ARTICLES

EXPANDING EARTH?

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WHAT THIS ARTICLE IS ABOUT

Plate tectonics, which suggests that the crust of the earth is composed of a few plates fitted together like pieces of a puzzle, has been very successful in explaining surface features of the earth, such as mountains, ocean trenches, volcanos and earthquakes. However, some of the evidence to support it is ambiguous and the source of plate motion has not been unequivocally identified. Motivated by these problems, a few earth scientists have proposed an alternative model, the expanding earth. This article first considers satellite and interferometry measurements which were supposed to provide a definitive test of the two models. However, despite phenomenal accuracy, the error associated with these measurements is still too large to distinguish between the models. Additional evidence favoring the expanding earth is discussed, including the superior fit of the continents that it allows. This is followed by some of the problems that are associated with it, such as the source of expansion. Finally, some of the problems of plate tectonics are considered, most significant of which may be the mechanism that moves the plates.

In summary, there are difficulties with both models. Currently, plate tectonics seems to be the more adequate of the two models, but that may reflect the time invested in it. Perhaps a more acceptable model would involve the synthesis of the two concepts. Unfortunately, it appears that such a combination would import the difficulties of finding suitable causes for both expansion and *plate motion.*

Plate tectonics has been a very successful model in describing and synthesizing information about the kinematics of the crust of the earth (Lithosphere 1983, p 1; Loper 1985). Briefly, it suggests that the surface of the earth is composed of a few plates which fit together like pieces of a spherical puzzle (Tarbuck & Lutgens 1984, p 400-406). The edges or boundaries of these plates are typically characterized by volcanoes and epicenters of earthquakes. Some of the boundaries, such as the mid-Atlantic ridge, are identified as spreading ridges, where birth is given to new crustal material; other boundaries, such as the trench of the west coast of South America, are identified as subduction zones where old crust is being pulled or pushed back into the interior of the earth; still other boundaries, like the San Andreas fault, are slip-strike faults where one plate slides past another; and others, such as the Himalayas, are interpreted to be places where plates are colliding. As suggested by the processes occurring at the boundaries, the plates are moving with respect to each other. Since the plate-tectonic model assumes a constant-sized earth (Tarbuck & Lutgens 1984, p 403), the sea-floor spreading that occurs at the ridges has to be compensated for by subduction and collisional compression.

However, a small but persistent group of earth scientists argue that the spreading sea floors and wandering continents are best explained in terms of an *expanding earth* (Carey 1976, Carey 1983a, Carey 1988, Crawford 1986, Glikson 1980, King 1983, Owen 1983a, Steiner 1977). In its most radical form this model assumes that sea-floor spreading is entirely compensated by the increasing area of an expanding earth so that no subduction occurs (Carey 1976, p 14; Carey 1988, ch 13; Crawford 1986). Some variations on this incorporate modest subduction and collision along with the expansion of the earth (Owen 1983b). In spite of the fact that a number of times the expanding earth is said to have been discredited (Kerr 1987; Smith 1976, 1977, 1978; Wood 1979) the expanding earth remains as an alternative model to plate tectonics.

S. Warren Carey, who can be considered the dean of the expanding-earth model, feels that all the apparent plate motion is due to the crust of the earth accommodating itself to an earth that is increasing in size. In his 1976 book, *The Expanding Earth* (Heirtzler 1977, Irving 1978, Karig 1978, Mundy 1985), Carey proposed three experimental tests to verify if the earth is expanding (Carey 1976, p 443). Variations on two of these suggestions have now been done: a) satellite laser ranging (SLR) and b) very long base interferometry (VLBI) (Anderson & Cazenave 1986, Stein 1987). Doppler satellite measurement techniques are also being developed.

