# RECENT DEATHS

**John P. Bowler**, 79; former dean, Dartmouth Medical School; 22 January.

**J. Russell Bright**, 65; professor of chemistry, Wayne State University; 20 December.

**Eleanor B. Browne**, 64; former professor of education, University of Florida; 2 February.

**Herbert E. Buchanan**, 92; professor emeritus of mathematics, Tulane University; 17 January.

**David L. Crawford**, 84; former president, University of Hawaii; 17 January.

**Vincent J. Dardin**, 73; professor emeritus of pathology, Georgetown University; 31 January.

**Edward T. Donovan**, 74; professor emeritus of mechanical engineering, University of New Hampshire; 3 January.

**George M. Hollenback**, 87; former chairman, fixed prosthetics department, University of Southern California; 30 November.

**Hubert A. Jones**, 88; professor emeritus of mathematics, Wake Forest University; 6 February.

**E. Henry Keutmann**, 77; professor emeritus of medicine and pharmacology, University of Rochester School of Medicine and Dentistry; 28 January.

**Desmond Magner**, 60; head, pathology department, University of Ottawa; 17 November.

**Charles F. Metz**, 69; group leader, chemical and instrumental analysis group, Los Alamos Scientific Laboratory; 10 February.

**Robert B. B. Moorman**, 69; professor emeritus of civil engineering, Polytechnic Institute of Brooklyn; 2 February.

**Elmer L. Ritter**, 90; professor emeritus of education, University of Northern Iowa; 17 January.

**George Scatchard**, 81; professor emeritus of chemistry, Massachusetts Institute of Technology; 10 December.

**Joseph R. Stern**, 54; chairman, biochemistry department, College of Dentistry, New York University; 15 January.

**Darrell R. Williams**, 44; chairman, electrical engineering department, Illinois Institute of Technology; 20 February.

**J. Enrique Zanetti**, 89; professor emeritus of chemistry, Columbia University; 26 January.

*Erratum*: In the 12 July issue, page 126, described George C. Guenther, former assistant secretary of labor for occupational safety and health, as the "former boss" of Marcus M. Key, director of the National Institute for Occupational Safety and Health (NIOSH). NIOSH in fact is part of the Department of Health, Education, and Welfare.

RESEARCH NEWS

# Plate Tectonics: Do the Hot Spots Really Stand Still?

With plate tectonics firmly established as a theory that explains to a large extent why the earth looks as it does, what do you do with the features that the theory doesn't explain? For instance, major oceanic ridges have been identified where plates are spreading apart, in the Atlantic, Pacific, and Indian oceans, causing many earthquakes underneath the ridges. But large ocean ridges are also found that have no earthquake activity underneath. How are they formed? What produced the long chain of volcanoes, mostly underwater, in the northern Pacific from the Hawaiian Islands almost all the way to Siberia? This island chain is far from the boundaries of the Pacific plate, and does not parallel any of the geologic features of the ocean floor in the region.

The tendency of most geophysicists is to group such inexplicable features together and say they were formed by "hot spots" under the moving plates. The Hawaiian chain, which includes approximately 80 volcanoes, was the first to be explained by a fixed hot spot periodically erupting through a plate. Now perhaps 200 features are called hot spots by one researcher or another, but they are not well understood. What causes the hot spots, whether they are really fixed in the deeper parts of the earth, and how applicable the term is to all the features left over from global tectonics are open questions.

The term hot spot sounds innocuous enough, like a soft patch in an asphalt road, but in fact it is the name for a source of prodigious energy. The hot spot in the earth's mantle under Hawaii is capable of producing volcanoes equal in height to Mount Everest, as measured from the ocean floor. The volcanoes that formed the Hawaiian archipelago and its northward underwater continuation, the Emperor seamounts, are broad, smooth structures called shield volcanoes which reach a diameter of 120 km at the base. The chain appears to have been formed along a number of loci, often with more than one volcano active at a time (Fig. 1). The oldest volcanoes are at the northern end of the chain and the youngest are on the island of Hawaii, where Mauna Loa and Kilauea are still active.

