6. D. J. DePaolo and B. L. Ingram, *Science* **227**, 938 (1985).
7. J. Hess, M. L. Bender, J.-G. Schilling, *ibid.* **231**, 979 (1986).
8. R. C. Capo and D. J. DePaolo, *ibid.* **249**, 51 (1990).
9. H. D. Holland, *The Chemistry of the Atmosphere and Oceans* (Wiley, New York, 1978).
10. M. R. Palmer and J. M. Edmond, *Earth Planet. Sci. Lett.* **92**, 11 (1989).
11. G. W. Brass, *Geochim. Cosmochim. Acta* **40**, 721 (1976).
12. M. A. Wadleigh, J. Veizer, C. Brooks, *ibid.* **49**, 1727 (1985).
13. F. Albarede and A. Michard, *Chem. Geol.* **64**, 55 (1987).
14. S. J. Goldstein and S. B. Jacobsen, *ibid.*, p. 245.
15. River water was collected in 1-liter Teflon bottles and immediately acidified with 4 N nitric acid. The water (100 to 500 ml) was brought to dryness under a heat lamp, and K, Rb, and Sr concentrations were measured by isotopic dilution. For isotopic analyses, 100 ng of Sr in nitric acid, followed by 2 μl of a tantalum oxide–phosphoric acid slurry were evaporated onto a Re filament, which was then heated until red hot. The $^{87}Sr/^{86}Sr$ ratios were measured on a VG Sector 354 multicollector mass spectrometer in dynamic multicollection mode.
16. The San Joaquin River drains granitic and metamorphic rocks in the southern Sierra Nevada; these rocks have an average $^{87}Sr/^{86}Sr$ ratio of about 0.707 to 0.709. The Sacramento River drains the northern Sierra Nevadan granitic and metamorphic rocks and the young Cascade volcanic rocks, which have $^{87}Sr/^{86}Sr$ ratios of 0.704 to 0.707 (*17*).
17. R. W. Kistler and Z. E. Peterman, *Geol. Soc. Am. Bull.* **84**, 3489 (1973); U. Masi, J. R. O'Neil, R. W. Kistler, *Contrib. Mineral. Petrol.* **76**, 116 (1981).
18. We converted the $^{87}Sr/^{86}Sr$ ratios to $\Delta^{87}Sr$ values to allow interlaboratory comparison: $\Delta^{87}Sr = (^{87}Sr/^{86}Sr_{sample}) - (^{87}Sr/^{86}Sr_{standard}) \times 100,000$. Because the isotopic ratio can be measured to ±1 unit of $\Delta^{87}Sr$ (or 1 part in 10^5 of the $^{87}Sr/^{86}Sr$ ratio), the predicted relations (Fig. 3, A and B) show that the $^{87}Sr/^{86}Sr$ measurements are useful as a proxy for all salinities but are particularly sensitive for those less than about 25 per mil.
19. Surface water samples from San Francisco Bay were collected on 11 March 1991, in 0.5-liter Teflon bottles, by A. Van Geen, U.S. Geological Survey, Menlo Park, California. The samples were not acidified after collection, which may account for the slightly lower than expected Sr concentrations seen in many of the samples.
20. D. Sloan, thesis, University of California, Berkeley (1981).
21. B. F. Atwater *et al.*, in *San Francisco Bay: The Urbanized Estuary*, T. C. Conomos, Ed. (Pacific Division, AAAS, San Francisco, 1979), pp. 347–385.
22. _____, B. E. Ross, J. F. Wehmiller, *Quat. Res.* **16**, 181 (1981).
23. D. G. Martinson *et al.*, *ibid.* **27**, 1 (1987).
24. D. Sloan, *Geol. Soc. Am. Bull.*, in press.
25. _____, in *Quaternary Depositional Environments of the Pacific Coast*, M. E. Field *et al.*, Eds. (Society of Economic Paleontologists and Mineralogists, San Francisco, 1980), pp. 1–12.
26. The marsh environments (<10 m water depth) represented at the base of the Yerba Buena mud have low salinities (10 to 30 per mil), in which *Elphidium gunteri* and *Trochammina* are the dominant foraminifers (biofacies A). Samples from the middle of the unit represent subtidal environments with depths of 20 m or less and salinities from 15 to 35 per mil, with *Elphidium excavatum* and *Ammonia beccarii* as the dominant species (biofacies B). The upper samples in the boreholes represent marine intertidal to subtidal environments with salinity and temperature comparable to conditions along the coast today (33 to 35 per mil, water depths up to 50 m) in which *Elphidiella hannai* and *Buccella frigida* are common (biofacies C and D).
27. $^{87}Sr/^{86}Sr$ ratios were measured on 0.5- to 2-mg samples of carbonate foraminifera shells. The samples were cleaned ultrasonically with Nannopure water, dried, dissolved in weak acetic acid (to minimize contamination from noncarbonate phases such as clays), and then centrifuged. One aliquot of the sample was used to determine Sr and Rb concentrations by isotope dilution. Another aliquot was passed through an ion-exchange column to separate purified Sr. One hundred nanograms of purified Sr was used for isotopic analysis [see (*16*)].
28. F. H. Nichols, J. E. Cloern, S. N. Luoma, D. H. Peterson, *Science* **231**, 567 (1986).
29. H. C. Fritts, *Mon. Weather Rev.* **93**, 421 (1965); _____, G. R. Lofgren, G. A. Gordon, *Quat. Res.* **12**, 18 (1979).
30. We thank D. J. DePaolo for use of the laboratories at the Center for Isotope Geochemistry of the University of California, Berkeley, and the Lawrence Berkeley Laboratory, and for helpful discussion of the data and reviews of the manuscript. We also thank J. C. Ingle, W. B. N. Berry, E. Clifton, W. E. Dietrich, and D. H. Peterson who provided insightful discussions and comments.

