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Plate Tectonics: A Paradigm Under Threat

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Abstract—This paper looks at the challenges confronting plate tectonics—the ruling paradigm in the earth sciences. The classical model of thin lithospheric plates moving over a global asthenosphere is shown to be implausible. Evidence is presented that appears to contradict continental drift, seafloor spreading, and subduction, as well as the claim that the oceanic crust is relatively young. The problems posed by vertical tectonic movements are reviewed, including evidence for large areas of submerged continental crust in today's oceans. It is concluded that the fundamental tenets of plate tectonics might be wrong.

Keywords: plate tectonics — continental roots — age of seafloor — vertical tectonics — surge tectonics.

Introduction

The idea of large-scale continental drift has been around for some 200 years, but the first detailed theory was proposed by Alfred Wegener in 1912. It met with widespread rejection, largely because the mechanism he suggested was inadequate: the continents supposedly plowed slowly through the denser oceanic crust under the influence of gravitational and rotational forces. Interest was revived in the early 1950s with the rise of the new science of paleomagnetism, which seemed to provide strong support for continental drift. In the early 1960s, new data from ocean exploration led to the idea of seafloor spreading. A few years later, these and other concepts were synthesized into the model of plate tectonics, which was originally called "the new global tectonics."

According to the orthodox model of plate tectonics, the earth's outer shell, or lithosphere, is divided into a number of large, rigid plates that move over a soft layer of the mantle known as the "asthenosphere" and interact at their boundaries, where they converge, diverge, or slide past one another. Such interactions are believed to be responsible for most of the seismic and volcanic activity of the earth. Plates cause mountains to rise where they push together, and continents to fracture and oceans to form where they rift apart. The continents, sitting passively on the backs of the plates, drift with them, at the rate of a few centimeters per year. At the end of the Permian, some 250 million years ago, all the present continents are said to have been gathered together in a single supercontinent, Pangaea, consisting of two major landmasses: Laurasia in the north, and Gondwanaland in the south. Pangaea is widely believed to have started fragmenting in the early Jurassic—although this is sometimes said to have begun earlier, in the Triassic, or even as late as the Cretaceous—resulting in the configuration of oceans and continents observed today.

It has been said that "a hypothesis that is appealing for its unity or simplicity acts as a filter, accepting reinforcement with ease but tending to reject evidence that does not seem to fit" (Grad, 1971, p. 636). Meyerhoff and Meyerhoff (1974b, p. 411) argued that this is "an admirable description of what has happened in the field of earth dynamics, where one hypothesis—the new global tectonics—has been permitted to override and overrule all other hypotheses." Nitecki et al. (1978) reported that in 1961 only 27% of western geologists accepted plate tectonics, but that during the mid-1960s a "chain reaction" took place, and by 1977 it was embraced by as many as 87%. Some proponents of plate tectonics have admitted that a bandwagon atmosphere developed and that data that did not fit into the model were not given sufficient consideration (e.g., Wyllie, 1976), resulting in "a somewhat disturbing dogmatism" (Dott and Batten, 1981, p. 151). McGeary and Plummer (1998, p. 97) acknowledge that "geologists, like other people, are susceptible to fads."

Maxwell (1974) stated that many earth-science papers were concerned with demonstrating that some particular feature or process may be explained by plate tectonics, but that such papers were of limited value in any unbiased assessment of the scientific validity of the hypothesis. Van Andel (1984) conceded that plate tectonics had serious flaws and that the need for a growing number of ad hoc modifications cast doubt on its claim to be the ultimate unifying global theory. Lowman (1992a) argued that geology has largely become "a bland mixture of descriptive research and interpretive papers in which the interpretation is a facile cookbook application of plate-tectonics concepts... used as confidently as trigonometric functions" (p. 3). Lyttleton and Bondi (1992) held that the difficulties facing plate tectonics and the lack of study of alternative explanations for seemingly supportive evidence reduced the plausibility of the theory.

Saull (1986) pointed out that no global tectonic model should ever be considered definitive, because geological and geophysical observations are nearly always open to alternative explanations. He also stated that even if plate tectonics were false, it would be difficult to refute and replace, for the following reasons: the processes supposed to be responsible for plate dynamics are rooted in regions of the earth so poorly known that it is hard to prove or disprove any particular model of them; the hard core of belief in plate tectonics is protected from direct assault by auxiliary hypotheses that are still being generated; and the plate model is so widely believed to be correct that it is difficult to get alternative interpretations published in the scientific literature.

When plate tectonics was first elaborated in the 1960s, less than 0.0001% of the deep ocean had been explored and less than 20% of the land area had been mapped in meaningful detail. Even by the mid-1990s, only about 3%–5% of the deep ocean basins had been explored in any kind of detail, and not much more than 25%–30% of the land area could be said to be truly known (Meyerhoff et al., 1996a). Scientific understanding of the earth's surface features is clearly still in its infancy, to say nothing of the earth's interior.

Beloussov (1980, 1990) held that plate tectonics was a premature generalization of still very inadequate data on the structure of the ocean floor and had proven to be far removed from geological reality. He wrote:

> It is...quite understandable that attempts to employ this conception to explain concrete structural situations in a local rather than a global scale lead to increasingly complicated schemes in which it is suggested that local axes of spreading develop here and there, that they shift their position, die out, and reappear, that the rate of spreading alters repeatedly and often ceases altogether, and that lithospheric plates are broken up into an even greater number of secondary and tertiary plates. All these schemes are characterised by a complete absence of logic, and of patterns of any kind. The impression is given that certain rules of the game have been invented, and that the aim is to fit reality into these rules somehow or other (1980, p. 303).

Criticism of plate tectonics has increased in line with the growing number of observational anomalies. This paper outlines some of the main problems facing the theory.

Plates in Motion?

According to the classical model of plate tectonics, lithospheric plates creep over a relatively plastic layer of partly molten rock known as the "asthenosphere" (or low-velocity zone). According to a modern geological textbook (McGeary and Plummer, 1998), the lithosphere, which comprises the earth's crust and uppermost mantle, averages about 70 km thick beneath oceans and is at least 125 km thick beneath continents, while the asthenosphere extends to a depth of perhaps 200 km. It points out that some geologists think that the lithosphere beneath continents is at least 250 km thick. Seismic tomography, which produces three-dimensional images of the earth's interior, appears to show that the oldest parts of the continents have deep roots extending to depths of 400–600 km and that the asthenosphere is essentially absent beneath them (Figure 1). McGeary and Plummer (1998) say that these findings cast doubt on the original, simple lithosphere-asthenosphere model of plate behavior. They do not, however, consider any alternatives.

Despite the compelling seismotomographic evidence for deep continental roots (Dziewonski and Anderson, 1984; Dziewonski and Woodhouse, 1987; Grand, 1987; Lerner-Lam, 1988; Forte, Dziewonski, and O'Connell, 1995; Gossler and Kind, 1996), some plate tectonicists have suggested that we just happen to live at a time when the continents have drifted over colder mantle (Anderson, Tanimoto, and Zhang, 1992), or that continental roots are really no more than about 200 km thick, but that they induce the downwelling of cold

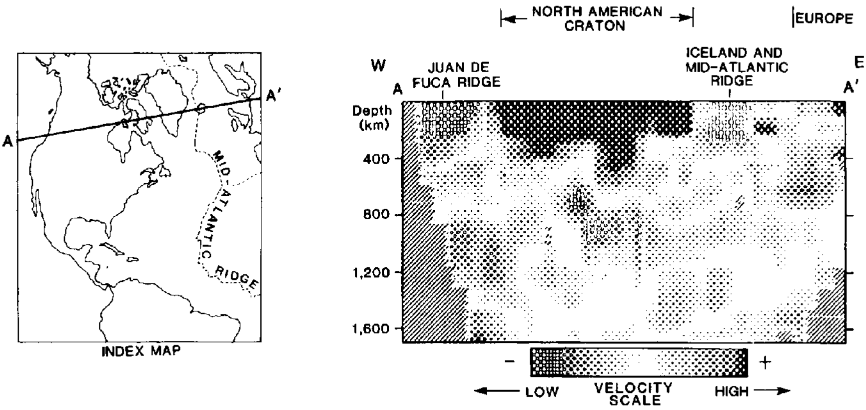


Fig. 1. Seismotomographic cross-section showing velocity structure across the North American craton and North Atlantic Ocean. High-velocity (colder) lithosphere, shown in dark tones, underlies the Canadian shield to depths of 250–500 km. (Reprinted with permission from Grand, 1987. Copyright by the American Geophysical Union.)

mantle material beneath them, giving the illusion of much deeper roots (Polet and Anderson, 1995). However, evidence from seismic-velocity, heat-flow, and gravity studies has been building up for several decades, showing that ancient continental shields have very deep roots and that the low-velocity asthenosphere is very thin or absent beneath them (e.g., Jordan, 1975, 1978; MacDonald, 1963; Pollack and Chapman, 1977). Seismic tomography has merely reinforced the message that continental cratons, particularly those of Archean and Early Proterozoic age, are "welded" to the underlying mantle, and that the concept of thin (less than 250 km thick) lithospheric plates moving thousands of kilometers over a global asthenosphere is unrealistic. Nevertheless, many textbooks continue to propagate the simplistic lithosphere-asthenosphere model and fail to give the slightest indication that it faces any problems (e.g., McLeish, 1992; Skinner and Porter, 1995; Wicander and Monroe, 1999).

Geophysical data show that, far from the asthenosphere being a continuous layer, there are disconnected lenses (asthenolenses), which are observed only in regions of tectonic activation and high heat flow. Although surface-wave observations suggested that the asthenosphere was universally present beneath the oceans, detailed seismic studies show that here, too, there are only asthenospheric lenses. Seismic research has revealed complicated zoning and inhomogeneity in the upper mantle and the alternation of layers with higher and lower velocities and layers of different quality. Individual low-velocity layers are bedded at different depths in different regions and do not compose a single layer. This renders the very concept of the lithosphere ambiguous, at least that of its base. Indeed, the definition of the lithosphere and asthenosphere has become increasingly blurred with time (Pavlenkova, 1990, 1995, 1996).

Thus, the lithosphere has a highly complex and irregular structure. Far from being homogeneous, "plates" are actually "a megabreccia, a 'pudding' of inhomogeneities whose nature, size, and properties vary widely" (Chekunov, Gordienko, and Guterman, 1990, p. 404). The crust and uppermost mantle are divided by faults into a mosaic of separate, jostling blocks of different shapes and sizes, generally a few hundred kilometers across, and of varying internal structure and strength. Pavlenkova (1990, p. 78) concludes: "This means that the movement of lithospheric plates over long distances, as single rigid bodies, is hardly possible. Moreover, if we take into account the absence of the asthenosphere as a single continuous zone, then this movement seems utterly impossible." She states that this is further confirmed by the strong evidence that regional geological features, too, are connected with deep (more than 400 km) inhomogeneities and that these connections remain stable during long periods of geologic time; considerable movement between the lithosphere and asthenosphere would detach near-surface structures from their deep mantle roots.

Plate tectonicists who accept the evidence for deep continental roots have proposed that plates may extend to and glide along the 400-km, or even 670-km, seismic discontinuity (Jordan, 1975, 1978, 1979; Seyfert, 1998). Jordan, for instance, suggested that the oceanic lithosphere moves on the classical low-velocity zone while the continental lithosphere moves along the 400-km discontinuity. However, there is no certainty that a superplastic zone exists at this discontinuity, and no evidence has been found of a shear zone connecting the two decoupling layers along the trailing edge of continents (Lowman, 1985). Moreover, even under the oceans, there appears to be no continuous asthenosphere. Finally, the movement of such thick "plates" poses an even greater problem than that of thin lithosphericic plates.

The driving force of plate movements was initially claimed to be mantle-deep convection currents welling up beneath midocean ridges, with downwelling occurring beneath ocean trenches. Since the existence of layering in the mantle was considered to render whole-mantle convection unlikely, two-layer convection models were also proposed. Jeffreys (1974) argued that convection cannot take place because it is a self-damping process, as described by the Lomnitz law. Plate tectonicists expected seismic tomography to provide clear evidence of a well-organized convection-cell pattern, but it has actually provided strong evidence *against* the existence of large, plate-propelling convection cells in the upper mantle (Anderson, Tanimoto, and Zhang, 1992). Many geologists now think that mantle convection is a *result* of plate motion rather than its cause and that it is shallow rather than mantle deep (McGeary and Plummer, 1998).

