Geomorphology of the Ninety-East Ridge

Michael H. Brill

Science Applications International Corp., 1710 Goodridge
Drive 1–11–1, McLean, VA 22102, USA

This paper is a speculation about the tectonic origins of the Ninety-East Ridge, based on the cartographic fact that the ridge is straight (adhering to a great circle on the Earth) over its 3,000 miles of extent. To account for this straightness as more than a phenomenal coincidence seems to require that the substructure of the ridge be made of a material of unprecedented strength, either to shear or to tensile stresses. A dimensional argument concludes that the material of the ridge substructure must be as much stronger than any known geological formations as a thread or hair is stronger than a congealing wax skin on top of liquid wax. The 'strong stuff' hypothesis is examined in terms of geophysical data from the Ninety-East Ridge, and a new experiment is suggested. A candidate material might be a strand of carbon 'buckytubes' related to the recently discovered fullerenes. Such a strand may have floated to the surface of the mantle, become snagged in the Indian continental plate, and then been pulled progressively out of its carbon-reservoir source (by the northward migration of the plate) into a 3,000-mile-long straight structure that supports the ridge.

Introduction

A bowl of cream soup left out to cool develops a skin of congealed material. When disturbed, this material acquires a topography relative to the size of the bowl that is much more rugged than are the mountains, relative to the size of the earth, on the continental plates moving over the 'porridge' of the Earth's molten interior. The skin on the soup is also very weak structurally (but not relatively so weak as the mountains), so we should be surprised to see a straight feature several inches long in the skin of the soup. In fact, upon seeing such a feature it would be natural to suspect it is caused by an underlying object – perhaps a floating hair under tension or a rigid toothpick.

Whatever is causing the straight feature has a structural integrity (under tension or shear forces) that is much greater than the skin of the soup. How much stranger, given the weakness of the material of the mountains on the size scale of the whole Earth, that a long, straight ridge extends for over 2,800 miles (from 9° N to 32° S) on the Indian-Ocean floor! This is the Ninety-East Ridge, and if its straightness is not complete coincidence (or the work of superhuman extra-terrestrials), there must be something under that ridge made of a material as much stronger than the mountains (or any material known to us) than a toothpick or hair is stronger than the curd on the top of a cream soup.

I review here the geological literature concerning the Ninety-East Ridge, with an eye to finding if any evidence supports my hypothesis that something inconceivably strong underlies the Ninety-East Ridge.

The Ninety-East Ridge: historical background

The Ninety-East Ridge has inspired a certain amount of awe that shows up in both popular and scientific descriptions of it. A popular description states:[1] "[The ridge] runs 1,500 miles south from the Bay of Bengal... It is the longest rectilinear geotectonic structure in the world. Put simply, this means that it is the world's longest straight physical feature". This description is both linguistically and numerically conservative as descriptions go. The consensus is that the ridge is actually at least 3,000 miles long.[2–4] And consider the description by Sclater and Fisher:[3] "Together [with Chagos-Laccadive Ridge], these meridional highs resemble train tracks, fancifully marking the route of India after the sundering of Gondwanaland". Fisher is also quoted as saying,[2] "It's a fantastic feature. It's 10,000 feet high, as wide as the Sierra Nevadas and flat on top. On the map. it's a straight line... it looks like a big freight train".

Sclater and Fisher[3] offer an excellent history of scientific investigations of the Ninety-East Ridge. As early as 1902, British cable-route surveys discovered part of the ridge at about 13–15° S. The northernmost few hundred kilometres of the ridge (in the Bay of Bengal) was described in 1925 by Seymour Sewell, and named Carpenter Ridge. However, the full extent of the ridge was not delineated until the International Indian Ocean Expedition of 1960–65. This delineation brought to light the continuity and straightness of the ridge, which Heezen and Tharp in 1965 called the Ninety-East ridge because of its proximity to the 90° E meridian. A topographic map of the Indian Ocean (with elevation suggested by an artistic rendering of shading by a light source) appeared in the October, 1967, issue of the *National Geographic*.[5] The map, one of many based on the work of Heezen and Tharp, showed the ridge as spectacularly straight and continuous. A later map from the *Encyclopedia Britannica* [ref.4] shows the ridge as having block-like parts, and also reveals the transform faults that were discovered in the South-East Indian Ridge south of the Ninety-East Ridge. This later map gives us the benefit of more details about the Ridge itself, and also shows the understanding of transform faults in mid-ocean ridges that emerged after 1967. Interestingly, it also shows an absence of transform faults along the Ninety-East Ridge itself.