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Production of Isotopic Variability in Continental Basalts by Cryptic Crustal Contamination

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Regional variations in the Nd, Sr, and Pb isotopic compositions of Neogene basalts from the western United States are commonly interpreted to originate in the subcontinental mantle. In southern California, isotopic variability is restricted to lavas that lack mantle-derived xenoliths; xenolith-bearing basalts have uniform isotopic compositions similar to those of ocean-island basalts (OIBs). Combined with available geochemical data, these observations suggest that isotopic variability at these volcanoes results from subtle crustal contamination, locally by mafic crust, of primitive OIB-like magma. Recognition of such cryptic contamination may help to reconcile local discrepancies between tectonic and isotopic views of the subcontinental mantle.

ISOTOPIC VARIATIONS IN BASALTS CAN yield information about the geodynamic history of the mantle. For example, variations in the Sr and Nd isotopic compositions of basalts have been used to infer the presence of old, isolated, lithospheric mantle beneath continents (*1–6*) and to track changes in mantle structure resulting from subduction and extension (*7, 8*). These conclusions are valid only if the basalts are unaffected by crustal contamination, but recent data (*9*) support Moyer and Esperança's (*10*) claim that isotopic variability can result from subtle crustal contamination that is not detectable by common geochemical screens.

In this study of Neogene basalts from the Mojave Desert of southern California we show that lavas bearing mantle xenoliths consistently have Nd and Sr isotopic compositions similar to those of modern-day ocean island basalts (OIBs), whereas xenolith-free basalts have a wider range of isotopic compositions that trend from OIB toward values expected for the continental lithosphere. This observation can be explained if xenolith-bearing magmas traversed the crust rapidly without interaction, whereas xenolith-free magmas stalled in the crust long enough for entrained xenoliths to be dropped or digested and for crustal interaction to occur.

Small-volume Neogene basalts occur throughout much of the Mojave Desert region (Fig. 1). These lavas range from alkali olivine basalts to hawaiites (*9, 11, 12*) and most have elemental characteristics that are traditionally invoked as evidence against significant silicic crustal contamination [high P_2O_5/K_2O ratios; high large-ion-lithophile, rare earth element, Sr, and Ni concentrations; and nepheline-normative compositions (*1, 2, 13, 14*)]. The lavas show a wide range of correlated Nd and Sr isotopic compositions (Table 1; Fig. 2), from values typical of asthenosphere-derived, OIBs (ε_{Nd} = +6 to +9 and $^{87}Sr/^{86}Sr$ ratios of 0.7025 to 0.7035) to values generally attributed to ancient lithospheric mantle underlying the North American craton [ε_{Nd} = −3 to +6 and $^{87}Sr/^{86}Sr$ ratios of 0.7035 to 0.7067 (*3, 6, 15, 16*)].

