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The Necessity for Earth Expansion

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Abstract

Pangaea, reconstructed on a globe of present Earth radius, occupies a little more than a hemisphere, the remainder being the EoPacific Ocean. Opening of the Arctic, Atlantic, Indian, and Southern Oceans, nearly doubled the area of Pangaea. Hence on a constant-radius Earth the Pacific would have been reduced virtually to zero. This is not so. Instead, each of the continental blocks around the Pacific has separated from its neighbours by large amounts in the direction of the Pacific perimeter, so that the Pacific, far from reducing to near zero, has greatly increased in area. This is impossible except on an expanding Earth.

Palaeomagnetic measurements show that all of the continents except Antarctica have converged on the Arctic by several tens of degrees since the Permian. Wholly independent data from the Triassic Jurassic and Cretaceous give the same conclusion in progressively diminishing degree. Yet throughout this time the Arctic has been an area of extension. This is absurd unless the Earth has greatly expanded.

Several other independent sets of data set out herein require Earth expansion. All the characters of orogens — heat flux, vulcanism, plutonics, attitudes of thrusts and lineations, incidence of metamorphics, distribution and incidence of seismicity, and others, fit better the expansion model of diapiric orogenesis than the subduction model.

Expansion has been denied on limits of palaeogravity, palaeomagnetic compilations, and the condition of other planets. Many of these criticisms are Quixotic — setting up a model, then proceeding to demolish it, but the criticisms do not apply to the model herein proposed. Others are simply invalid.

Through the nineteen-thirties, 'forties and early fifties I believed and taught, in the face of rejection and ridicule, what is now called plate tectonics, including the swallowing of the ocean floors at the trenches (see American Geophysical Union correspondence of 1953 reproduced in Carey, 1976, pp.10-11) and the strip-by-strip addition of new ocean floor from the mantle at the mid-ocean ridges (see report of the 1956 continental drift symposium pp.179-191). My confidence in my orocline method of restoration of early Mesozoic configurations was vindicated by the repeated confirmation of my oroclinal rotations whenever palaeomagnetic measurements were made (Table I).

During those years the possibility of large changes of the Earth's diameter just had not occurred to me, although, stimulated by Wegener, expansion had been fully developed in Germany as a better alternative by Lindemann (1928), Hilgenberg (1932), and Keindl (1940), but they had been ignored in Germany and were not available in English until I translated them twenty years ago. Neither Wegener's 1929 edition (including editor's updated bibliography to 1966) nor Du Toit (1938) mention them.

THE GAPING SECTOR OF PANGAEA

However, during the 'forties and early 'fifties, I had increasing difficulty in extending assembly of the continents over the whole of Pangaea. I could make sketches, but I was working more accurately than my contemporaries, and calculated hundreds of oblique projections (by logarithms in those pre-computer times) to eliminate projection errors, I also built a 30-inch-diameter hemispherical table to match my globe, and moulded plastic film to fit both accurately (Carey, 1955b; 1958, p.218-226). The precision only confirmed the impossibility of assembling Pangaea without a gape appearing on its perimeter somewhere, in the form of a 50° open sector extending right to the centre. Everyone who has since attempted to reassemble Pangaea assuming Earth of constant radius has found such a gaping sector (Figure 1). It has become conventional to follow my 1945 assembly and leave the gape between Australia and Indochina, assume it to be real, and call it Tethys. Because I believed the gape in this position to be an artefact I tried other locations for it, with even more obvious disjuncts. But the Pangaean continuity of East Asia and Australasia was attested by the Early Cambrian archaeocyathids, Cambrian trilobites of the *Redlichia* fauna, Ordovician cephalopods and Calymenid trilobites, Llandovery corals, Devonian brachiopods, Carboniferous foraminifera, Permocarboniferous blastoids, the mingling of Gondwana and Cathaysian floras in New Guinea Sumatra Thailand and China*, the late Triassic *Monotis* faunas from Siberia to New Zealand, and the distribution of Triassic amphibians and reptiles.

Gradually this and other anomalies accumulated to convince me that the constant-radius model, which looks so good for a couple of continents, could not work for the whole globe.

*Archbold, Pigram, Ratman & Hakim (*Nature* 206, p.556) report a New Guinea fauna which indicates the geographical proximity of Thailand and New Guinea during the Permian.

TABLE I

Rotations predicted tectonically, subsequently confirmed palaeomagnetically

Rotated Block	Rotation predicted by Carey	Palaeo-magnetic rotation observed	References
N. America to Europe	30°	30°	*8*, figs 5, 9, 10, 13, 14; *9*, table 4; *35*
Africa to S. America	45°	45°	*8*, figs 14, 17, 21, 24; *24*, fig 5
Newfoundland	25°	25° s	*10; 11; 12; 17*, figs 6, 7; *18; 35*
Spain	35° s	35° s	*1; 5*, figs 2, 3; *6; 8*, fig 33; *13; 19*, fig. 10.10; *25a; 28; 30; 33; 35*
Italy	110° s	107° s	*5*, fig 21; *8*, figs 31, 32; *13*, p.84; *17*, figs 4, 5; *23; 35; 46; 50; 54*
Corsica and Sardinia	90° s	50° s	*5*, fig 21; *8*, figs 31, 32, 51; *17*, figs 4, 5; *22*, fig 2; *29; 32; 35; 37; 49*
Sicily to Africa	0°	0°	*5*, figs 20, 21; *8*, fig 32; *17*, fig 32; *41*
Arabia to Africa	3½°s	7° s	*5*, fig 12; *8*, figs 1, 2, 36; *14; 17*, fig 7; *25b*
India to Africa	70° s	70° s	*5*, figs 10, 12; *6; 8*, figs 1, 2, 36, 51; *19; 31*
New Guinea	35°	40°	*3*, figs 23, 25; *8*, fig 38b; *27; 35*
Honshu N. and S.	40°	58°	*8*, figs 40b, 40c; *15*, fig 7; *19*, p.249, fig 10.5; *32; 35*, figs 1, 4
Mendocino orocline	60° d	63° d	*2; 4; 7; 8*, fig 56; *11; 19*, p.249; *21*, figs 1, 3; *26; 32; 35; 38*, p.93; *52*
Puerto Rico to S. America	45° s	53° s	*17*, figs 12-14; *36; 40*
Jamaica to S. America	42° s	50° s	*17*, figs 12-14; *39; 40; 44; 48*
Hispaniola to S. America	39° s	40° s	*17*, figs 12-14; *43; 48*
Colombia	large s	80° s	*8*, fig 26; *40*
Appalachian Arcs	20°-40°	29°	*16*, p.142; *20*, p.165; *32*
Malay Peninsula	Ca 70° d	70° d	*3; 8; 34; 45*, p.645; *47*, figs 43, 53
Seram	large s	98° s	*3; 8; 17; 35; 47; 51; 53*
Scotia oroclinotath	large	90° d	*55*

References

1 Argand, 1924; *2* Becker, 1934; *3* Carey, 1938; *4* Torreson, Murphy, & Graham, 1949; *5* Carey, 1955a; *6* Clegg, Deutsch, Everitt, & Stubbs, 1957; *7* Cox, 1957, *8* Carey, 1958a; *9* Irving, 1958; *10* Du Bois, 1959; *11* Irving, 1959; *12* Nairn, Frost, & Light, 1959; *13* Van Hilten, 1960; *14* Irving & Tarling, 1961; *15* Kawai, Ito, & Kume, 1961; *16* Carey, 1962a; *17* Carey, 1963; *18* Black, 1964; *19* Irving, 1964; *20* Irving & Opdyke, 1964; *21* Watkins, 1964a, 1964b; *22* Ashworth & Nairn, 1965; *23* De Boer, 1965; *24* Creer, 1965; *25* Girdler, 1965a, 1965b; *26* Watkins, 1965; *27* Green & Pitt, 1967; *28* Van der Voo, 1967; *29* Nairn & Westphal, 1968; *30* Watkins & Richardson, 1968; *31* Wensink, 1968; *32* Tarling, 1969; *33* Van der Voo, 1969; *34* Kawai, Hirooka, & Nakajima, 1969; *35* Carey, 1970; *36* Fink & Harrison, 1971; *37* Alvarez, 1972; *38* Irving & Yole, 1972; *39* Dasgupta & Vincenz, 1973, 1975; *40* MacDonald & Opdyke, 1973; *41* Nairn, Gregor, & Negendank, 1973; *42* Vincenz & Dasgupta, 1973; *43* Vincenz, Dasgupta, & Steinhauser, 1973; *44* Vincenz, Steinhauser, & Dasgupta, 1973; *45* McElhinny, Haile, & Crawford, 1974; *46* Lowrie & Alvarez, 1974; *47* Carey, 1975; *48* Dasgupta & Vincenz, 1975; *49* Orsini, Velluntini, & Westphal, 1975; *50* Lowrie & Alvarez, 1975; *51* Carey, 1976; *52* Simpson & Cox, 1977; *53* Haile, 1978; *54* Vandenberg, Klootivijk, & Wonders, 1978; *55* Kellog, 1980.

s = sinistral rotation d = dextral rotation

I realized finally that the error lay in the fact that my spherical table matched my reference globe and that my projection assembly base had the same radius, instead of a smaller radius appropriate to the earlier Earth, like trying to button a coat over a fattened belly. On a smaller globe the gaping sector closed.

THE PACIFIC PARADOX

Figure 1 shows three versions of Pangaea at the beginning of the Mesozoic: Wegener 1951, Carey 1945, and Dietz & Holden 1970, all assuming constant Earth-radius. On each the heavy broken line is a hemisphere (the distorted shape of the hemisphere in Wegener and to a less extent in Dietz & Holden is an artefact of the Aitoff projection used). In each an asterisk marks the centre of the bounding hemisphere. Each has the gaping sector of nearly 50° which is unavoidable with the constant-radius assumption. (In Dietz & Holden the gape looks wider, but they state (p.4943) that "New Guinea, New Zealand and southeast Asia have been omitted for cartographic convenience"); in Wegener the gape looks narrower, but he has stretched south Asia palinspastically to undo his postulated Lemurian compression.

