. 625; S. M. Klein, *U.S. Geol. Surv. Circ. 850-E*, in press; Geophysics Programs of the University of Washington, *Nature (London)* **285**, 529 (1980).
2. R. P. Hoblitt, D. R. Crandell, D. R. Mullineaux, *Geology* **8**, 555 (1980); R. P. Hoblitt, N. G. Banks, N. G. Ryan, M. P. Rosenbaum, M. J. Davis, *Geol. Soc. Am. Abstr. Programs* **12**, 447 (1980).
3. D. P. Dethier, D. Frank, D. R. Pevear, *U.S. Geol. Surv. Open File Rep. 80-81* (1981), p. 24; *U.S. Geol. Surv. Prof. Pap. 1250*, in press; D. P. Dethier, personal communication.
4. G. C. Bortleson, N. P. Dion, J. B. McDonnell, L. M. Nelson, *U.S. Geol. Surv. Water Supply Bull. 43* (1976), p. 197.
5. K. B. Krauskopf, *Geochim. Cosmochim. Acta* **10**, 1 (1956).
6. J. D. Hem, *U.S. Geol. Surv. Water-Supply Pap. 1473* (1971).
7. J. S. Fruchter *et al.*, *Science* **209**, 1116 (1980); H. E. Taylor and F. E. Lichte, *Geophys. Res. Lett.* **7**, 949 (1980).
8. W. Stumm and S. S. Morgan, *Aquatic Chemistry* (Wiley-Interscience, New York, 1970).
9. E. B. Welch and D. E. Spyridalis, in *Research on Coniferous Forest Ecosystems; First Year Progress in the Coniferous Forest Biome*, J. E. Franklin, L. J. Dempster, R. H. Waring, Eds. (Government Printing Office, Washington, D.C., 1972), pp. 301–315.
10. R. E. Stoiber, S. N. Williams, L. L. Malinconico, *Science* **208**, 1258 (1980).
11. W. I. Rose, Jr., *Geology* **5**, 621 (1977).
12. G. C. Bortleson, R. T. Wilson, B. L. Foxworthy, *U.S. Geol. Surv. Prof. Pap. 1022-B* (1977), p. B30.
13. I. I. Kurenkov, *Limnol. Oceanogr.* **11**, 426 (1966); H. Sigurdsson, *J. Volcanol. Geothermal Res.* **2**, 165 (1977); P. H. Poe, thesis, University of Washington, Seattle (1980).
14. W. E. Pereira, C. E. Rostad, H. E. Taylor, J. M. Klein, in preparation.
15. R. C. Wissmar, A. H. Devol, J. T. Staley, J. R. Sedell, *Science* **216**, 178 (1982); R. C. Wissmar, unpublished data; J. Baross, A. Ward, C. Dahm, M. Lilley, personal communication; R. C. Wissmar, paper presented at the Mount St. Helens "One Year Later" Symposium, Eastern Washington University 17–18 May 1981.
16. Analysis by S. A. Stanford and J. Lamb, University of Montana Biological Station, Bigfork.
17. Analysis by F. C. Sung, Fisheries Research Institute, College of Fisheries, University of Washington, Seattle.
18. J. D. H. Strickland and T. R. Parsons, *Fish. Res. Board Can. Bull. 167* (1972).
19. We thank P. Poe, R. Donnelly, and T. Cline for the 4 April 1980 sampling and Columbia Air Services for field laboratory facilities. Supported by NSF grant DEB 7811339 and U.S. Department of Agriculture Forest Service Agreement PNW-80-178. Contribution No. 566, College of Fisheries, University of Washington, Seattle.