VLBI AND SLR RESULTS

VLBI consists of a pair of receivers, at different locations on the earth, looking at the same quasar (Carter & Robertson 1986, Herring et al. 1986). Quasars are so far from the earth that parallax is negligible even over the distance of the diameter of the earth. These quasars are also radio sources which can serve as a random "universal bar code" (Stein 1988). When two receivers are oriented as shown in Figure 1, receiver A will receive a code before receiver B. Using the time delay and a little

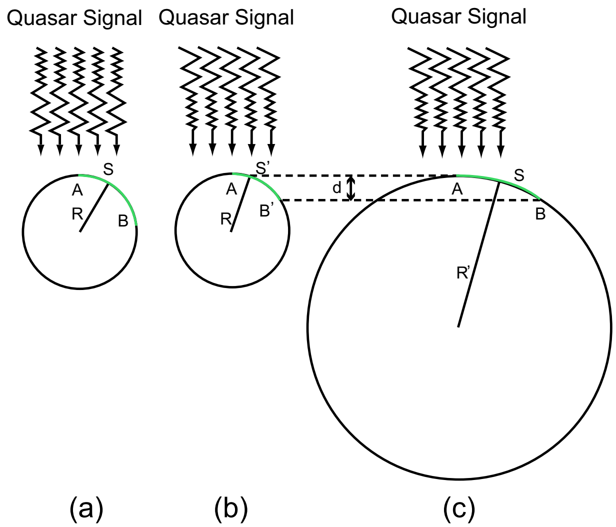

FIGURE 1. R, the radius of the unexpanded earth, the same in (a) and (b); S, the arc length between stations A and B, the same in (a) and (c); d, the difference in distance from stations A and B to the quasar, the same in (b) and (c).

geometry, the distance between the two stations can be determined. Now, at a later time, when station A is again oriented with respect to the quasar as before, if B has moved so that it is closer to A the delay time between the reception of a code will be less than before. But notice that if the distance between receivers A and B has remained fixed but the earth has expanded in the mean time, this would also reduce the delay time between the two receivers.

SLR consists of beaming lasers toward satellites that have been fitted with reflectors (Christodoulidis, Smith & Kolenkiewicz 1985; Tapley, Schutz & Eanes 1985). This provides independent but similar measurements to VLBI, with the same ambiguity as to whether there has been surface movement or earth expansion.

Measurements made over the last ten years using VLBI and SLR have yielded similar results (Kolenkiewicz, Ryan & Torrence 1985; Stein 1987). Amazingly, these plate speeds and directions also correspond nicely within measurement error (correlation of 0.91 for SLR data), with the geotectonic calculations of Minster and Jordan (1978) which are based on paleomagnetic, earthquake and fault azimuth data, which are presumed to be averaged over geologic periods of time (Christodoulidis et al. 1986, Herring 1986, Minster & Jordan 1978). There are some tantalizing, though

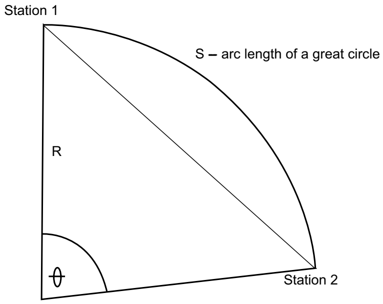

FIGURE 2. Geometry for inter-continental measurement on a great circle.

marginally significant, differences: across the “stable” North American plate for which Minster and Jordan naturally calculate a relative velocity of zero, the VLBI measurements indicate that the two locations are *approaching* each other at a rate of about one centimeter per year (-1.0 cm/yr); or this could be explained by an earth expansion of about two centimeters per year (2.0 cm/yr) while the actual surface separation remains constant. If measurements are made between three stations that lie on a great circle of the earth then we can dispense with the requirement that any of them be located on stable plates but can in fact make intercontinental (interplate) measurements (Carey 1988, p 168-170). Using the geometry shown in Figure 2, we can relate the chord length C between two stations, the radius R of the earth and the enclosed angle θ by the expression, $C = 2R\sin(\theta/2)$. Taking the time derivative, we get

