nated by forms such as *Cribroelphidium, Elphidiella,* and others. Thus, in southeastern Alaska there was a deep-water marine basin or series of basins in which the Poul Creek deposition occurred. Basin-filling predominated beginning in the early and middle Miocene and was followed by rapid sedimentation and the introduction of marine glacial deposits intermittently during the later Miocene and the Pliocene. These gave way to the mostly nonmarine tillites of the classic Quaternary as represented in modern exposures.

ORVILLE L. BANDY
Department of Geological Sciences, University of Southern California, Los Angeles 90007

E. ANN BUTLER
Atlantic Richfield Company, Box 7190, Tulsa, Oklahoma 74105

RAMIL C. WRIGHT
Department of Geology, Beloit College, Beloit, Wisconsin

References and Notes

1. C. Craddock, T. W. Bastien, R. H. Rutford, in *Antarctic Geology*, R. J. Adie, Ed. (North-Holland, Amsterdam, 1964), p. 171; O. L. Bandy, *Palaeogeogr. Palaeoclimatol. Palacoecol.* **5**, 63 (1968).
2. F. Lona, *Bol. Soc. Geol. Ital.* **81**, 89 (1962).
3. O. L. Bandy, *G. Geol. Ann. Museo Geol. Bologna* **35**(2), 277 (1968).
4. D. B. Marchetti, *Int. Geol. Congr. 23rd Czech. Abstr.* 271 (1968).
5. O. L. Bandy and J. C. Ingle, Jr., *Geol. Soc. Amer. Spec. Pap. 124* (1969).
6. O. L. Bandy, E. Vincent, R. C. Wright, *Rev. Espan. Micropaleontol.* **1**, No. 2 (1969).
7. D. G. Jenkins, *N.Z. J. Geol. Geophys.* **10**, 1064 (1967).
8. ———, *Micropaleontology N.Y.* **13**, 195 (1967).
9. D. J. Miller, *J. Geol.* **61**, 17 (1953); *U.S. Geol. Surv. Oil Gas Invest. Map OM-187* (1957).
10. F. S. MacNeil, J. A. Wolfe, D. J. Miller, D. M. Hopkins, *Bull. Amer. Ass. Petrol. Geol.* **45**, 1801 (1961); G. Plafker, *U.S. Geol. Surv. Misc. Geol. Invest. Map I-484* (1967).
11. G. H. Denton and R. L. Armstrong, *Amer. J. Sci.*, in press.
12. O. L. Bandy, *Micropaleontology N.Y.* **10**, (1964).
13. J. A. Wolfe and E. B. Leopold, in *The Bering Land Bridge*, D. M. Hopkins, Ed. (Stanford Univ. Press, Palo Alto, Calif., 1967), pp. 193–206.
14. W. W. Rau, *Contrib. Cushman Found. Foraminiferal Res.* **14**, 135 (1963).
15. O. L. Bandy and M. A. Chierici, *Mar. Geol.* **4**, 259 (1966).
16. We thank NSF for support under grants GA-10204 and GB-8628, and Atlantic Richfield Company for assistance and permission to publish this discovery. The study was conducted in the micropaleontology laboratory of the University of Southern California (Allan Hancock Foundation) and in the research laboratory of Atlantic Richfield. Foraminiferal illustrations were made by R. C. Wright in the Central Electron Microscope Laboratory of the University of Illinois. The instrument used, the Cambridge Stereoscan Mark II, was purchased by funds from NSF (NSF GA-1239), PHS (PH FR-07030), and the Illinois University Research Board. We thank Dr. B. V. Hall, Director of CEM Laboratory, and Dr. W. W. Hay, L. Dryer, R. Harmer, and Mrs. O. Stayton for aid and assistance. This is contribution No. 212 of the Department of Geological Sciences, University of Southern California.