Radioactive dating of samples by G. Brent Dalrymple and his colleagues at the U.S. Geological Survey in Menlo Park, California, shows that the volcanoes are progressively older to the northwest, but not in a linear fashion. Until recently data were available for dating the chain only as far out as Midway, which is 2400 km from Kilauea and about 18 million years old. Using data from this section of the chain, Dalrymple and his associates estimated that the average velocity of the plate over the hot spot was 13 cm/year, too fast for the hot spot to be considered fixed, according to most estimates.

New data from volcanoes farther out in the Hawaiian-Emperor chain show that the age progression, averaged over a longer time, was considerably slower. Samples from the Koku and Yuryaku seamounts now indicate that the age of the Hawaiian bend is 41 to 43 million years. Those dates, obtained by Dalrymple, David Clague of the Scripps Institution of Oceanography in La Jolla, California, and R. Moberly of the University of Hawaii, Honolulu, indicate that the average rate of migration of volcanism has been about 8 cm/year, a number that jibes well with the motion of the Pacific plate at the present time (the last 10 million years). While they do not prove that the Hawaiian chain was caused by a fixed hot spot, the new dates seem to many geophysicists to indicate that the data are more favorable than ever before.

The Hawaiian-Emperor chain is not the only string of volcanic islands in the Pacific that could have been produced by a hot spot. In 1971, W. Jason Morgan at Princeton University, introducing the plume hypothesis (see below), suggested that the Austral-Cook-Marshall Islands and the Tuamotu-Line Islands were also produced by hot spots (Fig. 2). These two island chains have a bend with the same general orientation as the Hawaiian-Emperor chain. Morgan suggested that all three island chains, plus another near Alaska, were produced as the Pacific plate moved over fixed hot spots. The bends occurred, he postulated, because the plate changed its direction of motion. Fewer volcanoes have been dated in the Austral-Cook-Marshall and Tuamotu-Line Islands than in the Hawaiian chain, but as more data are gathered, the evidence for age progression seems to improve.

While the Pacific plate has the most dramatic examples of island chains, hot spots are scattered over the rest of the earth too. For most of the accepted hot spots, indeed most of those in Fig. 2, the direction of the island chain or ridge (the trace of the hot spot) can be well established. Because the plates are rigid and there can be no gaps between them, their relative movements can now be very accurately determined from data on spreading rates, fracture zone trends, and earthquake slip vectors.

What emerges from a study of such data is a computer-based model of the relative motions of the major plates. If the hot spots are really fixed in the mantle, then there must be some mathematical frame of reference in which the relative plate motions over the hot spots accurately predict the traces of the hot spots on the surface. To project such an analysis very far back into geologic time is a difficult mathematical problem, but modeling of the "instantaneous" plate motions at the present time is tractable. (Again, the present time means during the last 10 million years.)

A very recent study of this sort indicated that the hot spots are fixed, within the uncertainty of the available data. The study was undertaken by J. B. Minster at the University of Paris, E. Haines at the California Institute of Technology, T. H. Jordan at Princeton, and P. L. Molnar at the Massachusetts Institute of Technology, Cambridge. Only for Iceland is their evidence that the hot spot may be moving. According to Jordan, the study does not prove the validity of the fixed hot spot hypothesis, but "right now it looks pretty good." While the plates move from 2 to 10 cm/year, Jordan says no one has convinced him that the hot spots move more than 1 cm/year.

The evidence that the hot spots are all relatively fixed seems to confirm that they are anchored somehow. As far as Jordan and his co-workers can determine, the frame of reference in which the hot spots stand still is just the mantle. While it is conceivable that one or two hot spots are moving with the same speed as the plates but in the opposite direction, and thus appear to stand still, why should hot spots in the Atlantic stand still with respect to those in the Pacific?

Three years ago, before these facts were known, Morgan suggested an answer. He proposed that the hot spots were caused by narrow plumes of primordial material rising rapidly from very deep in the mantle to the region where the plates and mantle meet (asthenosphere). Rapidly, for convection in the mantle, means 1 to 2 m/year, and narrow means about 150 km in diameter. If plumes originate near the earth's core, they could extend downward 2500 km.

Convection in the mantle was certainly not a new idea. For many years it has been thought that the earth carries heat away from the interior by means of great circular convection patterns in the mantle, called convection cells, on the order of 1000 km across and moving a few centimeters per year. But Morgan was the first to propose a narrow rising stream, almost like a thunderhead, upwelling and carrying excess heat to the plates. The plumes were not accompanied by similar sites for downwelling because the return flow would be dispersed throughout the mantle. Morgan thought the plumes were not only the source of volcanism, but were also capable of breaking up the plates to form the Atlantic Ocean and of continually driving the plates apart at the mid-oceanic ridges. As can be seen from Fig. 2, many plumes, especially in the Atlantic, are near ridges.