On each of these assemblies Pangaea (including its inherent gaping sector) just spills over a hemisphere. Hence the ancestral Pacific (excluding the gape) must have been nearly a hemisphere in area. Since then the area of "Pangaea" has nearly doubled through the insertion between its parts of the Arctic, Atlantic, Indian and Southern Oceans. This means that the Pacific should have been great-

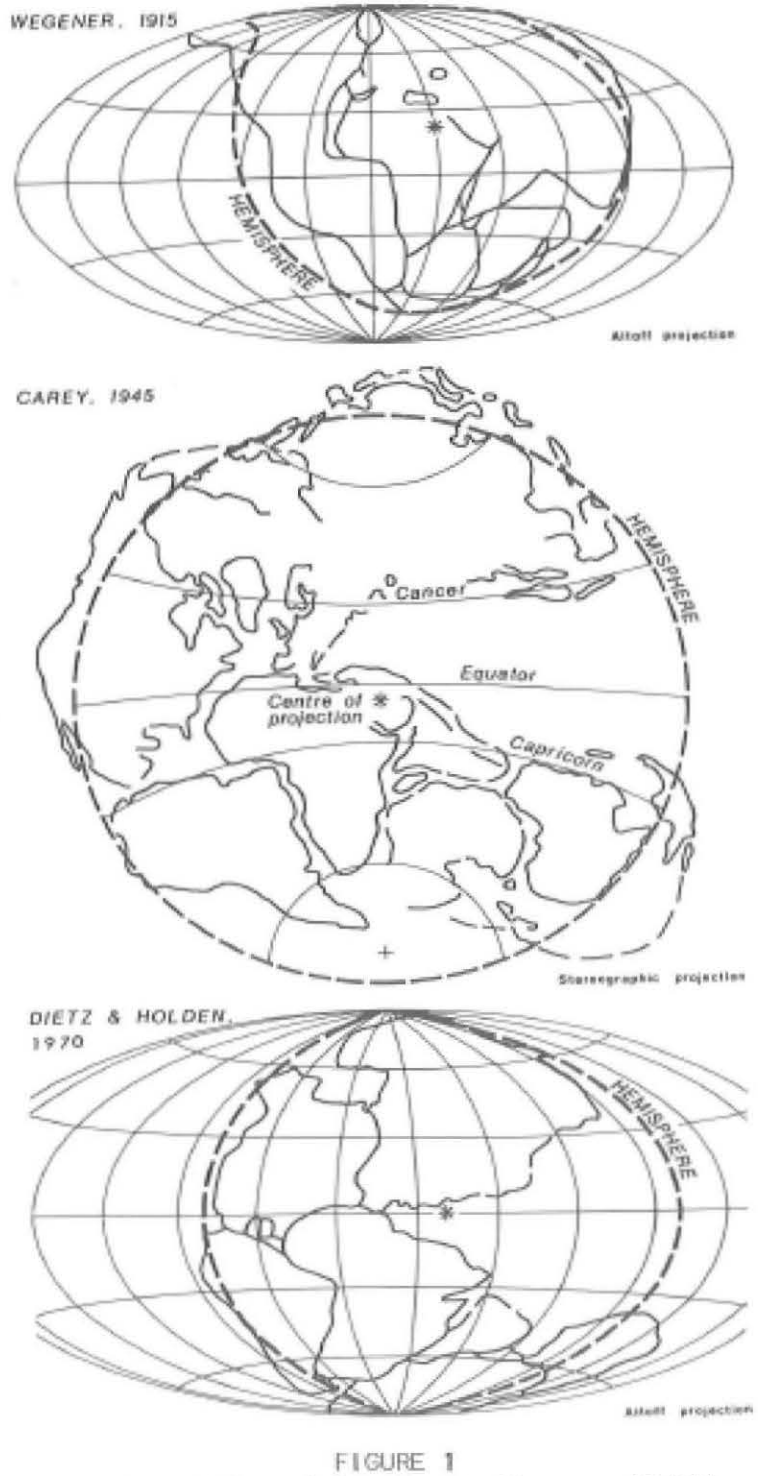

FIGURE 1
Assemblies of Pangaea by Wegener (1951), Carey (1945), and Dietz & Holden (1970, assuming that Earth-radius has not changed.

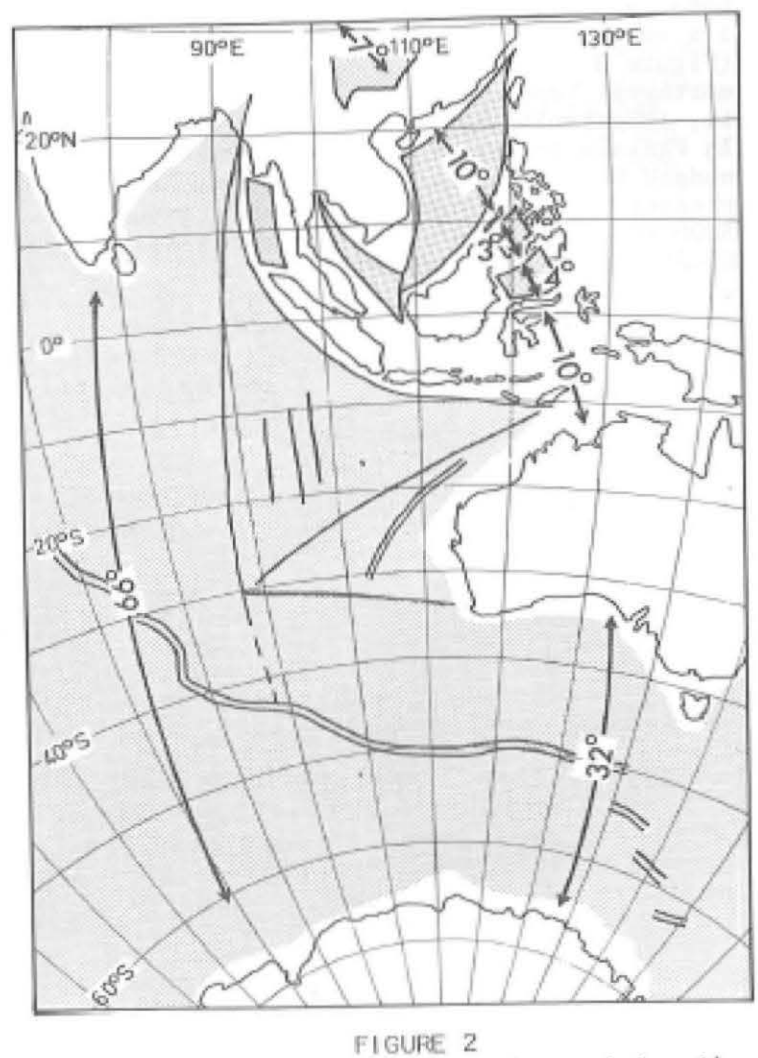

FIGURE 2
Distributed extension between Antarctica through Australia & China equals the single separation between Antarctica and India.

ly reduced in area to approach zero. But the Pacific, including its newly-opened marginal seas, is still not much less than a hemisphere. This is impossible unless the Earth has greatly expanded! This paradox cannot be relieved by adding that gaping sector into the Pacific, claiming that it has been closed by subduction, because on the present globe the distance between continental Australia and continental China is still 47° (about what it was on the plate reconstruction), and if you insist on including the contorted Indonesian arcs and measure only the ocean-type floors between Australia and Asia, these add up to 34° (Figure 2). Another check is to measure the amount of new ocean crust which has appeared between Antarctica and Asia, which is 66° whether measured via the Indian Ocean or via Australia and Indonesia to China.

THE PACIFIC PERIMETER PARADOX

The Pacific is a roughly circular ocean - the more so when we remove the Tethyan shear which displaced all the southern blocks east with respect to the northern blocks (see pp. in this volume). Each of the continents which rim the Pacific has moved away from its neighbours during the dispersion of Pangaea (Figure 3). In Pangaea central Mexico abutted northwest Venezuela, but is now 2500 km from it, lengthening the Pacific rim by this amount. In Pangaea Antarctica wrapped around Africa and nudged Madagascar, and the movement of its present position lengthened the Pacific rim by 3200 km. In Pangaea Antarctica fitted into the Great Australian Bight; dispersion to the present configuration lengthened the Pacific rim by 3500 km. Elimination of the gaping sector artefact between Australia and China described above means that this part of the Pacific rim has been extended by 3800 km. Altogether the Pacific rim has increased by a little more than one third, which means that the area of the Pacific has doubled, when according to the plate tectonic theory the area of the Pacific should have halved through reduction by the combined area of the Arctic, Atlantic, Indian and Southern Oceans. This is absurd unless the surface of the Earth has greatly expanded.

It is fatuous for Dooley (this volume) to argue in circles on azimuthal equidistant projections (or other projections) in an effort to escape Meservey's argument. The perimeter of Dooley's projection (the largest circle of all) is in fact a point! Using a globe the constant-radius model required Pangaea (including the sector gape) to be very close to a *great-circle* (Figure 1) and the complementary EoPacific to be the other quasi-hemisphere. During the dispersion, the continental blocks which form the bordering rim have changed little but they have separated from each other enlarging the rim by about 35% - implying a *great-circle* increasing by 35%, which is impossible. In the expansion model Pangaea with the same area as at present occupied much more than a hemisphere of the smaller radius Earth, the EoPacific being very much less than a hemisphere. Since then all the continents of Pangaea have dispersed, the Pacific has also increased in area in about the same proportion, so that its rim has increased towards a great-circle on the present-radius Earth.