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Biological Responses of Lakes in the Mount St. Helens Blast Zone

Abstract. *Loadings of dissolved organics and suspended particulates from destroyed forests and volcanic debris produced by the 18 May 1980 eruption of Mount St. Helens altered the trophic structure of many blast zone lakes to the extent that anoxic conditions and chemoorganotrophic and chemolithotrophic microorganisms prevailed. High bacterial counts and high adenosine triphosphate concentrations were directly related to enhanced concentrations of dissolved organic carbon, and plankton chlorophyll a was inversely related to light extinction. The recovery of these lakes to the preeruption state appears dependent upon the oxidation of organics and the stabilization of watersheds.*

The 18 May 1980 volcanic eruption of Mount St. Helens devastated lakes and watersheds near the mountain. A major difference between lakes impacted by this eruption and previously studied volcanically influenced waters was that, in addition to volcanic material, many lakes within the Mount St. Helens blast zone received high loadings of organic matter (*1, 2*). The eruption produced superheated magmatic gases, pyroclastic material, and steam which pyrolyzed and extracted organic matter from surrounding soils and forests (*2–4*). Virtually all fish, their food chains, and their habitats were destroyed. The lake chemistries were so altered that the trophic structure of many lakes appeared to be dominated by chemoorganotrophic and chemolithotrophic microorganisms in anoxic waters. This eruption offered a unique opportunity to study for the first time the unique and rapid evolution of the highly impacted lake ecosystems. We describe here the first step in that process for lakes inside and outside the immediate blast zone (radius of 16 to 28 km northwest and northeast of the crater).

The lakes were in four deposit areas: U, morphologically unaffected regions outside the blast zone; S, scorched areas on the edge of the blast zone; B, timber-blowdown areas within the blast zone; and M, regions of blast zone mudflows, debris avalanches, and pyroclastic flows (*2*). Spirit Lake, an area M lake (8 km north of the crater), was sampled both before (4 April 1980) and after the eruption. Our preeruption data from Spirit Lake are in agreement with the limited historical data available for lakes near Mount St. Helens (*5*) as well as with data from similar, subalpine Cascade Mountain lakes (*6*). Lake locations and additional chemical features of biological significance are given elsewhere (*2*).

In most respects, the posteruption condition of Spirit Lake was typical of the highly affected lakes (area M lakes). Inputs of organics, pyroclastic materials, and soil extracts resulted in a 33-fold increase in suspended particulate matter (SPM) and a 36-fold increase in the light extinction coefficient [Table 1 (*7*)]. The lake temperature increased to 34°C on 20 May 1980 (*8*) but cooled to a more normal but still somewhat elevated value of 22°C by 30 June. Although particulate organic carbon (POC) and particulate organic nitrogen (PON) showed, respectively, only moderate one- and twofold increases, dissolved organic carbon (DOC) was enriched 48-fold. The dramatic increase in DOC was accompanied by a 17-fold increase in living matter as measured by adenosine triphosphate (ATP). This increase was not attributable to algal growth because chlorophyll a concentrations decreased substantially after the blast. Furthermore, the ATP increase corresponded not only with higher DOC but with lower dissolved oxygen concentrations.

The physical and chemical characteristics of the unaffected lakes (Merrill, McBride, June, and Blue) (Table 2) were comparable to those of Spirit Lake prior to the eruption (Table 1). Merrill and June lakes had POC, PON, chlorophyll a, and ATP concentrations comparable to oligotrophic Findley Lake (*9*), a totally unaffected mountain lake about 200 km north of Mount St. Helens. McBride and Blue lakes had somewhat higher concentrations of POC, PON, chlorophyll a, and ATP because of more abundant phytoplankton and invertebrate communities (*10*).

As in Spirit Lake, almost all lakes within the blast zone had higher SPM concentrations, light extinction coefficients, and DOC, POC, and PON concentrations than lakes outside the blast zone (Table 2). The highest DOC and ATP concentrations were observed in the highly impacted organically enriched Ryan and Spirit lakes and in the newly formed East Castle, West Castle, and South Coldwater lakes. These high ATP values were similar to values reported for oxygen-depleted waters with dense heterotrophic microbial populations (*11*). Again, the increased ATP concentrations could not be attributed to algal growth because most blast zone lakes had undetectable concentrations of chlorophyll a and few phytoplankton and zooplankton (*10*).

Total bacterial counts [Table 2 (*12*)] in the unaffected lakes ranged between 1×10^5 and 8×10^5 per milliliter and were similar to the highest annual counts for Findley Lake (*9*). Although Panhandle, Boot, and Venus lakes contained bacterial numbers comparable to those of the unaffected lakes, most blast zone lakes had bacterial counts above 10^6. Ryan and West Castle lakes contained in excess of 10^7.