Other models do not require that hot spots originate so deep in the mantle. J. Tuzo Wilson's original proposal, in 1963, was not very precise; he simply suggested that there was an anomalously hot area in the mantle just below the plates. Ian McDougall is the most recent earth scientist to suggest that the island chains are produced because a hot spot causes a fracture in the plate that propagates, in time producing a whole chain of volcanism. Herbert Shaw, at the U.S. Geological Survey,

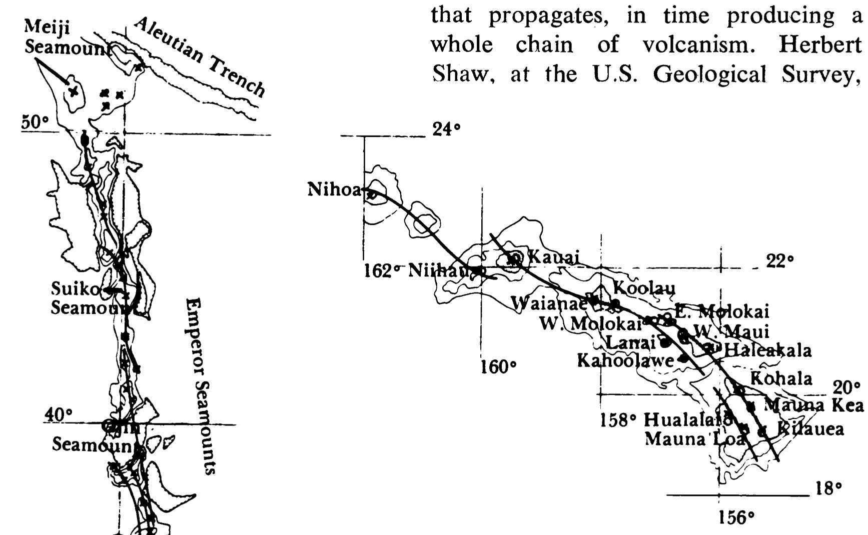


Fig. 1. The Hawaiian Islands, the Hawaiian Ridge, and the Emperor seamounts form a continuous chain that grows older to the northwest. The serpentine lines are loci on which volcanoes were formed, often two or more at a time.

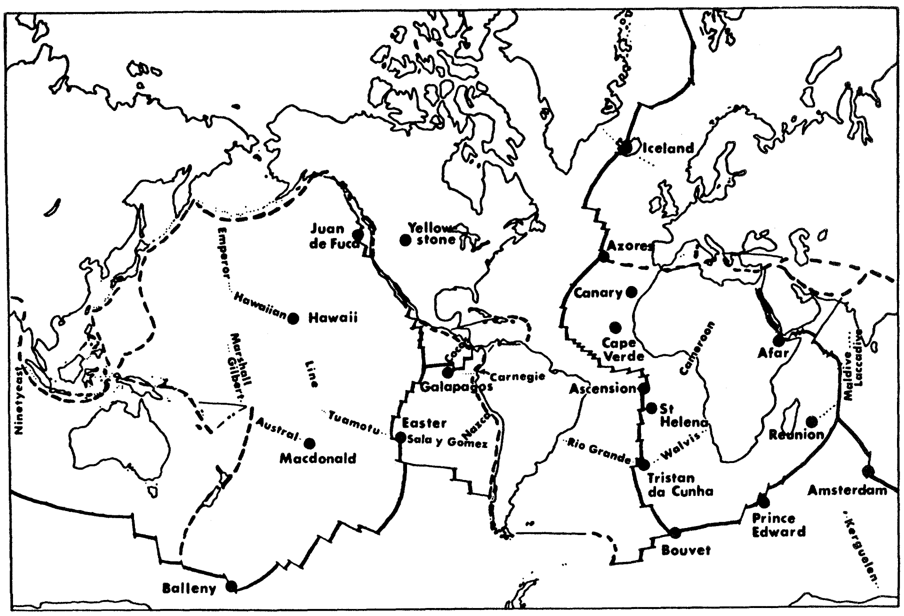


Fig. 2. Major hot spots are labeled on this map of world plate boundaries. Ridges are denoted by solid lines and trenches by dashed lines.