One interpretation of this data set is that low-ε_{Nd} basalts were derived from ancient lithospheric mantle and high-ε_{Nd} basalts from upwelling asthenospheric mantle. However, this interpretation fails to account for three aspects of the lavas: (i) lavas that carry mantle xenoliths (for example, peridotite) generally have OIB-like isotopic ratios, whereas lavas without mantle xenoliths scatter from OIB-like ratios to lower ε_{Nd} values and higher $^{87}Sr/^{86}Sr$ values (Fig. 2); (ii) the observation that high-ε_{Nd} and low-ε_{Nd} lavas are interleaved in both space and time (Ta-

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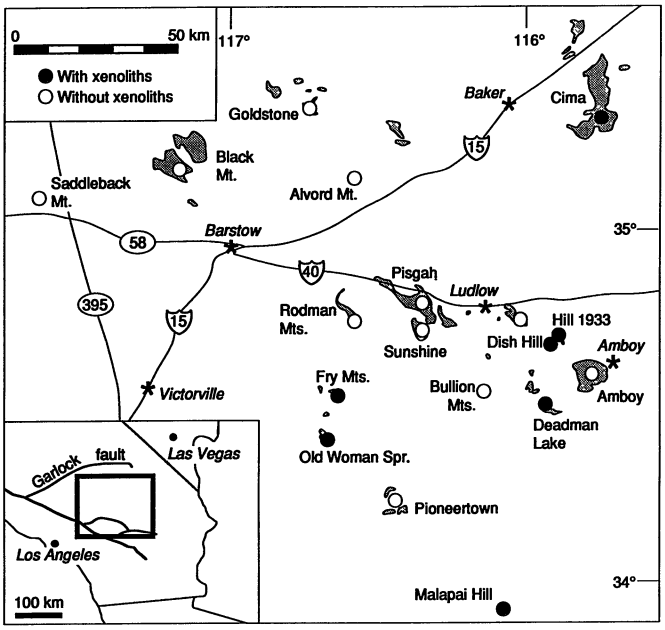
Fig. 1. Locations of flat-lying Neogene basalts in the Mojave Desert region of California. Only undeformed or weakly deformed, generally mid-Miocene to Pleistocene basalts are shown (shaded areas). Samples from Saddleback Mountain and the Bullion Mountains are from deformed early Miocene volcanic sequences, which crop out extensively in this region. Symbols give general locations of samples in Table 1; where several samples were taken from a given locality, only one symbol is plotted.



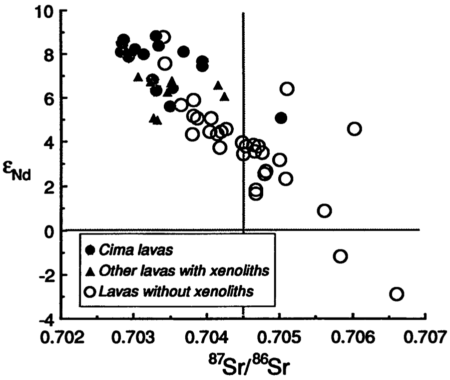


Fig. 2. Nd-Sr isotope relations. Only lavas without mantle xenoliths have low ε_{Nd} values and high $^{87}Sr/^{86}Sr$ ratios, characteristics that are generally ascribed to derivation from ancient lithospheric mantle. Lavas that carry mantle xenoliths (and presumably traversed the crust rapidly, avoiding contamination) consistently have high ε_{Nd} values and low $^{87}Sr/^{86}Sr$ ratios. Slight alteration probably accounts for high $^{87}Sr/^{86}Sr$ (0.705) of Cima sample Ci-53. Data shown include 20 analyses of xenolith-free Pisgah and Amboy basalts from (*9*) which are not listed in Table 1.