Counts of viable heterotrophic bacteria (*13*) were low and varied little (1×10^3 to 5×10^3 per milliliter) in the unaffected lakes. However, counts in many blast zone lakes were so unexpectedly high that they were not accurately assessed by the dilutions initially used. Some blast zone lakes had counts exceeding 10^4. In fact, counts of viable bacteria for all lakes were 0.02 to 3 percent of the total bacterial counts, an indication of moderately eutrophic conditions (*14*).

Although total and fecal coliform bacteria (*15*) were undetectable (< 0.1 per 100 ml) in McBride and Merrill lakes, and were similar to preeruption Spirit Lake values (*5*), most blast zone lakes contained total coliform bacteria ranging from 15 to 145 per 100 ml. West Castle Lake had a concentration of $> 10^4$ per 100 ml. Three lakes, Fawn, Hanaford, and West Castle, also contained fecal coliform bacteria. We have tentatively identified one of the coliform isolates as *Klebsiella pneumoniae*, a potential pathogen that has been reported to occur in association with terrestrial vegetation (*16*).

The highest total bacterial counts, ATP concentrations, and DOC values were observed in the most volcanically disturbed lakes, Ryan, Spirit, East Castle, West Castle, and South Coldwater. The possibility that the development of dense bacterial communities and the high concentrations of ATP were associated with enhanced DOC concentrations in many blast zone lakes is shown by the significant regressions between them (Fig. 1A). The labile DOC compounds are not known but probably include products of primary metabolism (that is, sugars, amino acids, and other low molecular weight compounds) which came from the pyrolyzed and steam-leached vegetation and soils. If present, these labile organics would have been readily used by the developing bacterial communities. In contrast to the stimulatory effect of organics on bacterial numbers, algal bioassays with Mount St. Helens ash samples containing organic compounds of terrestrial origin implied inhibitory effects on phytoplankton development (*17*).

Nevertheless, the primary reason for the low phytoplankton numbers in the blast zone lakes was probably light limitation rather than toxicity of dissolved organics or competition by dense bacterial populations for nutrients. A significant inverse relation was observed between chlorophyll a concentrations and light extinction (Fig. 1B). Moreover, the minimal influence of high DOC concentrations upon chlorophyll a concentrations was indicated by the lack of an inverse correlation between them. Similarly, the lack of any relationship between chlorophyll a and either bacterial numbers or ATP suggests little competition for nutrients.

The return of these lakes to more "typical" conditions with ecosystems dominated by phytoplankton or zooplankton will probably depend upon how

Table 1. Biological and physiochemical characteristics of Spirit Lake water before and after the 18 May 1980 volcanic eruption of Mount St. Helens. Response and enrichment factors correspond to values for 30 June 1980 divided by 4 April 1980 values. Samples were taken 0.25 m below the water surface. Methods are described in (*7*).

Characteristic	1980		Response or enrichment
	4 April	30 June	
Light extinction coefficient (α_a)	0.17	6.05	36
SPM (mg liter^{-1})	0.75	24.61	33*
Dissolved oxygen (mg liter^{-1})	†	2.35	
Temperature (°C)	4	22.4	
DOC (mg liter^{-1})	0.83	39.9	48*
POC (μg liter^{-1})	435	570	1*
PON (μg liter^{-1})	47	70	2*
Chlorophyll a (μg liter^{-1})	2.5	0.3	0.1
ATP (μg liter^{-1})	0.25	4.3	17

*Enrichment. †Since the dissolved oxygen concentration was 9.0 mg liter^{-1} at 16°C in August 1974 (*5*), the dissolved oxygen concentrations were most likely supersaturated on 4 April 1980.

