LESSON 12

MOUNTAINS, TRENCHES, SUNKEN ISLANDS
The Great Revolution in Earth Science

1 So young a science
2 So young a seafloor – and sinking
3 Discoveries that needed explaining
4 Magnetic stripes hold the answer
5 Corollaries of the new theory
6 Hotspots and the tracking of plate motion
7 Hot vents and the stability of seawater
8 The discovery of a new ecosystem

Fig. 12.01. Sierra Nevada, California. The Sierras are the result of uplift from collision of the western edge of North America with the Pacific sea floor. The rocks exposed are mountain roots made of igneous rocks.

What do the mountains of the Sierra Nevada (Fig. 12.01) have in common with the San Andreas Fault System of California and with the island chain of Hawaii?

They are among the large linear features that characterize the surface of our planet, and which result from the motions of large pieces of real estate called *plates*. There are about a dozen plates. The largest comprises much of the Pacific basin, the next largest includes much of the Indian Ocean and both India and Australia, the next the Americas and the western half of the Atlantic basin, and so on down to the smallish Cocos and Caribbean plates flanking the Panama Isthmus (Fig. 12.02). Their existence and their motions are a result of convection within the mantle. The basaltic mantle rock, when under pressure and hot, can flow slowly, and does so at a rate of roughly an inch per year. Volcanism, earthquakes, tsunamis – all these phenomena on the surface of Earth are linked to the convection-driven motions of the plates in recognizable patterns.

The discoveries that led to a new all-encompassing theory of the Earth were made primarily in the 1950s and early 1960s; the theory itself has roots older than that but emerged in modern fashion in the 1970s. The core statement of the theory is that seafloor is created all the time, at spreading centers making up the Mid-Ocean Ridge, and is destroyed in the subduction zones, whose position is marked by trenches and strong deep earthquakes. Such earthquakes, in some cases, are the source of devastating great waves spreading across the sea, waves known as *tsunamis.* The subsea volcanism at the spreading centers produces hot springs, and the chemical reactions of hot seawater with hot basalt stimulate bacterial activity, which in turn supports a hot vent fauna with unusual animals.

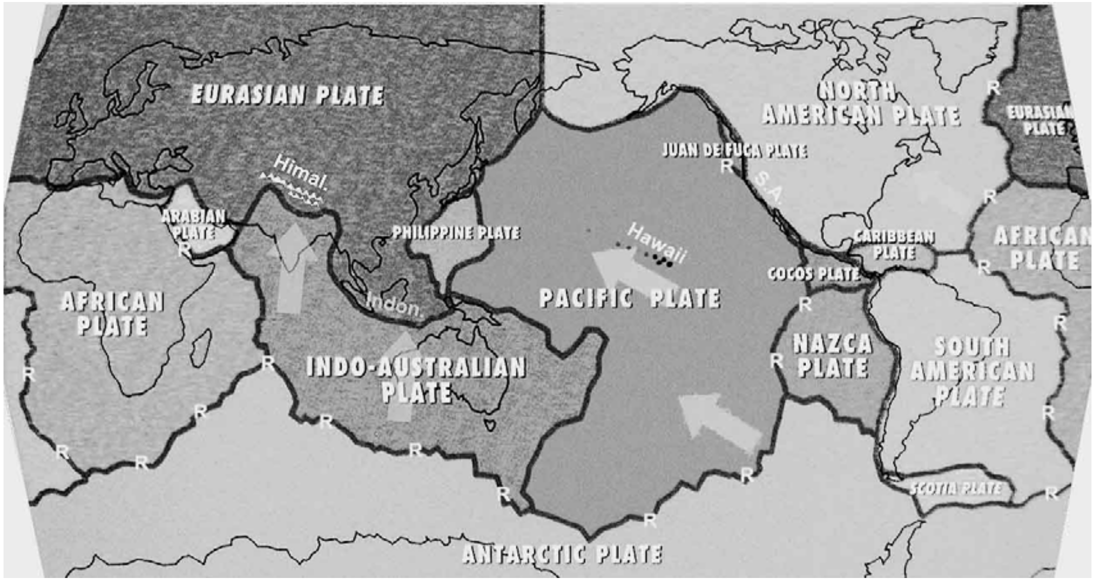


Fig. 12.02. The great tectonic provinces on the surface of Earth, called "plates." Plates move as rigid bodies. High mountains such as the Himalayas (*Himal.)* mark continent-continent collision. Earthquakes and volcanoes mark all boundaries (e.g. Indonesia, *Indon.*; San Andreas, *S.A.*) The Hawaiian island chain is the offspring of a deep volcanic source overrun by the Pacific Plate. **R**, crest of the Mid-Ocean Ridge, site of seafloor spreading.