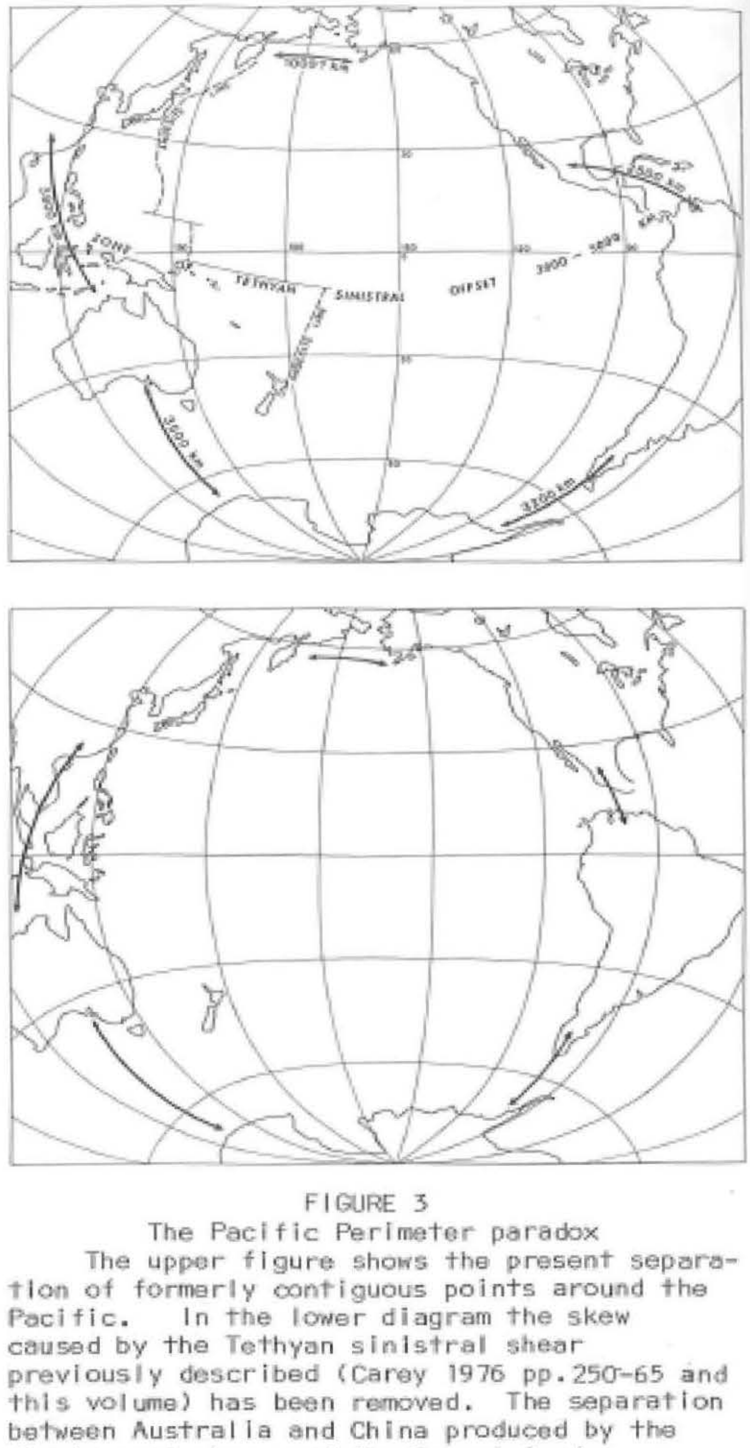

FIGURE 3

The Pacific Perimeter paradox

The upper figure shows the present separation of formerly contiguous points around the Pacific. In the lower diagram the skew caused by the Tethyan sinistral shear previously described (Carey 1976 pp.250-65 and this volume) has been removed. The separation between Australia and China produced by the Ninety-east shear and the Bengal-Sunda coupled oroclines previously described (Carey 1976 pp.406-11 and this volume) extended the Pacific perimeter there by 3700 km. The perimeter of the Pacific has increased by a little more than one third.

THE ARCTIC PARADOX

Tropical fossils and palaeomagnetic data prove that the Permian equator crossed Texas and New York. The present equator crosses Brazil. Hence North America is now some 35° nearer the north pole than it was in the Permian Similarly European fossil and palaeomagnetic evidence indicate that the Permian equator was a few degrees south of France. The present equator is in central Africa. Hence Europe is now some 40° nearer the north pole than it was during the Permian. Likewise Siberia is about 20° nearer the north pole than its Permian position. So since the Permian the continents have converged from three sides on the Arctic, which consequently should have contracted by some 5000 km. Did it? Just the opposite. During all that time the Arctic has been extending region, opening the Arctic Ocean. This is impossible except on an expanding Earth. Data from the Triassic, Jurassic, and Cretaceous periods all *independently* give the same conclusion, but in progressively diminishing degree, indicating that the expansion has been progressive.

FIGURE 4

Overshoot of regional Quaternary poles beyond the mean Quaternary pole (after Wilson, 1970). Open circles are the centroids of sampling sites, and the filled circles are the corresponding calculated poles.

PARADOX OF PALAEOPOLE OVERSHOOT

Palaeomagnetic inclinations averaged over thousands of years reproduce the contemporary rotation pole. Wilson (1970) and Watkins (1972) found that the Quaternary palaeopole so determined for any region was a little further away than the mean palaeopole determined from all of them (Figure 4). This is precisely what the expansion model predicts, because the geocentric angle corresponding to a surface kilometre gets progressively smaller as the Earth expands. Wilson & McElhinny (1975) also found that this palaeopole overshoot increases with age (Figure 5), which again is the prediction of a progressively expanding Earth. Palaeomagneticians, wedded to their constant-radius creed, seek to explain these anomalies by invoking *ad hoc* departure from their central dipole model, whereas these overshoots really only bring right up to the present day the Arctic paradox just described for the Permian and Mesozoic. On Figure 5 the Permian overshoot would be about 25° compared with 6° for the Neogene, 3½° for the Pliocene, and 1½° for the Pleistocene. These figures agree with all other empiricisms that the expansion rate has accelerated with time. Scrutiny of such data globally shows that the overshoots also record the expansion asymmetry (Tethyan shear and the greater expansion of the southern hemisphere — see Carey, 1976, p.216-218). Where subsequent extension has occurred between the palaeomagnetic site and the palaeopole, appropriate corrections have to be made.

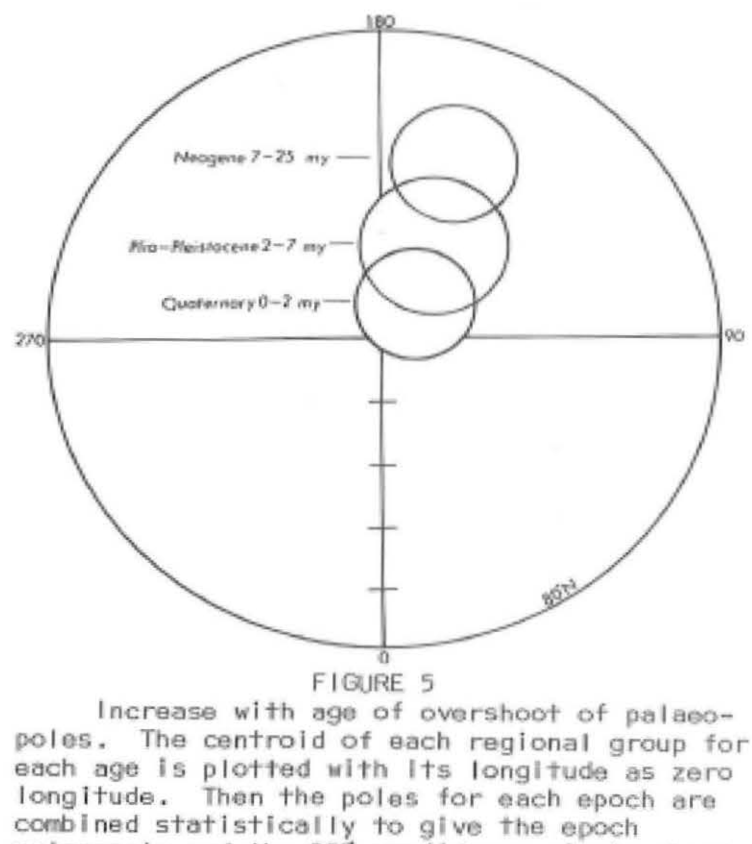

FIGURE 5

Increase with age of overshoot of palaeopoles. The centroid of each regional group for each age is plotted with its longitude as zero longitude. Then the poles for each epoch are combined statistically to give the epoch palaeopole and the 95% confidence circle shown (After Wilson and McElhinny, 1974).

THE INDIA PARADOX

India has close faunal and palaeogeographic ties with Australia, Antarctica, Madagascar, East Africa, Arabia, and also with Iran, Afghanistan, Kazakhstan and Tibet (for references see Carey, 1976, p.435 *et seq.*). Authors variously hold some of these, and sacrifice others. None can satisfy them all on constant-radius assemblies. King (1973, p.855) partly solved the problem by detaching Iran and Afghanistan from Laurasia and holding them against India and East Africa south of the wide Tethys. But this could not satisfy Meyerhoff & Meyerhoff (1972, pp.294-300) who insist that India has never been far from China and Russia. To quote them: "India has been part of Asia since Proterozoic or earlier time. This is a geologic fact, which nothing can change." Enigmatically India's bonds to Africa, Madagascar, Antarctica, and Australia are just as unbreakable. Crawford (1974) tried to solve the enigma in a similar way to King (above) by detaching Tibet and south China from Laurasia and place them between India and Australia in Gondwanaland. Johnston (this volume) found it necessary to ferry Timor back and forth across the alleged Tethyan gape to satisfy the alternating proximity demands of Asia and Australia.* Although palaeogeography required Malaysia to have been closely tied to Gondwanaland, McElhinny *et al.* (1974) concluded from their palaeomagnetic data that Malaysia could not have been part of Gondwanaland. What they should have concluded from their data was that Malaysia could not have been part of Gondwanaland if the present Earth-radius be assumed for the past.

The India paradox resolves into one of total surface area. It is impossible to satisfy the valid proximity demands of one insistent neighbour without leaving wide blank spaces between India and others whose proximity demands are equally compelling. On a smaller Earth the unwanted space vanishes (by the elision of younger oceanic crust) and all proximity demands are satisfied.

* A recent report (Nature 206, p.556) requires New Guinea to shuttle also!

FIGURE 6
Lithosphere first-order blocks surrounded by circum-continental spreading diapirs, represent the primary rupture of the whole mantle right down to the fluid core (compare Figure 10).

THE AFRICA PARADOX

Like all continents, Africa is surrounded by its ocean-floor-spreading rift zone, shaped like an inflated caricature of Africa, more than twice its own area (Figure 6). New crust, youngest at the rift, ages from Quaternary through Tertiary and Cretaceous. Somewhere within Africa plate theory demands a sink which has swallowed an area of crust lithosphere greater than the whole of Africa. Where is it? Such just does not exist! On the contrary, between the Atlantic and Indian Ocean ridges is the great rift valley system of latitudinal extension, itself a nascent spreading ridge.

To escape this dilemma plate advocates opt for a worse contradiction, by transferring Africa's subduction problem to the Pacific trenches and to Antarctica. The Peru-Chile trench then has to swallow more than 1600 km of Africa's share, plus more than 1400 km of South America's share, plus 3700 km from the south Pacific, making a total of 7000 km of lithosphere underthrust below the Andes, mostly during the 50 Ma since the Palaeocene. This underthrust has to outcrop in a trench where the sedimentation during that time shows no disturbance (Figure 7), below the Andes which shows extensional epeirogenesis throughout that

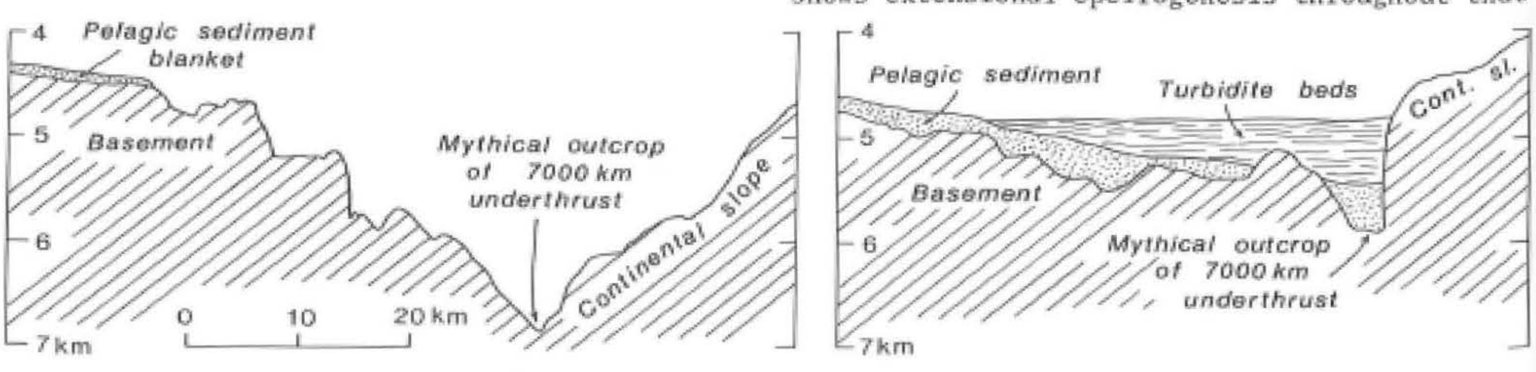

FIGURE 7
Some sections of the Peru-Chile Trench are empty (e.g. at 28°S, left above), others are filled with undisturbed Tertiary sediments (e.g. at 37°S, right above), where, according to the subduction hypothesis, the 7000 km underthrust crops out. V/H is 7/1. (After Scholl *et al.*, 1968).

time (Katz, 1971), and there is a total absence of the accumulated scrapings of 7000 km of oceanic sediments, either in the trench (some of it is empty!) or onshore. Is this really credible?