Sample	Locality	Age	$^{87}Sr/^{86}Sr$	$\varepsilon_{Nd}(0)$
		Without mantle xenoliths		
KW-1	RM	P	0.70467	1.68
KW-2	″	″	0.70510	6.40
KW-3	″	″	0.70476	3.51
KW-4	″	″	0.70561	0.88
BMB-4	BM	Po	0.70342	7.59
OPAL-6	″	″	0.70340	8.76
LVLK-3	SC	″	0.70470	3.75
MS4-7	PT	lt M	0.70417	3.71
MS5-9	″	″	0.70450	3.45
LNMT-17	G	e-m M	0.70481	2.67
LNMT-18	″	″	0.70508	2.34
NBPS-6	BU	″	0.70583	−1.19
SADL-1	SM	″	0.70465	3.53
LUDL-C	L	″	0.70662	−2.98
LUDL9012A	″	″	0.70467	1.85
ALVO-3	AM	″	0.70603	4.58
		With mantle xenoliths		
Ci-15	C	Po–P	0.70313	8.00
Ci-43	″	″	0.70293	8.04
Ci-6-1	″	″	0.70292	7.90
Ci-20	″	″	0.70299	8.15
Ci-12	″	″	0.70349	5.62
Ci-60	″	″	0.70334	8.39
Ci-57	″	″	0.70393	7.69
Ci-56	″	″	0.70368	8.10
CD-1	″	″	0.70300	8.25
CD-3	″	″	0.70285	8.64
CD-5	″	″	0.70331	8.86
CD-9	″	″	0.70284	8.49
CD-13	″	″	0.70282	8.13
DL-5	DL	″	0.70349	6.40
DL-8-1	″	″	0.70306	6.94
MH-1	MH	″	0.70329	5.05
MH-2	″	″	0.70330	4.99
BA-2-102	DH	″	0.70415	6.55
BA-3-101	H	″	0.70324	6.71
Ci-10-101	C	lt M	0.70324	6.81
Ci-53	″	″	0.70502	5.03
Ci-49	″	″	0.70330	6.34
Ci-16	″	″	0.70394	7.45
CD-8	″	″	0.70352	6.44
FRY9013B	FM	″	0.70353	6.75
OWSP9013B	OWS	″	0.70425	6.03

Table 1. Sr and Nd isotopic ratios of Miocene-Recent basalts from the Mojave Desert. Values listed are present-day ratios; for the oldest samples, age corrections are generally less than 0.0001 for $^{87}Sr/^{86}Sr$ ratios and 0.1 for ε_{Nd} values. Internal precisions (2σ) for $^{87}Sr/^{86}Sr$ ratios and ε_{Nd} values are ±0.00001 and 0.25, respectively. Analytical procedures are the same as those described in (*9*). Samples from Cima field are listed as xenolith-bearing, even though some of sampled flows lack xenoliths, because the field as a whole is rich in mantle xenoliths and megacrysts. The notation $\varepsilon_{Nd}(0)$ refers to ε_{Nd} calculated relative to a present-day chondritic reservoir. P, Pleistocene; Po, Pliocene; M, Miocene; e-m to middle; lt, late; RM, Rodman Mountains; BM, Black Mountain; SC, Sunshine cone; PT, Pioneertown; G, Goldstone; BU, Bullion Mountains; SM, Saddleback Mountain; L, Ludlow; AM, Alvord Mountain; C, Cima; DL, Deadman Lake; MH, Malapai Hill; DH, Dish Hill; H, Hill 1933; FM, Fry Mountains; OWS, Old Woman Springs.

ble 1 and Fig. 2) rules out tectonic replacement of one type of mantle by another; and (iii) tectonic studies indicate that lithospheric mantle should have been swept from beneath southern California by shallow subduction in the early Tertiary (*17, 18*).

Correlation of the abundance of mantle xenoliths with isotope ratios is particularly difficult to account for with models in which two distinct mantle sources are invoked. For example, Pleistocene Pisgah and Amboy cones (Fig. 1), which are barren of xenoliths, erupted low-ε_{Nd} lavas, whereas nearby Pleistocene xenolith-rich lavas at Dish Hill and Deadman Lake have OIB-like ratios. Xenolith-free late Miocene basalts near Pioneertown have low ε_{Nd} values, whereas xenolith-rich late Miocene basalts from the nearby Fry Mountains and Old Woman Springs (Fig. 1) have high ε_{Nd} values.

We interpret the relation between xenolith abundance and isotope ratios to reflect variations in the ascent rate and crustal residence time of magmas. Rapid ascent keeps xenoliths suspended (*19*) and minimizes the possibility of interaction between magma and crust, a scenario consistent with the high ε_{Nd} and low $^{87}Sr/^{86}Sr$ values of xenolith-bearing basalts in the Mojave Desert. Slow ascent and storage in crustal reservoirs allow chemical interaction between crust and magma, producing the low ε_{Nd} and high $^{87}Sr/^{86}Sr$ values of the xenolith-free basalts, and allows entrained xenoliths to settle out or to be disaggregated. A likely place for such interaction is at midcrustal density interfaces, where basaltic magmas can be trapped by density crossovers (*9, 20*).