Images

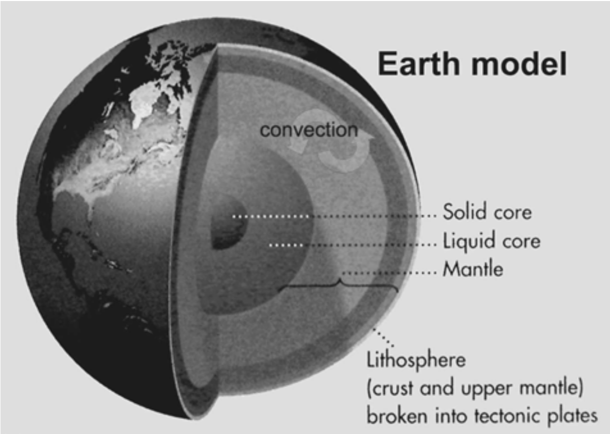


Fig. 12.03. Layered structure of the Earth. Convection of the mantle holds the clue to the origin of mountains chains, lines of volcanoes, trenches, and earthquakes.

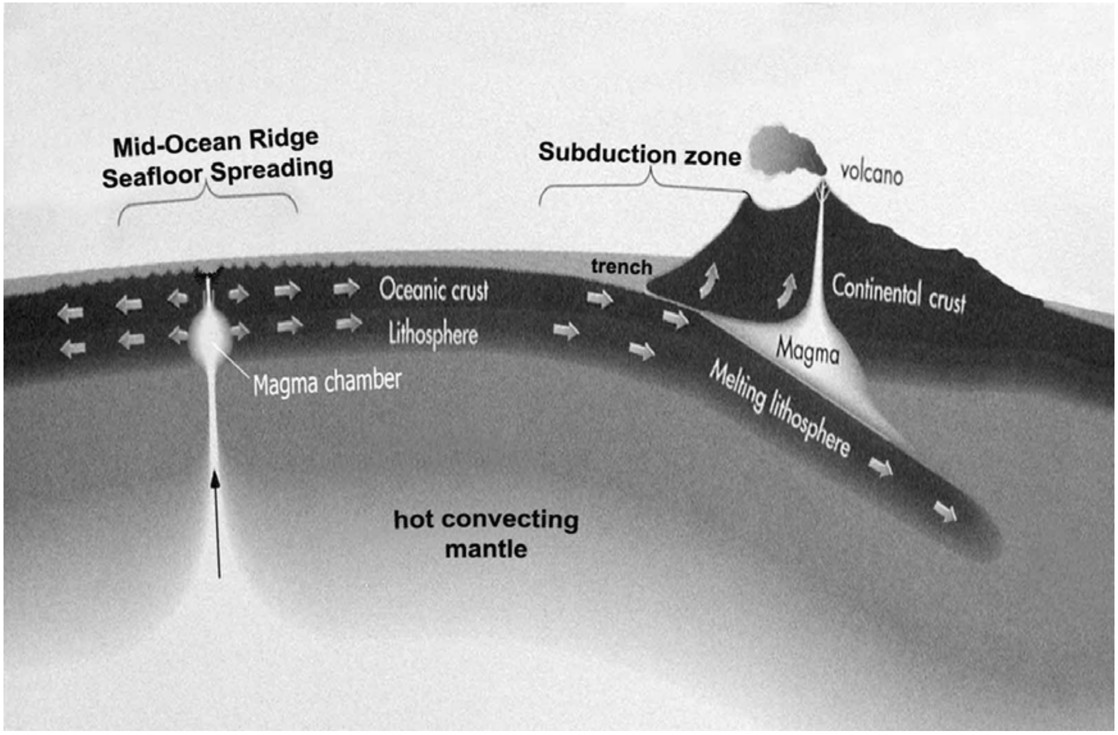


Fig. 12.04. The chief elements of plate tectonics: seafloor spreading and subduction.