The favored plate-driving mechanisms at present are "ridge push" and "slab pull," though their adequacy is very much in doubt. Slab pull is believed to be the dominant mechanism and refers to the gravitational subsidence of subducted slabs. However, it will not work for plates that are largely continental or that have leading edges that are continental, because continental crust cannot be bodily subducted due to its low density, and it seems utterly unrealistic to imagine that ridge push from the Mid-Atlantic Ridge alone could move the 120°-wide Eurasian plate (Lowman, 1986). Moreover, evidence for the long-term weakness of large rock masses casts doubt on the idea that edge forces can be transmitted from one margin of a "plate" to its interior or opposite margin (Keith, 1993).

Thirteen major plates are currently recognized, ranging in size from about 400 by 2,500 km to 10,000 by 10,000 km, together with a proliferating number of microplates (over 100 so far). Van Andel (1998) writes:

> Where plate boundaries adjoin continents, matters often become very complex and have demanded an ever denser thicket of ad hoc modifications and amendments to the theory and practice of plate tectonics in the form of microplates, obscure plate boundaries, and exotic terranes. A good example is the Mediterranean, where the collisions between Africa and a swarm of microcontinents have produced a tectonic nightmare that is far from resolved. More disturbingly, some of the present plate boundaries, particularly in the eastern Mediterranean, appear to be so diffuse and so anomalous that they cannot be compared to the three types of plate boundaries of the basic theory.

Plate boundaries are identified and defined mainly on the basis of earthquake and volcanic activity. The close correspondence between plate edges and belts of earthquakes and volcanoes is therefore to be expected and can hardly be regarded as one of the "successes" of plate tectonics (McGeary and Plummer, 1998). Moreover, the simple pattern of earthquakes around the Pacific Basin on which plate tectonics models have hitherto been based has been seriously undermined by more recent studies showing a surprisingly large number of earthquakes in deep-sea regions previously thought to be aseismic (Storetvedt, 1997). Another major problem is that several "plate boundaries" are purely theoretical and appear to be nonexistent, including the northwest Pacific boundary of the Pacific, North American, and Eurasian plates, the southern boundary of the Philippine plate, part of the southern boundary of the Pacific plate, and most of the northern and southern boundaries of the South American plate (Stanley, 1989).

Continental Drift

Geological field mapping provides evidence for horizontal crustal movements of up to several hundred kilometers (Jeffreys, 1976). Plate tectonics, however, claims that continents have moved up to 7,000 km or more since the alleged breakup of Pangaea. Measurements using space-geodetic techniques—very long baseline interferometry, satellite laser-ranging, and the global positioning system—have been hailed by some workers as having proved plate tectonics. Such measurements provide a guide to crustal strains but do not provide evidence for plate motions of the kind predicted by plate tectonics unless the relative motions predicted among *all* plates are observed. However, many of the results have shown no definite pattern and have been confusing and contradictory, giving rise to a variety of ad hoc hypotheses (Fallon and Dillinger, 1992; Gordon and Stein, 1992; Smith et al., 1994).

Japan and North America appear, as predicted, to be approaching each other, but distances from the Central South American Andes to Japan or Hawaii are more or less constant, whereas plate tectonics predicts significant separation (Storetvedt, 1997). Trans-Atlantic drift has *not* been demonstrated, because baselines within North America and western Europe have failed to establish that the plates are moving as rigid units; they suggest in fact significant intraplate deformation (James, 1994; Lowman, 1992b). Space-geodetic measurements to date have therefore not confirmed plate tectonics. Moreover, they are open to alternative explanations (e.g., Carey, 1994; Meyerhoff et al., 1996a; Storetvedt, 1997). It is clearly a hazardous exercise to extrapolate present crustal movements tens or hundreds of millions of years into the past or future. Indeed, geodetic surveys across "rift" zones (e.g., in Iceland and East Africa) have failed to detect any consistent and systematic widening as postulated by plate tectonics (Keith, 1993).

Fits and Misfits

A "compelling" piece of evidence that all the continents were once united in one large landmass is said to be the fact that they can be fitted together like pieces of a jigsaw puzzle. Many reconstructions have been attempted (e.g., Barron, Harrison, and Hay, 1978; Bullard, Everett, and Smith, 1965; Dietz and Holden, 1970; Nafe and Drake, 1969; Scotese, Gahagan, and Larson, 1988; Smith and Hallam, 1970; Smith, Hurley, and Briden, 1981; Tarling, 1971), but none are entirely acceptable (Figures 2 and 3).

In the Bullard, Everett, and Smith (1965) computer-generated fit, for example, there are a number of glaring omissions. The whole of Central America and much of southern Mexico are left out, despite the fact that extensive areas of Paleozoic and Precambrian continental rocks occur there. This region of some 2,100,000 km^2 overlaps South America in a region consisting of a craton at least 2 billion years old. The entire West Indian archipelago has also been omitted. In fact, much of the Caribbean is underlain by ancient continental crust, and the total area involved (300,000 km^2) overlaps Africa (Meyerhoff and Hatten, 1974). The Cape Verde Islands-Senegal Basin, too, is underlain by ancient continental crust, creating an additional overlap of 800,000 km^2.

Several major submarine structures that appear to be of continental origin are ignored in the Bullard, Everett, and Smith (1965) fit, including the Faeroe-Iceland-Greenland Ridge, Jan Mayen Ridge, Walvis Ridge, Rio Grande Rise, and the Falkland Plateau. However, the Rockall Plateau was included for the sole reason that it could be "slotted in." This fit postulates an east-west shear zone through the present Mediterranean and requires a rotation of Spain, but

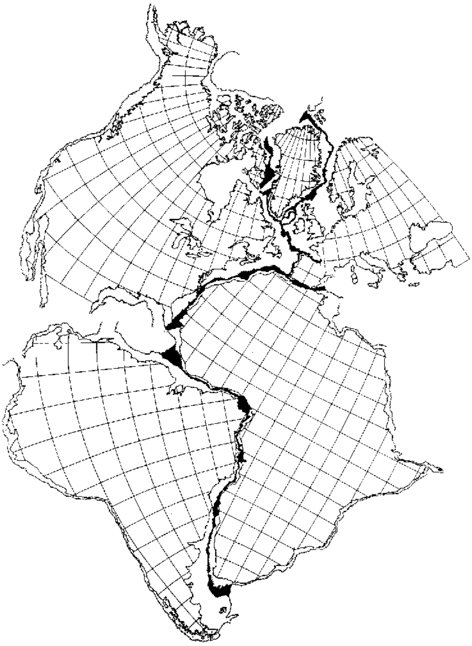


Fig. 2. The Bullard fit. Overlaps and gaps between continents are shown in black. (Reprinted with permission from Bullard, Everett, and Smith, 1965. Copyright by The Royal Society.)

field geology does not support either of these suppositions (Meyerhoff and Meyerhoff, 1974a). Even the celebrated fit of South America and Africa is problematic, as it is impossible to match all parts of the coastlines simultaneously; e.g., there is a gap between Guyana and Guinea (Eyles and Eyles, 1993).

Like the Bullard, Everett, and Smith (1965) fit, the Smith and Hallam (1970) reconstruction of the Gondwanaland continents is based on the 500-fathom depth contour. The South Orkneys and South Georgia are omitted, as is Kerguelen Island in the Indian Ocean, and there is a large gap west of Australia. Fitting India against Australia, as in other fits, leaves a corresponding gap in the western Indian Ocean (Hallam, 1976). Dietz and Holden (1970) based their fit on the 1,000-fathom (2-km) contour, but they still had to omit the Florida-Bahamas platform, ignoring the evidence that it predates the alleged commencement of drift. In many regions, the boundary between continental and oceanic crust appears to occur beneath oceanic depths of 2–4 km or more (Hallam, 1979), and in some places, the ocean-continent transition zone is several hundred kilometers wide (Van der Linden, 1977). This means that any reconstructions based on arbitrarily selected depth contours are flawed. Given the liberties that drifters have had to take to obtain the desired continen-

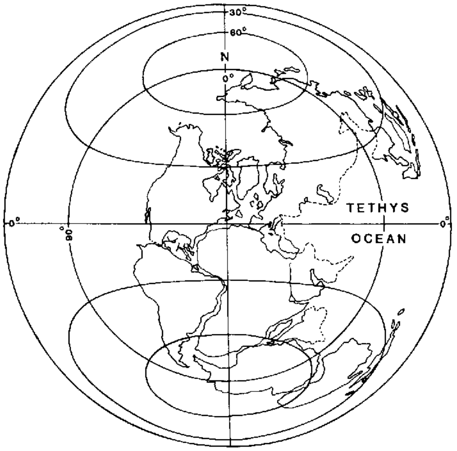


Fig. 3. Computer-derived plate tectonic map for Permian time. (Reprinted with permission from Meyerhoff, 1995. Copyright by Elsevier Science.)

tal matches, their computer-generated fits may well be a case of "garbage in, garbage out" (Le Grand, 1988).

The similarities of rock types and geological structures on coasts that were supposedly once juxtaposed are hailed by drifters as further evidence that the continents were once joined together. However, they rarely mention the many geological *dissimilarities*. For instance, western Africa and northern Brazil were supposedly once in contact, yet the structural trends of the former run north to south while those of the latter run east to west (Storetvedt, 1997). Some predrift reconstructions show peninsular India against western Antarctica, yet Permian Indian basins do not correspond geographically or in sequence to the western Australian basins (Dickins and Choi, 1997). Gregory (1929) held that the geological resemblances of opposing Atlantic coastlines are due to the areas having belonged to the same tectonic belt, but that the differences are sufficient to show that the areas were situated in distant parts of the belt. Bucher (1933) showed that the paleontological and geological similarities between the eastern Alps and central Himalayas, 4,000 miles apart, are just as remarkable as those between the Argentine and South Africa, separated by the same distance.

The approximate parallelism of the coastlines of the Atlantic Ocean may be due to the boundaries between the continents and oceans having been formed by deep faults, which tend to be grouped into parallel systems (Beloussov, 1980). Moreover, the curvature of continental contours is often so similar that many of them can be joined if they are given the necessary rotation. Lyustikh (1967) gave examples of 15 shorelines that can be fitted together quite well even though they can never have been in juxtaposition. Voisey (1958) showed that eastern Australia fits well with eastern North America if Cape York is placed next to Florida. He pointed out that the geological and paleontological similarities are remarkable, probably due to the similar tectonic backgrounds of the two regions.

Paleomagnetic Pitfalls

One of the main props of continental drift is paleomagnetism—the study of the magnetism of ancient rocks and sediments. The inclination and declination of fossil magnetism can be used to infer the location of a virtual magnetic pole relative to the location of the sample in question. When virtual poles are determined from progressively older rocks from the same continent, the poles appear to wander with time. Joining the former averaged pole positions generates an apparent polar wander path. Different continents yield different polar wander paths, and from this, it has been concluded that the apparent wandering of the magnetic poles is caused by the actual wandering of the continents over the earth's surface. The possibility that there has been some degree of true polar wander—i.e., a shift of the whole earth relative to the rotation axis (the axial tilt remaining the same)—has not, however, been ruled out.

That paleomagnetism can be unreliable is well established (Barron, Harrison, and Hay, 1978; Meyerhoff and Meyerhoff, 1972). For instance, paleomagnetic data imply that during the mid-Cretaceous, Azerbaijan and Japan were in the same place (Meyerhoff, 1970a)! The literature is in fact bursting with inconsistencies (Storetvedt, 1997). Paleomagnetic studies of rocks of different ages suggest a different polar wander path not only for each continent, but also for different parts of each continent. When individual paleomagnetic pole positions, rather than averaged curves, are plotted on world maps, the scatter is huge, often wider than the Atlantic. Furthermore, paleomagnetism can determine only paleolatitude, not paleolongitude. Consequently, it cannot be used to prove continental drift.