Correlation between the occurrence of mantle xenoliths and basalt isotopic compositions provides strong circumstantial evidence that crustal contamination plays a role in producing low ε_{Nd} values in some basalts. This conclusion is supported by detailed studies at Pisgah and Amboy volcanoes (*9*), where chemical and isotopic variability in the basalts is likely a result of mixing of an OIB-like basalt with partial melts of mafic crustal rocks. This variability is best exhibited at Pisgah, where lavas evolved from those with high-MgO contents (8.5% by weight), high ε_{Nd} values (+6), and low $^{87}Sr/^{86}Sr$ ratios (0.7036), to those with low MgO contents (5%), low ε_{Nd} (+2.3) values, and high $^{87}Sr/^{86}Sr$ ratios (0.705) over the course of a few decades. Closed-system differentiation alone cannot account for either the range of isotopic compositions or the positive correlation between incompatible element concentrations and MgO content.

The good correlation between Sr, Nd, and Pb concentrations and isotopic compositions at Pisgah and Amboy indicates that the basalts are mixtures of two magmas. The high-MgO, high-K_2O component has an isotopic composition similar to OIB and most likely represents a mantle-derived magma. The low-MgO component is tightly constrained by major and trace-element data to have ~51% by weight SiO_2, 4% MgO, 0.8% K_2O, an ε_{Nd} value of ~+1.5, and a $^{87}Sr/^{86}Sr$ ratio of ~0.7055. Late Jurassic gabbros and Proterozoic diabases in the Mojave Desert have appropriate compositions and isotope ratios to be the source of the low-MgO mixing component (*21*). Large degrees (~50%) of partial melting of such mafic crustal rocks could produce the low-MgO basaltic magmas observed at Pisgah (*9*).

Recognition of subtle contamination of basalts may help to reconcile conflicting tectonic and isotopic views of the mantle in the southwestern United States. For example, basalts with low ε_{Nd} values and high $^{87}Sr/^{86}Sr$ ratios have been used as evidence that ancient lithospheric mantle underlies much of the area north and northeast of the Mojave Desert (*1–3, 8, 14, 22*). Tectonic studies, however, suggest that such mantle should have been stripped from beneath the Mojave Desert during shallow subduction in the late Mesozoic and early Cenozoic (*17, 18*). In the northern Mojave Desert and southern Sierra Nevada, where schists thought to be part of the subducted Farallon plate are found thrust directly beneath lower crustal rocks of the North American plate (*18*), there is thus little room for the preservation of thick, ancient, lithospheric mantle.

These observations can be reconciled in two ways. If the low ε_{Nd} values and high $^{87}Sr/^{86}Sr$ ratios of basalts north and northeast of the Mojave Desert originate from lithospheric mantle, then there must be a major boundary in the mantle near the Garlock fault that separates ancient mantle to the north from OIB-like mantle to the south. Alternatively, some of these anomalous isotopic ratios may result from cryptic contamination of OIB-like magmas. Delineation of the presence, location, and significance of a mantle boundary will require careful consideration of the effects of cryptic contamination.