$$dC/dt = 2dR/dt \sin(\theta/2) + Rdh/dt \cos(\theta/2).$$

Solving this equation simultaneously for each of the three pairs, Australia-Hawaii (-7 cm/yr), Hawaii-USA (+4 cm/yr), and Australia-USA (-3 cm/yr), Carey got dR/dt = 2.8 cm/yr (negative numbers mean moving closer; positive numbers moving apart). But the error associated with the measurements that he used are such that this could be zero! And, unfortunately, it is proving difficult to improve the accuracy of these measurements, so it may be several more years before more definitive results can be obtained (Herring 1986, Parsons 1988, Smith & Christodoulidis 1985). At this time the results may be consistent with an expanding earth, but they are ambiguous. However, it is expected that these measurements will provide the final evidence whether or not continental drift is occurring (Martin 1987).

EVIDENCE FOR EXPANDING EARTH

Maps are what initiated the development of plate tectonics. And maps provide motivation for the expanding-earth model (Carey 1988, p 93, 166, 167). A casual glance at a globe of the earth suggests that the east coasts of North and South America might nicely fit against the west coasts of Africa and Europe. Such fits have been made, first of all by sliding cutouts of continents around on a globe, now by computer simulations. Good fits can be obtained. The differences obtained by different cartographers are due to such considerations as how much of the continental shelves are included with the continents and different interpretations of paleomagnetic data (Chatterjee & Hotton III 1986; Hartnady 1988; Jackson 1988; Lawver 1984; Powell, Johnson & Veevers 1980; Rickard & Belbin 1980; Stock & Molnar 1987). Typically, even with the best fits, there are some overlaps and/or gaps between the continents when the fits are made on a globe scaled to the present size of the earth. Carey, Owen and others have noticed that they could improve the fits and avoid a questionable Tethys ocean if the continents were cut out and fitted on a smaller globe (Carey 1976, p 27,40; Carey 1988, p 143, 164-167; Crawford 1986; Harland 1979; Owen 1979; Owen 1983a, p 3; Owen 1984; Schmidt & Embelton 1981; Vogel 1984). This suggests an earth that has expanded over time. Carey, who has been most aggressive with this argument, suggests that the earth had a radius of about 60% of its current value during the Jurassic era, and hence no subduction need to occur. Owen starts with an earth with a Jurassic radius of 80% of its current value, so he has to allow for some subduction in his model. In a critique of Owen's work, Hallam allows that Owen's strong point is geometric but goes on to argue that the edges of the continents are not well defined and that there is evidence that some continental pieces have "subsided" or been "attenuated" (Hallam 1976). However, Harland states that "Owen's work is so thorough that it cannot be ignored" (Harland 1979).

Another argument for an expanding earth is that all the present ocean floors are geologically young (Carey 1976, p 53; Carey 1988, p 147, 186; Glikson 1980; Vogel 1984). With the plate-tectonic model, it is presumed this is because older oceanic crust has been subducted (Scholl & Vallier 1983, Smith 1985). So an area equivalent to the Pacific Ocean is usually assumed to have been subducted under the Americas since the Jurassic with no debris or remnants of older oceanic crust left behind. Glikson states, "I am unaware of any constant radius models capable of accounting for the nature of about three fourths of the earth's crust during Precambrian time" (Glikson 1979). The expanding earth provides a natural explanation: the ocean floors are just the new surface that has emerged during the expansion process.

The distributions of fossil plants and animals have been used as indications of the past locations of continents and oceans (Ahmad 1983;

Davidson 1983; Fallow 1983; Shields 1979). A recently reported study of brachiopods concludes that "the balance of evidence seems to require an expanding earth" (Ager 1986).