Paleomagnetism is plagued with uncertainties. Merrill, McElhinny, and McFadden (1996, p. 69) state that "there are numerous pitfalls that await the unwary: first, in sorting out the primary magnetization from *secondary magnetizations* (acquired subsequent to formation), and second, in extrapolating the properties of the primary magnetization to those of the earth's magnetic field." The interpretation of paleomagnetic data is founded on two basic assumptions: (a) when rocks are formed, they are magnetized in the direction of the geomagnetic field existing at the time and place of their formation, and the acquired magnetization is retained in the rocks at least partially over geologic time; and (b) the geomagnetic field averaged for any period of the order of 10^5 years (except magnetic-reversal epochs) is a dipole field oriented along the earth's rotation axis. Both these assumptions are questionable.

The gradual northward shift of paleopole "scatter ellipses" through time, and the gradual reduction in the diameters of the ellipses suggest that remanent magnetism becomes less stable with time. Rock magnetism is subject to modification by later magnetism, weathering, metamorphism, tectonic deformation, and chemical changes. Moreover, the geomagnetic field today deviates substantially from that of a geocentric axial dipole. The magnetic axis is tilted by about 11° to the rotation axis, and on some planets, much greater offsets are found: 46.8° in the case of Neptune and 58.6° in the case of Uranus (Merrill, McElhinny, and McFadden, 1996). Nevertheless, because Earth's magnetic field undergoes significant long-term secular variation (e.g., a westward drift), it is thought that the time-averaged field will closely approximate a geocentric axial dipole. However, there is strong evidence that the geomagnetic field had long-term nondipole components in the past, though they have largely been neglected (Kent and Smethurst, 1998; Van der Voo, 1998). To test the *axial* nature of the geomagnetic field in the past, scientists have to use paleoclimatic data. However, several major paleoclimatic indicators, along with paleontological data, provide powerful evidence *against* continental-drift models, and therefore *against* the current interpretation of paleomagnetic data (see below).

It is possible that the magnetic poles have wandered considerably with respect to the geographic poles in former times. Also, if in past geological periods, there were stable magnetic anomalies of the same intensity as the present-day East Asian anomaly (or slightly more intensive), this would render the geocentric axial dipole hypothesis invalid (Beloussov, 1990). Regional or semiglobal magnetic fields might be generated by vortexlike cells of thermal-magmatic energy, rising and falling in the earth's mantle (Pratsch, 1990). Another important factor may be magnetostriction—the alteration of the direction of magnetization by directed stress (Jeffreys, 1976; Munk and MacDonald, 1975). Some workers have shown that certain discordant paleomagnetic results that could be explained by large horizontal movements can be explained equally well by vertical block rotations and tilts and by inclination shallowing resulting from sediment compaction (Butler et al., 1989; Dickinson and Butler, 1998; Irving and Archibald, 1990; Hodych and Bijaksana, 1993). Storetvedt (1992, 1997) has developed a model known as "global wrench tectonics" in which paleomagnetic data are explained by in situ horizontal rotations of continental blocks, together with true polar wander. The possibility that a combination of these factors could be at work simultaneously significantly undermines the use of paleomagnetism to support continental drift.

Drift Versus Geology

The opening of the Atlantic Ocean allegedly began in the Cretaceous by the rifting apart of the Eurasian and American plates. However, on the other side of the globe, northeastern Eurasia is joined to North America by the Bering-Chukotsk shelf, which is underlain by Precambrian continental crust that is continuous and unbroken from Alaska to Siberia. Geologically these regions constitute a single unit, and it is unrealistic to suppose that they were formerly divided by an ocean several thousand kilometers wide, which closed to compensate for the opening of the Atlantic. If a suture is absent there, one ought to be found in Eurasia or North America, but no such suture appears to exist (Beloussov, 1990; Shapiro, 1990). If Baffin Bay and the Labrador Sea had formed by Greenland and North America drifting apart, this would have produced hundreds of kilometers of lateral offset across the Nares Strait between Greenland and Ellesmere Island, but geological field studies reveal no such offset (Grant, 1980, 1992). Greenland is separated from Europe west of Spitsbergen by only 50–75 km at the 1,000-fathom depth contour, and it is joined to Europe by the continental Faeroe-Iceland-Greenland Ridge (Meyerhoff, 1974). All these facts rule out the possibility of east–west drift in the northern hemisphere.

Geology indicates that there has been a direct tectonic connection between Europe and Africa across the zones of Gibraltar and Rif on the one hand, and Calabria and Sicily on the other, at least since the end of the Paleozoic, contradicting plate-tectonic claims of significant displacement between Europe and Africa during this period (Beloussov, 1990). Plate tectonicists hold widely varying opinions on the Middle East region. Some advocate the former presence of two or more plates, some postulate several microplates, others support island-arc interpretations, and a majority favor the existence of at least one suture zone that marks the location of a continent-continent collision. Kashfi (1992, p. 119) comments:

> Nearly all of these hypotheses are mutually exclusive. Most would cease to exist if the field data were honored. These data show that there is nothing in the geologic record to support a past separation of Arabia-Africa from the remainder of the Middle East.

India supposedly detached itself from Antarctica sometime during the Mesozoic, and then drifted northeastward up to 9,000 km, over a period of up to 200 million years, until it finally collided with Asia in the mid-Tertiary, pushing up the Himalayas and the Tibetan Plateau. That Asia happened to have an indentation of approximately the correct shape and size and in exactly the right place for India to "dock" into would amount to a remarkable coincidence (Mantura, 1972). There is, however, overwhelming geological and paleontological evidence that India has been an integral part of Asia since Proterozoic or earlier time (Ahmad, 1990; Chatterjee and Hotton, 1986; Meyerhoff et al., 1991; Saxena and Gupta, 1990). There is also abundant evidence that the Tethys Sea in the region of the present Alpine-Himalayan orogenic belt was never a deep, wide ocean but rather a narrow, predominantly shallow, intracontinental seaway (Bhat, 1987; Dickins, 1987, 1994c; McKenzie, 1987; Stöcklin, 1989). If the long journey of India had actually occurred, it would have been an isolated island continent for millions of years—sufficient time to have evolved a highly distinct endemic fauna. However, the Mesozoic and Tertiary faunas show no such endemism but indicate instead that India lay very close to Asia throughout this period, and not to Australia and Antarctica (Chatterjee and Hotton, 1986). The stratigraphic, structural, and paleontological continuity of India with Asia and Arabia means that the supposed "flight of India" is no more than a flight of fancy.

A striking feature of the oceans and continents today is that they are arranged antipodally: The Arctic Ocean is precisely antipodal to Antarctica; North America is exactly antipodal to the Indian Ocean; Europe and Africa are antipodal to the central area of the Pacific Ocean; Australia is antipodal to the small basin of the North Atlantic; and the South Atlantic corresponds—though less exactly—to the eastern half of Asia (Bucher, 1933; Gregory, 1899, 1901; Steers, 1950). Only 7% of the earth's surface does not obey the antipodal rule. If the continents had slowly drifted thousands of kilometers to their present positions, the antipodal arrangement of land and water would have to be regarded as purely coincidental. Harrison et al. (1983) calculated that there is one chance in seven that this arrangement is the result of a random process.

Paleoclimatology

The paleoclimatic record is preserved from Proterozoic time to the present in the geographic distribution of evaporites, carbonate rocks, coals, and tillites. The locations of these paleoclimatic indicators are best explained by stable rather than shifting continents, and by periodic changes in climate, from globally warm or hot to globally cool (Meyerhoff and Meyerhoff, 1974a; Meyerhoff et al., 1996b). For instance, 95% of all evaporites—a dry-climate indicator—from the Proterozoic to the present lie in regions that now receive less than 100 cm of rainfall per year, i.e. in today's dry-wind belts. The evaporite and coal zones show a pronounced northward offset similar to today's northward offset of the thermal equator. Shifting the continents succeeds at best in explaining *local* or *regional* paleoclimatic features for a particular period and invariably fails to explain the *global* climate for the same period.

In the Carboniferous and Permian, glaciers covered parts of Antarctica, South Africa, South America, India, and Australia. Drifters claim that this glaciation can be explained in terms of Gondwanaland, which was then situated near the South Pole. However, the Gondwanaland hypothesis defeats itself in this respect because large areas that were glaciated during this period would be removed too far inland for moist ocean-air currents to reach them. Glaciers would have formed only at its margins while the interior would have been a vast, frigid desert (Meyerhoff, 1970a; Meyerhoff and Teichert, 1971). Shallow epicontinental seas within Pangaea could not have provided the required moisture because they would have been frozen during the winter months. This glaciation is easier to explain in terms of the continents' present positions: nearly all the continental ice centers were adjacent to or near present coastlines, or in high plateaus and/or mountain lands not far from present coasts.

Drifters say that the continents have shifted little since the start of the Cenozoic (some 65 million years ago), yet this period has seen significant alterations in climatic conditions. Even since Early Pliocene time the width of the temperate zone has changed by more than 15° (1,650 km) in both the northern and southern hemispheres. The uplift of the Rocky Mountains and Tibetan Plateau appears to have been a key factor in the late Cenozoic climatic deterioration (Manabe and Broccoli, 1990; Ruddiman and Kutzbach, 1989). To decide whether past climates are compatible with the present latitudes of the regions concerned, it is clearly essential to take account of vertical crustal movements, which can cause significant changes in atmospheric and oceanic circulation patterns by altering the topography of the continents and ocean floor, and the distribution of land and sea (Brooks, 1949; Dickins, 1994a; Meyerhoff, 1970b).

Biopaleogeography

Meyerhoff et al. (1996b) showed in a detailed study that most major biogeographical boundaries, based on floral and faunal distributions, do not coincide with the partly computer-generated plate boundaries postulated by plate tectonics. Nor do the proposed movements of continents correspond with the known, or necessary, migration routes and directions of biogeographical boundaries. In most cases, the discrepancies are very large, and not even an approximate match can be claimed. The authors comment, "What is puzzling is that such major inconsistencies between plate tectonic postulates and field data, involving as they do boundaries that extend for thousands of kilometers, are permitted to stand unnoticed, unacknowledged, and unstudied" (p. 3).

The known distributions of fossil organisms are more consistent with an earth model like that of today than with continental-drift models, and more migration problems are raised by joining the continents in the past than by keeping them separated (Khudoley, 1974; Meyerhoff and Meyerhoff, 1974a; Smiley, 1974, 1976, 1992; Teichert, 1974; Teichert and Meyerhoff, 1972). It is unscientific to select a few faunal identities and ignore the vastly greater number of faunal dissimilarities from different continents that were supposedly once joined. The widespread distribution of the *Glossopteris* flora in the southern continents is frequently claimed to support the former existence of Gondwanaland, but it is rarely pointed out that this flora has also been found in northeast Asia (Smiley, 1976).

Some of the paleontological evidence appears to require the alternate emergence and submergence of land dispersal routes only after the supposed breakup of Pangaea. For example, mammal distribution indicates that there were no direct physical connections between Europe and North America during Late Cretaceous and Paleocene times but suggests a temporary connection with Europe during the Eocene (Meyerhoff and Meyerhoff, 1974a). Continental drift, on the other hand, would have resulted in an initial disconnection with no subsequent reconnection. A few drifters have recognized the need for intermittent land bridges after the supposed separation of the continents (e.g., Briggs, 1987; Tarling, 1982). Various oceanic ridges, rises, and plateaus could have served as land bridges, as many are known to have been partly above water at various times in the past. It is also possible that these land bridges formed part of larger former landmasses in the present oceans (see below).

Seafloor Spreading and Subduction

According to the seafloor-spreading hypothesis, new oceanic lithosphere is generated at midocean ridges ("divergent plate boundaries") by the upwelling of molten material from the earth's mantle, and as the magma cools, it spreads away from the flanks of the ridges. The horizontally moving plates are said to plunge back into the mantle at ocean trenches or "subduction zones" ("convergent plate boundaries"). The melting of the descending slab is believed to give rise to the magmatic-volcanic arcs that lie adjacent to certain trenches.

