It is unlikely that serious, systematic errors will reduce the mid-Cretaceous pulse in oceanic crustal production as shown in Fig. 1 because I (2) deliberately chose the radioisotopic time scale (7) with the longest mid-Cretaceous time interval to test rigorously for such a pulse. The choice of any other recently published time scale would increase the amplitude of this pulse, and the most recent time scale (8) would increase the amplitude by about 20% relative to the steady state baselevel. The total increase in mid-Cretaceous crustal production (Fig. 1) is about what is necessary to account for the 250 m of eustatic sealevel elevation (9) during that period.

The misuse of crustal volume data in the study by Ingram et al. (1) points out an interesting question regarding the source locations in the oceanic crust where S is leached by hot, hydrothermal fluids. Experimental results (10) suggest that fluid leaching diabase dikes at 400°C matches the output of ridge crest hot springs and that basalts are much less susceptible to leaching. Field studies on ophiolites (11) confirm this result. Such source rocks and conditions probably are present directly above the 1.5 to 3 km deep (12) magma chambers at fast and intermediate spreading ridge crests. Fluid circulation must penetrate this deeply because convective cooling has depressed these magma chambers well below the 0.5-km level of neutral buoyancy (12–14). The situations for oceanic plateaus and
slow spreading ridges are less clear, but these may be less important sources because they would have more moderate geothermal gradients above their deeper magma chambers and because mid-plate plateau lack a tensile tectonic environment to promote the cracking necessary for fluid penetration. Fluids may penetrate into the intrusive sections on ridge flanks, but the volumes and temperatures probably are too low to mobilize significant Sr. Excessive in situ pressure and the lack of tensile stress make it unlikely that the greatly thickened intrusive sections of oceanic plateaus could be permeated by any fluids (15). Thus, it is unlikely that the intrusive sections of either ridges or plateaus are significant sources of hydrothermal Sr, and the uppermost sections of their extrusive layers probably are also excluded by their temperature and rock type. The source location probably is confined to a layer about 1 km or less in thickness (11) near the extrusive-intrusive interface, and ridges with rates of spreading that are moderate to fast are probably the most important sources.

Thus, an alternate explanation of the mid-Cretaceous Sr isotope anomaly is that it is primarily a result of variations in crustal production from spreading ridges, and plateau production is unimportant. The percentage increase in hydrothermal flux (figure 3A in (1)) that was necessary to match their largest Sr isotope anomaly appears to be about 25% over the base value. The mid-Cretaceous anomaly in ridge production (Fig. 1) is about a 5 km$^3$ per year rate increase over a ridge baselevel of 18.5 km$^3$ per year (4). This increase to an average of 23.5 km$^3$ per year is 28% above the ridge baselevel, and thus is a close match to the largest increase calculated by Ingram et al. in hydrothermal flux. This approach follows that of Jones et al. (16) who worked with a more complete data set than the one in question (1), and produced a more quantified and successful model of Sr isotope ratio variations from 120 to 40 Ma (mid-Cretaceous to the Eocene) as a function of variations in area of oceanic crustal production from spreading ridges. Jones et al. also did not account for oceanic plateau production, and extracted their area parameter from my oceanic ridges histogram (Fig. 1) by dividing out the constant, 6.5 km thickness for that type of oceanic crust. Thus, my assumptions about the main sources of the hydrothermal flux are essentially equivalent to those of Jones et al. (16) and are in sharp contrast to those of Ingram et al. (1).

Such simple models may be complicated by a nonlinear dependency on spreading rate and at least two other problems. First, increased oceanic crustal production will increase continental weathering, and thus the oceanic Sr isotope ratio, by an unquantifiable amount because of processes proposed by Weissert (17). Thus, the observed Sr isotope ratio always should be higher than predictions based only on increases in the hydrothermal flux, as it would be in my above example. Second, the exact shape of the spreading-ridge anomaly in mid-Cretaceous oceanic crustal production is unknown because it occurred during the Cretaceous magnetic superchron when spreading rates must be averaged over 40 Ma. The general concept that oceanic crustal production controls hydrothermal Sr flux and thus influences oceanic Sr isotope ratios is almost certainly correct, but quantification of this controlling function is a complex and uncertain business.

Roger L. Larson
Graduate School of Oceanography
University of Rhode Island
Narragansett, RI 02882, USA

REFERENCES AND NOTES

3. ibid. 963.
60.
8. F. M. Gradstein, F. P. Agterberg, J. G. Ogg, J. Hard-
9. M. A. Korninz, in International Unconformities and
Hydrocarbon Accumulation, J. S. Schlee, Ed. (Amer.
127.
15. E. Schreiber and P. J. Fox, Geol. Soc. Amer. Bull. 88,
600 (1977).
16. C. E. Jones, H. C. Jenkyns, A. L. Coe, S. P. Has-
18. I thank my "strontium support group," consisting of
D. J. Allard, R. T. Bird, S. N. Carey, C. E. Jones, J. H.
Natland, B. N. Opdyke, J. G. Schilling, and P. A.
Wilson for their advice in preparing this technical comment.

Fig. 1. World oceanic crustal production for the past 150 Ma, including all igneous extrusive and intrusive material above the Mohorovicic Discontinuity. The histograms for ridges (2) indicate crust formed by seafloor spreading, and the histogram for oceanic plateaus and seamount chains (3-5) indicate crust formed by mantle plumes. The world total histogram (3) is the sum of the other three histograms.
Strontium Isotopes in Mid-Cretaceous Seawater

Roger L. Larson

Science 266 (5190), 1584-1585.
DOI: 10.1126/science.266.5190.1584