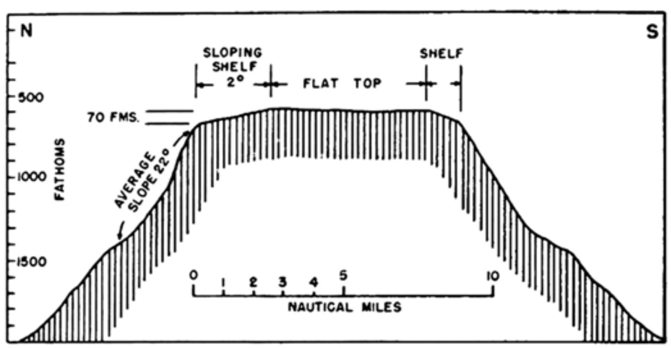


FIGURE 1.—*Profile of a typical central Pacific guyot*
(From Hess, 1946)

Fig. 12.05. A typical guyot, as redrawn by Hamilton (in 1956) from Hess (1946).

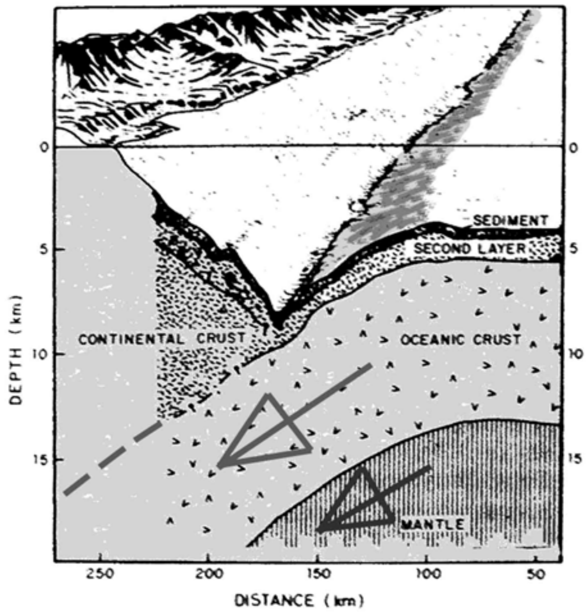


Fig. 12.06. Seafloor subduction closes Hutton’s rock cycle, by taking the ocean floor down below the edge of the continent, to make mountain roots in the collision zone. Before the arrows could be drawn, thanks to plate tectonics, the situation had to be depicted (as done by R. Fisher and R. Raitt in 1962; shading and arrows here added).

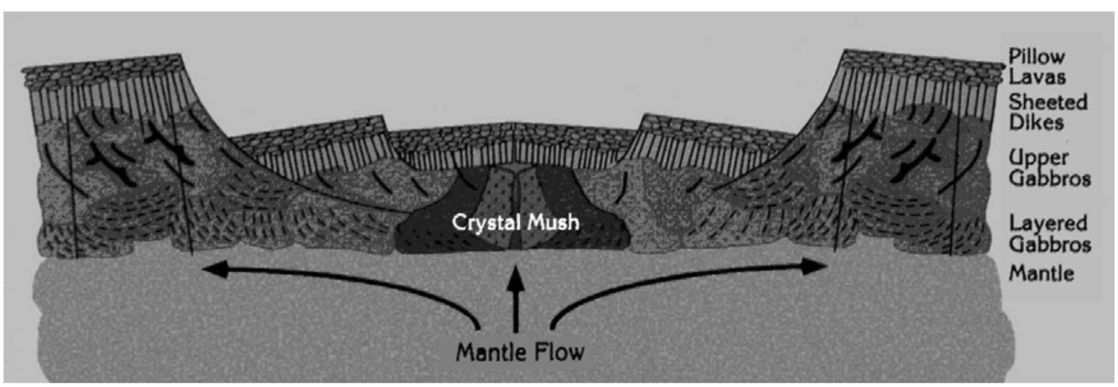


Fig. 12.07. Seafloor spreading as a result of mantle flow, in a modern version of the concept. Note the layered structure of the basaltic crust. Sediments not shown.

