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9
Introduction

Paul E. Olsen and J. Gregory McHone

Large igneous provinces (LIPs) comprise enormous edifices of basaltic lava and associated igneous rocks emplaced over a relatively brief time interval (Coffin and Eldholm 1994). Two of the largest terrestrial LIPs, the Siberian Traps ($\sim 2.5 \times 10^6$ km^3) and Deccan Traps ($\sim 2.6 \times 10^6$ km^3), are continental flood basalts associated in time with a mass extinction—the Siberian Traps with the end-Permian extinction at 250 Ma and the Deccan Traps with the end-Cretaceous extinction at 65 Ma (McLean 1985; O'Keefe and Ahrens 1989; Caldeira and Rampino 1990; Courtillot et al. 1994) (figure 9.1). The early Mesozoic basaltic rocks of eastern North America recently have been recognized as part of a third giant continental LIP closely associated in time with a mass extinction, this time the Triassic–Jurassic ($\sim$201 Ma) boundary (Marzoli et al. 1999; Olsen 1999) (figure 9.2). These lavas and associated igneous intrusions are now called the Central Atlantic Magmatic Province (CAMP) (Marzoli et al. 1999). The CAMP, the topic of part II of this volume, covers major parts of at least four tectonic (continental) plates and is integral to the rifting of the supercontinent of Pangea and formation of the Atlantic Ocean.

Although CAMP has very familiar geologic features with a venerable literature (e.g., Percival 1842; Davis 1883; Darton 1890; Walker 1940; May 1971), the fact that it may well be the largest continental LIP on Earth has been recognized within only the past few years (Marzoli et al. 1999). According to J. Gregory McHone and John H. Puffer (chapter 10), CAMP originally may have produced lavas extending over more than 7×10^6 km^2 prior to the formation of the Atlantic. In their chapter, McHone and Puffer review the distribution, chemistry, age, and stratigraphic setting of the CAMP, and they suggest that the eruption of the lavas could have triggered ecologically catastrophic climate change through massive input of volatiles into the atmosphere, as has been suggested for several other LIPs (McLean 1985; Rampino and Stothers 1988; Courtillot et al. 1994; Renne et al. 1995; McHone 1996, 2000). Recent direct fossil evidence does suggest a link to the CAMP (McElwain, Beerling, and Woodward 1999; Palfy et al. 2000).

To one extent or another, the other chapters in part II consider the somewhat controversial origin of the CAMP and the geodynamic conditions necessary for the production of LIPs. The controversy centers on the "deep-mantle plume" model versus the "shallow-mantle convection" model for generating large amounts of basalt (essentially Campbell and Griffiths's [1990] model versus King and Anderson's [1995]). Wilson (1997) and McHone (2000), among others, have suggested applications of these contrasting models to the CAMP. Although both models are essentially variations on the geometry of mantle upwelling (figure 9.3), there are fundamental differences in how each can cause continents to rift and massive basalts to erupt, so both deserve serious attention. Geophysical data that can conclusively demonstrate the requisite mantle geodynamics unfortunately are exceedingly difficult to collect and afterward to interpret. Needed are testable

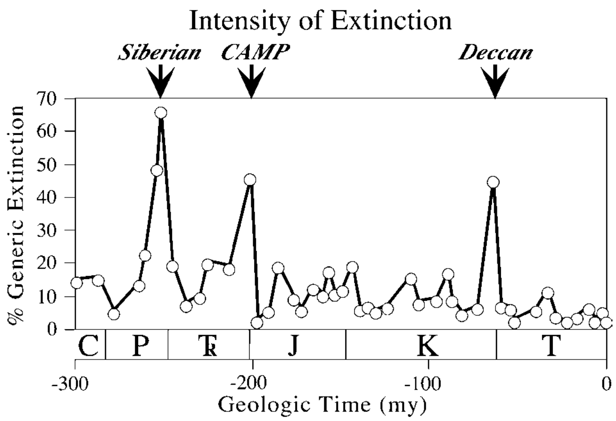

FIGURE 9.1 Extinction rate of "shelly" marine invertebrates through the Phanerozoic, showing the major continental LIPs. (Based on Sepkoski 1997, with timescale modified according to Kent and Olsen 1999)

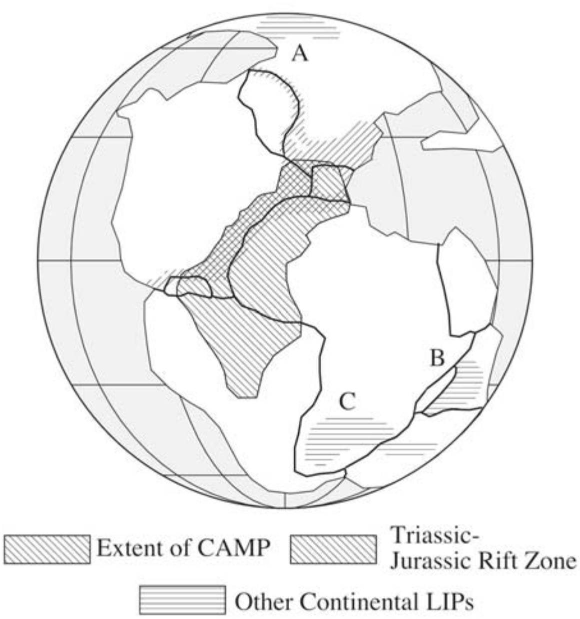

FIGURE 9.2 Distribution of the CAMP, Siberian Traps, and Deccan Traps with a Late Triassic plate configuration. (Based on Olsen 1999)