REFERENCES AND NOTES

1. C. E. Hedge and D. C. Noble, *Geol. Soc. Am. Bull.* **82**, 3503 (1971).
2. W. P. Leeman, *ibid.* **93**, 487 (1982).
3. M. A. Menzies, W. P. Leeman, C. J. Hawkesworth, *Nature* **303**, 205 (1983).
4. S. H. Richardson, J. J. Gurney, A. J. Erlank, J. W. Harris, *ibid.* **310**, 198 (1984).
5. F. Ö. Dudás, R. W. Carlson, D. H. Eggler, *Geology* **15**, 22 (1987).
6. M. A. Menzies, *J. Geophys. Res.* **94**, 7899 (1989).
7. F. V. Perry, W. S. Baldridge, D. J. DePaolo, *Nature* **332**, 432 (1988).
8. D. S. Ormerod, C. J. Hawkesworth, N. W. Rogers, W. P. Leeman, M. A. Menzies, *ibid.* **333**, 349 (1988).
9. A. F. Glazner, G. L. Farmer, W. T. Hughes, J. L. Wooden, W. Pickthorn, *J. Geophys. Res.* **96**, 13,673 (1991).
10. T. C. Moyer and S. Esperança, *N.M. Bur. Mines Miner. Resour. Bull.* **131**, 198 (1989).
11. W. S. Wise, *Contrib. Mineral. Petrol.* **23**, 53 (1969); W. P. Leeman and J. J. W. Rogers, *ibid.* **25**, 1 (1970); S. L. Neville, P. Schiffman, P. Sadler, *Am. Mineral.* **70**, 668 (1985); H. G. Wilshire, A. V. McGuire, J. S. Noller, B. D. Turrin, *J. Petrol.* **32**, 169 (1991).
12. A. F. Glazner and G. L. Farmer, unpublished data.
13. D. R. Dickinson, M. H. Dodson, I. G. Gass, D. C. Rex, *Earth Planet. Sci. Lett.* **6**, 84 (1969).
14. G. L. Farmer *et al.*, *J. Geophys. Res.* **94**, 7885 (1989).
15. F. V. Perry, W. S. Baldridge, D. J. DePaolo, *ibid.* **92**, 9193 (1987). Nd isotope ratios are quoted in ε notation, where ε_{Nd} is defined as $10^4[(^{143}Nd/^{144}Nd_{rock}(T)/^{143}Nd/^{144}Nd_{CHUR}(T)) - 1]$, *T* is the age of the rock, and CHUR refers to a model chondritic reservoir. Complete analytical details and normalization factors are in (*19*).
16. J. H. Wittke, D. Smith, J. L. Wooden, *Contrib. Mineral. Petrol.* **101**, 57 (1989).
17. R. S. Yeats, *Stanford Univ. Publ. Geol. Sci.* **11**, 307 (1968); P. Bird, *Science* **239**, 1501 (1988); A. F. Glazner and J. R. O'Neil, *J. Geophys. Res.* **94**, 7861 (1989).
18. B. C. Burchfiel and G. A. Davis, in *The Geotectonic Development of California*, W. G. Ernst, Ed. (Prentice-Hall, Englewood Cliffs, NJ, 1981), pp. 217–252.
19. I. S. E. Carmichael, J. Nicholls, F. J. Spera, B. J. Wood, S. A. Nelson, *Philos. Trans. R. Soc. London Ser. A* **286**, 373 (1977).
20. A. F. Glazner and W. Ussler III, *Geophys. Res. Lett.* **15**, 673 (1988).
21. J. G. Hammond and J. L. Wooden, in *Mafic Dykes and Emplacement Mechanisms*, A. J. Parker, P. C. Rickwood, D. H. Tucker, Eds. (Balkema, Rotterdam, 1990), pp. 145–156; M. W. Martin, J. S. Miller, A. F. Glazner, J. D. Walker, *Geol. Soc. Am. Abstr. Progr.* **22**, A63 (1990).
22. D. S. Coleman and J. D. Walker, *Mem. Geol. Soc. Am.* **176**, 391 (1990); J. D. Walker and D. S. Coleman, *Geology* **19**, 971.

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The Antiquity of Oxygenic Photosynthesis: Evidence from Stromatolites in Sulphate-Deficient Archaean Lakes

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The Tumbiana Formation, about 2700 million years old, was largely deposited in ephemeral saline lakes, as judged by the unusual evaporite paragenesis of carbonate and halite with no sulfate. Stromatolites of diverse morphology occur in the lacustrine sediments, some with palimpsest fabrics after erect filaments. These stromatolites were probably accreted by phototropic microbes that, from their habitat in shallow isolated basins with negligible sulfate concentrations, almost certainly metabolized by oxygenic photosynthesis.

Earth's unusually oxygenated atmosphere was not produced by abiogenic processes alone. Its redox state is clearly influenced by organisms metabolizing by oxygenic photosynthesis, that is, those that use water rather than exogenous reducing power as the electron donor for CO_2 reduction, liberating oxygen in the process. Just when organisms first evolved this ability to modify the atmosphere is unclear (*1*). Early Precambrian microfossils (*2*), stromatolite fabrics (*3*), and carbon isotope data (*4*) suggest, but do not prove, that aerobic photosynthesizers first appeared during the Archaean (*1*). Global mass balances of biogeochemically important elements (*5*) depend, for primeval times, upon poorly constrained quantities. Potentially, a more robust record of the early evolution of oxygenic photosynthesis is obtainable from microbial remains in environments isolated from external sources of reducing power. Here I report on a stromatolite assemblage from the late Archaean Fortescue Group of Western Australia, members of which were accreted by phototropic filamentous microorganisms in sulfate-deficient evaporative lakes. Their presence in such a setting indicates that by 2700 million years ago, complex microbial communities with a trophic hierarchy based on oxygenic photosynthesis were already extant.

The Fortescue Group unconformably overlies the early Archaean granitoid-supracrustal basement of the Pilbara Craton in northwestern Australia (Fig. 1). Northern exposures of Fortescue rocks are only slightly metamorphosed [sub-greenschist facies

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