trations in 1962 and 1963, in the waters on the south side of Jones Sound throughout the periods of phytoplankton development. In each summer, phosphates showed relatively little depletion but nitrates were completely exhausted in and below the euphotic zone, and the plant cells exhibited symptoms of nitrate deficiency (*15*). Silicates were substantially reduced each year, but were not completely exhausted. It is interesting that these two nutrients in critical supply for phytoplankton development in arctic waters are those which appear to be augmented by glacial activity, at least in South Cape Fiord.

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Volcanic Production Rates: Comparison of Oceanic Ridges, Islands, and the Columbia Plateau Basalts

Abstract. *New potassium-argon age data from the Columbia Plateau suggest a basalt production rate of 10^8 cubic meters per year during a middle Miocene volcanic episode. This is two to three times the production rate in some oceanic islands, and about four to six times the production rate in spreading mid-oceanic ridge systems.*

The most spectacular accumulations of basaltic rock on the earth are the mid-oceanic ridge systems, the oceanic islands, and the great plateau basalts. According to Holmes (*1*) there are only four plateau basalt accumulations which exceed 2×10^5 km^3 in volume: the Deccan of India, which is the largest; part of Western Siberia; the Parana of South America; and the Columbia Plateau, which is the youngest of the four. Sea floor spreading, which is best understood to result from crustal extension accompanied by dike injection at oceanic ridge crests, would appear to have been a fairly continuous activity, at least since the late Mesozoic. Using estimated spreading rates, Menard (*2*) calculated that this crustal extension requires the addi-