5 June 1969

Topological Inconsistency of Continental Drift on the Present-Sized Earth

Abstract. *Certain continents have in the past moved with respect to each other in a manner clearly implied by sea-floor spreading and other data. However, the resulting collective motion of all the continents was apparently not topologically possible on the present-sized earth. An expanding earth might resolve this difficulty.*

The old hypothesis (*1, 2*) that the present continents split off from one supercontinent and moved to their present positions is now supported by an enormous array of evidence (*3*). This evidence is derived from measurements of geological structure and age (*4, 5*), from paleomagnetism, from the geometrical fit, and, perhaps most convincing of all, from the evidence of previous history as recorded in the magnetic age and fracture zone patterns associated with ocean-floor spreading (*6, 7*).

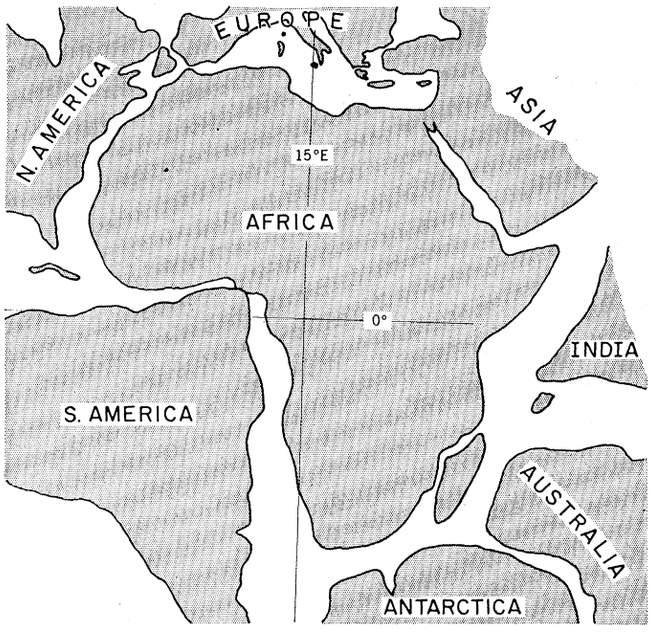
The latest reconstruction of South America, Africa, Europe, Greenland, and North America by Bullard *et al.* (*8*) is similar to that given by Baker (*2*, p. 14) in 1911 and is almost universally accepted. A reconstruction of Africa, Antarctica, Australia, India, and Mozambique has recently been given by Hurley (*5*) on the basis of geological data. This is similar to past reconstructions and also seems implied by the evidence from the magnetic and fracture zone patterns for the floor of the Indian Ocean. An approximate combination of these reconstructions is shown in Fig. 1. This figure is not an exact reconstruction of the former positions of the continents, but it does show the approximate relative positions of the continental masses before they split apart from Africa, as suggested by Hurley (*5*) and Bullard *et al.* (*8*) and much other data.

The hypothesis that the present continents were once part of a single continental mass is still somewhat controversial. However, the other conjecture that there were two original continental masses with the southern continents grouped around the South Pole and the northern continents grouped around the North Pole with a large ocean floor intervening seems to be contradicted by the presently accepted reconstruction of North America, South America, Africa, Europe, and Greenland, at least in the time period in question, which is from the present to approximately 150 million years ago.

Although the theory that the continents split apart and subsequently moved is widely accepted, the questions of why and how are still being argued. One group (the majority) believes that a thermally driven slow convective flow in the mantle of the earth split the crust of the original supercontinent and carried the fragments apart as a new ocean floor welled up from the interior. A minority group believes that continental separation was caused by an expansion of the interior of the earth (*9*). According to this view, which apparently goes back at least to Hilgenberg (*10*) and Halm (*11*), the expansion of the earth's interior split the original earth's crust and, as the earth expanded, the ocean floors were formed in the voids between the continents. Some of the expansionists have suggested that this radical expansion took place because of a gradual decrease in the gravitation constant, such as Dirac (*12*) had suggested for completely different reasons. In addition to the advocates of continental drift and large expansion of the earth, there are others who have proposed a combination of the two processes. All of these positions have been expounded at length, and there are arguments for and against every explanation.

The purpose of this report is specific. On the basis of very widely accepted interpretations of ocean-floor spreading and continental separation, a topological argument is developed. This argument appears to show that the separation and movement of the continents in the last 150 million years cannot be explained by continental drift on the surface of the present-sized earth.