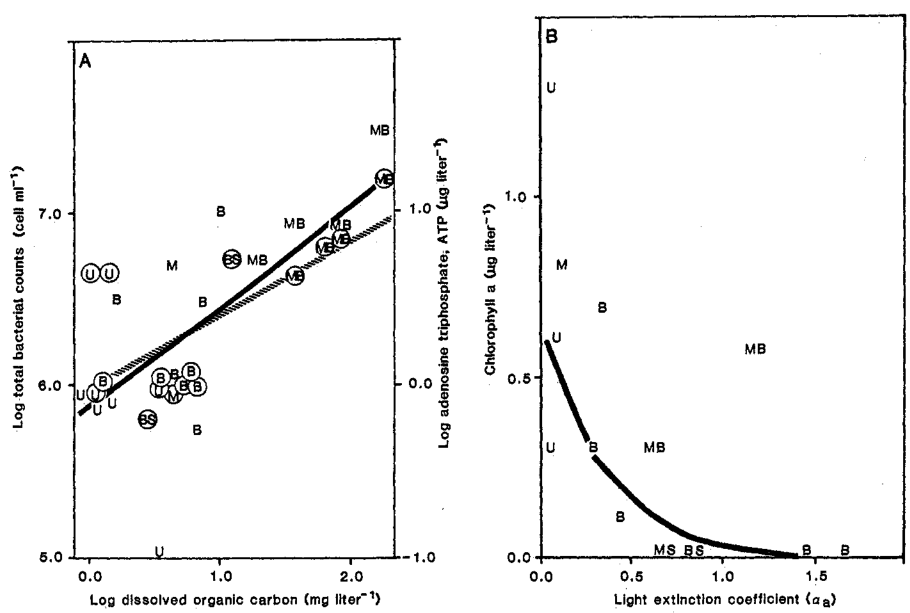

Fig. 1. (A) Relation between DOC concentrations of total bacterial counts (solid line and uncircled letters) and ATP concentrations (dashed line and circled letters) for four lake groups; *BS* and *MB* are for lakes overlapping two categories. The solid line represents the least-squares fit of the total bacterial counts [$y = 5.72 + 0.67x$, x = DOC, r (correlation coefficient) = .75, $N = 17$; significant at $P = .10$]. The dashed line represents the least-squares fit of ATP ($y = -0.11 + 0.43x$, x = DOC, $r = .66$, $N = 16$; significant at $P = .10$). (B) Relation between the chlorophyll a concentrations and the light extinction coefficient (α_a). The solid line represents exponential fit ($y = 0.61e^{-0.25x}$, $x = \alpha_a$, $r = .69$, $N = 13$; significant at $P = .10$) with zero chlorophyll a values represented as 0.01 μg liter^{-1} in calculations.

Table 2. Biological and physiochemical characteristics of lakes near Mount St. Helens. Samples were taken 0.25 m below the water surface on 30 June 1980. The lakes are grouped into four blast deposit areas (see text); BS and MB refer to lakes having features of more than one area. Methods are described in (*7, 12, 13, 15*).

Characteristic	Lakes outside blast zone				Lakes inside blast zone											
	U				B					BS		M	MB			
	Merrill	McBride	June	Blue	Hanaford	Fawn	St. Helens	Panhandle	Boot	Venus	Ryan	Debris flow pond*	West Castle*	East Castle*	South Coldwater*	Spirit
Light extinction coefficient	0.56	0.59		0.71	4.28	3.04		16.38	14.30	3.75	7.82	1.19	12.43		7.21	6.05
SPM (mg liter^{-1})	1.23	1.33	3.15	8.17	28.36	24.60	81.72	132.83	188.76	51.00	19.43	12.14	46.36	49.10	89.58	24.61
Dissolved oxygen (mg liter^{-1})	8.75	8.35	11.2	8.00	6.60	7.25	8.85	8.32	7.90	8.15	3.60	8.90	3.00	10.0	6.90	2.35
Temperature (°C)	18.3	17.6	7.5	15.5	15.5	19.5	9.4	13.8	18.9	19.0	25.5	20.5	20.0	13.0	16.2	22.4
DOC (mg liter^{-1})	1.09	1.29	2.28	0.65	4.79	1.34	2.42	3.60	4.98	1.91	10.97	2.79	148.65	65.80	23.14	39.9
POC (μg liter^{-1})	197	565	240	635	485	395	574	813	985	497	827		5925	259	3690	570
PON (μg liter^{-1})	15	62	18	49	45	43	29	38	48	29	104		1305	27	402	70
Chlorophyll a (μg liter^{-1})	0.3	1.3	0.1	0.6	0.1	0.3	0.0	0.0	0.0	0.7	0.0	0.8	0.6	0.0	0.0	0.3
ATP (μg liter^{-1})	0.6	3.7	0.7	3.6	1.1	1.0	1.0	0.6	0.7	0.3	3.6	0.8	15.2	4.6	2.6	4.3
Total bacteria (ml^{-1})	5×10^5	6×10^5	1×10^5	8×10^5	2×10^6	2×10^6	1×10^6	7×10^5	3×10^5	7×10^5	1×10^7	3×10^6	2×10^7	6×10^6	7×10^6	5×10^6
Viable bacteria (ml^{-1})	1×10^3	2×10^3		2×10^3	4×10^3	5×10^3	$>10^4$	$>10^4$	$>10^4$	$>10^4$	3×10^3	4×10^3	3×10^3		$>10^4$	$>10^4$
Total coliform (1/100 ml)	0	0			20	20	20		45		60		$>10^4$		145	15
Fecal coliform (1/100 ml)	0	0			10	5	0		0		0		70		0	0