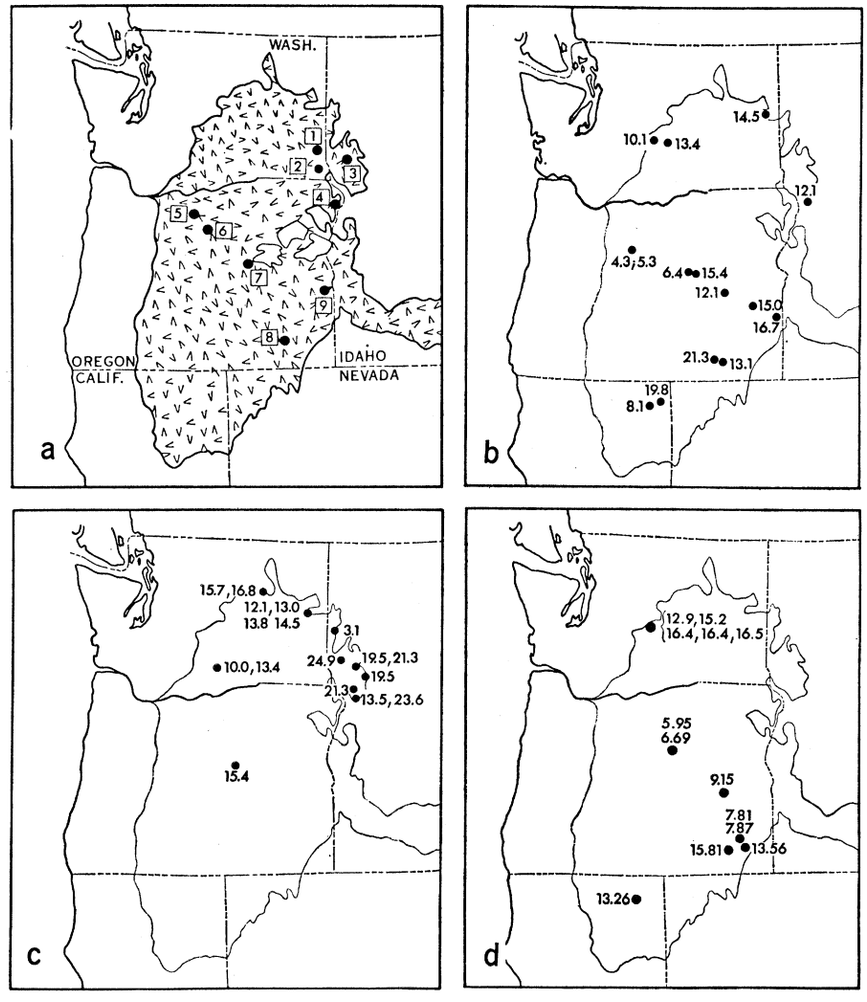

Fig. 1. (a) Map showing the limits of the plateau basalts of the Pacific Northwest and the locations of the nine sections examined in the study reported here. The outline of the plateaus includes the eastward-extending Snake River Plain, but the basalts of the Washington and Oregon coast are excluded. See Table 1 for exact locations and descriptions of the vertical extent and number of lavas in each section. (b–d) Maps showing potassium-argon ages in millions of years: (b) given by Evernden and James (*14*); (c) given by Gray and Kittleman (*13*); and (d) given by Dalrymple *et al.* (*15*) for Oregon and California, and by Holmgren (*16*) for Washington.

tion of 25×10^3 to 45×10^3 m^3 of basaltic material per year per kilometer of ridge. In total this would amount to between 5000×10^6 and 6000×10^6 m^3/year for the entire oceanic ridge system.

By definition, volcanic islands are regions resulting from anomalously high igneous productivity. Decker's (*3*) data from Iceland and Hawaii suggest accumulation rates of 30×10^6 and 40×10^6 m^3/year, respectively. A similar result has been obtained by Walker (*4*) for the Azores Islands. If Menard's (*2*) estimate of the production rate in ocean floor spreading is applied to a length of ridge equal to the north-south dimension of Iceland, which is about 400 km, a figure of about 13×10^6 m^3/year is obtained. This suggests that a production rate of the order of two to four times that resulting from the regional crustal spreading process is required to produce substantial volcanic islands.

Estimates of the production rates of any of the great plateau basalt provinces have not yet been attempted. It is the purpose of this report to present over 80 new potassium-argon age determinations for basalts of the Columbia Plateau. Together with previously published data, these results will facilitate an estimate of the rate of accumulation of the plateau.

The Columbia Plateau, which constitutes almost all the volcanics of the Pacific Northwest (Fig. 1), is divided into two distinct petrological provinces: (i) the thick widespread tholeiitic lavas, called the Columbia River Basalt (*5, 6*), which are dominantly those lavas north of the Ochoco–Blue Mountains axis in north-central Oregon, and (ii) the high-alumina and alkali olivine basalts of southern Oregon, northern Nevada and California, and southwestern Idaho, which extend into the Basin and Range structural province. Contrasts between the two regions have been discussed by several authors (*7–9*), and Walker (*8*) has summarized the suspected and proved stratigraphic relationships. In the northern province, the Columbia River Basalt is divided into the older Picture Gorge and younger Yakima members (*5, 6*). These terms are now applied to the whole of the northern province (*10*). The Yakima is believed to be 2×10^5 km^3 in volume (*5, 11, 12*), and Waters (*6*) suggests that the volume of the Picture Gorge is about one-third that of the Yakima. In the south, stratigraphic nomenclature tends to be more geographically restricted, but the Steens Basalt (*8*) of southeastern Oregon and northern Nevada appears to be the most widespread stratigraphic unit. We suggest that a conservative estimate of the total volume of the Columbia River Basalt and volcanics of the southern province would be 3.5×10^5 km^3. As in other volcanic provinces, stratigraphic mapping presents great difficulties because of the general lack of useful paleontological markers, or distinctive petrographic types. As Gray and Kittleman (*13*) have stressed, the Picture Gorge and Yakima are "not necessarily respectively chronologic or mineralogic equivalents throughout the lava fields of the Pacific Northwest."

Table 1. Potassium-argon age determinations for Columbia Plateau basalts. For section numbers and locations see Fig. 2a. Flow numbers refer to the field collection numbering system Full stratigraphic details will be presented in a later publication (*21*). The symbol $^{40*}Ar$ denotes radiogenic argon; m.y., million years. The constants used for the age calculations are the beta decay constant for ^{40}K, $\lambda_\beta = 4.72 \times 10^{-10}$ $year^{-1}$; the electron capture decay constant for ^{40}K, $\lambda_e = 5.84 \times 10^{-11}$ $year^{-1}$; and the ratio $^{40}K/K = 1.19 \times 10^{-4}$, where K is total potassium.