The essence of this argument can be understood by reference to Fig. 2. This figure is an equidistant projection of the earth's surface with the origin of the projection in the central Pacific on the



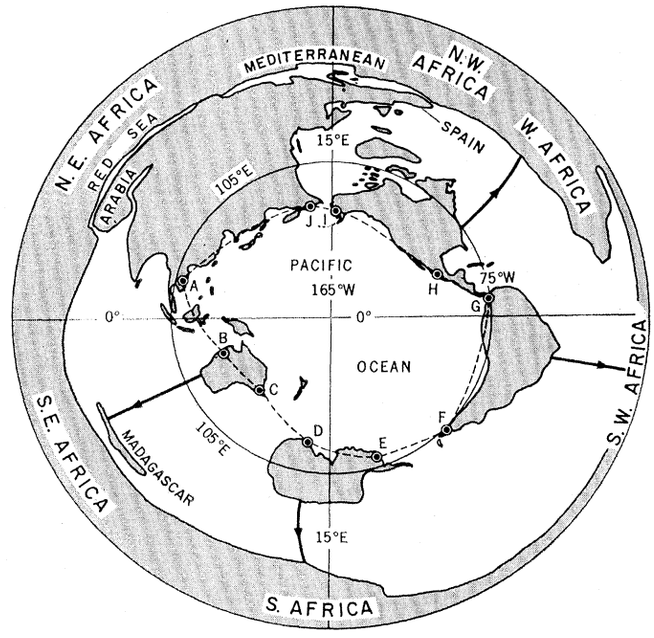


Fig. 1 (left). Proposed original relative positions of the present continents with respect to Africa; the drawing combines the essential features of reconstructions by Bullard *et al.* (*8*) and Hurley (*5*). Fig. 2 (right). Equidistant equatorial projection of the present earth showing the perimeter of the Pacific and the motions of the various continents necessary to achieve the reconstruction shown in Fig. 1.

equator at 165°W. This projection preserves undistorted the radial direction and distance along the great circles passing through the origin. The perimeter of the outermost circle represents the point opposite to the origin in Africa on the equator at 15°E. The circle formed by the meridians 105°E and 75°W forms the circumference of the earth halfway between the origin and its opposite point.

Figure 2 shows the present positions of the continents. If the continents have drifted on the surface of the earth from the arrangement shown in Fig. 1, then we should be able to reverse the process, by starting from the present and going backward in time, and trace the paths to the original positions. The apparent paths of reversed drift are shown by the arrows (Fig. 2), and, since these paths are almost entirely radial, they are not significantly distorted in direction or distance by this projection. These paths seem to follow from the pattern of sea-floor spreading in the Indian, Atlantic, and South Pacific oceans (*6*). If this motion as we go backward in time is to be topologically possible, the area enclosed by the average perimeter of the Pacific (Fig. 2, points *A* through *J*) must increase as we go backward in time in order that it could fit over the circumference of the earth formed by the meridians 105°E and 75°W and continue to the other side of the earth to form the proposed supercontinent shown in Fig. 1. This is necessary because the present average perimeter of the Pacific (Fig. 2, points *A* through *J*) encloses an area equal to only 0.35 of the earth's surface.

The term average perimeter is used here to mean the combined length of the sides of the spherical polygon shown in Fig. 2. It is assumed that the continental blocks are essentially rigid plates which retain their basic shape, although small linkages between them and minor features may be subjected to strong distortions. These physical properties of the continental plates are essential to explain the excellence of the geometrical fit of the accepted reconstructions. From this viewpoint the average perimeter is the shortest distance along the continental plates connected by the shortest distances of intervening ocean or isthmus (Fig. 2, points *A* through *J*).