Ansatz: scaling arguments in geophysics

It has been known since the time of Galileo that larger objects are relatively weaker than smaller objects of the same shape and material. For example,[6] an elephant has (proportionally) thicker legs than an insect because the supportive strength of a leg varies as the square of its thickness, but the weight of an object varies as the cube of a characteristic length (such as leg thickness).

Philip Morrison (a professor of Physics at MIT) gives a model in his lectures that most startlingly conveys how weak things get when they are large. Morrison asks, if a globe is sprayed with a can of whipped cream, which is stronger (on its own scale), the whipped cream on the globe or the mountains on the Earth. The answer is that the whipped cream is much stronger, because mountains on the Earth do not sustain a relief nearly so large compared to the Earth's radius as the relief of the whipped cream relative to the radius of the globe. It was this argument, and the sight of the straightness of the Ninety-East Ridge on a relief map, that led to the present inquiry.

It is interesting at this point to note other scale models in geophysics, which provide a context and precedent for the qualitative arguments in the present paper. Alfred Wegener himself became convinced of his theory of continental drift by tearing a stack of paper sheets and not being able to fit pieces together from opposite sides of the tear unless the pieces had come from the same sheet of paper.[7]. More recently, the formation of transform faults perpendicular to tectonic plate boundaries has been modelled by a tray full of hot wax with a congealing surface, through which a paddle is dragged.[8,9] Parallel to the direction of drag, dislocations form on each side of the paddle, and persist for certain kinds of wax (but, puzzlingly, not for others). Even more literally, plate migration has been modelled by using the freezing skin on a lava column found in Hawaii.[10] Finally, the very large scale magma convection that occurs in the Earth's mantle and which is responsible for volcanic 'hot spots', has been modelled by injecting dye-laden hot glucose solution into a cooler undyed glucose solution.[11]

Geological theories in light of the new hypothesis

After the initial naming of the Ninety-East Ridge during the era from 1960–65, there was quite a bit of investigation of the area during the Deep-Sea Drilling Project of the early 1970s.[12] At least three kinds of data were amassed during these years:[3,13] Magnetic anomalies detected in the sea floor adjacent to the ridge, the stratigraphic succession from drill sites on the ridge crest (through a drilling depth of 500 meters of sediment and basalt), and bathymetric (depth) measurements.

The origin of the ridge is acknowledged not to be completely understood, but one hypothesis,[3] is that the ridge is the result of an extrusive volcanic hot-spot underneath the Indian tectonic plate, which remained stationary while the plate moved to the north in its collision with Asia. It is difficult to imagine a motion that is so close to a great circle (straight line) occurring over millions of years, but the 'hot-spot' hypothesis is confirmed by the fact that the volcanic rock is younger at the south end of the ridge than at the north end.

More recently. investigators conducted surface-wave seismic propagation studies to discover the nature of the upper mantle beneath the ridge.[14] It was discovered that the seismic waves were taking longer to travel from the earthquake epicentre to the receiver when a part of the ridge was interposed. Souriau interpreted this result as meaning that a material of low density (hence low seismic-wave speed) comprises the ridge or subridge mantle of the earth. However, this interpretation does not allow for the possibility that the seismic wave has to travel around the ridge substructure because the structure has such a high elastic modulus that the seismic wave cannot penetrate it at all. (Mantle inhomogeneities would allow the seismic wave to take a circuitous route about the ridge.)

Finally, computer-modelling of plate motion over volcanic 'hot-spots' in the

Indian ocean has yielded a quasi-straight trace for the Ninety-East Ridge.[11,15] However, the results of the simulation show a modelled 'hot-spot' trace that is not nearly so straight as the Ninety-East Ridge. Whether the departure of the modelled ridge from the actual one is the result of small modelling errors or bathymetric measurement errors on the actual ridge is a matter for future discussion and investigation.

Experimentum Crucis

I have argued that experiments so far do not rule out the possibility that the substructure of the Ninety-East Ridge is made of an extraordinarily strong material. Core samples to a depth of 500 meters in a 3,000-meter-high ridge are clearly not conclusive (any more than would be a mosquito drilling for bone samples on a human being). The observed long latency of seismic waves may not be from straight paths through the ridge substructure, but from paths that go around the ridge substructure.