Vertical extent (m)	Flow No.	K (%)	Ar determinations (*N*)	$^{40*}Ar$ [cm^3/g (STP)] $\times 10^7$	Calculated age (m.y.)	Mean age for section (m.y.)
		Section 1. Snake River Bend, Asotin Co. (46°31'N, 117°15'W)				
530	4	0.733	4	4.14	14.1	14.4 ± 0.3
	7	1.37	1	7.92	14.3	
	16	0.694	2	4.05	14.6	
		Section 2. Lapwai Creek (46°14'N, 116°36'W)				
340	6	1.21	2	7.29	15.0	15.2 ± 0.3
	12	1.20	1	7.37	15.4	
		Section 3. Grande Ronde (46°05'N, 117°12'W)				
490	9	1.41	2	8.13	14.4	14.3 ± 0.4
	27	1.48	2	8.41	14.2	
		Section 4. Imnaha (45°32'N, 116°47'W) (29)				
850	8	1.24	2	7.55	15.2	15.3 ± 0.3
	19	1.42	3	8.69	15.3	
		Section 5. Butler Canyon (45°17'N, 121° 10'W)				
270	14	1.53	2	8.94	14.6	
	18 (*30*)	1.57	3	10.30	16.4	
		Section 6. Cow Canyon (44°51'N, 120°54'W)				
200	2	2.75	3	17.0	15.4	15.4 ± 0.3
	8	1.47	2	9.05	15.3	
		Section 7. Picture Gorge (44°31'N, 119°37'W)				
200	14	0.632	2	3.78	14.9	15.2 ± 0.6
	13	.475	2	3.03	15.9	
	8	.495	9	3.16	15.9	
	5	.658	4	3.83	14.5	
	5	.656	5	4.00	15.2	
	4	.470	4	2.80	14.9	
	4	.451	5	2.65	14.7	
	4	.426	8	2.50	14.6	
	3	.386	5	2.41	15.6	
	1	.436	5	2.74	15.7	
		Section 8. Steens Mountain (42°40'N, 118°33'W)				
500	11	1.61	2	9.89	15.3	15.1 ± 0.3
	11–70 (*31*)		29		15.1 ± 0.3	
		Section 9. Owyhee Ridge (43°37'N, 117°17'W)				
300	5	1.04	2	5.58	13.4	13.5 ± 0.3
	16	0.895	1	4.91	13.6	

The available potassium-argon data for the Columbia Plateau are presented in Fig. 1, b, c, and d. Most of these results have been acquired as part of attempts to establish ages of Tertiary floras (*13, 14*), or to define the geomagnetic polarity history (*15*). Only Holmgren (*16*) has integrated the method into a stratigraphic study, but this involved only five lavas in a restricted part of north-central Washington, although the lavas are suspected to be widespread. Since these determinations in general lack replicate analyses, data from lavas in known stratigraphic sequences, and any evaluation of problems such as contamination by atmospheric argon, they do not facilitate confident estimates of the time ranges represented in the lava fields, although the paleontologically derived Miocene age for most of the plateau is verified. We have therefore carried out an extensive series of age determinations on nine separate sequences of basalts in widely separated parts of the plateau. These are shown in Fig. 1a. The total vertical extent of each section is included in Table 1.

No fewer than two separate oriented cores of average mass 120 g were drilled from each lava in each section. The paleomagnetic properties have been published (*7, 17*). The magnetic polar-

ity data for the lava sequences can be interpreted to show that the Columbia River Basalt was extruded over a longer period than the Steens Basalt (*18*). The same samples have now been used for potassium-argon dating.

Specimens were crushed to 10 to 30 mesh. Part of each crushed sample was removed and crushed to −100 mesh for a potassium determination. The rest of the crushed sample was used for argon analysis. The importance of using powdered samples rather than single large pieces of Columbia River basalt for argon extraction purposes has been discussed (*19*). The potassium and argon determinations were carried out by using conventional methods (*20*). The initial results showed that high concentrations of atmospheric argon appear to be characteristic of the Columbia River basalts. In contrast, the Steens basalt has relatively low concentrations. This fact makes us less confident about the meaning of much of the previously published data; for example, the materials used in one study (*13*) were obtained from single, widely separated sites from the Columbia River Basalt.