*Newly formed (2).

fast the high concentrations of organic matter are oxidized or otherwise removed (for example, by permanent burial in sediments or loss through outflow). This will in turn depend on the ease of oxidizability of organics in the waters and sediments. Data from September 1980 indicate even higher bacterial densities but similar DOC and POC concentrations (*18*). Four vertical profiles in Ryan, Spirit, South Coldwater, and West Castle lakes showed no oxygen below the surface, high concentrations of methane, carbon dioxide, and reduced iron throughout the water column (*18, 19*). The pronounced odor of hydrogen sulfide was strongly evident in most water samples. These observations indicate the potential for development of dense chemolithotrophic microbial communities. As part of the recovery process, transient producer and consumer communities will probably develop. For example, during chemoorganotrophic and chemolithotrophic phases, bacteria-zooplankton food chains may predominate. As turbidity decreases, phytoplankton primary production should increase to produce mixed bacteria-phytoplankton-zooplankton communities. However, given the denuded lake watersheds and continual inputs by wind and water, these lakes may not recover from the effects of the eruption until after significant mineral alterations, degradation of organics, and regrowth of vegetation in the deposit areas.

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References and Notes

1. R. E. Wilcox, *U.S. Geol. Surv. Bull.* **1028-N**, 409 (1958); I. I. Kurenkov, *Limnol. Oceanogr.* **11**, 426 (1966); W. I. Rose, Jr., *Geology* **5**, 621 (1977); H. Sigurdsson, *J. Volcanol. Geothermal Res.* **2**, 165 (1977); P. H. Poe, thesis, University of Washington, Seattle (1980).
2. R. C. Wissmar, A. H. Devol, A. E. Nevissi, J. R. Sedell, *Science* **215**, 175 (1982).
3. C. L. Rosenfeld, *Am. Sci.* **68**, 494 (1980).
4. W. E. Pereira, C. E. Rostad, H. E. Taylor, *Geophys. Res. Lett.*, in press.
5. G. C. Bortelson, N. P. Dion, J. B. McConnell, L. M. Nelson, *U.S. Geol. Surv. Water Supply Bull. 43* (1976), p. 197.
6. R. C. Wissmar, J. E. Richey, D. E. Syridakis, *J. Fish. Res. Board Can.* **34**, 1410 (1977); J. E. Richey and R. C. Wissmar, *Ecology* **60**, 318 (1979); R. C. Wissmar, J. E. Richey, A. H. Devol, D. M. Eggers, in *Natural Behavior and Response to Stress of Western Coniferous Forests*, R. L. Edmonds, Ed. (Dowden, Hutchinson, & Ross, Stroudsburg, Pa., in press).