Seafloor Spreading

The ocean floor is far from having the uniform characteristics that conveyor-type spreading would imply (Keith, 1993). Although averaged surface-wave data seemed to confirm that the oceanic lithosphere was symmetrical in relation to the ridge axis and increased in thickness with distance from the axial zone, more detailed seismic research has contradicted this simple model. It has shown that the mantle is asymmetrical in relation to the midocean ridges and has a complicated mosaic structure independent of the strike of the ridge. Several low-velocity zones (asthenolenses) occur in the oceanic mantle, but it is difficult to establish any regularity between the depth of the zones and their distance from the midocean ridge (Pavlenkova, 1990).

Boreholes drilled in the Atlantic, Indian, and Pacific Oceans have shown the extensive distribution of shallow-water sediments ranging from Triassic to Quaternary. The spatial distribution of shallow-water sediments and their vertical arrangement in some of the sections refute the spreading mechanism for the formation of oceanic lithosphere (Ruditch, 1990). The evidence implies that since the Jurassic, the present oceans have undergone large-amplitude subsidences, and that this occurred mosaically rather than showing a systematic relationship with distance from the ocean ridges. Younger, shallow-water sediments are often located farther from the axial zones of the ridges than older ones—the opposite of what is required by the plate tectonics model, which postulates that as newly formed oceanic lithosphere moves away from the spreading axis and cools, it gradually subsides to greater depths. Furthermore, some areas of the oceans appear to have undergone continuous subsidence, whereas others underwent alternating subsidence and elevation (Figure 4). The height of the ridge along the Romanche fracture zone in the equatorial Atlantic is 1–4 km above that expected by seafloor-spreading models. Large segments of it were close to or above sea level only 5 million years ago, and subsequent subsidence has been one order of magnitude faster than that predicted by plate tectonics (Bonatti and Chermak, 1981).

According to the seafloor-spreading model, heat flow should be highest

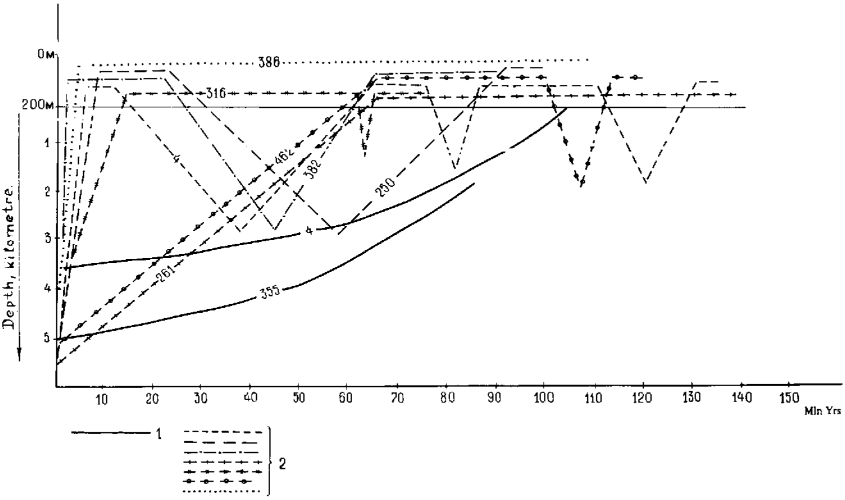


Fig. 4. Vertical movements of the ocean bed during the last 160 million years: (1) according to the seafloor-spreading model, (2) the real sequence of vertical movements at the corresponding deep-sea drilling sites. The curves in the upper scaleless part of the diagram are tentative. (Reprinted from Ruditch, 1990.)

along ocean ridges and fall off steadily with increasing distance from the ridge crests. Actual measurements, however, contradict this simple picture: Ridge crests show a very large scatter in heat-flow magnitudes, and there is generally little difference in thermal flux between the ridge and the rest of the ocean (Keith, 1993; Storetvedt, 1997). All parts of the Indian Ocean display a cold and rather featureless heat-flow picture except the Central Indian Basin. The broad region of intense tectonic deformation in this basin indicates that the basement has a block structure and presents a major puzzle for plate tectonics, especially since it is located in a "midplate" setting.

Smoot and Meyerhoff (1995) have shown that nearly all published charts of the world's ocean floors have been drawn deliberately to reflect the predictions of the plate-tectonics hypothesis. For example, the Atlantic Ocean floor is unvaryingly shown to be dominated by a sinuous, north–south midocean ridge, flanked on either side by abyssal plains, cleft at its crest by a rift valley, and offset at more or less regular 40-to-60-km intervals by east–west-striking fracture zones. New, detailed bathymetric surveys indicate that this oversimplified portrayal of the Atlantic Basin is largely wrong, yet the most accurate charts now available are widely ignored because they do not conform to plate tectonic preconceptions.

According to plate tectonics, the offset segments of "spreading" oceanic ridges should be connected by "transform fault" plate boundaries. Since the late 1960s, it has been claimed that first-motion studies in ocean fracture zones provide overwhelming support for the concept of transform faults. The results of these seismic surveys, however, were never clear cut, and contradictory evidence and alternative explanations have been ignored (Storetvedt, 1997; Meyerhoff and Meyerhoff, 1974a). Instead of being continuous and approximately parallel across the full width of each ridge, ridge-transverse fracture zones tend to be discontinuous, with many unpredicted bends, bifurcations, and changes in strike. In places, the fractures are diagonal rather than perpendicular to the ridge, and several parts of the ridge have no important fracture zones or even traces of them. For instance, they are absent from a 700-km-long portion of the Mid-Atlantic Ridge between the Atlantis and Kane fracture zones. There is a growing recognition that the fracture patterns in the Atlantic "show anomalies that are neither predicted by nor...yet built into plate tectonic understanding" (Shirley, 1998a, 1998b).

Side-scanning radar images show that the midocean ridges are cut by thousands of long, linear, ridge-parallel fissures, fractures, and faults. This strongly suggests that the ridges are underlain at shallow depth by interconnected magma channels, in which semifluid lava moves horizontally and *parallel* with the ridges rather than at right angles to them. The fault pattern observed is therefore totally different from that predicted by plate tectonics, and it cannot be explained by upwelling mantle diapirs as some plate tectonicists have proposed (Meyerhoff et al, 1992a). A zone of thrust faults, 300–400 km wide, has been discovered flanking the Mid-Atlantic Ridge over a length of 1,000 km (Antipov et al., 1990). Because it was produced under conditions of compression, it contradicts the plate-tectonic hypothesis that midocean ridges are dominated by tension. In Iceland, the largest landmass astride the Mid-Atlantic Ridge, the predominant stresses in the axial zone are likewise compressive rather than extensional (Keith, 1993). Earthquake data compiled by Zoback et al. (1989) provide further evidence that ocean ridges are characterized by widespread compression, whereas recorded tensional earthquake activity associated with these ridges is rarer. The rough topography and strong tectonic deformation of much of the ocean ridges, particularly in the Atlantic and Indian Oceans, suggest that instead of being "spreading centers," they are a type of foldbelt (Storetvedt, 1997).

The continents and oceans are covered with a network of major structures or lineaments, many dating from the Precambrian, along which tectonic and magmatic activity and associated mineralization take place (Anfiloff, 1992; Gay, 1973; Katterfeld and Charushin, 1973; Dickins and Choi, 1997; O'Driscoll, 1980; Wezel, 1992). The oceanic lineaments are not readily compatible with seafloor spreading and subduction, and plate tectonics shows little interest in them. GEOSAT data and SASS multibeam sonar data show that there are NNW–SSE and WSW–ENE megatrends in the Pacific Ocean, composed primarily of fracture zones and linear seamount chains, and these orthogonal lineaments naturally intersect (Smoot, 1997b, 1998a, 1998b, 1999). This is a physical impossibility in plate tectonics, as seamount chains supposedly indicate the direction of plate movement, and plates would therefore have to move in two directions at once! No satisfactory plate-tectonic explanation of any of these megatrends has been proposed outside the realm of ad hoc "microplates," and they are largely ignored. The orthogonal lineaments in the Atlantic Ocean, Indian Ocean, and Tasmanian Sea are also ignored (Choi, 1997, 1999a, 1999c).

Age of the Seafloor

The oldest known rocks from the continents are just under 4 billion years old, whereas—according to plate tectonics—none of the ocean crust is older than 200 million years (Jurassic). This is cited as conclusive evidence that oceanic lithosphere is constantly being created at midocean ridges and consumed in subduction zones. There is in fact abundant evidence against the alleged youth of the ocean floor, though geological textbooks tend to pass over it in silence.

The oceanic crust is commonly divided into three main layers: Layer 1 consists of ocean floor sediments and averages 0.5 km in thickness; Layer 2 consists largely of basalt and is 1.0 to 2.5 km thick; and Layer 3 is assumed to consist of gabbro and is about 5 km thick. Scientists involved in the Deep Sea Drilling Project (DSDP) have given the impression that the basalt (Layer 2) found at the base of many deep-sea drill holes is basement, and that there are no further, older sediments below it. However, the DSDP scientists were apparently motivated by a strong desire to confirm seafloor spreading (Storetvedt, 1997).

Of the first 429 sites drilled (1968–1977), only 165 (38%) reached basalt, and some penetrated more than one basalt. All but 12 of the 165 basalt penetrations were called "basement," including 19 sites where the upper contact of the basalt with the sediments was baked (Meyerhoff et al., 1992a). Baked contacts suggest that the basalt is an intrusive sill, and in some cases this has been confirmed, as the basalts turned out to have radiometric dates *younger* than the overlying sediments (e.g., Macdougall, 1971). One hundred one sediment-basalt contacts were never recovered in cores, and therefore never actually seen, yet they were still assumed to be depositional contacts. In 33 cases, depositional contacts *were* observed, but the basalt sometimes contained sedimentary clasts, suggesting that there might be older sediments below. Indeed, boreholes that have penetrated Layer 2 to some depth have revealed an alternation of basalts and sedimentary rocks (Anderson et al., 1982; Hall and Robinson, 1979). Kamen-Kaye (1970) warned that before drawing conclusions on the youth of the ocean floor, rocks must be penetrated to depths of up to 5 km to see whether there are Triassic, Paleozoic, or Precambrian sediments below the so-called "basement."

Plate tectonics predicts that the age of the oceanic crust should increase systematically with distance from the midocean ridge crests. Claims by DSDP scientists to have confirmed this are not supported by a detailed review of the drilling results. The dates exhibit a very large scatter, which becomes even larger if dredge hauls are included (Figure 5). On some marine magnetic anomalies, the age scatter is tens of millions of years (Meyerhoff et al., 1992a). On one seamount just west of the crest of the East Pacific Rise, the radiometric dates range from 2.4 to 96 million years. Although a general trend is discernible from younger sediments at ridge crests to older sediments away from them, this is in fact to be expected, because the crest is the highest and most active part of the ridge; older sediments are likely to be buried beneath younger volcanic rocks. The basalt layer in the ocean crust suggests that magma flooding was once oceanwide, but volcanism was subsequently restricted to an increasingly narrow zone centered on the ridge crests. Such magma floods were accompanied by progressive crustal subsidence in large sectors of the present oceans, beginning in the Jurassic (Beloussov, 1980; Keith, 1993).

The numerous finds in the Atlantic, Pacific, and Indian Oceans of rocks far older than 200 million years—many of them continental in nature—provide strong evidence against the alleged youth of the underlying crust. In the Atlantic, rock and sediment age should range from Cretaceous (120 million years) adjacent to the continents to very recent at the ridge crest. During legs 37 and 43 of the DSDP, Paleozoic and Proterozoic igneous rocks were recovered in cores on the Mid-Atlantic Ridge and the Bermuda Rise, yet not one of these occurrences of ancient rocks was mentioned in the Cruise Site Reports or Cruise Synthesis Reports (Meyerhoff et al., 1996a). Aumento and Loncarevic (1969) reported that 75% of 84 rock samples dredged from the Bald Mountain region just west of the Mid-Atlantic Ridge crest at 45°N consisted of continental-type rocks and commented that this was a “remarkable phenomenon”; so remarkable, in fact, that they decided to classify these rocks as “glacial erratics” and to give them no further consideration. Another way of dealing with “anomalous” rock finds is to dismiss them as ship ballast. However, the Bald Mountain locality has an estimated volume of 80 km^3, so it is hardly likely to have been rafted out to sea on an iceberg or dumped by a ship! It consists of granitic and silicic metamorphic rocks ranging in age from 1,690 to 1,550 million years and is intruded by 785-million-year mafic rocks (Wanless et al., 1968). Ozima et al. (1976) found basalts of Middle Jurassic age (169 million years) at the junction of the rift valley of the Mid-Atlantic Ridge and the Atlantis fracture zone (30°N), an area where basalt should theoretically be extremely young, and stated that they were unlikely to be ice-rafted rocks. Van Hinte and Ruffman (1995) concluded that Paleozoic limestones dredged from Orphan Knoll in the northwest Atlantic were in situ and not ice rafted.