Our results are summarized in Table 1. The error in the mean ages reported was estimated to be about 3 percent for all but one of the sections. The results will be analyzed in detail, together with the paleomagnetic polarity data for each flow in all sections, in a later publication (*21*). In the context of the problems under consideration here, it is sufficient to state that we have detected a limited period (between 16.0 and 13.0 million years ago) during the middle Miocene when volcanism was very widespread in the Pacific Northwest. We add these results to the data shown in Fig. 1, b, c, and d, and note that although volcanism is indicated between 4.3 and 10.0 million years ago, particularly toward the center of the plateau, it is evident that volcanism during the period 16 and 13 million years ago is represented in most parts of the region. In addition, volcanism approximately 15 million years ago has been reported by Pansze (*22*) in Owyhee County, Idaho, on the southeast edge of the plateau; and Tatsumoto and Snavely (*23*) reported basaltic volcanism east of the Cascade Mountains on the northwestern coast of Oregon, at 16 million years ago. Since we believe that the sequences studied (Fig. 1a) represent the greatest part of the outcropping vertical extent of the entire plateau (*24*), we propose that 80 percent of the estimated volume of 3.5×10^5 km^3 for the Columbia River and Steens basalts accumulated almost entirely in no more than 3 million years. We stress the fact that the precision of isotope dating is such that the period involved may be only 2 million years or even less. This accumulation rate is therefore a minimum of 100×10^6 m^3/year, which is two to three times the rate of production of lavas on volcanic islands (*3, 4*) and at least four to six times that rate in a typical spreading ridge system 600 km in length. Whether the other great plateau basalts (*1*) were produced at similar rates remains to be seen, but models of detailed upper mantle petrogenesis in the Pacific Northwest will have to incorporate limitations implied by these substantial basalt production rates (relative to mid-oceanic processes): this is at variance with Kuno's (*12*) proposal of a prolonged source of heat energy rather than unusually large concentrations of heat energy, as a necessary condition for plateau basalt formation. An immense and probably shallow magma reservoir, capable of sustained regeneration, is clearly required.

The cause of this Pacific Northwest volcanic pulse, which is appropriately called the Columbia volcanic episode, is clearly a speculative matter. We suggest, however, that the complex interaction of western North America and an ancestral offshore spreading and subduction system (*25*) may have reached a critical stage between 16 and 13 million years ago. McKee *et al.* (*26*) have suggested that the cessation of Great Basin volcanism (mostly in Nevada) between 20 and 17 million years ago is similarly involved with megatectonic events (*27*). Perhaps the mechanism involved in the initiation of the opening of the Gulf of California 15 million years ago (*28*) triggered the Columbia volcanic episode.

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Detritus in Lake Tahoe: Structural Modification by Attached Microflora

Abstract. *Readily identifiable groups of microorganisms present on nonliving particulate organic matter (detritus) in the upper waters of Lake Tahoe are attached in specific ways and appear responsible for detrital aggregation. This microflora is associated with active heterotrophic metabolism, but deeper waters possess little detrital microflora and little heterotrophic activity.*

An appreciable pool of organic carbon, nitrogen, and phosphorus is present in suspended matter in lakes. The mean ratio of dissolved to particulate organic carbon is approximately 10 : 1 (*1*). Lake Tahoe, in east California and west Nevada, which has ultraoligotrophic offshore areas not yet affected by man's activity in the watershed (*2*), has ratios of dissolved to particulate organic carbon well below the 10/1 norm. The amount of carbon, nitrogen, and phosphorus in particulate form is a large fraction (20 to 40 percent) of the total standing stock. Due to land disturbance and resultant siltation as well as increased algal growth of both planktonic and attached forms, inputs of particulate organic carbon are increasing. Little is known about the possible use of this material by microorganisms. A basic question persists in the study of microbial utilization of detritus: Do certain microorganisms (bacteria plus fungi) attach to detritus?