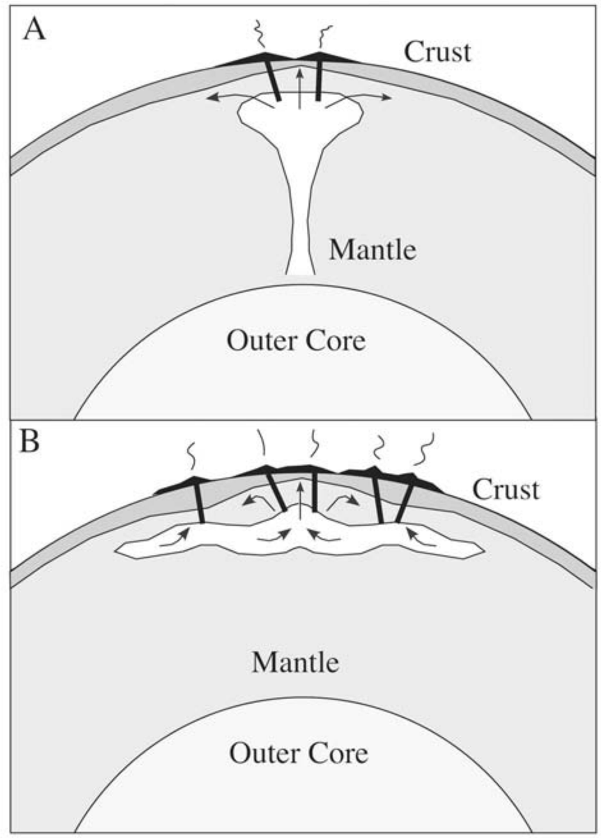

FIGURE 9.3 General geodynamic patterns envisioned for (*A*) the deep-mantle plume model and (*B*) the upper-mantle convection model. Note the more narrowly focused volcanism attributed to the plume model versus the wider-ranging volcanism from upper-mantle convection.

hypotheses that predict associated chemical, physical, dimensional, and temporal characteristics unique to each model (or, quite possibly, unique to some variant model yet to be realized).

In chapter 11, John H. Puffer places the CAMP flood basalts in a larger petrological context with various other continental flood basalt LIPs, including those of the Rodinian and pre-Rodinian supercontinent, the Siberian Traps, the Karoo Province, the Deccan Traps, and the Columbia River Basalts. Surprisingly, CAMP basalts appear similar to arc volcanics, and Puffer concludes that global plate reorganization was the motive force behind the emplacement of the gigantic igneous province, unlike some other continental LIPs that may have been produced by hot spots. Paul C. Ragland, Vincent J. M. Salters, and William C. Parker (chapter 12) examine a massive database of major-oxide analyses from the southeastern U.S. portion of the CAMP and hypothesize that the observed chemical trends indicate melting at deeper levels toward the southwestern portion of the southeastern United States in an area of thicker crustal derivation of the magma from more "fertile" mantle influenced by a hot spot. The different models for origin of LIPs, especially the CAMP, make different prediction of the mechanism of emplacement though dikes. In chapter 13, Jelle Zeilinga de Boer, Richard E. Ernst, and Andrew G. Lindsey describe anisotropy of magnetic susceptibility (AMS) data from the northeastern United States that they conclude indicates northeasterly directed lateral flow in dikes. This flow would be more compatible with a southeastern United States mantle plume source than with any other mechanism.

McHone and Puffer (chapter 10) and Ragland and colleagues (chapter 12) also briefly discuss one of the largest and most critical unanswered questions about the CAMP: What is the relationship between the CAMP and the seaward-dipping reflectors off the eastern United States (Holbrook and Kelemen 1993; Talwani et al. 1995; Withjack, Schlische, and Olsen 1998)? This question, unlikely to be dealt with seriously without extensive scientific drilling (Olsen, Kent, and Raeside 1999), bears directly on the mechanism of supercontinent breakup, the origin of initial oceanic crust, and the magnitude of the CAMP and its environmental effects.

Literature Cited

Caldeira, K. G., and M. R. Rampino. 1990. Deccan volcanism, greenhouse warming, and the Cretaceous/Tertiary boundary. *Geological Society of America Bulletin* 247:117–123.

Campbell, I. H., and R. W. Griffiths. 1990. Implications of mantle plume structure for the evolution of flood basalts. *Earth and Planetary Science Letters* 99:79–93.