In another attempt to explain away anomalously old rocks and anomalously shallow or emergent crust in certain parts of the ridges, some plate tectonicists have argued that “nonspreading blocks” can be left behind during rifting and that the spreading axis and related transform faults can jump from place to place (e.g., Bonatti, 1990; Bonatti and Crane, 1982; Bonatti and Hon-

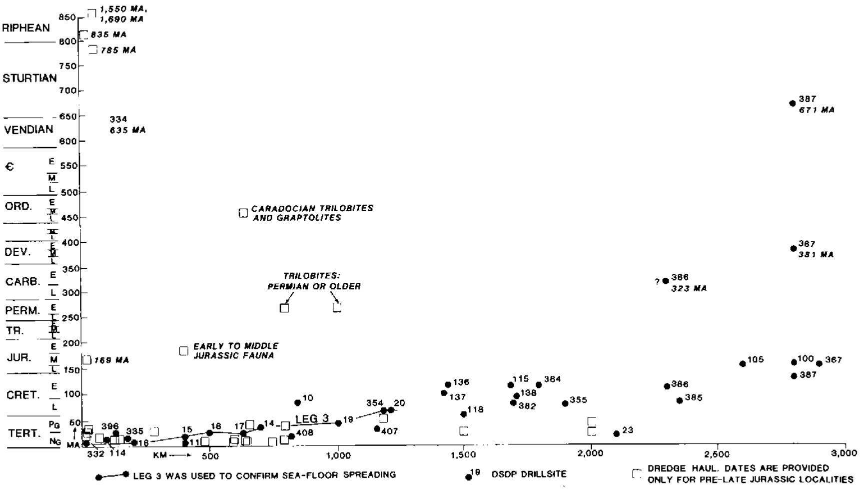


Fig. 5. A plot of rock age versus distance from the crest of the Mid-Atlantic Ridge. The figure shows (to scale) rocks of all ages, whether from drill holes or dredge hauls. (Reprinted with permission from Meyerhoff et al., 1996a, fig. 2.35. Copyright by Kluwer Academic Publishers.)

norez, 1971). This hypothesis was invoked by Pilot et al. (1998) to explain the presence of zircons with ages of 330 and 1,600 million years in gabbros beneath the Mid-Atlantic Ridge near the Kane fracture zone. Yet another way of dealing with anomalous rock ages is to reject them as unreliable. For instance, Reynolds and Clay (1977), reporting on a Proterozoic date (635 million years) near the crest of the Mid-Atlantic Ridge, wrote that the age *must* be wrong because the theoretical age of the site was only about 10 million years.

Paleozoic trilobites and graptolites have been dredged from the King's Trough area, on the opposite side of the Mid-Atlantic Ridge to Bald Mountain, and at several localities near the Azores (Furon, 1949; Smoot and Meyerhoff, 1995). Detailed surveys of the equatorial segment of the Mid-Atlantic Ridge have provided a wide variety of data contradicting the seafloor-spreading model, including numerous shallow-water and continental rocks, with ages of up to 3.74 billion years (Timofeyev et al., 1992; Udintsev, 1996; Udintsev et al., 1993). Melson, Hart, and Thompson (1972), studying St. Peter and Paul's Rocks at the crest of the Mid-Atlantic Ridge just north of the equator, found an 835-million-year rock associated with other rocks giving 350-, 450-, and 2,000-million-year ages, whereas according to the seafloor-spreading model, the rock should have been 35 million years old. Numerous igneous and metamorphic rocks giving late Precambrian and Paleozoic radiometric ages have been dredged from the crests of the southern Mid-Atlantic, Mid-Indian, and Carlsberg ridges (Afanas'yev, 1967).

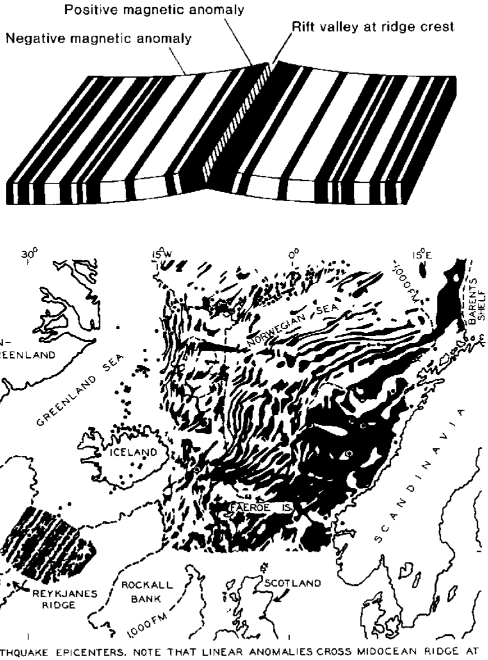
Precambrian and Paleozoic granites have been found in several "oceanic" plateaus and islands with anomalously thick crusts, including Rockall Plateau, Agulhas Plateau, the Seychelles, the Obruchev Rise, Papua New Guinea, and the Paracel Islands (Ben-Avraham et al., 1981; Sanchez Cela, 1999). In many cases, structural and petrological continuity exists between continents and anomalous "oceanic" crusts—a fact incompatible with seafloor spreading; this applies, for example, in the North Atlantic, where there is a continuous sialic basement, partly of Precambrian age, from North America to Europe. Major Precambrian lineaments in Australia and South America continue into the ocean floors, implying that the "oceanic" crust is at least partly composed of Precambrian rocks, and this has been confirmed by deep-sea dredging, drilling, and seismic data, and by evidence for submerged continental crust (ancient paleolands) in the present southeast and northwest Pacific (Choi, 1997, 1998; see below).

Marine Magnetic Anomalies

Powerful support for seafloor spreading is said to be provided by marine magnetic anomalies—approximately parallel stripes of alternating high and low magnetic intensity that characterize much of the world's midocean ridges. According to the Morley-Vine-Matthews hypothesis, first proposed in 1963, as the fluid basalt welling up along the midocean ridges spreads horizontally and cools, it is magnetized by the earth's magnetic field. Bands of high intensity are believed to have formed during periods of normal magnetic polarity, and bands of low intensity during periods of reversed polarity. They are therefore regarded as time lines or isochrons. As plate tectonics became accepted, attempts to test this hypothesis or to find alternative hypotheses ceased.

Correlations have been made between linear magnetic anomalies on either side of a ridge, in different parts of the oceans, and with radiometrically dated magnetic events on land. The results have been used to produce maps showing how the age of the ocean floor increases steadily with increasing distance from the ridge axis (McGeary and Plummer, 1998, fig. 4.19). As shown above, this simple picture can be sustained only by dismissing the possibility of older sediments beneath the basalt "basement" and by ignoring numerous "anomalously" old rock ages.

The claimed correlations have been largely qualitative and subjective and are therefore highly suspect; virtually no effort has been made to test them quantitatively by transforming them to the pole (i.e., recalculating each magnetic profile to a common latitude). In one instance where transformation to the pole was carried out, the plate-tectonic interpretation of the magnetic anomalies in the Bay of Biscay was seriously undermined (Storetvedt, 1997). Agocs, Meyerhoff, and Kis (1992) applied the same technique in their detailed, quantitative study of the magnetic anomalies of the Reykjanes Ridge near Iceland and found that the correlations were very poor; the correlation coefficient along strike averaged 0.31 and that across the ridge 0.17, with limits of +1 to – 1.



•EARTHQUAKE EPICENTERS. NOTE THAT LINEAR ANOMALIES CROSS MIDOCEAN RIDGE AT OBLIQUE ANGLE NORTH OF ICELAND

Fig. 6. Two views of marine magnetic anomalies. Top: A textbook cartoon. (Reprinted with permission from McGeary and Plummer, 1998. Copyright by The McGraw-Hill Companies.) Bottom: Magnetic anomaly patterns of the North Atlantic. (Reprinted with permission from Meyerhoff and Meyerhoff, 1972. Copyright by the American Geophysical Union.)

Linear anomalies are known from only 70% of the seismically active mid-ocean ridges. Moreover, the diagrams of symmetrical, parallel, linear bands of anomalies displayed in many plate-tectonics publications bear little resemblance to reality (Beloussov, 1970; Meyerhoff and Meyerhoff, 1974b) (Figure 6). The anomalies are symmetrical to the ridge axis in less than 50% of the ridge system where they are present, and in about 21% of it, they are oblique to the trend of the ridge. In some areas, linear anomalies are present where a ridge system is completely absent. Magnetic measurements by instruments towed near the sea bottom have indicated that magnetic bands actually consist of many isolated ovals that may be joined together in different ways.

The initial, highly simplistic seafloor-spreading model for the origin of magnetic anomalies has been disproven by ocean drilling (Hall and Robinson, 1979; Pratsch, 1986). First, the hypothesis that the anomalies are produced in the upper 500 m of oceanic crust has had to be abandoned. Magnetic intensities, general polarization directions, and often the existence of different polarity zones at different depths suggest that the source for oceanic magnetic anomalies lies in deeper levels of oceanic crust not yet drilled (or dated). Second, the vertically alternating layers of opposing magnetic polarization directions disprove the theory that the oceanic crust was magnetized entirely as it spread laterally from the magmatic center and strongly indicate that oceanic crustal sequences represent longer geologic times than is now believed. A more likely explanation of marine magnetic anomalies is that they are caused by fault-related bands of rock of different magnetic properties and have nothing to do with seafloor spreading (Choi, Vasil'yev, and Tuezov, 1990; Grant, 1980; Morris 1990; Pratsch, 1986).

The fact that not all the charted magnetic anomalies are formed of oceanic crustal materials further undermines the plate-tectonic explanation. In the Labrador Sea, some anomalies occur in an area of continental crust that had previously been defined as oceanic (Grant, 1980). In the northwestern Pacific, some magnetic anomalies are likewise located within an area of continental crust—a submerged paleoland (Choi, Vasil'yev, and Tuezov, 1990; Choi, Vasil'yev, and Bhat, 1992). Magnetic anomaly bands strike into the continents in at least 15 places and "dive" beneath Proterozoic or younger rocks. Furthermore, they are approximately concentric with respect to Archean continental shields (Meyerhoff and Meyerhoff, 1972, 1974b). These facts imply that instead of being a "taped record" of seafloor spreading and geomagnetic field reversals during the past 200 million years, most oceanic magnetic anomalies are the sites of ancient fractures, which partly formed during the Proterozoic and have been rejuvenated since. The evidence also suggests that Archean continental nuclei have held approximately the same positions with respect to one another since their formation—which is utterly at variance with continental drift.