PROBLEMS WITH EXPANDING EARTH

But the expanding-earth concept is not without its problems. A natural question is, how do mountains form on an expanding earth (Stocklin 1983)? In the context of plate tectonics, mountains are understood to be the consequence of colliding plates. But colliding plates would not be expected to be a prominent feature of an expanding earth. Carey has developed a "diapiric extension model" of "orogenesis" (Carey 1986). This model (see Figure 3) proposes that as the earth expands, the lithosphere thins at various locations and mantle material, with the reduced pressure, experiences phase changes, expands and rises sufficiently to maintain an isostatic balance. In the resulting break-up of the crust and elevation of mantle material, gravity spreading (downslope motion of overlying material) occurs. There are some similarities between the diapiric process and a very slow motion volcano. Characteristic patterns of mountains can thus be obtained. Carey has detailed the Himalayan tectonics and other mountain ranges using his model. See Figure 4. On the basis of faunal and floral elements, Ahmad concludes that "the Himalayas could neither have been born of collision nor of subduction, but resulted from vertical uplift" (Ahmad 1983). And while Stocklin does not feel that Carey's model of diapiric deformation is sufficient to account for the "general Himalayan style", he does allow that the "structure of the Himalaya is in no contradiction to an expanding earth" and that a previously smaller Earth radius would allow India, Africa and Eurasia to be positioned as required by paleomagnetic data without detaching India, which is just what geology requires (Stocklin 1983). Even advocates of standard plate tectonics recognize that Himalayan orogeny and the associated Tethyan paradox (lack of evidence for postulated Tethys ocean) are complex and elusive of interpretation, providing evidence that often leads to diverse and very incompatible models (Funk et al. 1987; Jiwen et al. 1987; Lemoine, Tricart & Boillot 1987; Searle et al. 1987; Sengor 1987; Srikantia 1987; Valdiya 1984; Verma & Kumar 1987).

Also, an expanding earth would suggest an increase in the moment of inertia of the earth, which would mean that the rate of rotation of the earth would have to decrease in order to conserve angular momentum. But the retardation that the earth does experience seems to be more than adequately explained by tidal friction (Bursa 1984, Bursa 1987, Van Diggelen 1976). However, Talobre claims that an expansion of the radius of the earth of