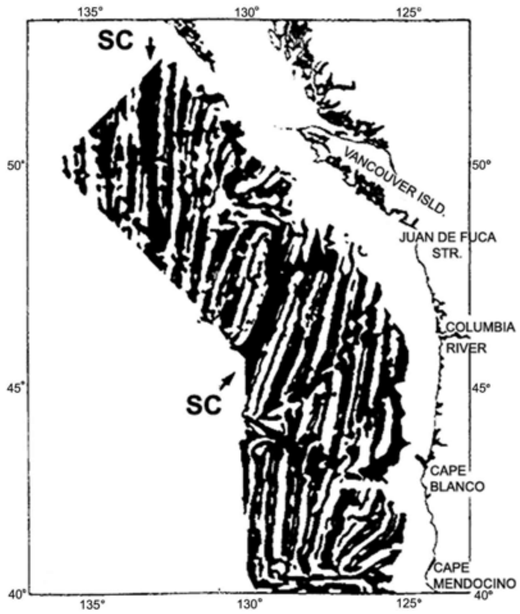


Fig. 12.08. Mason-Raff lineations of magnetic seafloor anomalies, northeastern Pacific. Positive anomalies black. The role of spreading centers (here marked SC) was unknown at the time of discovery of the "zebra" patterns.

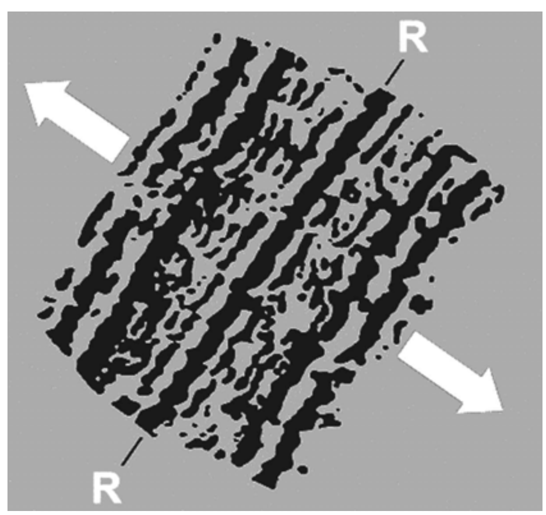


Fig. 12.09. The symmetry of magnetic lineations about the Ridge axis (R) was the crucial evidence for seafloor spreading. Lineations from a magnetic survey of Rejkjanes Ridge, J.R. Heirtzler et al., 1966. Arrows here added. R, ridge crest.

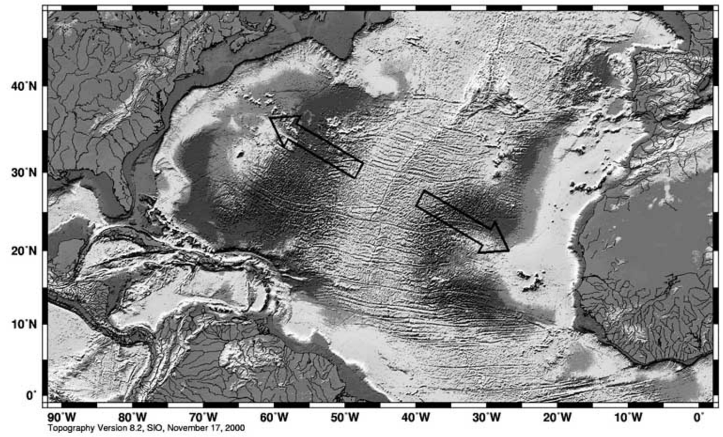
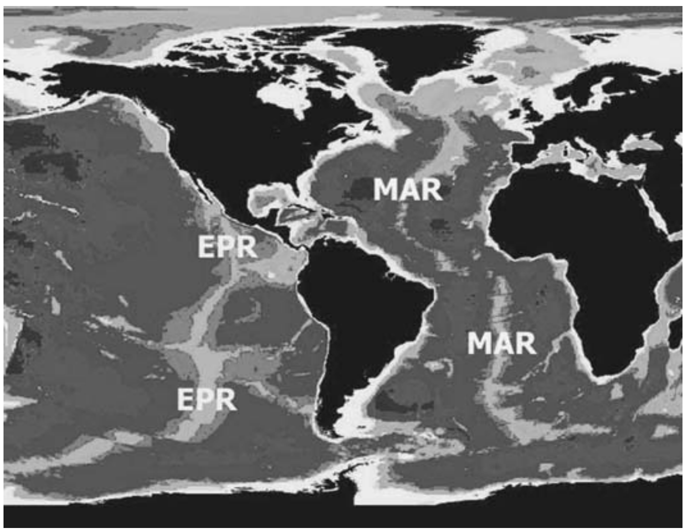


Fig. 12.10. The fit of North Atlantic coastlines as a result of seafloor spreading, as seen in a modern gravity-based topographic reconstruction of the seafloor. Arrows added.