The Kermadec trench (which would have to swallow 6000 km of oceanic lithosphere between Africa and Australia, plus 2000 km of Australia's allotment in the Tasman Sea, plus 5000 km from the East Pacific rise back to the trench) would have had to subduct 13000 km of lithosphere (one third of the circumference of the Earth) since the Jurassic, most of it since the Palaeocene! Where are the 13000 km of oceanic sediment scrapings? With no associated continent to hide them under, even that evasion is denied (Scholl & Vallier, this volume). Where are the colossal andesitic volcanoes in the tiny Kermadec Islands resulting from the processing of so much lithosphere? Is this really credible?

If Africa has a dilemma, worse befalls Antarctica (Figure 8), also surrounded by its own peripheral growth which doubles its area, plus stationary Africa's southern growth between the Atlantic and Indian triple points, all of which, according to subduction theory, had to be swallowed during the last hundred Ma *within Antarctica*, where no sign of such a subduction candidate exists. The only trench in the vicinity is the small South Sandwich trench, which is at right angles to the Antarctic growth, and in any case its function according to plate theory is to subduct South Atlantic crust east to Bouvet Island.

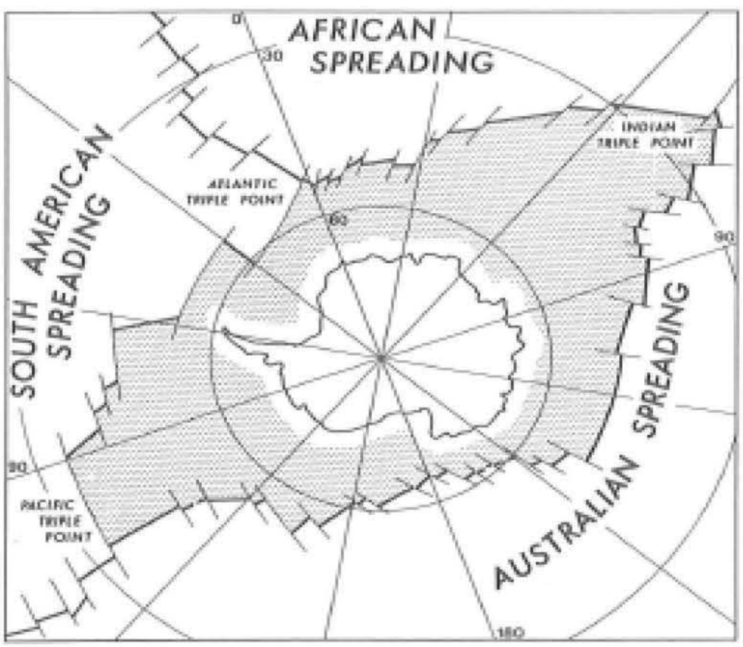

FIGURE 8

Circum-Antarctica spreading diapirs completely surround Antarctica, with no subduction zone to swallow the new lithosphere growth (stippled).

Surely the subduction model has to be abandoned!

MYTHICAL ANCIENT OCEANS

All agree that the floors of all existing oceans are very young, mostly less than 10 Ma old. None is as old as 200 Ma and even that is less than 5% of the Earth's age. Coverage is now complete enough to know that no Palaeozoic ocean crust exists anywhere. Where are the old oceans? Glickson (this volume) concluded that they never existed. Crook (this volume) points to the absence of oceanic-type sedimentation and facies generally before the Palaeozoic, which he adds could be explained by the absence of oceanic environments. Scholl & Vallier (this volume) report a total absence of the oceanic sediments which should have accumulated in vast volumes in the marginal orogens if ancient oceans had been subducted. Embleton, Schmist & Fisher (this volume) found to their great surprise that Proterozoic polar-wander paths indicate that continents then had the same relative radial positions from the centre of the Earth as they have now. In other words, the oceans have not been opened through the continents sliding apart horizontally, but the continents have moved straight out radially, with new oceanic crust progressively inserted between them. Indeed this is just what Vogel found when he fitted the continents together on a small globe inside a transparent outer globe of the present Earth (this volume). As he progressively eliminated the oceans, the continents converged as they went back in along the radius, and fitted together on a globe little more than half the size, enclosing it completely.

Neither the great Mesozoic ocean postulated between India and Asia, nor the great Palaeozoic ocean postulated between the Appalachians and the American maritime piedmont ever existed, as demonstrated previously in this volume. In the next section it will also be argued that the several wide oceans invoked to explain Palaeozoic faunal provinces never existed either.

All this convinced me that the great oceans as we now know them belong only to the latest stages of Earth evolution. By contrast, plate theory assumes that there were always great oceans just as now, and that they have all been subducted. Two-thirds of the Earth's surface subducted under the continental one-third in less than 5% of geological time! And with such regional precision that no fragment of any of the older oceanic crust survived anywhere! Is this really credible?

FAUNAL PROVINCIALISM

From the beginning faunal disjuncts have been extensively cited in evidence for former contiguity of regions now separated by ocean.

More recently incompatible faunal appositions have been cited as evidence of the subduction of a former ocean. Burrett in particular (this volume and earlier papers there cited) has sought increasing accuracy in specific identifications, combined with careful statisitical analysis of his data, to test the expansion model, specifically in the Early Palaeozoic. Rather than a coherent Pangaea he has identified a large number of minor continents which unite and separate like permutations of a barn dance, consistent with plate tectonics but inconsistent with Earth expansion.

The fallacy in his conclusion lies not in Burrett's method, but in his concept of the Earth before expansion, in which he expects free faunal interchange, with the major barriers to migration in other than wide oceans, being geographically oscillating isotherms cutting obliquely across mobile belts.

The Early Proterozoic lithosphere resembled a soccer football, broad stable epeiric basins separated by seams and welts where internal pressures strove to extrude, causing seismicity, high heat flux, vulcanism and rifts; some such welts were little more than narrow plateau swells between adjacent basins, some were like rift valleys, perhaps some more like the Red Sea, with thick eugeosynclinal sedimentation, later to be extruded as nappes over the miogeosynclinal flanks as the granitized core rose beneath them (Figure 9). The waters of some epeiric basins interconnected via through-going active rifts, others remained isolated, and hence suffered wide strand fluctuation caused by climatic cycles, with strongly rhythmic sedimentaion (characteristic of the banded-iron formations and associated sediments) and intermittent precipitation of gypsum and halite crystals, and rank growth of stromatolites. The universal occurrence of stromatolites in Proterozoic rocks of suitable facies has been taken by many to imply a universal Proterozoic ocean between the continents. However the panglobal distribution of stromatolites, which the Russians have developed for stratigraphic correlation, was windborne. Whenever a shore of an interior basin retreated through increasing desiccation, the cyanophytes and bacteria, which constitute stromatolites, became encysted and could be wind-borne many times around the world until they settled again in a suitable environment to seed a new colony. Dr M.R. Walter, the well-known authority on stromatolites has told me of "a famous example of this: an eminent taxonomist, F. Drouet, once re-examined a cyanophyte specimen that had been stored in a dessicated mount in a herbarium for eighty years. He added water, and within a few days the cyanophyte had become green and started growing again." Dr Walter continued: "Cyanophyte species, known only from hypersaline environments occur thousands of kilometres apart, e.g. in Shark Bay (Western Australia) and on the sabkhas of the Persian Gulf. That is, species have disjunct distributions, indicating their ability to survive long distance transport." The Ediacaran fauna (mainly cnidarians, like modern jellyfish and sea-pens), which is now known to have had a global range before the Cambrian, would also have been distributed encysted by the wind.

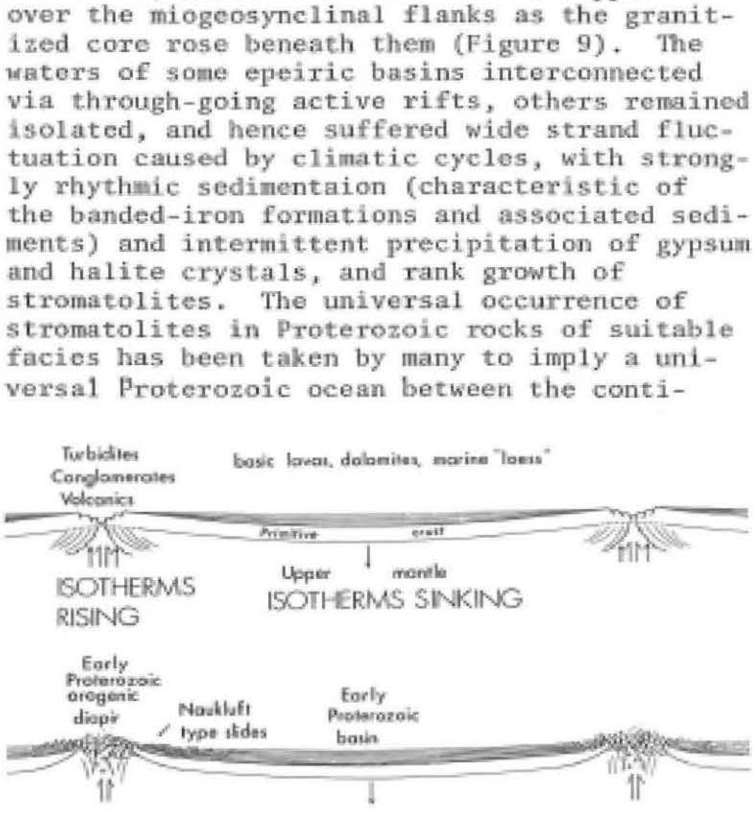

FIGURE 9

Early Proterozoic passive basins bordered by active diapiric swells or rifts. In later orogenic diapirs at continental-oceanic lithosphere boundaries, this initial asymmetry continues and intensifies.