The critical experiment I propose is to detonate explosive charges over the ridge, and then to measure the reflected returns from layers of material beneath the ridge. The acoustic receiver used to measure the returns should be located far enough down the ridge from the source that the measurement captures the modulus of the ridge material in the longitudinal direction (the direction in which I expect the material to be strongest). Numerical procedures can extract from these returns not only the depth of a given reflecting layer, but also its reflection coefficient. If the 'strong material' hypothesis is correct, a layer should be encountered with a reflection coefficient of 1: all the sound gets sent back, and none penetrates. Furthermore, after this return there should be a period of near silence, corresponding to the deeper layers being shielded from the incident sound wave and hence being unable to cause a return. If no such effect were observed, we would be forced to conclude that the straightness of the Ninety-East Ridge is a coincidence. At that point we should tolerate the coincidence with the same equanimity with which we accept the coincidence that the Moon and the Sun occupy about the same solid angle as seen from Earth.

Possible material for the ridge substructure

If the Ninety-East Ridge has a substructure that is made of an inconceivably strong material, what are some candidate materials for that substructure? Recent developments in carbon chemistry have opened a promising avenue of investigation, starting with the discovery of buckminsterfullerine. Also known as 'buckyballs' and most commonly found in the form C_{60}, this substance was discovered only three years ago and is the only known molecular form of carbon.[16]. Because only weak van der Waals forces exist between buckyballs, they are not by themselves candidates for the strong material we seek. However, perhaps the related tubular graphite discovered by Iijima[17] would offer the requisite strength – tensile or shear strength. Iijima's graphitic microtubules (now also called 'buckytubes') are made using the same kind of arc-discharge method used to create the fullerenes, and in fact are easier to make than fullerenes. Within the last year,[18] buckytubes have been created with great efficiency in the laboratory, and promise to be "100 times stronger than an iridium beam of the same length". The strength predicted above is exactly the sort required for a structure such as we are here attributing to the Ninety-East Ridge: A high bending strength also implies a high tensile strength.

Not only are buckytubes strong enough to fit our hypothesis, but recent scientific work supports the possibility of molecular carbon existing in large quantities deep in the Earth.[19] Gold argues that the Earth has always contained large quantities of abiogenic hydrocarbons in its interior (an argument supported by the fact that hydrocarbons exist on all the other planets). However, pure carbon must also be present deep in the earth: Gold himself attributes the formation of diamonds to such a presence.

Because the material in the Earth's interior is not in contact with any reactive gases, such as hydrogen or oxygen, it is plausible that molecular carbon should exist in the mantle, even as metallic iron does. Such carbon would naturally float to the Earth's surface, since it would be much lighter than the metals in the interior (predominantly iron). Why should there not be a long strand of the stuff in the Indian Ocean basin? And if one end of the strand is being dragged by northward translation of the Indian plate, the straightness of the strand is virtually assured so long as it can stand the tensile stresses.

A valid question (asked by a reviewer) is what happens when the known *rotation* of the Indian plate is included in the picture. Plate rotation would drag the strand in a direction not parallel to itself, and this creates two apparent difficulties: the strand leaves a trough in its wake, and it does not remain straight. (Of course, the track of a volcanic plume doesn't stay straight either, so the conventional theory has some of the same problems.) In answer to these objections, we have to revise the strand picture somewhat. First of all, maps reveal that the Ninety-East Ridge lies entirely in the Indian plate, although its southern end is quite close to the South-East Indian Ridge that bounds the plate. With this in mind, the following theory of the ridge origins suggests itself:

A large, diffuse. carbon-rich region in the mantle gave rise, millions of years ago, to a buckytube structure that began to float to the surface, where it became enmeshed with the Indian plate and created the ridge (by flotation). The north end of the structure (which was still quite short) rose first, and was dragged along by the plate. The southern tip remained in the carbon reservoir, where it accreted more carbon and grew in a straight direction. As the Indian plate moved to the north, the accretion continued and more of the ridge became enmeshed in the plate. The predominant linear motion of the plate gave rise to the predominant direction of the ridge; the quasi-crystalline growth of the structure in the carbon reservoir caused the growing end to remain straight because of the great bending strength of the buckytube material; finally, the carbon reservoir has been large enough so the growing end of the structure has remained in the reservoir even though it is forced to move due to rotation of the plate.