Most investigators agree that attachment is common (*3, 4*). Surprisingly, there is little evidence that conclusively demonstrates attachment to detrital matter. Some workers have provided evidence by using phase and ultraviolet light microscopy to substantiate microbial attachment (*3*). The use of stains in light microscopy (*5*) gives results which are difficult to interpret since stains often fail to differentiate between microbes and nonliving material. Autoradiography reveals uptake of organic carbon associated with detritus (*6*), but it is difficult to see cells or mycelia associated with the uptake. Freeze-etch electron microscopy (*7*) and transmission electron microscopy (*8*) yield excellent resolution and have provided workers with detailed photographs of detritus. But the depth of field is limited with the latter technique and attachment to particles is difficult to demonstrate.

Scanning electron microscopy (SEM), in combination with routine sampling and fixing techniques, was therefore employed in order to overcome limitations in resolution and depth of field.

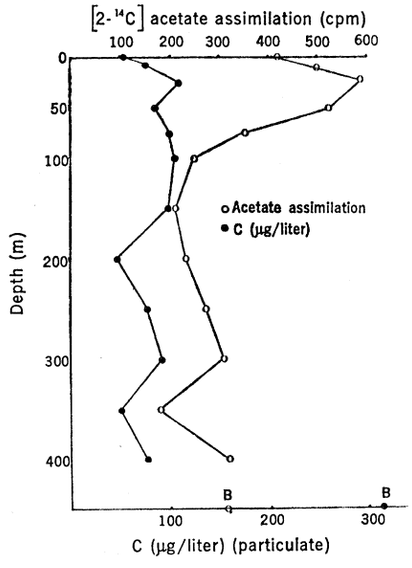

Fig. 1. Relation between heterotrophic activity and particulate carbon in a deep-water profile. Lines are not drawn to the bottom samples, labeled *B*, because of the striking differences in the carbon content of these samples compared to the water column. The maximum sampling depth is 440 m.

Detritus was examined over a vertical profile (0 to 440 m) which was sampled in the middle of Lake Tahoe during the summer of 1972. Subsamples (100 ml) were filtered and prepared for SEM. Gelman 0.45-μm Metricel filters (2.54 cm in diameter) were used. These filters proved to be resistant to organic solvents used in later steps and had fairly smooth surfaces when viewed with SEM. Filtration was carried out at gentle vacuum pressures (less than 500 torr). Filters were folded in half and clamped in place with a small piece of aluminum foil, which could be labeled. This step was performed within 1 minute after filtration was completed in order to prevent desiccation. Filters were then fixed in 2 percent glutaraldehyde buffered with 0.1*M* sodium cacodylate. Fixation for 45 minutes at 5°C gave good results. Dehydration was done by stepwise immersion of the fixed material plus filters in increasing concentrations of ethyl alcohol. Filters were allowed to remain in each concentration of absolute alcohol (10, 25, 50, 75, and 100 percent) for 10 minutes. After dehydration the filters were transferred to amyl acetate for at least 4 hours in preparation for critical point drying (*9*). Solvent exchange was from amyl acetate to carbon dioxide.

Small squares (25 mm^2) were cut from the dried filters and mounted directly on stubs with a silver base adhesive. The stubs were coated in vacuum with two layers of gold, each 100 Å thick, and viewed with a Cambridge Stereoscan scanning electron microscope.

The same samples were monitored for microbial heterotrophic activity. This has been shown to be a sensitive measurement of relative mineralization rates of lacustrine microbes (*6*). Duplicate subsamples were taken at each depth and transferred to sterile 125-ml darkened Pyrex reagent bottles. A trace amount (10 ng of acetate per liter) of [2-^{14}C]acetate was added to each sample. The incubation time was 1 hour in a dark incubator set at sampling temperature. Rates of assimilation of acetate over the 1-hour period were compared for samples taken at all 13 depths. The acetate concentration in the lake varied from 1 to 10 μg/liter. The values were derived from both gas chromatographic analyses and kinetic plots. Assimilation of acetate has been shown to be largely by bacteria (*6*). Determinations of total particulate carbon were made at each depth. One-liter subsamples were fil-