During the late Proterozoic a through-going equatorial rift, beginning like the great equatorial rift zone of Mars (Figure 15), had widened to form the EoPacific. By the early Palaeozoic, this Pacific rift had turned 60° to the equator, and a new equatorial rift zone developed, to form the Caledonian-Appalachian-Tasman geosynclinal belt. Many of the epeiric basins connected directly with the EoPacific (Cordilleran) or Caledonian rift, or to forks from them. But strong endemism of faunas was characteristic of the epeiric seas. The seaway connection between two such basins, adjacent through several epochs, might be very long and ecologically disparate.

Burrett's findings "that the Early Palaeozoic faunas are strongly provincial" and that "the imprisonment of faunas in individual cratons or small groups of cratonic blocks continued" through the whole of the Lower Palaeozoic, accords precisely with my expectations of the expansion model.

CONTINENTAL GRAVITY ANOMALIES

Dooley (1973, 1974, and this volume) has sought to deny Earth expansion on arguments from continental gravity anomalies. He assumes a model of a continental cap whose curvature must reduce as the Earth expands. Of course this would apply to every part of the Earth's surface, not just continents. The northwest Pacific, for example, an area three times the area of Australia (bounded on the west by the Mariana arc, east on 10°S to 180°, thence northwest to the Kuriles) with a lithosphere surely as strong as Australia's, has been stable for the last hundred million years when the most rapid expansion has occurred.

Dooley's premise is the *ex cathedra* statement that "a continent, which does not change appreciably in area, would tend to remain a domed cap of smaller radius of curvature than the Earth as a whole, and would have to sink and push outwards on its margins". Would it? What force would elevate any part of it *above* its gravity equilibrium level? Certainly not gravity, which Dooley agrees is the relevant operating force. In fact, no part ever rises above its contemporary equilibrium figure (except through some other cause). Indeed, no part goes into tangential compression (the whole surface is extending!). All points move radially outwards, always more or less in adjustment with the geodetic figure. Continents, and also oceanic lithosphere are patterned with polygonal basins and swells (Figure 10). The basins are passive; they are not caused by depression, but by lag in rising. The swells are active, with background seismicity, higher heat flux, and faulting, sometimes becoming rift valleys. They rise ahead of the lagging basins simply because higher temperature and general horizontal extension causes phase change to less dense paramorphs compared with similar levels below the passive belts. Figure 11 shows schematically great reduction in convexity without change in area, and without ever forming a domed cap. Each of these second-order polygons undergoes further adjustment on higher-order fractures (Carey, 1976, pp.42-46) until a limit is reached where loads are sustained. Even the first-order polygons

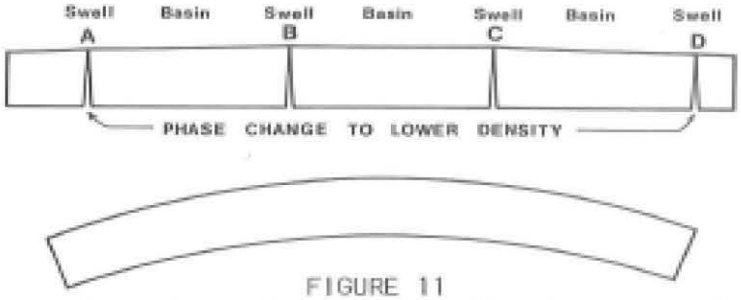

FIGURE 11
Reduction of convexity without increase in area does not imply residual doming.

(Figure 6) tend towards a gross basin-and-rim pattern, for example the Amazon basin with drainage inwards away from the Atlantic rift coast, Australia's great Artesian Basin also with drainage inwards from its rift coast, and others.

This is to be expected when the time scale of curvature adjustments are considered. Estimates of sub-crustal notional viscosities range from 10^{21} to 10^{23} poises, which imply a relaxation time of 10^{10} to 10^{12} seconds, which means that stress differences would be expected to relax to $^1/e$ in less than 5000 years, to $^1/e^2$ in 10,000 years, and $^1/e^3$ in 20,000 years, so stress difference would relax to less than one-hundredth in 25,000 years. This is in accord with empirical experience of the post-glacial uplift of Fennoscandia and Hudsons Bay, the uplift of Lake Bonneville, and experience generally. These movements are fifty times as fast as required for curvature adjustment to expansion. Hence adjustment would be virtually complete within 100,000 years, so far as other rheological thresholds permit.

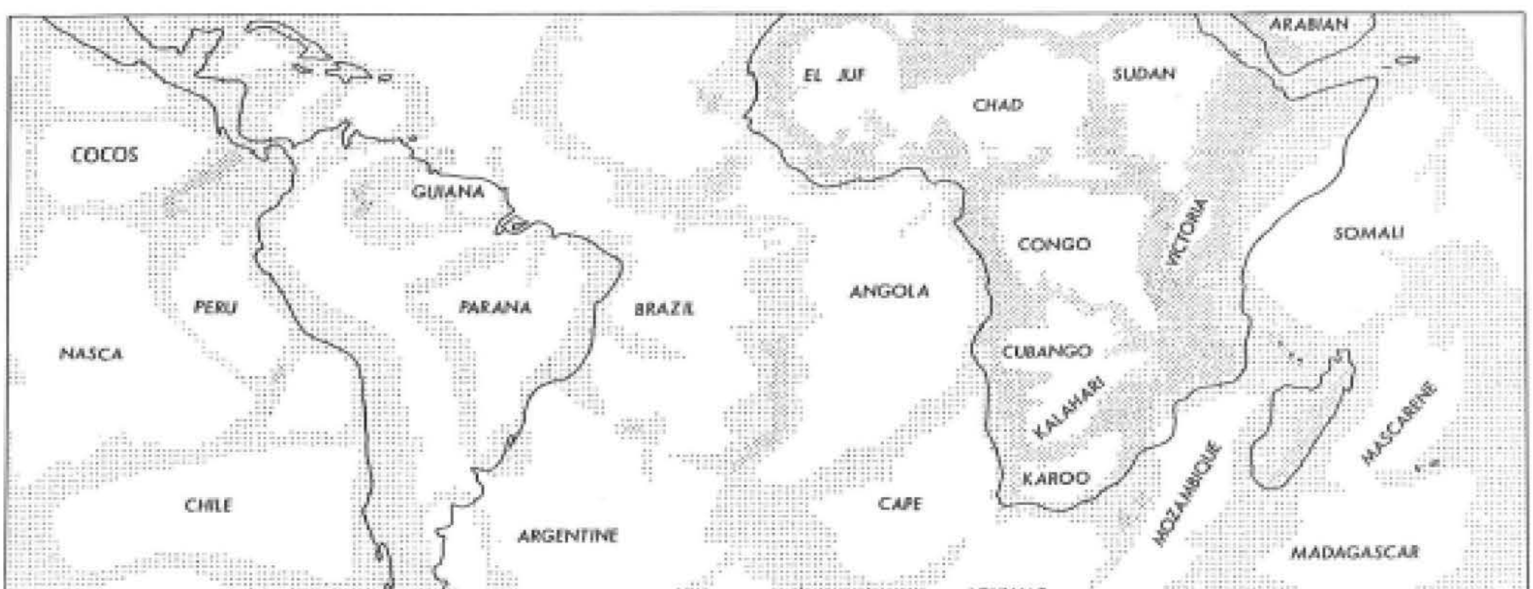

FIGURE 10
The basin-and-swell pattern develops throughout continental and oceanic lithosphere equally, and represents second-order adjustment down to the asthenosphere. Compare Figure 6.

What then is the origin of the gravity anomalies cited by Dooley, which he says are centred on the "continental cap"? In the first place his negative anomalies are not centred on the continents! In Dooley's Australian example the negative anomaly is the flank of a deep sigmoidal trough in the geoid (Figure 12), the axis of which runs from near the north pole through Siberia and India, and south and southeast through the Indian Ocean towards Macquarie Island. At its deepest point just south of Ceylon it is more than one hundred metres below the mean. A similar trough not quite so intense runs from the Arctic north of Alaska southeastwards across Labrador to its deepest point in the Bahamas where it is fifty metres below the mean, then across the northeast tip of Brazil to the South Sandwich Islands. These depressions in the geoid ignore continents and oceans, not correlating with either, and clearly have their origin in the mantle.

It is naive to assume that broad negative anomalies indicate areas standing below their equilibrium. A free-air gravity anomaly is the difference between the observed gravity (corrected to sea-level by ignoring the mass above sea-level) and a theoretical value of gravity at that latitude for an assumed figure of the Earth. The best theoretical figure is a uniaxial spheroid adjusted to leave the least statistical residuals for each latitude, but commonly the mid-latitude correction is ignored, and the best-fit uniaxial ellipsoid is used. (Some figures allow some equatorial ellipticity, or even for the slight north-south asymmetry, but these are rarely used, nor would they be relevant in the present context.) The figure does not allow for continents and oceans, so one would expect some systematic anomaly with respect to each. In an isostatically balanced Earth (as distinct from hydrostatically balanced) such anomalies would reflect the deficiencies of the reference figure, not regions standing higher or lower than equilibrium.

Apart from such artefactual anomalies, there are a variety of other possible causes of anomalies correlation with continents.

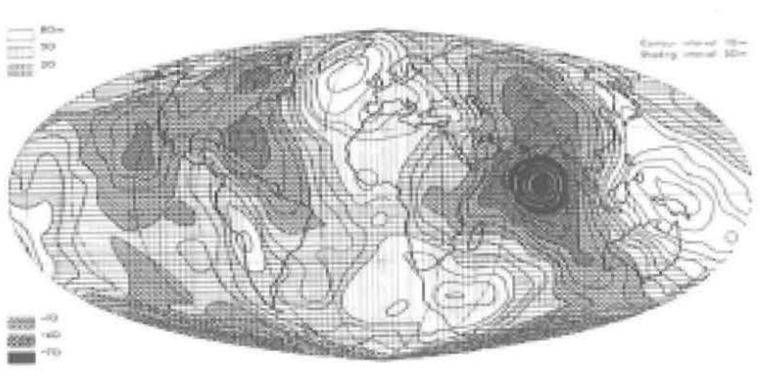

FIGURE 12
The Geord (after Rapp, 1974).

In the expansion model (and this is the model Dooley discusses) continents remain on the same underlying mantle throughout geological time (and do not slide over the mantle as in the plate-tectonics model). Hence one would expect *a priori* differences in the mantle column below continents and below oceans, right down to the core. Gravity anomalies over tens of degrees (or thousands of kilometres) certainly reflect the mantle, which is only 3000 km thick. Density differences in the mantle are not allowed for in the reference figure and would produce anomalies not implying departure from equilibrium. Abundant evidence exists for such mantle differences. For example, the heat flux through the continents is not significantly different from that through the oceans. As the continental lithosphere rocks average about ten times the radiogenic heat generation of oceanic lithosphere rocks, clearly the sub-continental mantle cannot be the same as sub-oceanic mantle.