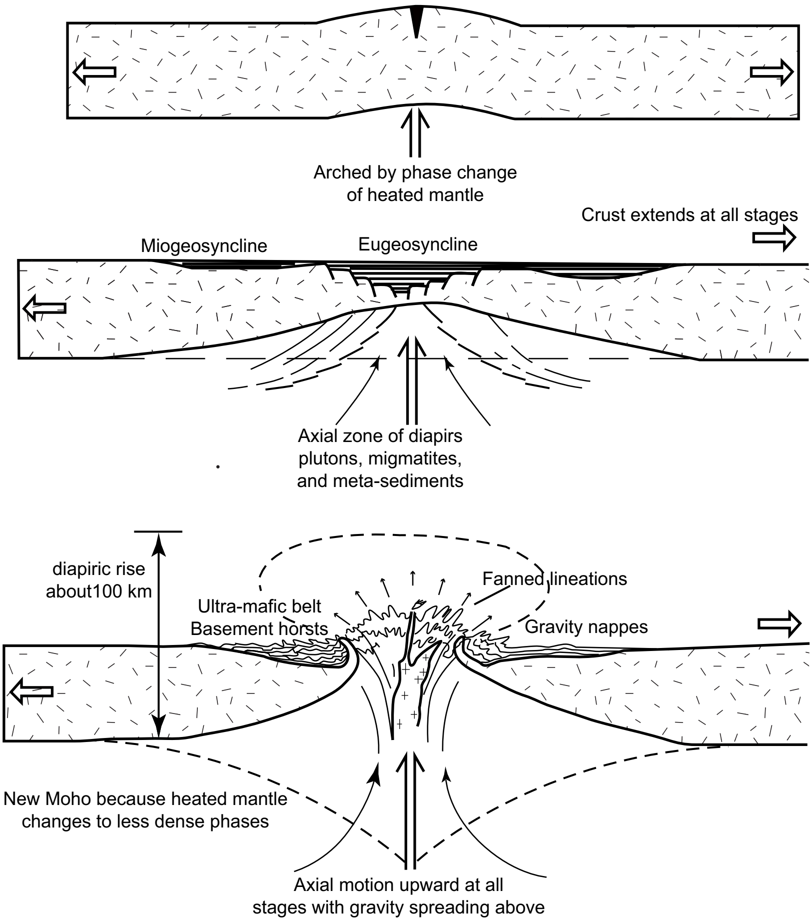

FIGURE 3. Model of the development of a geosyncline and orogen during continuous crustal extension and continuous diapiric rise of about 100 km. Figure 1 in: Carey SW. 1986. Diapiric krikogenesis. In: Wezel F-C, editor. The Origin of Arcs. The Netherlands: Elsevier Science Publishers, p 6. Reproduced by permission of the publisher.

about two centimeters per year is necessary to account for the increased duration of the day (Talobre 1983). On the other hand, it is possible to have a constant-mass object expanding and differentiating in such a way that the moment of inertia stays constant or even decreases (Carey 1988, p 196).

Burrett has also noted that "no reconstruction of the Early Paleozoic hypothesis [based on the expanding-earth model] has yet been produced

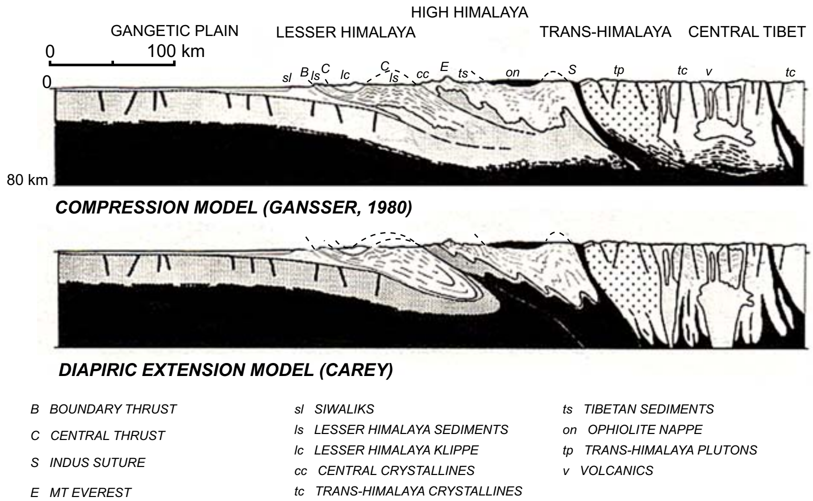

FIGURE 4. Compressional and diapiric models of the Himalaya. Figure 8 in: Carey SW. 1986. Diapiric krikogenesis. In: Wezel F-C, editor. The Origin of Arcs. The Netherlands: Elsevier Science Publishers, p 15. Reproduced by permission of the publisher.

that places the north pole in any paleomagnetically or paleoclimatically reasonable position” (Burrett 1983).

But the main problems associated with the expanding earth are the mechanism of expansion and some of the consequences associated with some of the most commonly suggested mechanisms (Taylor 1983). The most frequently mentioned mechanism is a structural or a chemical phase change that involves an increase in volume with constant mass (Carey 1976, p 124, 450; Stewart 1983). (The development of ice from liquid water, for example, involves a structural change in which there is an increase in volume.) This could be occurring at the core/mantle interface. In this process the mass of the earth would remain essentially constant while its volume is increased. Consequently, if the radius of the earth doubled, the force due to gravity on the surface of the earth would now be only one fourth of what it was prior to the expansion. But paleogravity studies indicate that the force of gravity has never been significantly greater than it is now (Stewart 1983).

