and southern Rocky Mountain provinces (*29*), can be similarly related to the shallow part of the inner eastern subduction zone.

Reconstruction of the inferred Pleistocene paleoseismic zone under the Oregon and Washington Cascade volcanic chain (*21*) indicates dips of 40° to 50°. We suggest that the low-angle imbricate Eocene subduction system in the Pacific Northwest (Fig. 3) was replaced in early Oligocene time by a steeper subduction zone that was active until recently. This shift is reflected by the termination of andesitic volcanism in the continental interior (Montana, Wyoming, and Idaho) about 40 million years ago (Fig. 2) and its continuation in the Cascade region through Quaternary time (*30*).

In the western and southwestern United States the low-angle imbricate subduction system operated through Oligocene time, as indicated by the distribution of Oligocene andesitic volcanic rocks in these regions (Fig. 2b). Predominantly calc-alkalic intermediate-composition volcanism terminated in the southwestern United States at about the end of the Oligocene, but it continued in Miocene and Pliocene time in parts of western Nevada and eastern California and through the Quaternary in the Cascade Range (*6*). Initial intersection of the Pacific and American plates (Fig. 2b) probably also occurred at about the end of Oligocene time (*1*). We interpret the enlarging gap in the belt of late Cenozoic andesitic volcanism in western North America as reflecting the growing zone of contact between the American and Pacific plates (Fig. 1), where the intervening plate had been consumed and the trench replaced by a transform boundary system (*1, 6*).

This analysis leaves unresolved problems such as the cause of the abrupt shift in subduction geometry at about the end of Cretaceous time, the persistence of the potentially unstable imbricate geometry over much of the Tertiary, and the periodicity of subduction-related igneous activity—with well-defined Laramide and middle Tertiary peaks. We suspect that these features reflect factors such as changes of subduction rate with time, velocity differences between the two imbricate subduction zones, mobility of the asthenosphere between the two zones, and changes in absolute motion of the main American plate relative to the underlying asthenosphere. In particular, analysis of plate motions with respect to mantle "hot-spots" (*31*) suggests that the American plate moved westward especially rapidly from about 80 to 40 million years ago (*32*). A rapidly moving American plate could have recurrently overridden and entrapped gently dipping lobes of Farallon plate, which would have become attenuated and separated from the main Farallon plate and could then descend slowly, because of density differences, into the asthenosphere, as the main subduction boundary was reestablished farther west.

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Precambrian Columnar Stromatolite Diversity: Reflection of Metazoan Appearance

Abstract. *Columnar stromatolites (organosedimentary structures built by blue-green algae) show a marked decrease in diversity in the Late Precambrian; this decrease in diversity occurs at approximately the same time as the appearance of metazoans, 600 to 700 million years ago.*

Stromatolites constitute the most abundant fossils in the Precambrian. Their widespread occurrence in carbonates continues into the early Lower Paleozoic, but by Middle Ordovician time they begin to decline (*1*). Garrett (*2*) attributes this decline in the Phanerozoic to the evolution and diversification of grazing and burrowing metazoans. In effect, these animals restricted stromatolites to one or a combination of the following environments: (i) intertidal-supratidal zones, (ii) hypersaline regions, and (iii) environments where strong current and high sediment movement exclude burrowers and grazers (*2*).

Before the rise of metazoans, the only ecologic restrictions on stromatolite growth probably were (i) depth of

Table 1. Ediacaran metazoan occurrences and ages.

Location	Rock unit	Isotopic age (million years)
Ediacara, South Australia	Pound quartzite	
Flinders Range, South Australia	Pound quartzite	
Punkerri Hills, South Australia	Punkerri sandstone	
Deep Well, Northern Territory, Australia	Arumbera sandstone	
Charnwood Forest, England	Woodhouse beds	574–684
South West Africa	Kuibis quartzite	> 510
Torneträsk, Sweden		~ 600
Podolia, Ukraine	Bernashov beds	590
Yarensk, U.S.S.R.	Gdov laminarites beds	~ 590
Olënek, U.S.S.R.	Khatyspyt formation	550–675
Rybatschii Peninsula, U.S.S.R.		670–900
Central and eastern Russian Platform		550–675
Southeast Newfoundland	Conception Bay group	?574 ± 11

light penetration; (ii) possible temperature limitations; (iii) unfavorable chemical and nutrient conditions; (iv) possible prolonged exposure to ultraviolet radiation (*3*) in the shallow subtidal, intertidal, and supratidal environments; (v) the rate of sediment deposition exceeding microorganism growth; and (vi) the current and wave action of an exceptionally rigorous environment preventing establishment of algal mats.