Again, when a continent rifts and separates, mantle rises between by about thirty kilometres. If this happended instantaneously, all the isotherms would be raised by this amount, and level for level, temperatures would be several hundred degrees hotter far down into the mantle. It doesn't happen instantaneously, but rather the rising mantle process goes on continuously as the ocean widens. But the relaxation time for the excess heat is geologically long. This contributes to the anomalous equality of continental and oceanic heat flux mentioned above. The elevated temperature at any given level implies that phase changes would be shifted towards the lower density forms throughout the column. This would be reflected in gravity anomalies, because the reference figure assumes uniform densities at each level.

Hence if all stresses were relaxed to give ideal isostasy, the centres of continents would not necessarily rise as Dooley suggests. They may be in equilibrium regionally. For this reason ocean floors steadily sink as the excess heat below them gradually dissipates, and newly-formed ocean floors are two kilometres shoaler than those several tens of million years older, below which mantle rocks have already reverted to their denser paramorphs.

Dynamic equilibrium is also a probable contributor. Water in a bath-tub has a level surface. When the plug is pulled, a depression forms above the outlet. The mass of water to fill this depression equals the sum of the vertical components of the viscous drag of the descending water. If the water level is maintained, the depression is sustained in dynamic equilibrium. If any circulation occurs in the mantle, regions of upward flow would elevate the geoid and those of downward flow would depress the geoid. Because the reference spheroid takes no account of such differences of elevation, they would show as gravity anomalies, even though they be in dynamic equilibrium while the flow continues. Those who propose mantle circulation place their downward flow below the continents. Even if the only flow were upward to fill the opening rifts, the mean figure would be below the rising mantle areas and above the stable continents, which would record negative anomalies, even though they were in equilbrium.

Dooley's "simple physical test of Earth expansion" began with an impossible premise, and was invalid even if that premise were allowed.

PALAEOGRAVITY

Expansion from half the present radius has been criticised because the implied surface gravity *g* would have been four times its present value. Stewart (1978, 1979, and this volume) has set limits to palaeogravity which deny this. But this argument assumes the mass of the Earth to have been constant.

Theories of Earth expansion fall into four categories:

1. Lindemann (1927), Halm (1935), Keindl (1940), Egyed (1956, 1957), Kremp (this volume), and Pfeufer (this volume) assume constant mass, and a superdense metastable inner core which has changed in phase with time to matter of "normal" density.

2. Shields (this volume), Dachille (this volume), and others regard meteoritic accretion as significant.

3. Dirac (1937), Jordan (1955, 1964), Ivanenko & Sagitov (1961), Dicke (1962), Dearnley (1965a, 1965b, 1966), Glasshof (1966), and Wesson (1973), who assume constant mass and declining gravitational constant *G*.

4. Yarkovskii (1899), Hilgenberg (1933, 1965), Kort (1949), Kirillov (1958), Neiman (1962 and this volume), Blinov (1973, 1977a, 1977b and this volume), Wesson (1968, 1978), and myself (1976, 1978, and this volume) who propose that the cause of expansion is cosmological, and that the mass of the Earth has increased with time. This group does not deny the possibility of contributing phase change or declining *G*, but regard increasing mass as the principal cause.

Stewart's criticism is valid for the phase-change theories and for those depending on diminishing gravitational constant but not for the third group who assume increasing mass from cosmological causes.

VOLUME OF OCEAN WATER

Bailey & Stewart (this volume) have pointed out that with elimination of all oceans so that the continents completely enclosed a smaller Earth, all continents would be drowned under 8 km of water. In my model (Carey, 1976, p.121 *et seq.*) the whole of the present atmosphere and hydrosphere have been outgassed from the interior at an increasing rate during geological time. However Bailey & Stewart regard this as highly improbable because, they claim, the main source of oceanic gases is through calc-alkaline magmatism, and in any case the need is not just water but brines.

I suggest that in this budget the contribution from calc-alkaline vulcanism can be ignored as of minor importance. In the expansion it is the whole column of atmosphere, hydrosphere, oceanic lithosphere and underlying mantle which has been added at an accelerating rate through geological time, the volatile accretion must be primarily at the growing ridges and rift zones. The fluids emerging through the floor of the Sea of Galilee in the Dead Sea rift and the Red Sea rifts are brines. Bromine, mentioned by Bailey & Stewart as a problem is a product of the Dead Sea which oversaturates the world market. The widespread albitization of rift basalts does not suggest any lack of sodium.

As the ocean waters and the ocean floors both have the same origin it is to be expected that they should be produced *pari passu*, with the volume of ocean water keeping step with the growth of ocean crust.

THE PALAEOMAGNETIC SMOKE-SCREEN

Palaeomagnetism has been the most useful tool discovered this century for the elucidation of the evolution of the Earth. It rests on the assumptions that the geomagnetic field has been an axial dipole since quite early times, and that the tens-of-degrees movements of the magnetic pole over thousands of years statistically reproduce the rotation pole of the time. The palimpsest problem of overprinting by strong but unstable magnetizations has been largely overcome, but too-young age assignments through remagnetizations during recrystallization can still mislead.

However, despite its great achievements, palaeomagnetism remains a blunt tool, incapable of sharp angular precision within a few degrees. It is excellent for proving rotation of blocks relative to adjacent blocks (see Table I), for large latitude changes (see the Arctic paradox), for large latitude shifts oblique to latitude lines (see the Caledonian shear), and for testing claims for opening and closing of oceans (see the EoAtlantic myth) except where the alledged movement is mainly latitudinal.

All these successes involve relatively large angular differences of latitude or azimuth, and palaeomagnetism otherwise remains a relatively blunt tool. Unfortunately some inbred priests of palaeomagnetism apply it below its threshold of sensitivity to measure palaeoradius by statistical scatter, and claim *ex cathedra* to prove thereby that the Earth has not expanded.

Egyed (1960) proposed two methods to measure palaeoradius, the common-meridian and the minimum-scatter methods, which, although theoretically sound, fail through the imprecision of the data, and the crucial departure from reality of the models.

Two hundred years before Christ, Eratosthenes measured the radius of the Earth by observing that the noon summer solstice Sun was reflected back up a well at Syrene as it passed directly overhead, whereas a tower at Alexandria cast a shadow slanting 7½°. As 7½° is one-fiftieth of the 360° circumference, the distance from Syrene to Alexandria (measured by camel travel time at 5000 stadia) must be one-fiftieth of the Earth circumference. Hence the radius of the Earth must be $25/2\pi \times 10^4$ stadia, or 46,250 km in modern measure, which is within 15% of the correct value, or closer than 1% if an alternative meaning of stadion is adopted.

Egyed's common-meridian method is identical: the difference of palaeolatitude of two sites, with rocks of the same age, on the same great circle (the palaeomeridian), gives a fraction of the palaeocircumference. Cox & Doell (1961) applied Erastosthenes' method to Permian sites in Europe and Siberia more than 60° apart, and found that the angular difference in palaeolatitude was not significantly different from the present angular great-circle difference between the sites, and hence concluded that the Earth could not have expanded significantly since the Permian. However, this conclusion was invalid, because it is known that the lithosphere between the European and Siberian sites has extended by about 10° by the opening of the West Siberian sphenochasm (see Carey, 1958, pp.203-204, and 1976, pp.185-190). This means that this segment of the meridian has increased by about one-sixth since the Permian, which is about the expansion I had previously suggested since the Permian. Far from denying expansion, Cox & Doell had virtually proved it, as 10° exceeds the bluntness of the palaeomagnetic probe.

More recently Schmidt & Clark (1980) have returned to the common-meridian method and re-affirmed its theoretical validity (which no-one had disputed). The difficulty has been to find sites of the same age, on one palaeomeridian, within an unbroken block which has not been extended, and far enough apart to be beyond the angular uncertainty of the palaeomagnetic method. This combination of restraints has not been met. Even with the sites as much as 30° apart in palaeolatitude on a coherent block on the same palaeomeridian (if such could be found) the difference caused by expansion is only of the same order as the statistical uncertainty of palaeolatitude. Unbroken segments greater than 30° are unlikely anywhere, because that is the thickness of the mantle which determines the scale of fragmentation.

The minimum-scatter method determines the pole position implied by each pair of sites of the same age on a single block, and seeks the minimum scatter of such poles with successive assumptions of palaeoradius. As the present radius gives the lowest minimum scatter, significant expansion has not occurred, or so they claim.

The distance to the palaeopole depends on the angle of convergence of the palaeomeridians of the two sites. The first problem is how does this angle change as the surface adjusts to the flattening convexity. Ward (1963), who first used this method, adopted the orthocentre of the sites as his centre for a notional azimuthal equidistant projection of all sites, and assumed that the errors in angles whereby introduced would not be great. Van Hilten (1967) showed with trials that the result was very sensitive to the choice of projection centre, and preferred to adopt the orthocentre of the continent as projection centre, but he did not thereby escape the errors. Both assumed that radial rifts would have to occur in the continent as the surface convexity flattened. (This in fact is not the way the continent or ocean lithosphere adjusts.)

Unfortunately the computer programme adopted to process the data is biassed in favour of pairs of sites furthest out. This is necessary because with sites only a few degrees apart the statistical errors swamp the convergence angles to the poles and produce a wide scatter. But the wider pairs are those in which the errors intrinsic to the projection are greatest, so the minimum scatter procedure favours the largest artefactual errors.

Again, whereas the angles of a plane triangle add up to 180°, the angles of a triangle on a sphere add up to something between 180° and 540° according to the ratio of the size of the triangle to the radius of the sphere. Hence the angles between two meridians painted on the surface each pointing to the pole would get smaller as the Earth expands, and still point to the more distant pole, thus tending to continuously cancel the evidence that the Earth is expanding.

Map projections are arbitrary, whether drawn on paper or adopted notionally in a computer programme. Correct area can be held by sacrificing shape (that is angles); by sacrificing areas and distances, angles can be held locally (but not over large distances); angles from *one point* can be held globally conserving areas at the same time, but only by severely distorting angles from all other points, and without changing radius.

In *drawing* such maps, or using them notionally, there is freedom of choice. But in representing Earth expansion there is no choice but what the Earth actually did! Earth did her own thing! And her own thing did not follow any of these restraints for angles, shape, or area. The palaeomagneticians assume that continents behaved differently from oceans. But the whole lithosphere behaved the same way (Figure 10), except along the currently spreading ridges, thousands of kilometres apart. The lithosphere, continental and oceanic alike, adjusted similarly. So in addition to their errors of the geometrical artefacts, the minimum-scatter method ignores the billions of minute adjustments on regional ruptures and on smaller and smaller scales right down to ordinary joints. If each joint yielded only one-thousandth of a degree, the error could be 10° in a kilometre! As joints are inherently systematic in response to a pervasive stress field, they are of necessity additive. It recalls the popular puzzle of the vanishing square (Figure 13). Here are two rectangles, 12 squares by 5 squares. Triangle A is clearly the same as triangle A'; triangle B is clearly the same as B', 7 squares by 3; triangle C is the same as triangle C', 5 by 2. Block D is clearly the same as that block D', with 5 squares on top and 2 below; and block E, with 2 squares on top and 5 below is the same as block E'. Then where does square F come from? The answer is that triangle A is larger than triangle A' by the area of the black square. The tangent of angle θ is 2/5, which is not quite the same as the tangent of angle θ' which is 3/7. There are 12 extra tiny bits along the apparent hypoteneuse of A which add up to square F.