Subduction

Benioff zones are distinct earthquake zones that begin at an ocean trench and slope landward and downward into the earth. In plate tectonics, these deep-rooted fault zones are interpreted as "subduction zones" where plates descend into the mantle. They are generally depicted as 100-km-thick slabs descending into the earth either at a constant angle, or at a shallow angle near the earth's surface and gradually curving around to an angle of between 60° and 75°. Neither representation is correct. Benioff zones often consist of two separate sections: an upper zone with an average dip of 33° extending to a depth of 70–400 km, and a lower zone with an average dip of 60° extending to a depth of up to 700 km (Benioff, 1954; Isacks and Barazangi, 1977). The upper and lower segments are sometimes offset by 100–200 km, and in one case by 350 km (Benioff, 1954, Smoot, 1997a). Furthermore, deep earthquakes are disconnected from shallow ones; very few intermediate earthquakes exist (Smoot, 1997a). Many studies have found transverse as well as vertical discontinuities and segmentation in Benioff zones (e.g., Carr, 1976;

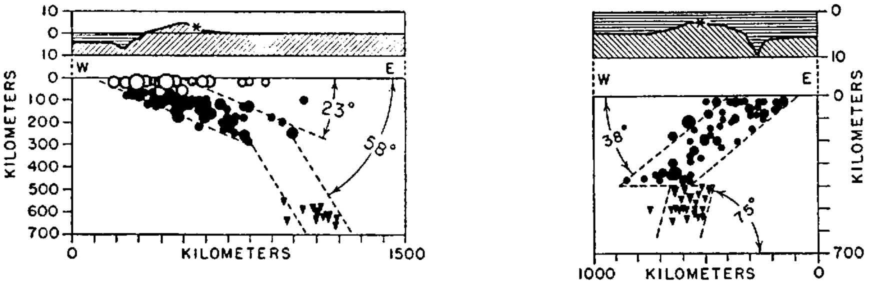


Fig. 7. Cross-sections across the Peru-Chile trench (left) and Bonin-Honshu arc (right), showing hypocenters. (Reprinted with permission from Benioff, 1954. Copyright by the Geological Society of America.)

Carr, Stoiber, and Drake, 1973; Ranneft, 1979; Spence, 1977; Swift and Carr, 1974; Teisseyre et al., 1974). The evidence therefore does not favor the notion of a continuous, downgoing slab (Figure 7).

Plate tectonicists insist that the volume of crust generated at midocean ridges is equaled by the volume subducted. But whereas 80,000 km of mid-ocean ridges are supposedly producing new crust, only 30,500 km of trenches exist. Even if we add the 9,000 km of "collision zones," the figure is still only half that of the "spreading centers" (Smoot, 1997a). With two minor exceptions (the Scotia and Lesser Antilles trench/arc systems), Benioff zones are absent from the margins of the Atlantic, Indian, Arctic, and Southern Oceans. Many geological facts demonstrate that subduction is not taking place in the Lesser Antilles arc; if it were, the continental Barbados Ridge should now be 200–400 km beneath the Lesser Antilles (Meyerhoff and Meyerhoff, 1974a). Kiskyras (1990) presented geological, volcanological, petrochemical, and seismological data contradicting the belief that the African plate is being subducted under the Aegean Sea.

Africa is allegedly being converged on by plates spreading from the east, south, and west, yet it exhibits no evidence whatsoever for the existence of subduction zones or orogenic belts. Antarctica, too, is almost entirely surrounded by alleged "spreading" ridges without any corresponding subduction zones but fails to show any signs of being crushed. It has been suggested that Africa and Antarctica may remain stationary while the surrounding ridge system migrates away from them, but this would require the ridge marking the "plate boundary" between Africa and Antarctica to move in opposite directions simultaneously (Storetvedt, 1997)!

If up to 13,000 km of lithosphere had really been subducted in circum-Pacific deep-sea trenches, vast amounts of oceanic sediments should have been scraped off the ocean floor and piled up against the landward margin of the trenches. However, sediments in the trenches are generally not present in the volumes required, nor do they display the expected degree of deformation

(Choi, 1999b; Gnibidenko, Krasny, and Popov, 1978; Storetvedt, 1997; Suzuki et al., 1997). Scholl and Marlow (1974), who support plate tectonics, admitted to being "genuinely perplexed as to why evidence for subduction or offscraping of trench deposits is not glaringly apparent" (p. 268). Plate tectonicists have had to resort to the highly dubious notion that unconsolidated deep-ocean sediments can slide smoothly into a Benioff zone without leaving any significant trace. Moreover, fore-arc sediments, where they have been analyzed, have generally been found to be derived from the volcanic arc and the adjacent continental block, not from the oceanic region (Pratsch, 1990; Wezel, 1986). The very low level of seismicity, the lack of a megathrust, and the existence of flat-lying sediments at the base of oceanic trenches contradict the alleged presence of a downgoing slab (Dickins and Choi, 1998). Attempts by Murdock (1997), who accepts many elements of plate tectonics, to publicize the lack of a megathrust in the Aleutian trench (i.e., a million or more meters of displacement of the Pacific plate as it supposedly underthrusts the North American plate) have met with vigorous resistance and suppression by the plate-tectonics establishment.

Subduction along Pacific trenches is also refuted by the fact that the Benioff zone often lies 80 to 150 km landward from the trench, by the evidence that Precambrian continental structures continue into the ocean floor, and by the evidence for submerged continental crust under the northwestern and southeastern Pacific, where there are now deep abyssal plains and trenches (Choi, 1987, 1998, 1999c; Smoot 1998b; Tuezov, 1998). If the "Pacific plate" is colliding with and diving under the "North American plate," there should be a stress buildup along the San Andreas Fault. The deep Cajon Pass drill hole was intended to confirm this but showed instead that no such stress is present (C. W. Hunt, 1992).

In the active island-arc complexes of southeast Asia, the arcs bend back on themselves, forming hairpin-like shapes that sometimes involve full 180° changes in direction. This also applies to the postulated subduction zone around India. How plate collisions could produce such a geometry remains a mystery (Meyerhoff, 1995; H. A. Meyerhoff and Meyerhoff, 1977). Rather than being continuous curves, trenches tend to consist of a row of straight segments, which sometimes differ in depth by more than 4 km. Aseismic buoyant features (e.g., seamounts), which are frequently found at the juncture of these segments, are connected with increased deep-earthquake and volcanic activity on the landward side of the trench, whereas theoretically their "arrival" at a subduction zone should reduce or halt such activity (Smoot, 1997a). Plate tectonicists admit that it is hard to see how the subduction of a cold slab could result in the high heat flow or arc volcanism in back-arc regions or how plate convergence could give rise to back-arc spreading (Uyeda, 1986). Evidence suggests that oceanic, continental, and back-arc rifts are actually tensional structures developed to relieve stress in a strong compressional stress system, and therefore have nothing to do with seafloor spreading (Dickins, 1997).

An alternative view of Benioff zones is that they are very ancient contraction fractures produced by the cooling of the earth (Meyerhoff et al., 1992b, 1996a). The fact that the upper part of the Benioff zones usually dips at less than 45° and the lower part at more than 45° suggests that the lithosphere is under compression and the lower mantle under tension. Furthermore, because a contracting sphere fractures along great circles (Bucher, 1956), this would account for the fact that both the circum-Pacific seismotectonic belt and the Alpine-Himalayan (Tethyan) belt lie on approximate circles. Finally, instead of oceanic crust being absorbed beneath the continents along ocean trenches, continents may actually be overriding adjacent oceanic areas to a limited extent, as is indicated by the historical geology of China, Indonesia, and the western Americas (Krebs, 1975; Pratsch, 1986; Storetvedt, 1997).

Uplift and Subsidence

Vertical Tectonics

Classical plate tectonics seeks to explain all geologic structures primarily in terms of simple lateral movements of lithospheric plates—their rifting, extension, collision, and subduction. But random plate interactions are unable to explain the periodic character of geological processes, i.e., the geotectonic cycle, which sometimes operates on a global scale (Wezel, 1992). Nor can they explain the large-scale uplifts and subsidences that have characterized the evolution of the earth's crust, particularly those occurring far from "plate boundaries" such as in continental interiors, and vertical oscillatory motions involving vast regions (Beloussov, 1980, 1990; Chekunov, Gordienko, and Guterman, 1990; Genshaft and Saltykowski, 1990; Ilich, 1972). The presence of marine strata thousands of meters above sea level (e.g., near the summit of Mount Everest) and the great thicknesses of shallow-water sediment in some old basins indicate that vertical crustal movements of at least 9 km above sea level and 10–15 km below sea level have taken place (Spencer, 1977).

Major vertical movements have also taken place along continental margins. For example, the Atlantic continental margin of North America has subsided by up to 12 km since the Jurassic (Sheridan, 1974). In Barbados, Tertiary coals representing a shallow-water, tropical environment occur beneath deep-sea oozes, indicating that during the last 12 million years, the crust sank to over 4–5 km depth for the deposition of the ooze and was then raised again. A similar situation occurs in Indonesia, where deep-sea oozes occur above sea level, sandwiched between shallow-water Tertiary sediments (James, 1994).

The primary mountain-building mechanism in plate tectonics is lateral compression caused by collisions—of continents, island arcs, oceanic plateaus, seamounts, and ridges. In this model, subduction proceeds without mountain building until collision occurs, whereas in the noncollision model subduction alone is supposed to cause mountain building. As well as being mutually contradictory, both models are inadequate, as several supporters of plate tectonics have pointed out (e.g., Cebull and Shurbet, 1990, 1992; Van Andel, 1998). The noncollision model fails to explain how continuous subduction can give rise to discontinuous orogeny, while the collision model is challenged by occurrences of mountain building where no continental collision can be assumed, and it fails to explain contemporary mountain-building activity along such chains as the Andes and around much of the rest of the Pacific rim.

Asia supposedly collided with Europe in the late Paleozoic, producing the Ural mountains, but abundant geological field data demonstrate that the Siberian and East European (Russian) platforms have formed a single continent since Precambrian times (Meyerhoff and Meyerhoff, 1974a). McGeary and Plummer (1998) state that the plate tectonic reconstruction of the formation of the Appalachians in terms of three successive collisions of North America seems "too implausible even for a science fiction plot" (p. 114) but add that an understanding of plate tectonics makes the theory more palatable. Ollier (1990), on the other hand, states that fanciful plate-tectonic explanations ignore all the geomorphology and much of the known geological history of the Appalachians. He also says that of all the possible mechanisms that might account for the Alps, the collision of the African and European plates is the most naive.

The Himalayas and the Tibetan Plateau were supposedly uplifted by the collision of the Indian plate with the Asian plate. However, this fails to explain why the beds on either side of the supposed collision zone remain comparatively undisturbed and low-dipping, whereas the Himalayas have been uplifted, supposedly as a consequence, some 100 km away, along with the Kunlun Mountains to the north of the Tibetan Plateau. River terraces in various parts of the Himalayas are almost perfectly horizontal and untilted, suggesting that the Himalayas were uplifted vertically, rather than as the result of horizontal compression (Ahmad, 1990). Collision models generally assume that the uplift of the Tibetan Plateau began during or after the early Eocene (post-50 million years), but paleontological, paleoclimatological, paleoecological, and sedimentological data conclusively show that major uplift could not have occurred before earliest Pliocene time (5 million years ago) (Meyerhoff, 1995).

There is ample evidence that mantle heat flow and material transport can cause significant changes in crustal thickness, composition, and density, resulting in substantial uplifts and subsidences. This is emphasized in many of the alternative hypotheses to plate tectonics (for an overview, see Yano and Suzuki, 1999), such as the model of endogenous regimes (Beloussov, 1980, 1981, 1990, 1992; Pavlenkova, 1995, 1998). Plate tectonicists, too, increasingly invoke mantle diapirism as a mechanism for generating or promoting tectogenesis; there is now abundant evidence that shallow magma chambers are ubiquitous beneath active tectonic belts.

The popular hypothesis that crustal stretching was the main cause of the formation of deep sedimentary basins on continental crust has been contradicted by numerous studies; mantle upwelling processes and lithospheric density increases are increasingly being recognized as an alternative mechanism (Anfiloff, 1992; Artyushkov, 1992; Artyushkov and Baer, 1983; Pavlenkova, 1998; Zorin and Lepina, 1989). This may involve gabbro-eclogite phase transformations in the lower crust (Artyushkov, 1992; Haxby, Turcotte, and Bird, 1976; Joyner, 1967), a process that has also been proposed as a possible explanation for the continuing subsidence of the North Sea Basin, where there is likewise no evidence of large-scale stretching (Collette, 1968).