Paleoecological interpretations of Precambrian stromatolite environments range from intertidal, periodically exposed environments to subtidal regions below the wave base, with little evidence of agitation (*4*).

Columnar stromatolites (*5*), particularly *Conophyton*, seem to be the most common subtidal stromatolites in the Precambrian (*6*). The subtidal nature of most columnar stromatolites is inferred from the lack of criteria indicating a periodically exposed intertidal to supratidal environment [desiccation cracks, salt casts, rain impressions, and truncated or disrupted stromatolitic laminae (*7*)]. The great size exhibited by many columnar stromatolites in the Precambrian also favors a subtidal environment. I find it inconceivable that conical columnar stromatolites (*8*), up to 10 m in diameter and 15 m in vertical relief, could have grown in an artificial environment.

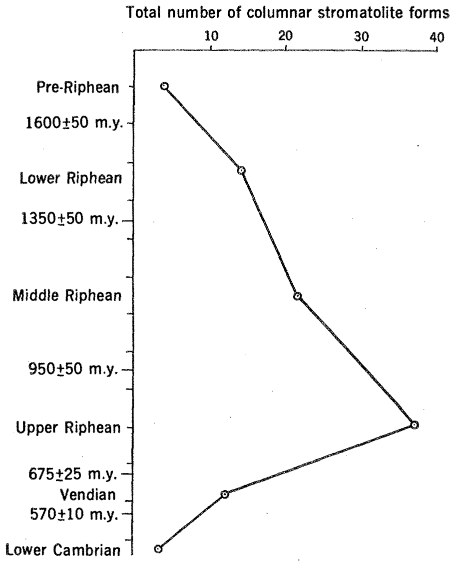

Fig. 1. Diversity curve for Precambrian columnar stromatolites.

Several distinct morphotypes of columnar stromatolites have been found to have limited ranges within Precambrian time (*9*). Figure 1 is a diversity curve based on taxonomically well-defined columnar stromatolites (both time-stratigraphic significant forms and others not restricted in time); it represents the occurrence of the total number of distinctive stromatolite morphologies within subdivisions of the Precambrian and Lower Cambrian (*10*). It is evident that in the Vendian there is a marked decrease in the diversity of columnar stromatolites. I postulate that this decrease reflects the evolution of bottom deposit feeders and burrowing metazoans in the Late Precambrian. It is reasonable to assume that the first environment inhabited by these metazoans would have been the subtidal region. The first stromatolites to reflect this appearance, therefore, would have been the subtidal forms, among which the columnar forms were dominant.

The apparent "extinction" of many columnar stromatolites in the Late Precambrian reflects the destruction of stromatolites by burrowing metazoans, the inhibition of stromatolite growth by metazoans feeding on bottom deposits, and the restriction of stromatolites to specialized environments (those that exclude metazoans), such as regions in which columnar forms are presently growing in Shark Bay, Western Australia (*11*).

According to available data (*12*), metazoans similar to the Ediacaran and Nama faunas appeared 600 to 700 million years ago (Table 1). Presumably, these types of faunas included pelagic and attached benthic forms, annelids, and arthropods resembling trilobites (*13*); these included burrowers and probably bottom feeders. The time of appearance of these metazoans is in agreement with the columnar stromatolite diversity curve, which shows that diversity sharply decreased in the Vendian (570 ± 10 to 675 ± 25 million years ago) (*14*).

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5. Columnar stromatolites are defined as individually isolated algal structures with a pronounced vertical expression in growth above the substrate. Laminae in the axial zone are thicker than laminae at the periphery, and successive laminae may or may not overlap the base of preceding laminae. Branching may or may not be common in nonconical (excluding *Conophyton*) forms.
6. I do not wish to imply that all columnar stromatolites are subtidal. P. Hoffman, B. W. Logan, and C. D. Gebelein (in preparation) describe Recent columnar stromatolites growing in an intertidal, unprotected environment in Shark Bay, Western Australia; this may also be true of some Precambrian columnar stromatolites.
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15. I thank H. E. Andrews, E. S. Barghoorn, C. Jones, B. Kummel, and J. Sepkoski (Harvard University) and M. R. Walter (Yale University) for comments and aid in preparing this report. C. Jones drafted the figure.