By ignoring billions of tiny adjustments along billions of joints, palaeomagneticians pretend to prove that the Earth has not expanded. They join George Gaylord Simpson, Harold Jeffreys, and Bailey Willis, three of the great men in their fields, who ridiculed continental drift on wrong reasoning, and their prestige delayed the acceptance of continental drift for a whole generation.

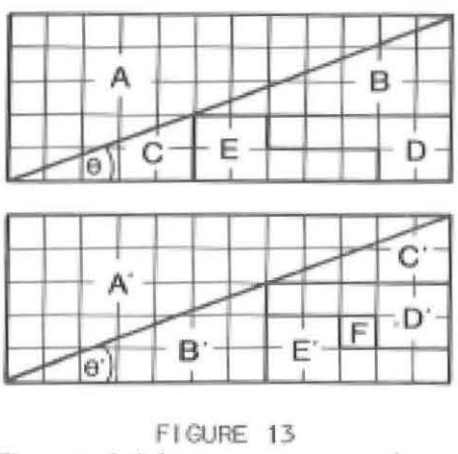

FIGURE 13
The vanishing square puzzle.

PULSED EXPANSION

Every facet of tectonic evolution indicates that the rate of expansion has increased exponentially with time. The Tertiary Period yielded twice as much new oceanic crust as the Mesozoic Era three times as long, the Palaeozoic accretion was much less again in still longer time, and Proterozoic expansion was minor in comparison. This exponential growth curve was pulsed, and with diminishing pulse interval. This pulsation is further modulated by higher frequency rhythms expressed by cyclic sea-level rise and fall (Vail *et al.*, 1977). The cause of the primary pulsation is presumed to lie in known physical thresholds of deformation behaviour.

As I interpret the record, such cycles may reduce or even suspend the rate of expansion, but do not reverse it. However, some authors, including particularly Steiner in Calgary and Milanovsky in Moscow, interpret the pulsations as compressional reversals interrupting the general expansion. For although they recognize expansion, they regard intermittent compression as necessary to explain folding generally, nappes, the Benioff zone, and blue schists. In contrast, I believe that every lineament of orogenesis is directly consequential on expansion and secondary adjustment to gravity equilibrium.

The pattern of expansion faithfully expressses the zonation of the Earth. Because the Earth consists of a crystalline mantle some 3000 km thick over a fluid core, the first result of expansion is the rupture of the whole mantle into polygonal blocks of about this size (Figure 6). If the mantle were thinner, the primary polygons would be correspondingly smaller. The boundaries of these blocks go right down to the core. Current expansion occurs mainly at the inter-block boundaries — 'blocks', not 'plates', because a plate is large in area compared with thickness, whereas these blocks are about as deep as they are wide.

Because the surface has to adjust to diminishing curvature, the lithosphere within each block breaks into second-order polygons (Figures 9 and 10) with passive basins separated by active rims. The size of these second-order polygons is determined by the next zonation of the Earth, the thickness of lithosphere down to the yielding asthenosphere, a few hundred kilometres. If the asthenosphere were shallower, these basin-and-swell polygons would be smaller. Further adjustment continues down through a hierarchy of fractures ultimately to ordinary joints (Carey, 1976, pp.42-46).

The orogenic belts are just as much part of the primary peri-continental expansion polygon system as the ocean-spreading ridges. Along both, asthenoliths rise right through the mantle (compare Figures 15 and 16). The essential difference between an orogenic belt and an oceanic spreading-ridge is the presence of large volumes of added terrigenous sediments in the one, but not in the other. Bereft of its crumpled sediment blanket, topographical and geophysical profiles of the Rocky Mountains are virtually indistinguishable from the profiles of the Mid-Atlantic Ridge (see Longwell & Flint, 1959, fig.2-4). The profiles of the African rifts, the Red Sea, and the Eauripik-New Guinea and Shatsky rises, illustrate differing degrees of development of the same diapiric process, where the increasing volume of the deep interior relieves itself by breaking through to the surface (see Holmes, 1965, fig.704; and Carey, 1976, fig.132). Where the East Pacific Ridge converges on the Coast Ranges of California and begins to receive voluminous sedimentary overburden, it merges and continues as an orogen. Where the median ridge of the northwest Indian Ocean continues up the Red Sea, it eventually becomes an integral part of the Mediterranean orogenic cyctem, which of course involves considerable north-south extension between Africa and Europe.

The initiation of primary stretching in continental crust leads first to "necking"

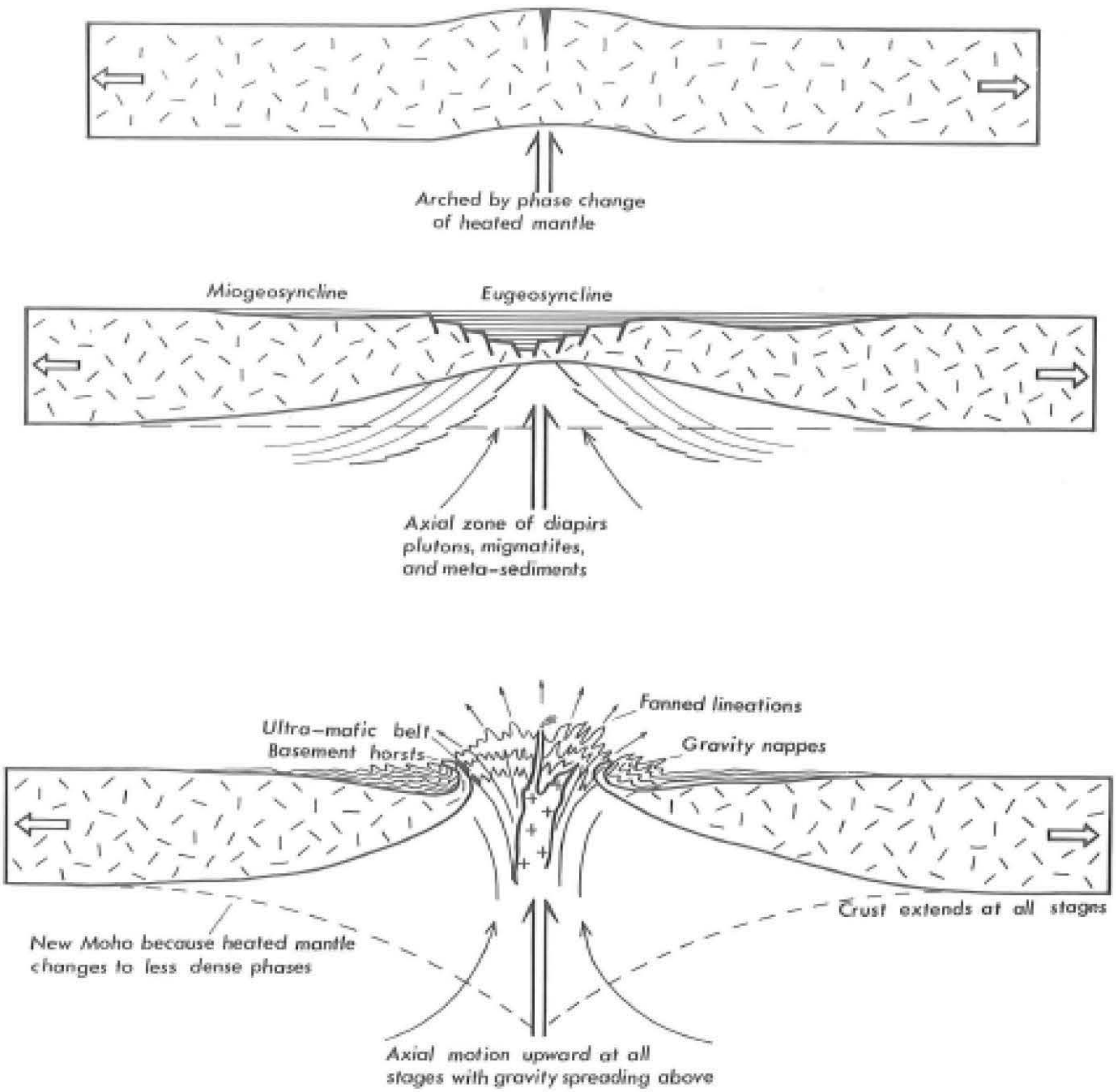

FIGURE 14
Extension and diapiric rise are continuous through the geosynclinal and orogenic cycles.

thinning of the continent with the surface of the "sial" and the bottom of the "sial" converging towards zero at some five kilometres below sea-level. Thus, although the surface of the "sial" steadily goes down, the bottom of the "sial" and the mantle diapir below it steadily rises, as it continues to do throughout orogenesis. By the time the "sial" has thinned to zero, the asthenolith has already risen some thirty kilometres. The continuing and accelerating ascent of the deep diapir then begins to drive out the new sediments, regurgitating the geosynclinal gut, which then spreads laterally at the surface (Figure 14). The lineations and thrust surfaces are all in the direction of the laminar flow, inner zones over-riding their flanking neighbours, most steeply near the centre, but becoming flatter and flatter outwards, as thinning nappes override the miogeosyncline.

TRULY GLOBAL TECTONICS

The median ridge *cum* subduction paradigm has led to myopic distortion of the gross tectonics of the Earth:

Benioff zones and trenches are circum-Pacific, which is the same as saying they are peri-Pangaean (here "Pangaea" includes the intra-Pangaean rift oceans).

Mid-ocean ridges are a Pangaean phenomenon. Spreading ridges in the Pacific are not mid-oceanic, not even remotely so.

Spreading ridges are circum-continental, with a triple point corresponding to each three continental blocks (Figure 6).

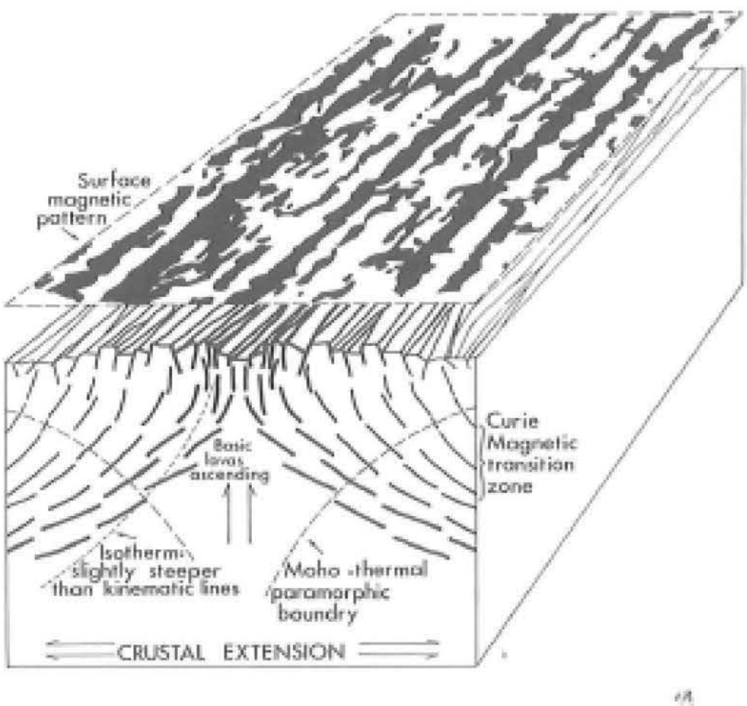

FIGURE 15
Spreading ridge is genetically similar to orogen except for absence of sediments.