Another suggested phenomenon is a change in Newton’s universal gravitational constant, G (Van Flandern 1979). This possibility was earlier suggested by Dirac to explain an expanding universe (Heirtzler 1977, Stewart 1983). As applied to the earth, the idea is that if G decreases, then the earth would expand due to reduced interior gravitational pressure. But, of course, if such expansion happened for the earth it would also happen for other planets, moons and the sun. And most astrophysicists see little evidence that such expansion happened on other planets such as Mars (McElhinny, Taylor & Stevenson 1978). Also, any significant change in G during the existence of the solar system would noticeably change the planetary distances which would change the thermal environment of the earth. Finally, calculations of the equation of state for the earth have been made in the context of general relativity (Einstein's gravitational theory) which shows that a changing G would not affect the size of the earth (Canuto 1981). Some scalar models of gravity would even have the earth shrink if G were to become smaller.

Perhaps the most radical suggestion is Carey's "null universe" in which it is envisioned that matter is continuously created (Carey 1983b; Carey 1988, p 338-342). (Carey rejects the "big bang" in favor of this continuous process.) The "null" is motivated by the assumption that all conserved quantities (momentum, energy, etc.) have net values of zero. That this could be true for momentum, for example, is evident. That this could also be true for energy becomes apparent when it is realized that the positive mass energy, mc^2, of an object can be offset by its negative gravitational potential energy, $-GMm/R$, where M is the mass of the universe and R is its radius (the Hubble radius). Tryon has shown that within observational uncertainties, $mc^2 - GMm/R \approx 0$ which is consistent with the suggestion that the net energy of the universe is zero (Tryon 1973, Tryon 1983). (Actually, the general theory of relativity, as currently understood, allows only an ambiguous concept of net energy.)

Although conservation of the standard conserved physical quantities is a high-lighted feature of the model, the "null universe" does not conserve baryon number, which would require, under present conditions, the creation of an equal number of particles *and* anti-particles. Other difficulties of the "null universe" that Tryon points out are:

1. Typically, only elementary particles are created in particle production which might possibly eventuate in simple atoms such as hydrogen. But currently hydrogen is only a minor constituent of the earth.
2. If particle creation is responsible for earth expansion, then it ought to cause other planets to expand also. But there is evidence that the earth's moon and Mercury have not expanded. Furthermore, if stars, including the earth's sun, have similarly expanded, then many of them should have become massive enough to have become blackholes.

3. Such expansion of the stars would alter their luminosities dramatically, which cannot be reconciled with observations that the distant and near galaxies look similar to each other.

Tryon also critiques the idea that the earth may be participating in a fundamental process that would also explain the Hubble expansion of the universe. This type of expansion would affect the entire earth, surface as well as core, uniformly and there would be no cracks or other surface evidence of expansion.

PROBLEMS WITH PLATE TECTONICS

Now let us consider some of the problems of the standard plate-tectonics model that, in fact, have motivated the search for an alternative model such as the expanding earth. One problem is how to move continents around (Kundt & Jessner 1986, Loper 1985, Lowman 1985a, Pavoni 1986, Runcorn 1980, Walzer & Maaz 1983). No good mechanism has been devised to push or pull them about. Further, recent evidence suggests that some of the continents have deep roots, going down as deep as 700 km (Kerr 1986, Lay 1988, Lowman 1985a). The movement of plates with such deep roots seems so incredible that a fixed-earth plate-tectonic model has recently been proposed that requires subduction zones which have not been suspected heretofore and for which there is little evidence (Lowman 1985b, Lowman 1986, Martin 1987, Schmidt & Embleton 1986).

Another difficulty is that both the African and the Antarctic tectonic plates are almost completely surrounded by spreading ridges with no significant subduction zones on their boundaries (Bevis & Payne 1983; Carey 1976, p 57; Carey 1983c; Carey 1988, p 174-176; Karig 1978). Consequently, the subduction zones available to accommodate the spreading are not near by; and these expansion ridges themselves would have to migrate toward distant subduction zones. In fact, models of relative plate motions have not been unambiguously established yet, particularly for the circum-Pacific (Kamp & Fitzgerald 1987).