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Eutrophication of Lake Water Microcosms: Phosphate versus Nonphosphate Detergents

Abstract. *The eutrophication potentials of a phosphate-containing detergent and two phosphate-free detergents, as determined in oligotrophic algal microcosms after activated sludge treatment, were not significantly different. All activated sludge effluents, including those from detergent-free waste water, lowered the algal diversity of the microcosms to about the same extent below that of the lake water controls.*

In their concern for the environment, federal and local legislators have introduced a deluge of bills aimed at controlling various pollutants. In particular, the detergent industry has been pressured to eliminate phosphates from detergent formulations. Some observers have expressed concern that excessive emotion and precipitous action may lead to ineffective and toxic detergent formulations (*1*), and yet the rush to pass new legislation continues.

Eutrophication is a surface water problem that has reached widespread proportions (*2*). Although there is some argument about which nutrients are the causative agents in eutrophication (*3*), many ecologists, limnologists, and environmental engineers agree that control and elimination of sources of phosphorus can control the nuisance blue-green algae blooms which often accompany eutrophic conditions in a lake. In general, only 50 percent or less of the total phosphate in lakes enters through domestic waste water (*4*); this source is, however, the one now receiving most attention.

Present-day domestic waste water contains about 10 mg of total phosphorus per liter, and one-half to two-thirds of this amount is from detergent phosphates (*5*). Thus, even with the elimination of detergent phosphates, about 3 to 4 mg of phosphorus per liter would remain in effluents from domestic waste water treatment plants, since conventional treatment generally does not remove much phosphate. Therefore, the real question is: Would a 50 to 60 percent reduction in phosphorus concentrations in domestic waste water significantly reduce the eutrophic conditions in our lakes?

I here report some direct experimental evidence indicating that the elimination of phosphates from detergents would make no significant improvement in eutrophic conditions in the lake receiving the resulting waste water effluent. The microcosm algal assay procedure developed by Mitchell and Buzzell (*6*) was used. The ecological significance of the various waste waters tested was assessed in terms of the resulting algal diversity calculated as Shannon's diversity index (*7*)

$$H_1 = -\Sigma P_i \log P_i$$

where $P_i = n_i/N$, n_i is the population of the ith species, and N is the population of the total community. The index ranges from zero for unialgal populations to unity for very diverse algal communities.

In general, the diversity of a lake's algal community diminishes with eutrophication (*8*). Thus, oligotrophic lakes would probably have diversity indices of from 0.7 to 1.0, and, as the lakes become eutrophic, the diversity index would drop to 0.3 or less.

Three detergent formulations were chosen for this study from store shelves to give a wide range of composition (Table 1). Product 1 was a phosphate-containing anionic surfactant formulation. The other two detergents were phosphate-free formulations, with nonionic and anionic surfactants. Both products 2 and 3 have been extensively advertised as "ecologically safe" for the environment.

A synthetic waste water was prepared whose composition was based on the glucose-peptone waste water designed by Wiener (*9*) to model domestic waste water in activated sludge treatment, but with the inclusion of a bicarbonate buffer in place of the phosphate buffer. A stock solution of the synthetic waste water was made up to 1 liter deionized water as follows: 16.0 g of glucose, 16.5 g of peptone, 2.5 g of urea, and 10.0 g of sodium bicarbonate for buffering. The syn-

Table 1. Composition and properties of detergents.

Characteristics	Detergent		
	1	2	3
*Ingredients (% by weight)**			
Anionic surfactant	18		5
Nonionic surfactant	2	11	2
Sodium tripolyphosphate	50		
Sodium carbonate		65	21
Sodium silicate solids (from liquids)	6	8	
Sodium metasilicate pentahydrate			21
Sodium chloride			45
Sodium sulfate	14		4
Sodium carboxymethyl cellulose (65% pure)	< 1	5	1
Water	10	10	
Brighteners, perfume, etc. (estimated)	< 1	< 1	< 1
Properties			
Loose density (g/cm^3)	0.33	1.04	0.85
Solution *p*H in the concentration used	9.7	10.8	11.3
Alkalinity (% Na_2O)†	9.6	42	19
Recommended amount (cups)	1¼	½	1
Grams per wash load	98	123	201
Solution concentration for the recommended amount of detergent (% by weight)	0.15	0.19	0.31

* Values are based on analyses of purchased samples carried out in the Monsanto detergent laboratory. † Titration to *p*H 4.