Reston, Virginia, proposes that the source of heat is not some mysterious concentration of energy in the mantle, but the friction of the plate moving over the semiviscous material below it. These models give somewhat different predictions for the movements of the hot spots and age progressions in island chains, but most scientists who have studied the question seem to think it is too early to choose between them.

To answer the crucial question about hot spots—at what depth in the mantle they originate—no data seem to be available. The mineral properties of basalt samples that have been collected from hot spots only tell the depth at which they were last in equilibrium with the heavier residues left behind—about 50 to 100 km. Most geophysicists think that seismology offers the best hope for learning what happens at greater depth. Some studies already published hint that there is an anomaly in the mantle under Hawaii, and other studies should give more information in the near future. But for now there is hard evidence that tells where the island basalts do not originate. They do not come from the same place as the ridge basalts.

The basalts formed as lava flows up through the mid-oceanic ridges are very different in composition from the island basalts, particularly in the strontium isotopes. About 30 islands have been examined by now, and almost all show consistently higher ratios of $^{87}Sr$ to $^{86}Sr$ than the ridges. Strontium-87 is produced by the decay of one of the common isotopes of rubidium. According to Stan Hart at the Carnegie Institution, Washington, D.C., all the oceanic islands which have been looked at, and many of the seamounts, have a geochemistry distinct from that of the ridge basalts. Besides strontium ratios, the two types also differ in the concentrations of lead isotopes and certain trace elements.

Specifically, almost all the island basalts have $^{87}Sr/^{86}Sr$ ratios of 0.7030 or more, while the ridge basalts measure 0.7026. The difference, although small, is quite significant, since isotope ratios can be measured very accurately. One problem in discriminating between the geologic origins of rocks on the basis of strontium ratios is that exchanging ions with seawater (0.7090) can raise the ratio so that it no longer represents the composition of magma emerging from the earth's mantle. But a study of basalt samples from Iceland presents fairly convincing evidence that different strontium ratios are related to the sources of hot spots and ridges, not the amount of contamination by seawater.

Iceland sits over a well-known hot spot, which produced new volcanic activity only 1 year ago on the island of Heimaey, and it is also centered over the Mid-Atlantic Ridge. J.-G. Schilling, at the University of Rhode Island, Kingston, collected samples of basalt onshore from the Reykjanes peninsula 500 km northeast, and offshore by dredging along the ridge as far as 500 km southwest of the peninsula. Not only did the onshore samples show typical strontium ratios for island basalts and the offshore samples typical values for ridge basalts, but there was a sharp transition between the two types. The island basalt seems to be coming from a different source in the mantle than the ridge basalt, because such large differences cannot be generated by chemical fractionation, in the view of most geochemists. In short, the difference must occur because the basalts came from regions of the mantle which originally had different ratios of rubidium to strontium and which did not subsequently mix. How long ago these two sources of material were separated into discrete regions can be determined rigorously from new data on lead isotopes, refined by S. S. Sun at the State University of New York at Stony Brook, and Robert Kay at Lamont-Doherty Geological Observatory. The two discrete sources in the mantle have been closed off from one another for 2 billion years.

At this point, geochemists seem to be saying to geophysicists, propose any model you want for hot spots, but put the hot spot sources far away from the ridge sources, or find some other way to prevent the two from mixing. For their part, geophysicists have been aware that some geochemical constraints might apply to the hot spot problem, but they are only now seriously studying the data. At a recent Penrose conference held by the Geological Society of America, informal afternoon tutorials in geochemistry were held for those who wanted to determine for themselves the enormity of the problem.

The plume hypothesis seems to have polarized the opinions of researchers studying the solid earth. Some think it has had some of the harmful effects that often occur in a discipline when too many investigators get on a bandwagon. The opinions are still mixed. While some participants at the Penrose conference thought the evidence in favor of plumes was growing, others said the conference had marked the death of the idea.

But plumes seem to account for the lack of mixing between hot spots and ridges, by being narrow and rapid, and to account for the apparent fixity of hot spots by emerging from very deep in the mantle. Most observers bet that surface geology will not determine whether plumes exist, but that deep mantle seismology may.

—William D. Metz