Finally, Carey has been most critical of the very concept of subduction (Carey 1976, p 16, 50, 54; Carey 1988, ch 13). He has argued that typically slabs that are presumed to be thrust under plates show characteristics of tension rather than compression. And he has noticed that frequently there is little evidence of sediment accretion in subduction trenches. Chudinov also argues that evidence for subduction is weak and the phenomena observed in active marginal oceanic zones are best explained by “eduction” (extrusion of mantle material at the edge of the continental block) (Chudinov 1981). However, current plate-tectonic theory suggests that slabs are being pulled down by their own weight more than they are being pushed from the expanding ridge or by the force of plates gravitationally "sliding downhill" across the ocean floor from ridges to subduction zones (Jurdy 1987, Sekiguchi 1985, Spence 1986, Spence 1987). This can explain tensional characteristics frequently found in subduction zones. But, this does assume that oceanic plates which were less dense than the mantle when they emerged from the ridges have cooled sufficiently to become more dense than the mantle into which they are being reintroduced (Grow & Bowin 1975, Kerr 1988, Park 1988). Also it leaves unanswered what causes the low-density continental slab to descend under the Alps (Mueller & Panza 1986). Additional problems have been raised by Uyeda (1986). Subduction is a complex process involving an interplay of various forces that are difficult to quantify (Jarrard 1986). Unequivocal subduction models are difficult to affirm because subduction destroys most of its evidence; so little is yet known about its mechanics (Anderson 1981, Rea & Duncan 1986).

With respect to this problem, subduction models have been developed that let sediments be dragged under with the slab and even allow the downgoing plate to erode the overriding plate (Scholl et al. 1980, Scholl & Vallier 1983, Wortel & Cloetingh 1986). Recent surveys of the Japan Trench using Seabeam mapping, gravity and geomagnetic measurements, and seismic reflections seem to justify these models (Cadet et al. 1986; Cadet et al. 1987a,b; Kobayashi et al. 1987; Le Pichon et al. 1987). Little evidence of accretion was found, although a fractured seamount was discovered that appears to be "falling" into the trench. The landward plate seems to be "lifted" by the front edge of the seamount in such a way that suggests the seamount is being pulled under, i.e., subducted. Bivalve communities along the continental shelf indicate that water is being pressed from the subducted material, and this may "lubricate" the contact between the plates so that the oceanic slab with the seamount can slide under the continental plate with relatively little friction.

Still other difficulties with the standard plate-tectonics model have been published. For instance, "the geotectonic phenomena operating in the island arc regions are rather different from those assumed to now" (Wezel 1986b). Rocks rather than oceanic sediments in trenches, old material rather than young sediments in trench slopes, subsistence rather than uplift observed during subduction in trench margins, including the Japan Trench, and tensional rather than compressional characteristics in subduction zones are listed as evidence to support the above assertion. Also, "the origin of volcanism and high heat flow and the origin of back-arc basins are still 'basic unsolved problems' in the context of the subduction model" (Wezel 1986b). So Wezel claims that "the tectonic processes hypothesized by the present [tectonic] models do not correspond to the geological reality of the arc systems" (Wezel 1986b).

Studies on the lithosphere have noticed the paradox of a model that seems to require the continental crust to be like a "thick elastic plate" in the neighborhood of mountains yet in other contexts it is required to be weaker than the oceanic crust (McNutt 1987).

Finally, a week-long workshop on the lithosphere convened by the U.S. Geodynamics committee in 1982 noted that "no generally accepted models exist for the initiation of [subduction]", "rates and mechanisms of assimilation of models for the heating of subducted slabs...[are] wholly inadequate...", and "gravity profiles across subduction zones and the published geoid data do not reflect the thermally predicted excess mass" (Lithosphere 1983, p 28, 29).

SUMMARY

Despite the success that standard plate-tectonics theory has enjoyed, there are phenomena that it currently is not able to model. Perhaps the most adequate model would incorporate Owens' suggestion that there is both subduction and expansion. This would allow the earth to expand at a modest rate with reasonable changes in surface gravitation and also require some subduction for which the evidence seems convincing. But such a model presents the difficulty of finding suitable mechanisms for expansion, plate motion and subduction!

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