Thus it is assumed that the perimeter of the Pacific in times past could only have changed by the change in length of the connecting links *AB*, *CD*, *EF*, *GH*, and *IJ*. My contention is that, on the basis of modern knowledge of ocean-floor spreading, it is quite unambiguous that the combined length of these links and the area enclosed by the perimeter decrease as we go backward in time at least from the present to 80 million years ago. If this conclusion is granted, it is topologically impossible to move simultaneously the four continents along the paths indicated by the arrows (considering also the points of attachment of Eurasia to Africa at Spain and Arabia, which has only recently separated from Africa by the action of the Red Sea rift). To achieve the arrangement shown in Fig. 1, the perimeter of the Pacific must have at some time enclosed at least half of the earth's surface in order for it to pass over the earth's circumference (as we go back in time) and be assembled on the opposite side of the earth. Thus there is no topologically possible transformation of the continents on an earth of the present size from their present positions to even approximately the positions shown in Fig. 1 if we accept the constraints on the perimeter.

One can question the assumptions about the past history of the linkages in the perimeter of the Pacific, but the evidence is strong for the view presented here, particularly from the maps of magnetic dating of ocean floors reported by Heirtzler *et al.* (*6*) and Heirtzler (*7*).

If we go back in time, the magnetic dating and fracture lines of the floor of the Atlantic Ocean show that *GH* decreases and the ocean floor south of Australia shows that *CD* decreases until Australia was in contact with Antarctica about 40 million years ago. The link *IJ* was not very active in this

time period, but faunal migrations imply a Bering land bridge 80 million years ago. The magnetic dating associated with the ridges in the eastern Pacific imply the decrease of *EF*. The magnetic dating and fault structure of the Indian Ocean show that Australia has moved slightly north of west (as we go backward in time) in relation to Africa in the given time period. Since Africa must simultaneously move slightly north compared with Asia, as demanded by the ridges in the Indian Ocean and the Red Sea, the link *AB* was apparently shorter. This is consistent with the accepted biological evidence that the marsupials arrived in New Guinea and Australia by way of a land connection to mainland Asia (and not from South America by way of Antarctica) and that this land connection was broken 70 million years ago or before (*13*). The reconstruction of Fig. 1 also leads to this conclusion. The evidence for the decrease of each of these linkages as we go back in time is rather strong, and it seems highly improbable that the area enclosed by the perimeter was ever as large as half the earth's present area in the last 150 million years.

The topological argument given above is independent of possible downwelling of the ocean floor. It is also apparently independent of shrinkage of the continents associated with mountain formation since the important mountain regions of the perimeter could be included without significant increase in the perimeter. The argument is not very sensitive to the exact time scale or to variations in the rate of ocean-floor spreading, as long as these were reasonably monotonic in the period in question, and could be adapted to most proposed reconstructions of a single supercontinent.

The only hypothesis that has been suggested thus far that resolves the paradox described above is that in the past the earth's interior has expanded considerably (the inverse process of a contraction of the crust of this magnitude has not been seriously suggested). It is conceivable that a rather small expansion, as suggested by Dicke (*14*) and by Wilson (*15*), might be consistent with the above argument. The most direct interpretation of the evidence, however, seems to be that a large expansion of the earth's interior has taken place in the last 150 million years. The nature of the physical process that could have led to such an expansion is highly conjectural, but such a process cannot be excluded on the basis of present physical knowledge. Because of the radical implications of the expansion hypothesis, the assumptions of the argument presented above will need to be examined with care and objectivity.

R. MESERVEY

Francis Bitter National Magnet Laboratory, Massachusetts Institute of Technology, Cambridge 02139