Coffin, M. F., and O. Eldholm. 1994. Large igneous provinces: Crustal structure, dimensions, and external consequences. *Review of Geophysics* 32:1–32.

Courtillot, V., J. J. Jaeger, Z. Yang, G. Firaud, and G. Hoffman. 1994. The influence of continental flood basalts on mass extinctions: Where do we stand? In G. Ryder, D. Fastovsky, and S. Gartner, eds., *The Cretaceous–Tertiary Event and Other Catastrophes in Earth History,* pp. 513–525. Geological Society of America Special Paper, no. 107. Boulder, Colo.: Geological Society of America.

Darton, N. H. 1890. The relations of the traps of the Newark system in New Jersey. *U.S. Geological Survey Bulletin* 67:1–82.

Davis, W. M. 1883. On the relations of the Triassic traps and sandstones of the eastern United States. *Bulletin of the Museum of Comparative Zoology* 7:249–309.

Holbrook, W. S., and P. B. Kelemen. 1993. Large igneous province on the U.S. Atlantic margin and implications for magmatism during continental breakup. *Nature* 364:433–436.

Kent, D. V., and P. E. Olsen. 1999. Astronomically tuned geomagnetic polarity timescale for the Late Triassic. *Journal of Geophysical Research* 104:12831–12841.

King, S. D., and D. L. Anderson. 1995. An alternative mechanism of flood basalt formation. *Earth and Planetary Science Letters* 136:269–279.

Marzoli, A., P. R. Renne, E. M. Piccirillo, M. Ernesto, G. Bellieni, and A. De Min. 1999. Extensive 200-million-year-old continental flood basalts of the Central Atlantic Magmatic Province. *Science* 284:616–618.

May, P. R. 1971. Pattern of Triassic–Jurassic diabase dikes around the North Atlantic in the context of predrift position of the continents. *Geological Society of America Bulletin* 82:1285–1291.

McElwain, J. C., D. J. Beerling, and F. I. Woodward. 1999. Fossil plants and global warming at the Triassic–Jurassic boundary. *Science* 285:1386–1390.

McHone, J. G. 1996. Broad-terrane Jurassic flood basalts across northeastern North America. *Geology* 24:319–322.

McHone, J. G. 2000. Non-plume magmatism and rifting during the opening of the central Atlantic Ocean. *Tectonophysics* 316:287–296.

McLean, D. M. 1985. Deccan Traps mantle degassing in the terminal Cretaceous marine extinctions. *Cretaceous Research* 6:235–259.

O'Keefe, J. D., and T. J. Ahrens. 1989. Impact production of CO_2 by the Cretaceous/Tertiary extinction bolide and the resultant heating of the Earth. *Nature* 338:247–249.

Olsen, P. E. 1999. Giant lava flows, mass extinctions, and mantle plumes. *Science* 284:604–605.

Olsen, P. E., D. V. Kent, and R. Raeside. 1999. International workshop for a climatic, biotic, and tectonic pole-to-pole coring transect of Triassic–Jurassic Pangea. *Newsletter, International Continental Drilling Program* (Potsdam) 1:16–20.

Palfy, J., J. K. Mortensen, E. S. Carter, P. L. Smith, R. M. Friedman, and H. W. Tipper. 2000. Timing the end-Triassic mass extinction: First on land, then in the sea? *Geology* 28:39–42.

Percival, J. G. 1842. *Report on the Geology of the State of Connecticut.* New Haven, Conn.: Osborn and Baldwin.

Rampino, M. R., and R. B. Stothers. 1988. Flood basalt volcanism during the past 250 million years. *Science* 241:663–668.

Renne, P. R., Z. Zhang, M. A. Richards, M. T. Black, and A. R. Basu. 1995. Synchrony and causal relations between Permian–Triassic boundary crises and Siberian flood volcanism. *Science* 269:1413–1416.

Sepkoski, J. J., Jr. 1997. Biodiversity: Past, present, and future. *Journal of Paleontology* 71:533–539.

Talwani, M., J. Ewing, R. E. Sheridan, W. S. Holbrook, and L. Glover III. 1995. The EDGE experiment and the U.S. East Coast Magnetic Anomaly. In E. Banda, M. Torne, and M. Talwani, eds., *Rifted Ocean–Continent Boundaries,* pp. 155–181. Dordrecht: Kluwer.

Walker, F. 1940. The Palisade sill of New Jersey. *Geological Society of America Bulletin* 51:1059–1105.

Wilson, M. 1997. Thermal evolution of the central Atlantic passive margins: Continental break-up above a Mesozoic super-plume. *Journal of the Geological Society of London* 154:491–495.

Withjack, M. O., R. W. Schlische, and P. E. Olsen. 1998. Diachronous rifting, drifting, and inversion on the passive margin of central eastern North America: An analog for other passive margins. *American Association of Petroleum Geologists Bulletin* 82:817–835.