Plate tectonics predicts simple heat-flow patterns around the earth. There should be a broad band of high heat flow beneath the full length of the mid-ocean rift system and parallel bands of high and low heat flow along the Benioff zones. Intraplate regions are predicted to have low heat flow. The pattern actually observed is quite different. There are criss-crossing bands of high heat flow covering the entire surface of the earth (Meyerhoff et al., 1996a). Intraplate volcanism is usually attributed to “mantle plumes”—upwellings of hot material from deep in the mantle, presumably the core-mantle boundary. The movement of plates over the plumes is said to give rise to hotspot trails (chains of volcanic islands and seamounts). Such trails should therefore show an age progression from one end to the other, but a large majority show little or no age progression (Baksi, 1999; Keith, 1993). On the basis of geological, geochemical, and geophysical evidence, Sheth (1999) argued that the plume hypothesis is ill-founded, artificial, and invalid, and has led earth scientists up a blind alley.

Active tectonic belts are located in bands of high heat flow, which are also characterized by several other phenomena that do not readily fit in with the plate-tectonics hypothesis. These include bands of microearthquakes (including “diffuse plate boundaries”) that do not coincide with plate-tectonic-predicted locations; segmented belts of linear faults, fractures, and fissures; segmented belts of mantle upwellings and diapirs; vortical geological structures; linear lenses of anomalous (low-velocity) upper mantle that are commonly overlain by shallower, smaller low-velocity zones; the existence of bisymmetrical deformation in all foldbelts, with coexisting states of compression and tension; strike-slip zones and similar tectonic lines ranging from simple rifts to *Verschluckungszonen* (“engulfment zones”); eastward-shifting tectonic-magmatic belts; and geothermal zones. Investigation of these phenomena has led to the development of a major new hypothesis of geodynamics, known as *surge tectonics*, which rejects both seafloor spreading and continental drift (Meyerhoff, 1995; Meyerhoff et al., 1992b, 1996a).

Surge tectonics postulates that all the major features of the earth’s surface, including rifts, foldbelts, metamorphic belts, and strike-slip zones, are underlain by shallow (less than 80 km) magma chambers and channels (known as “surge channels”). Seismotomographic data suggest that surge channels form an interconnected worldwide network, which has been dubbed “the earth’s cardiovascular system." Surge channels coincide with the lenses of anomalous mantle and associated low-velocity zones referred to above, and active channels are also characterized by high heat flow and microseismicity. Magma from the asthenosphere flows slowly through active channels at the rate of a few centimeters a year. Horizontal flow is demonstrated by two major surface features: linear, belt-parallel faults, fractures, and fissures; and the division of tectonic belts into fairly uniform segments. The same features characterize all lava flows and tunnels and have also been observed on Mars, Venus, and several moons of the outer planets.

Surge tectonics postulates that the main cause of geodynamics is lithosphere compression, generated by the cooling and contraction of the earth. As compression increases during a geotectonic cycle, it causes the magma to move through a channel in pulsed surges and eventually to rupture it so that the contents of the channel surge bilaterally upward and outward to initiate tectogenesis. The asthenosphere (in regions where it is present) alternately contracts during periods of tectonic activity and expands during periods of tectonic quiescence. The earth's rotation, combined with differential lag between the more rigid lithosphere above and the more fluid asthenosphere below, causes the fluid or semifluid materials to move predominantly eastward. This explains the eastward migration through time of many magmatic or volcanic arcs, batholiths, rifts, depocenters, and foldbelts.

The Continents

It is a striking fact that nearly all the sedimentary rocks composing the continents were laid down under the sea. The continents have suffered repeated marine inundations, but because sediments were mostly deposited in shallow water (less than 250 m), the seas are described as "epicontinental." Marine transgressions and regressions are usually attributed mainly to eustatic changes of sea level caused by alterations in the volume of midocean ridges. Van Andel (1994) points out that this explanation cannot account for the 100 or so briefer cycles of sea-level changes, particularly because transgressions and regressions are not always simultaneous all over the globe. He proposes that large regions or whole continents must undergo slow vertical, epeirogenic movements, which he attributes to an uneven distribution of temperature and density in the mantle, combined with convective flow. Some workers have linked marine inundations and withdrawals to a global thermal cycle, bringing about continental uplift and subsidence (Rutland, 1982; Sloss and Speed, 1974). Van Andel (1994) admits that epeirogenic movements "fit poorly into plate tectonics" (p. 170) and are therefore largely ignored (Figures 8 and 9).

Van Andel (1994) asserts that "plates" rise or fall by no more than a few hundred meters—this being the maximum depth of most "epicontinental" seas. However, this overlooks an elementary fact: huge thicknesses of sediments were often deposited during marine incursions, often requiring vertical crustal movements of *many kilometers*. Sediments accumulate in regions of

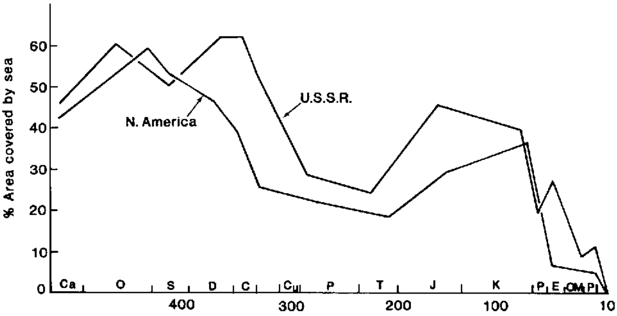


Fig. 8. Maximum degree of marine inundation for each Phanerozoic geological period for the former USSR and North America. The older the geological period, the greater the probability of the degree of inundation being underestimated due to the sediments having been eroded or deeply buried beneath younger sediments. (Reprinted with permission from Harrison et al., 1983. Copyright by the American Geophysical Union.)

subsidence, and their thickness is usually close to the degree of downwarping. In the unstable, mobile belts bordering stable continental platforms, many geosynclinal troughs and circular depressions have accumulated sedimentary thicknesses of 10–14 km, and in some cases of 20 km. Although the sedimentary cover on the platforms themselves is often less than 1.5 km thick, basins with sedimentary thicknesses of 10 km and even 20 km are not unknown (Beloussov, 1981; Dillon, 1974; C. B. Hunt, 1992; Pavlenkova, 1998).

Subsidence cannot be attributed solely to the weight of the accumulating sediments because the density of sedimentary rocks is much lower than that of the subcrustal material; e.g., the deposition of 1 km of marine sediment will cause only half a kilometer or so of subsidence (Holmes, 1965; Jeffreys, 1976). Moreover, sedimentary basins require not only continual depression of the base of the basin to accommodate more sediments, but also continuous uplift of adjacent land to provide a source for the sediments. In geosynclines, subsidence has commonly been followed by uplift and folding to produce mountain ranges, and this can obviously not be accounted for by changes in surface loading. The complex history of the oscillating uplift and subsidence of the crust appears to require deep-seated changes in lithospheric composition and density, as well as vertical and horizontal movements of mantle material. That density is not the only factor involved is shown by the fact that in regions of tectonic activity vertical movements often intensify gravity anomalies rather than acting to restore isostatic equilibrium. For example, the Greater Caucasus is overloaded, yet it is rising rather than subsiding (Beloussov, 1980; Jeffreys, 1976).

In regions where all the sediments were laid down in shallow water, subsidence must somehow have kept pace with sedimentation. In eugeosynclines, on the other hand, subsidence proceeded faster than sedimentation, resulting

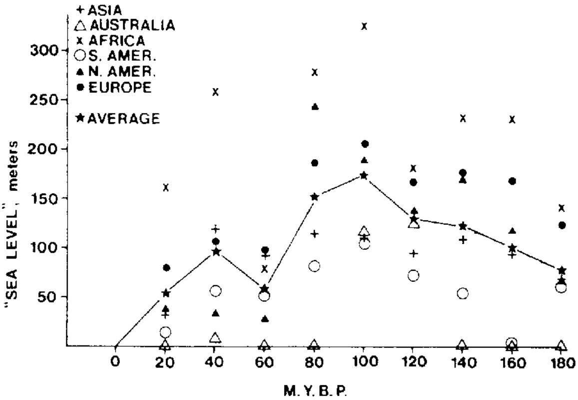


Fig. 9. Sea-level changes for six continents. For each time interval, the sea-level elevations for the various continents differ widely, highlighting the importance of vertical tectonic movements on a regional and continental scale. (Reprinted with permission from Hallam, 1977. Copyright by *Nature.*)

in a marine basin several kilometers deep. Examples of eugeosynclines prior to the uplift stage are the Sayans in the early Paleozoic, the eastern slope of the Urals in the early and middle Paleozoic, the Alps in the Jurassic and early Cretaceous, and the Sierra Nevada in the Triassic (Beloussov, 1980). Plate tectonicists often claim that geosynclines are formed solely at plate margins at the boundaries between continents and oceans. However, there are many examples of geosynclines having formed in intracontinental settings (Holmes, 1965), and the belief that the ophiolites found in certain geosynclinal areas are invariably remnants of oceanic crust is contradicted by a large volume of evidence (Beloussov, 1981; Bhat, 1987; Luts, 1990; Sheth, 1997).

The Oceans

In the past, sialic clastic material has been transported to today's continents from the direction of the present-day oceans, where there must have been considerable areas of land that underwent erosion (Beloussov, 1962; Dickins, Choi, and Yeates, 1992). For instance, the Paleozoic geosyncline along the seaboard of eastern North America, an area now occupied by the Appalachian mountains, was fed by sialic clasts from a borderland ("Appalachia") in the adjacent Atlantic. Other submerged borderlands include the North Atlantic Continent or Scandia (west of Spitsbergen and Scotland), Cascadia (west of the Sierra Nevada), and Melanesia (southeast of Asia and east of Australia) (Gilluly, 1955; Holmes, 1965; Umbgrove, 1947). A million cubic kilometers of Devonian micaceous sediments from Bolivia to Argentina imply an extensive continental source to the west where there is now the deep Pacific Ocean (Carey, 1994). During Paleozoic-Mesozoic-Paleogene times, the Japanese geosyncline was supplied with sediments from land areas in the Pacific (Choi, 1984, 1987).

When trying to explain sediment sources, plate tectonicists sometimes argue that sediments were derived from the existing continents during periods when they were supposedly closer together (Bahlburg, 1993; Dickins, 1994a; Holmes, 1965). Where necessary, they postulate small former land areas (microcontinents or island arcs), which have since been either subducted or accreted against continental margins as "exotic terranes" (Choi, 1984; Kumon et al., 1988; Nur and Ben-Avraham, 1982). However, mounting evidence is being uncovered that favors the foundering of sizable continental landmasses, whose remnants are still present under the ocean floor (see below).

Oceanic crust is regarded as much thinner and denser than continental crust: The crust beneath oceans is said to average about 7 km thick and to be composed largely of basalt and gabbro, whereas continental crust averages about 35 km thick and consists chiefly of granitic rock capped by sedimentary rocks. However, ancient continental rocks and crustal types intermediate between standard "continental" and "oceanic" crust are increasingly being discovered in the oceans (Sanchez Cela, 1999), and this is a serious embarrassment for plate tectonics. The traditional picture of the crust beneath oceans being universally thin and graniteless may well be further undermined in the future, as oceanic drilling and seismic research continue. One difficulty is to distinguish the boundary between the lower oceanic crust and upper mantle in areas where high- and low-velocity layers alternate (Choi, Vasil'yev, and Bhat, 1992; Orlenok, 1986). For example, the crust under the Kuril deep-sea basin is 8 km thick if the 7.9 km/s velocity layer is taken as the crust-mantle boundary (Moho), but 20–30 km thick if the 8.2 or 8.4 km/s layer is taken as the Moho (Tuezov, 1998).

Small ocean basins cover an area equal to about 5% of that of the continents and are characterized by transitional types of crust (Menard, 1967). This applies to the Caribbean Sea, the Gulf of Mexico, the Japan Sea, the Okhotsk Sea, the Black Sea, the Caspian Sea, the Mediterranean, the Labrador Sea and Baffin Bay, and the marginal (back-arc) basins along the western side of the Pacific (Beloussov and Ruditch, 1961; Choi, 1984; Grant, 1992; Ross, 1974; Sheridan, 1974). In plate tectonics, the origin of marginal basins, with their complex crustal structure, has remained an enigma, and there is no basis for the assumption that some kind of seafloor spreading must be involved; rather, they appear to have originated by vertical tectonics (Storetvedt, 1997; Wezel, 1986). Some plate tectonicists have tried to explain the transitional crust of the Caribbean in terms of the continentalization of a former deep ocean area, thereby ignoring the stratigraphic evidence that the Caribbean was a land area in the Early Mesozoic (Van Bemmelen, 1972).