Earth (both Pacific and Pangaea) has an east-west asymmetry, the east-facing coasts (of the Pacific or Pangaea) have extensional marginal seas from pole to pole; west-facing coasts have none. Island arcs are concave east (or rarely south) not west (or north). East Asian orogens overthrust east (towards the ocean), the Rocky Mountains also overthrust east (away from the ocean).

Earth has north-south asymmetry, vastly more new oceanic crust has appeared in the southern hemisphere than in the northern. Gondwana continents have dispersed very much more than those of Laurasia. The centre of maximum dispersion is near the Falkland Islands, and the centre of least dispersion is in east Siberia (Carey, 1970).

All continents have recorded increasingly northerly latitudes during the last 200 Ma. (Antarctica appears to be an exception, but not really so from a Falkland dispersion centre.

All Laurasian continents have moved west with respect to their Gondwana neighbours during the last 200 Ma.

East has no meaning except in terms of the Earth's rotation. Expansion is inherently asymmetric because of positive thermal feedback, hence the global asymmetries. Expansion is the prime mover; rotational inertia is the helm.

EXPANSION IN THE SOLAR SYSTEM

McElhinny, Taylor & Stevenson (1978) and Taylor (this volume) have stated that none of the other members of the solar system shows expansion, and that it is improbable that the Earth should be unique. If valid, this argument would also deny plate tectonics because there is no suggestion of this in any of the other bodies. However, in contrast to Taylor, A. N. Nikishin, and others, have interpreted surface features of Mars, Venus, and some of the Jovian satellites as evidence of their expansion. I also see evidence of expansion in all the planetary bodies.

Certainly we should expect the same physical laws to apply universally. However as I have pointed out elsewhere (1962b; 1976, pp.90-112) many physical processes are not continuous but have thresholds of size, time, pressure, temperature, etc., where quite different behaviour occurs. Such are: the Reynolds' threshold between laminar and turbulent flow; strength, governing the thresholds between elastic or rheid strain and fracture; temperature thresholds of melting and evaporation which separate physically quite different behaviour of the same substance; energy thresholds for nuclear fusion and fission; time-size threshold for magnetohydrodynamic phenomena; the Taylor threshold separating conduction and convective heat transfer, and many others known and unknown. Even if evidence of expansion was not detectable on other planets, it could not be arbitrarily assumed that such, potentially present, was not restricted by a physical threshold or the scale range of temperature, pressure, size, or time, or indeed of observation. (Recall Tycho Brahe's positive rejection of Copernicus's heliocentricity, because if true, Venus and Mercury would show phases and stars would show parallax, none of which had been observed by any competent astronomer.)

In the null universe model I have presented (1978 and in this volume) all matter grows at a rate depending (probably with large exponents) on concentration (pressure), temperature, and time. As Jeans (1928) has pointed out, the centres of nebulae appear like singular points at which matter is continuously poured into our universe. Meteorites on the other hand show no evidence of change through four billion years. On the curve between these extremes lies the Earth and the other planets. From the empiricism of the Earth's expansion history this curve is exponential — like the growth of the Earth's population — eons of imperceptible growth, but as the rate increases it accelerates. Evidence is strong that a major cataclism occurred some four billion years ago perhaps following a super-nova, and when the "dust" largely settled there was an Earth about half its present size. Through the three billion Precambrian years expansion was slow, although the processes were identical to now. As discussed earlier in relation to faunal realms the initial polygonal rifting gradually itensified until the first global through-going rift, the EoPacific, about a billion years ago. Then increasing rates produced in time the Caledonides and later again the Tethys, but the most rapid expansion occurred in the last 100 Ma, with maximum rate now.

One would expect Venus to be comparable to Earth, and what we know of it from radar surveys does not disagree with this. Mars should be a good deal further back along Earth's curve, and the great equatorial rift belt is much like what I expect the Earth to have looked like some time in the Proterozoic (Figure 16). Mercury is still further back, and the polygonal fracture system on Mercury (gratuitously interpreted by Danielson (1975) as compressional) recalls my model of the early Archaean Earth. The outer great planets, Jupiter, Saturn, Uranus, and Neptune are well beyond Earth's point on this curve. Perhaps they have already exploded but had sufficient self gravitation to fall together again, at lower densities. Jupiter is already more star-like than planet-like and perhaps should be coupled with the Sun as a binary.

It should not be assumed from this model that all satellites will progress along the same curve. This may be governed by initial size. The kind of speculative model I would

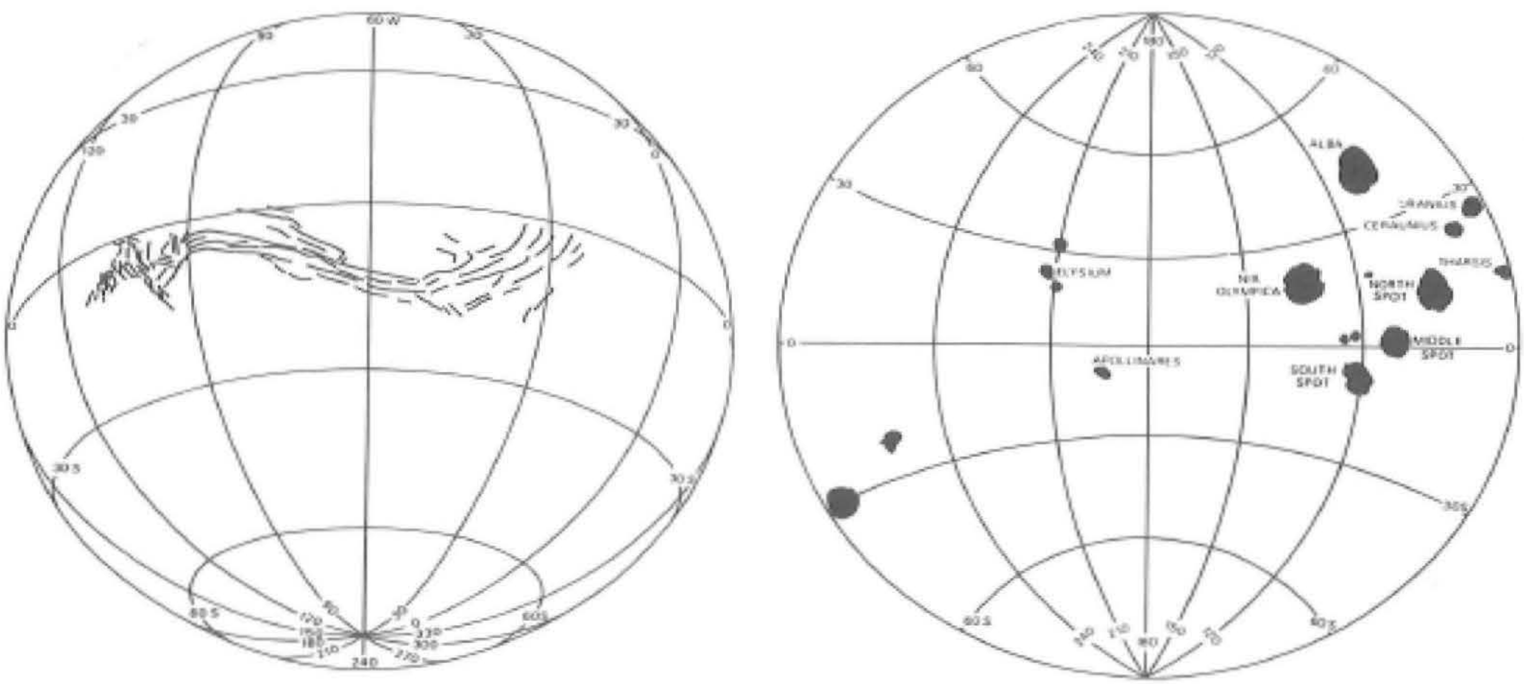

FIGURE 16
Asymmetry of Mars
At left, the great equatorial rift zone, which is confined to one quarter of the circumference. At right, the asymmetry of expansion, in that *all* the volcanoes are confined to one hemisphere.

contemplate to fit the empiricisms could be something like Figure 17, plotting rate of expansion against time, with expansion driven by a function of pressure, temperature, and time but limited by negative feedback unless terminated by explosion. Tiny bodies like meteorites would be represented by the bottom line, with expansion rates so low as to be unobservable. Moon would be represented by the next lime where scarcely any expansion has been observed during geological time. The third Iine could be Mercury where the expansion now visible resembles that of early Archaean Earth. Next Mars shows expansion resembling early Proterozoic Earth. Tatsch (1972), Ovenden (1972, 1973) and Guskover (1975) argued for a planet, variously called Aztex, Aster or Phaeton, which exploded to form the asteroids with much matter lost and some captured by Sun and Jupiter. Neptune could be the smallest planet sufficiently massive to reform after its explosicn. Between Mars and Aster is Earth which on the model would eventually explode unless stabilized by feedback before that event.

A curious fact about members of the solar system is their asymmetry — of figure and obliquity to the ecliptic. Because of positive feedback all expansion is asymmetric (see Carey, 1976, p.268 *et seq.* for a full discussion). Moon's figure bulges towards Earth, probably in isostatic equilibrium, all of Mars' volcanism is on one hemisphere as is the great equatorial rift; these asymmetries, and Jupiter's Great Red Spot, and the axial inclinations of all, are, I suggest, the direct consequence of their expansion.

Those Nelsons who deny evidence of expansion in Earth's companion bodies, have put their telescopes to the blind eye!

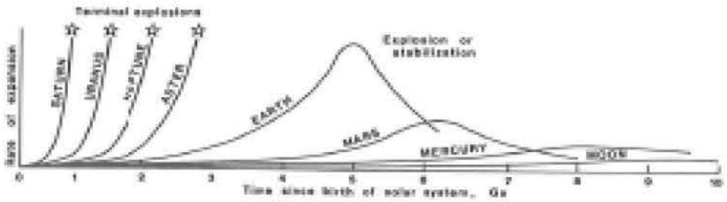

FIGURE 17
Speculation on different evolutionary paths of solar satellites according to size.

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