Fig. 12.11. Youthful seafloor (light gray) marks the shallow Mid-Ocean Ridge in all ocean basins. The East Pacific Rise (EPR) is broad, because of fast spreading; while the Mid-Atlantic Ridge (MAR) tends to be narrow and rugged.



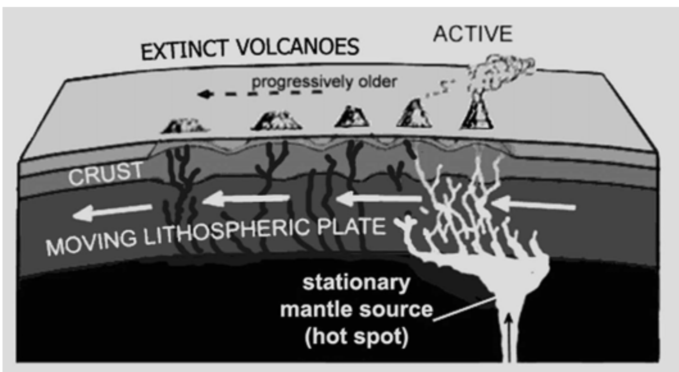


Fig. 12.12. Origin of the Hawaiian island chain, based on the hypothesis of J. Tuzo Wilson, 1963.

Fig. 12.13. Scenes of Hawaii (Volcano Park). Left: Lava making its way to the sea. Right: Waves attacking the basaltic cliffs.

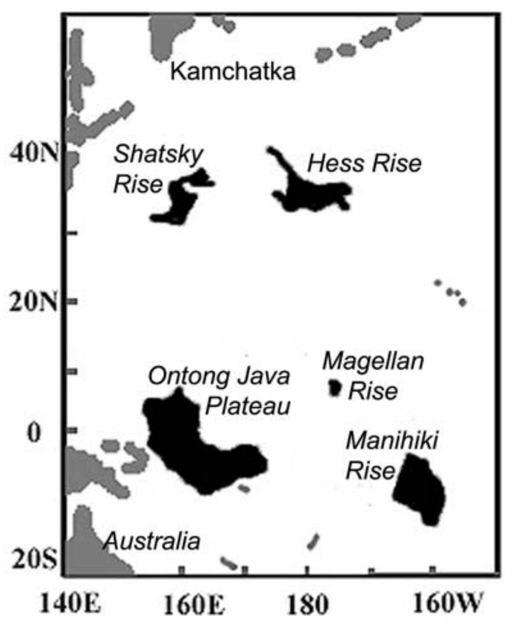


Fig. 12.14. Large basaltic plateaus in the western Pacific.

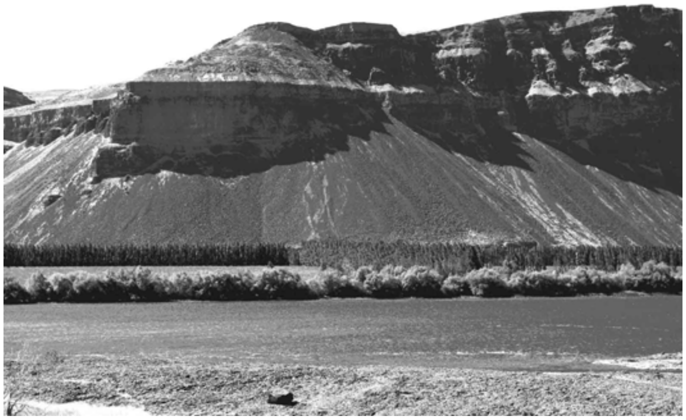


Fig. 12.15. The Columbia River, Washington, cuts into an enormous plateau of flood basalt. Yet bigger ones are in the western Pacific, below the sea surface.