7. Methods for obtaining the SPM and dissolved oxygen values in Table 1 are described in M. A. Franson, Ed., *Standard Methods* (American Public Health Association, Washington, D.C., ed. 14, 1976); DOC was determined according to the method of D. Menzel and R. Vaccaro, *Limnol. Oceanogr.* **9**, 138 (1964); chlorophyll a was measured according to the method of J. D. H. Strickland and T. R. Parsons, *Fish. Res. Board Can. Bull. 167* (1972); ATP was measured according to the method of O. Holm-Hansen and R. C. Booth, *Limnol. Oceanogr.* **11**, 510 (1966); and POC and PON were measured by means of a Perkin-Elmer model 240 elemental analyzer. Particulate organics are functionally defined as those materials that are retained by a Gelman type-A glass fiber filter; dissolved organics are defined as those materials that pass through such a filter. Light extinction was measured at 400 nm.
8. T. Casadevall, personal communication.
9. R. C. Wissmar, unpublished data.
10. Lakes outside the blast zone had a "normal" diversity of phytoplankton for the region (6). For example, McBride Lake was dominated (95 percent of 7373 total cells per milliliter) by unidentifiable unicellular blue-green and flagellated green algae. Other taxa included *Sphaerocystis, Scenedesmus, Asterionella, Monoraphidium, Dinobryon, Synedra, Chroomonoas, Aphanizomenon*, and *Lyngbya*. Some blast zone lakes had algae but less than McBride (that is, 878 total cells per milliliter in Fawn Lake and 250 in Ryan Lake). Fawn and Ryan lakes had the most diverse algal communities in the blast zone (*Chroococcus, Cryptomonas, Mallomonas, Chlorella, Chlamydomonas, Stephanodiscus, Euglena, Lyngbya*, and *Gymnodinium* in Ryan Lake). Spirit Lake contained *Chroomonoas, Synura, Melosira*, and unidentified blue-green colonies. The debris flow pond in the pyroclastic flow had a dense green bloom of *Oocystis* and *Achnanthes*. West Castle Lake contained *Cryptomonas*, an unidentified green alga, and dinoflagellates. Algae were not found in samples from South Coldwater Lake. Invertebrates of the lake water columns were represented by limnetic crustaceans, rotifers, and insects. For example, Merrill and McBride lakes contained crustaceans (*Diaptomus, Ceriodaphnia, Daphnia*, and *Bosmina*), rotifers (*Polyarthra, Hexarthra, Kellicottia*, and *Conochilus*), and insect larvae (*Chironomidae*). Animals in blast zone lakes were sparse. Fawn and Ryan lakes had cyclopoid copepods, *Diaptomus*, ostracods, *Kellicottia*, and chironomid larvae. Boot, Panhandle, Venus, and Hanaford lakes contained only copepods and chironomids. Spirit Lake contained rotifers (*Keratella, Filinia*, and *Hexarthra*), in distinct contrast to the diverse zooplankton community on 4 April 1980 (*Bosmina, Daphnia, Diaptomus*, cyclopoid copepods, and rotifers *Asplanchna* and *Kellicottia*). West Castle and South Coldwater lakes were devoid of invertebrates. Protozoans (ciliated and nonciliated) were observed in most of the lakes.
11. J. W. M. Rudd and R. D. Hamilton, *J. Fish. Res. Board Can.* **30**, 1537 (1973).
12. Method of J. E. Hobbie, R. T. Daley, and S. Jaspers [*Appl. Environ. Microbiol.* **33**, 1225 (1977)].
13. Viable bacteria were enumerated by spread plating on CPS culture medium [J. G. Jones, *J. Appl. Bacteriol.* **33**, 679 (1970)].
14. F. Ruttner, *Fundamental Limnology* (Univ. of Toronto Press, Toronto, 1965).
15. Coliform bacteria were counted on 11 September 1980 [M. A. Franson, Ed., in (7)].
16. C. Brown and R. J. Seidler, *Appl. Microbiol.* **25**, 900 (1973).
17. D. M. McKnight, G. L. Feder, E. A. Stiles, *Environ. Sci. Technol.* **15**, 362 (1981).
18. R. C. Wissmar, unpublished data; J. Baross and C. Dahm, personal communication; R. C. Wissmar, paper presented at the Mount St. Helens "One Year Later" Symposium, Eastern Washington University, 17–18 May 1981.
19. J. Baross, C. Dahm, A. Ward, M. Lilley, J. Sedell, in preparation.
20. We thank S. Abella, A. Litt, and T. Edmundson for plankton identification; M. Perkins for help with the DOC analysis; L. Lehmiche for counting the bacteria; P. Poe, R. Donnelly, and T. Cline for the 4 April 1980 sampling; and Columbia Air Services for field laboratory facilities. Supported by NSF grant DEB 7811339 and U.S. Department of Agriculture Forest Service Agreement PNW-80-178. Contribution No. 565, College of Fisheries, University of Washington, Seattle.