There are over 100 submarine plateaus and aseismic ridges scattered throughout the oceans, many of which were once subaerially exposed (Dickins, Choi, and Yeates, 1992; Nur and Ben-Avraham, 1982; Storetvedt, 1997)

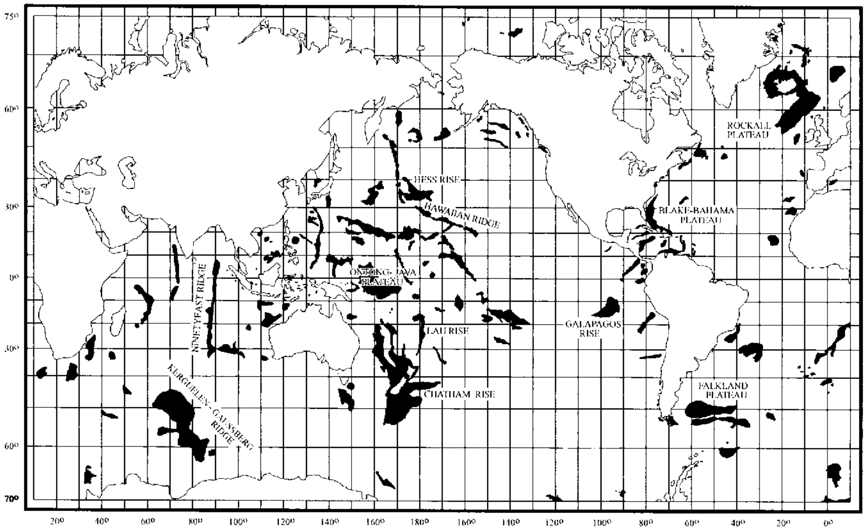


Fig. 10. Worldwide distribution of oceanic plateaus (black). (Reprinted with permission from Storetvedt, 1997. Copyright by Fagbokforlaget and K. M. Storetvedt.)

(Figure 10). They make up about 10% of the ocean floor. Many appear to be composed of modified continental crust 20–40 km thick—far thicker than "normal" oceanic crust. They often have an upper 10–15-km crust with compressional-wave velocities typical of granitic rocks in continental crust. They have remained obstacles to predrift continental fits and have therefore been interpreted as extinct spreading ridges, anomalously thickened oceanic crust, or subsided continental fragments carried along by the "migrating" seafloor. If seafloor spreading is rejected, they cease to be anomalous and can be interpreted as submerged, in situ continental fragments that have not been completely "oceanized."

Shallow-water deposits ranging in age from mid-Jurassic to Miocene, as well as igneous rocks showing evidence of subaerial weathering, were found in 149 of the first 493 boreholes drilled in the Atlantic, Indian, and Pacific Oceans. These shallow-water deposits are now found at depths of 1–7 km, demonstrating that many parts of the present ocean floor were once shallow seas, shallow marshes, or land areas (Orlenok, 1986; Timofeyev and Kholodov, 1984). From a study of 402 oceanic boreholes in which shallow-water or relatively shallow-water sediments were found, Ruditch (1990) concluded that there is no systematic correlation between the age of shallow-water accumulations and their distance from the axes of the midoceanic ridges, thereby disproving the seafloor-spreading model. Some areas of the oceans appear to have undergone continuous subsidence, whereas others experienced alternating episodes of subsidence and elevation. The Pacific

Ocean appears to have formed mainly from the Late Jurassic to the Miocene, the Atlantic Ocean from the Late Cretaceous to the end of the Eocene, and the Indian Ocean during the Paleocene and Eocene.

In the North Atlantic and Arctic Oceans, modified continental crust (mostly 10–20 km thick) underlies not only ridges and plateaus, but most of the ocean floor; only in deep-water depressions is typical oceanic crust found. Because deep-sea drilling has shown that large areas of the North Atlantic were previously covered with shallow seas, it is possible that much of the North Atlantic was continental crust before its rapid subsidence (Pavlenkova, 1995, 1998; Sanchez Cela, 1999). Lower Paleozoic continental rocks with trilobite fossils have been dredged from seamounts scattered over a large area northeast of the Azores. Furon (1949) concluded that the continental cobbles had not been carried there by icebergs and that the area concerned was a submerged continental zone. Bald Mountain, from which a variety of ancient continental material has been dredged, could certainly be a foundered continental fragment. In the equatorial Atlantic, shallow-water and continental rocks are ubiquitous (Timofeyev et al., 1992; Udintsev, 1996).

There is evidence that the midocean ridge system was shallow or partially emergent in Cretaceous to Early Tertiary time. For instance, in the Atlantic, subaerial deposits have been found on the North Brazilian Ridge (Bader et al., 1971), near the Romanche and Vema fracture zones adjacent to equatorial sectors of the Mid-Atlantic Ridge (Bonatti and Chermak, 1981; Bonatti and Honnorez, 1971), on the crest of the Reykjanes Ridge, and in the Faeroe-Shetland region (Keith, 1993) (Figure 11).

Oceanographic and geological data suggest that a large part of the Indian Ocean, particularly the eastern part, was land ("Lemuria") from the Jurassic until the Miocene. The evidence includes seismic and palynological data and subaerial weathering, which suggest that the Broken and Ninety East Ridges were part of an extensive, now sunken landmass; extensive drilling, seismic, magnetic, and gravity data pointing to the existence an Alpine-Himalayan foldbelt in the northwestern Indian Ocean, associated with a foundered continental basement; data that continental basement underlies the Scott, Exmouth, and Naturaliste plateaus west of Australia; and thick Triassic and Jurassic sedimentation on the western and northwestern shelves of the Australian continent, which shows progradation and current direction indicating a western source (Dickins, 1994a; Udintsev, Illarionov, and Kalinin, 1990; Udintsev and Koreneva, 1982; Wezel, 1988).

Geological, geophysical, and dredging data provide strong evidence for the presence of Precambrian and younger continental crust under the deep abyssal plains of the present northwest Pacific (Choi, Vasil'yev, and Bhat, 1992; Choi, Vasil'yev, and Tuezov, 1990). Most of this region was either subaerially exposed or very shallow sea during the Paleozoic to Early Mesozoic and first became deep sea about the end of the Jurassic. Paleolands apparently existed on both sides of the Japanese islands. They were largely emergent during the Paleozoic-Mesozoic-Paleogene but were totally submerged during Paleogene to

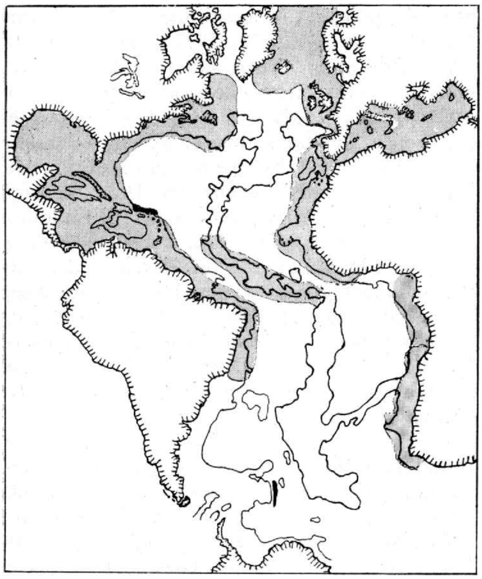


Fig. 11. Areas in the Atlantic Ocean for which past subsidence has been established. Subsided areas are shaded. (Reprinted with permission from Dillon, 1974. Copyright by the AAPG, whose permission is required for further use.)

Miocene times. Those on the Pacific side included the great Oyashio paleoland and the Kuroshio paleoland. The latter, which was as large as the present Japanese islands and occupied the present Nankai Trough area, subsided in the Miocene, at the same time as the upheaval of the Shimanto geosyncline, to which it had supplied vast amounts of sediments (Choi, 1984, 1987; Harata et al., 1978; Kumon et al., 1988). There is also evidence of paleolands in the southwest Pacific around Australia (Choi, 1997) and in the southeast Pacific during the Paleozoic and Mesozoic (Bahlburg, 1993; Choi, 1998; Isaacson, 1975; Isaacson and Martinez, 1995) (Figure 12).

After surveying the extensive evidence for former continental land areas in the present oceans, Dickins, Choi, and Yeates (1992) concluded,

> We are surprised and concerned for the objectivity and honesty of science that such data can be overlooked or ignored. There is a vast need for future Ocean Drilling Program initiatives to drill below the base of the basaltic ocean floor crust to confirm the real composition of what is currently designated oceanic crust. (p. 198)

Conclusion

Plate tectonics—the reigning paradigm in the earth sciences—faces some very severe and apparently fatal problems. Far from being a simple, elegant,

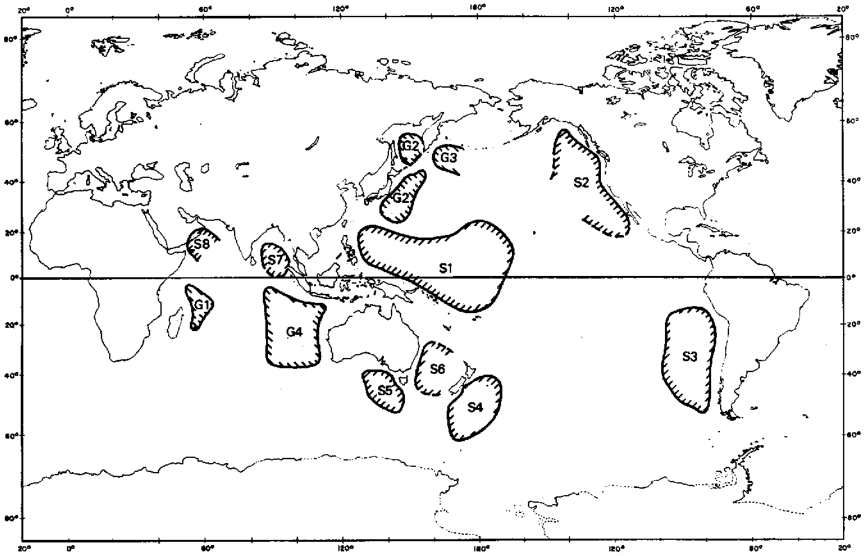


Fig. 12. Former land areas in the present Pacific and Indian Oceans. Only those areas for which substantial evidence already exists are shown. Their exact outlines and full extent are as yet unknown. G1, Seychelles area; G2, Great Oyashio Paleoland; G3, Obruchev Rise; G4, Lemuria; S1, area of Ontong-Java Plateau, Magellan Sea Mounts, and Mid-Pacific Mountains; S2, Northeast Pacific; S3, Southeast Pacific including Chatham Rise and Campbell Plateau; S4, Southwest Pacific; S5, area including South Tasman Rise; S6, East Tasman Rise and Lord Howe Rise; S7, Northeast Indian Ocean; S8, Northwest Indian Ocean. (Reprinted with permission from Dickins, 1994a, 1994b. Copyright by J. M. Dickins.)

all-embracing global theory, it is confronted with a multitude of observational anomalies and has had to be patched up with a complex variety of ad hoc modifications and auxiliary hypotheses. The existence of deep continental roots and the absence of a continuous, global asthenosphere to "lubricate" plate motions have rendered the classical model of plate movements untenable. There is no consensus on the thickness of the "plates" and no certainty as to the forces responsible for their supposed movement. The hypotheses of large-scale continental movements, seafloor spreading, and subduction, as well as the relative youth of the oceanic crust are contradicted by a substantial volume of data. Evidence for significant amounts of submerged continental crust in the present-day oceans provides another major challenge to plate tectonics. The fundamental principles of plate tectonics therefore require critical reexamination, revision, or rejection.

Acknowledgments

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