References and Notes

1. A. Wegener, *Die Entstehung der Kontinente und Ozeane* (Vieweg, Braunschweig, ed. 4, 1929; English translation, Dover, New York, 1966).
2. A. L. DuToit, *Our Wandering Continents* (Oliver and Boyd, Edinburgh, 1937).
3. P. M. S. Blackett, E. Bullard, S. K. Runcorn, *Phil. Trans. Roy. Soc. London Ser. A Math. Phys. Sci.* **258**, 1 (1965); G. D. Garland, Ed., *Continental Drift Symposium* (Univ. of Toronto Press, Toronto, 1966); S. K. Runcorn, Ed., *Continental Drift* (Academic Press, New York, 1962).
4. J. T. Wilson, *Sci. Amer.* **208**, No. 4, 86 (1963).
5. P. M. Hurley, *ibid.* **218**, No. 4, 53 (1968).
6. J. R. Heirtzler, G. O. Dickson, E. M. Herron, W. C. Pitman III, X. Le Pichon, *J. Geophys. Res.* **73**, 2119 (1968).
7. J. R. Heirtzler, *Sci. Amer.* **219**, No. 6, 60 (1968).
8. E. Bullard, J. E. Everett, A. G. Smith, *Phil. Trans. Roy. Soc. London Ser. A Math. Phys. Sci.* **258**, 41 (1965).
9. L. Egyed, *Geol. Rundsch.* **46**, 101 (1957); *Nature* **178**, 534 (1956); S. W. Carey, *Continental Drift, A Symposium 1958* (Univ. of Tasmania, Hobart, 1959), p. 177; P. Jordan, *Abh. Math.-Naturwiss. Kl. Akad. Wiss. Lit. Mainz* **1959**, 769 (1959); *Rev. Mod. Phys.* **34**, 569 (1962); B. C. Heezen, in *International Oceanographic Congress Preprints*, M. Sears, Ed. (AAAS, Washington, D.C., 1959), p. 26.
10. O. C. Hilgenberg, *Vom Wachsenden Erdball* (Giessmann and Barsch, Berlin, 1933).
11. J. K. E. Halm, *Astron. Soc. S. Africa* **4**, 1 (1935).
12. P. A. M. Dirac, *Nature* **139**, 323 (1937).
13. P. J. Darlington, Jr., *Biography of the Southern End of the World* (Harvard Univ. Press, Cambridge, Mass., 1965), p. 81.
14. R. H. Dicke, *Rev. Mod. Phys.* **29**, 355 (1957); *Amer. Sci.* **47**, 25 (1959).
15. J. T. Wilson, *Nature* **185**, 880 (1960).
16. Supported by U.S. Air Force Office of Scientific Research.

5 May 1969; revised 25 July 1969

Shallow Scattering Layer in the Subarctic Pacific Ocean: Detection by High-Frequency Echo Sounder

Abstract. *Shallow scattering layers consisting mainly of* Calanus cristatus *were detected on a trans-Pacific crossing to depths of 60 meters with a high-frequency echo sounder. Biomass estimates of these layers indicate concentrations of zooplankton that are greater and more extensive than previously reported in the open ocean.*

The extensive use of low-frequency sounders in the marine environment has shown the presence of deep scattering layers in many parts of the hydrosphere (*1*). These layers generally exist below 100 m in the oceans, but at least parts of the layers migrate at night from depths of 300 to 500 m into the surface waters. Thus far only limited use has been made of high-frequency echo sounders in plankton studies (*2*). The major limitation of high-frequency sounders in comparison to low-frequency sounders is that the signal of the former, which is very efficient at picking up small targets, has an effective range of no more than 200 m, whereas the latter unit, which is generally limited to large targets, commonly has a range in excess of 1000 m.

A high-frequency (200-khz) echo sounder (*3*) was operated continuously during two crossings of the Pacific Ocean, from 18 March to 5 May 1969, on board the Canadian research vessel *Endeavour*. The crossings (Fig. 1) followed an approximate great circle route through the subarctic Pacific between Esquimalt, British Columbia, Canada, and Tokyo, Japan, and from Hakodate, Japan, to Esquimalt.

A dense shallow scattering layer was observed to occur during daylight hours over most of the Pacific at varying depths and concentrations. Illustrated in Fig. 1 are the relative positions and daily occurrences of the scattering layers within the upper 100 m from 0600 hours to 1800 hours.

Night observations of the layer indicated that it was closer to the surface and was comprised of a variety of plankton species. Net tows at night yielded mixed catches of nekton and euphausiids, and other zooplankton. During daylight the layer varied in depth and thickness from 10 to 60 m; the intensity of the echo varied from no response at relatively few locations to a very heavy echo response corresponding to a layer thickness of approximately 40 m. The layers were usually arrayed between depths of 20 and 40 m.

Two types of apparatus for the sampling of zooplankton were used to examine the layers. One type was the Miller sampler (*4*), ten of which were