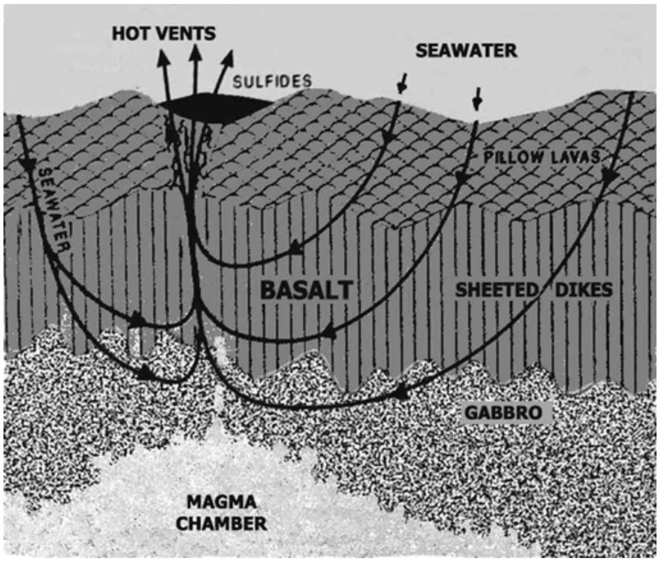


Fig. 12.16. Modern concept of the circulation above a magma chamber on the seafloor.

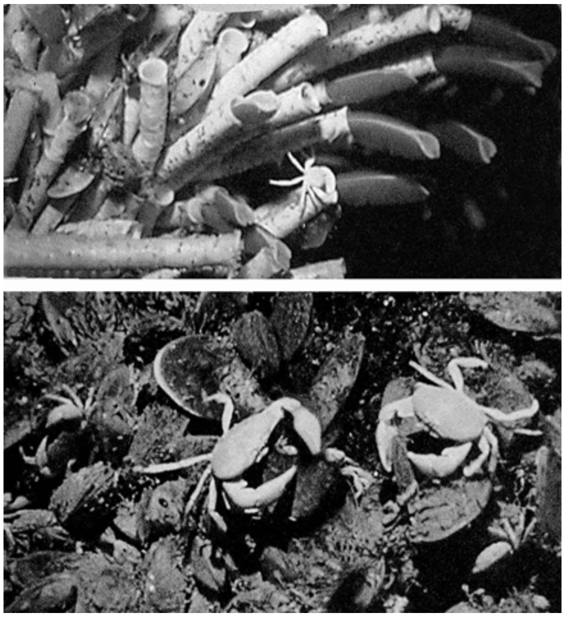


Fig. 12.17. Creatures of the abyssal hot vents: vestimentiferan worms, mussels, and crabs.

Fig. 12.18. Plate collision makes volcanoes in the Andes. Eruption of Tungurahua volcano, Ecuador, December 2003.

Figure sources (where based on sources in the literature, on the web or in museum exhibits: figures are considerably modified and adapted for present purposes, using Adobe Photoshop; drawings and photographs by the author are marked “orig.”): 1, orig.; 2, SIO Explorations; 3, SIO Explorations; 4, SIO Explorations; 5, Hess 1946; 6, Fisher and Raitt 1962; 7, Meyer and Gillis 1994; 8, R. Mason and A. Raff 1961; 9, Heirtzler et al. 1966; 10, courtesy David Sandwell, SIO; 11, NOAA; 12, orig. after J. T. Wilson (1963), and Seibold and Berger 1993 (see Ch. 4 for reference); 13, orig.; 14, Berger et al. 1994; 15, orig.; 16, Herzig and Hannington 2000; 17, Alvin photos, SIO Explorations; 18, courtesy Luz Chung, UCSD. **References**: H. Hess cited in E. L. Hamilton, 1956. *Sunken islands of the Mid-Pacific Mountains*. Geol. Soc. America Mem. 64, 1-97; R.L. Fisher and R.W. Raitt cited in E. Seibold and W.H. Berger, 1993 (see Ch. 4 for reference). P.S. Meyer and K.M. Gillis, 1994, *Oceanic crust composition and structure,* Oceanus 36 (4) 70-74 (Special Issue: 25 Years of Ocean Drilling); R.G. Mason and A.D. Raff cited in H.W. Menard, 1964. *Marine Geology of the Pacific.* McGraw-Hill, New York; J.R. Heirtzler, X. LePichon and J.G. Baron, 1966, cited in E. Seibold and W.H. Berger, 1993; W. Berger, T. Bickert, E. Jansen, G. Wefer, M. Yasuda, 1994, *The central mystery of the Quaternary ice age.* Oceanus, 36 (4) 53-56; P.M. Herzig and M.D. Hannington in H.D. Schulz and M. Zabel (eds) Marine Geochemistry, Springer Verlag, Berlin and Heidelberg, 455pp (p.399).