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Venus: Chemical Weathering of Igneous Rocks and Buffering of Atmospheric Composition

Abstract. *Data from the Pioneer Venus radar mapper, combined with measurements of wind velocity and atmospheric composition, suggest that surface erosion on Venus varies with altitude. Calcium- and magnesium-rich weathering products are produced at high altitudes by gas-solid reactions with igneous minerals, then removed into the hotter lowlands by surface winds. These fine-grained weathering products may then rereact with the lower atmosphere and buffer the composition of the observed gases carbon dioxide, water vapor, sulfur dioxide, and hydrogen fluoride in some regions of the surface. This process is a plausible mechanism for the establishment in the lowlands of a calcium-rich mineral assemblage, which had previously been found necessary for the buffering of these species.*

The most important geochemical processes at work on the surface of the earth are erosion and transport of material by running water and the atmosphere. On Venus running water is absent, yet radar images of the surface suggest the existence of some active processes which modify landforms (*1, 2*). Erosion produced by atmospheric motion has been suggested (*2, 3*). We examine the role of the hot, reactive, lower atmosphere in surface modification.

Measurements by the Pioneer Venus entry probes and the Soviet Venera landers reveal the lower atmosphere of Venus to be roughly adiabatic (*4*), although some stratification is present (*5*).

The mean Venus surface temperature is 740 K, at a pressure of 92 bars. The observed lapse rate is about 8 K/km, compared with about 6.6 K/km on the earth (*4, 5*). There is substantial disagreement between Soviet and American analyses of the composition of the lower atmosphere. A summary of the major and minor reactive constituents of the Venus atmosphere is given in Table 1. There are major uncertainties concerning the lower atmospheric abundance of water vapor (H_2O) and the sulfur-bearing gases COS, SO_2, and H_2S (*6*). Since reactions involving H_2O are crucial to weathering on Venus, we explored the consequences of a range (2×10^{-5} to 5×10^{-4}) of H_2O mole fractions. Chemical arguments based on the oxidation state of the crust and lower atmosphere (*7*) require the presence of COS; however, the Pioneer Venus mass spectrometer experiment was unable to detect the expected amount due to contamination by an ingested H_2SO_4 droplet. Because of the role sulfur plays in the chemistry of iron and in the buffering of the atmospheric oxidation state, more analyses of the lower atmosphere are required. Future experiments must be conducted with care to avoid contamination by cloud particles.

Table 1. Composition of the Venus atmosphere.

Species	Mole fraction	Source (*6, 7*)
CO_2	0.97	Pioneer and Venera
CO	$\sim 2 \times 10^{-4}$	Earth-based
H_2O	2×10^{-5} to 5×10^{-4}	Pioneer and Venera
HCl	$>10^{-6}$	Earth-based
HF	$>10^{-8}$	Earth-based
N_2	~ 0.03	Pioneer and Venera
$SO_2 + S_2$	$<3 \times 10^{-4}$	Pioneer and Venera
H_2S	$\sim 10^{-6}$	Pioneer
COS	$>3 \times 10^{-6}$	Pioneer

Wind speeds in the lower atmosphere of Venus have been measured by the Venera landers and by radio tracking of the four Pioneer Venus entry probes (*8*). The Soviet results are consistent with surface winds of 0.5 to 1.5 m/sec, which agree with the Pioneer Venus near-surface data. The Pioneer Venus measurements also show free-atmosphere wind speeds of about 5 m/sec at an altitude of 12 km. This suggests that wind shear near the surface boundary layer will be greater at high altitude; still, the observed surface winds are probably adequate for moving fine-grained material (*9*).

Radar images and altimetry from ground-based radar and from the Pioneer Venus orbiting radar are too poor in resolution for detailed geomorphological interpretation. Earth-based radar images portray surface roughness on a scale of centimeters, Pioneer Venus measurements reveal roughness at a scale of 1 m, and global altimetry reveals surface features with a vertical resolution of 200 m and horizontal resolution of 100 km. In addition, the Pioneer Venus measurements allow estimates of the surface dielectric constant in surface cells 10 to 100 km across. Radar measurements show Maxwell Montes, a peak 10.8 km above the mean planetary radius, to be

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