The apparent coincidence of the growth rate being the same as the plate migration rate might better be understood as technologists make larger buckytubes. It may be that the growth process can occur only at the boundary of the carbon reservoir, where certain chemical and electrical conditions prevail. In that case, growth can happen only as fast as the growing end is pulled through the reservoir/boundary region.

Conclusion

The straightness of the Ninety-East Ridge seems not to have been the primary reason for studying the ridge. Rather, the reconstructed paleohistory had a rather interesting set of complications in the neighbourhood of the ridge. The northern (old) part of the ridge is said to have begun as intra-plate volcanic activity due to motion of the plate over a volcanic plume, but the southern part of the ridge (new) has found emplacement along a transform fault from the edge of the Indian plate.[20] Why the transform fault is aligned with the old ridge is not explained. The complicated theory would have been acceptable were it not for the coincidental straightness of the ridge, which seems to have escaped attention lately because it does not fit conveniently into the theory. Perhaps nonetheless, the straightness was a motivation for much of the interest in the Ninety-East Ridge, and the interest waned only as scientific innocence was lost...

References

1 Barton, R. 1980. *The Oceans*, pp.41–42. Aldus Books, London.

2 Behrman, D. 1969. *The New World of the Oceans: Men and Oceanography*, p.396. Little, Brown and Co., Boston.

3 Sclater, J.G. and Fisher, R.L. 1974. Evolution of the East Central Indian Ocean with emphasis on the tectonic setting of the Ninety-East Ridge. *Bull. Geological Soc. Am.*, **85**, 683–702.

4 Jonsson, I.M, Cotter, C.H. and Kanayev, V.F. 1988. Oceans. *Encyclopedia Britannica*, Vol.25, excerpt on pp.191–197.

5 Matthews, S.W. 1967. Science explores the monsoon sea. *National Geographic*, **132**, October.

6 Thompson, d'A. 1961. *On Growth and Form*. Cambridge University.

7 Takeuchi, H., Uyeda, S. and Kanamori, H. 1967 *Debate About the Earth*, pp.45–46. Freeman Cooper and Co., San Francisco.

8 Oldenburg, D.W. and Brune, J.M. 1972. Ridge transform fault spreading pattern in freezing wax. *Science*, **178**, 301–304.

9 Oldenburg, D.W. and Brune, J.M. 1975. An explanation for the orthogonality of ocean ridges and transform faults. *J. Geophys. Res.*, **80**, 2275–2285.

10 Duffield, W.A. 1972. A naturally occurring model of global plate tectonics. *J. Geophys. Res.*, **77**, 2343–2355.

11 Duncan, R.A. and Richards, M.A. 1991. Hotspots, mantle plumes, flood basalt, and true polar wander. *Rev. Geophys.*. **29**, 31–50.

12 Van der Borch, C.C., Sclater, J.G. et al., 1974. *Inital Reports of the Deep sea Drilling Project,* Vol. 22: Darwin, Australia to Columbo, Ceylon, US Government Printing Office, Washington, DC.

13. Truswell, E.M. and Harris, W.K. 1977. The Palynology of Early Tertiary Sediments, Ninety–East Ridge, Indian Ocean. Paleontological Association, London.

14 Souriau, A. 1981. The upper mantle beneath Ninety-East Ridge and Broken Ridge, Indian-Ocean, from surface waves. *Geophys, J. Royal Astronom. Soc.*, **67**, 359–374.

15 Duncan, R.A. 1990. The volcanic record of the reunion hotspot. *Proceedings of the Ocean Drilling Program. Scientific Results*, Vol.115, pp.3–10.

16 Curl, R.F. and Smalley, R.E. 1991. Fullerenes. *Scientific American*, October, pp.54–63.

17 Iijima, S. 1991. Helical microtubules of graphitic carbon. *Nature*, 7 November, p.56.

18 Ross, P.E. 1992. Billions of buckytubes. *Scientific American*, October, pp.115–116.

19 Gold, T. 1987. *Power from the Earth: Deep Earth Gas-Energy for the Future*. J.M. Dent and Sons, Ltd., London.

20 Royer, J.-Y., Peirce, J.W. and Weissel, J.K. 1991. Tectonic constraints on the hot-spot formation of Ninety-East Ridge. In: Weissel, J.K., Peirce, J.W. and Taylor, E. (eds), *Proceedings of the Ocean Drilling Program: Scientific Results*, Vol.121, pp.763–776.

Received: 5 August 1992; *revised:* 3 November 1992; *accepted:* 9 November 1992; (communicated by A. Lakhtakia).