ANNALI DI GEOFISICA, VOL. 44, N. 1, February 2001

The global paleogeographical reconstruction of the Triassic in the Earth's dilatation framework and the paleoposition of India

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Abstract
Following the production of a series of three paleogeographical reconstructions for the Paleocene, Cretaceous and Jurassic (Scalera, 1995, 1998), a further reconstruction has been made here for the Triassic period, with the assistance of paleomagnetic data. The data provided by mutual fragment positions and paleomagnetic vectors, are best reconciled if the data are treated in an expanding Earth framework, and give credence to the view that this represents the real evolution of the Earth. In particular a new solution of the case of Indian paleoposition is given which could constitute the key to a reinterpretation of the Eurasia paleogeography throughout geological time. The main conclusion of this work is that the unambiguous choice between constant radius and increasing radius geodynamic frameworks (dR/dt ≈ 15 mm/yr on average in this work) can be made on the basis of the possibility to define the paleoposition and kinematics of India from the Triassic to the Paleocene.

Key words *expanding Earth – global palaeogeography – global geodynamics*

1. Method and data

In preceding papers (Scalera, 1988, 1990, 1991, 1993a,b, 1994, 1995, 1998) a global paleogeographical study was performed, following the old idea of an expanding Earth. The digitization was performed of all the ocean floor fragments of the same age and continental shields from the map «Bedrock Geology of the World» (Larson *et al.*, 1985), and of all the magnetic anomalies from the map «Identified Magnetic Sea-Floor Spreading Anomalies» of Roeser and Rilat (1982). Software was created to extract and use the data from the updated version of the Global Paleomagnetic Database (McElhinny and Lock 1990a,b) filtering the paleopole on the basis of their quality (Scalera *et al.*, 1993, 1996; Florindo *et al.*, 1994; Sagnotti *et al.*, 1994). Computer-assisted cartography was developed which permits the choice of the Earth's radius, and, as a consequence, avoids the use of the Euler principle of the uniqueness of the pole of rotation. Preference was given to the direct visual check of the position of the fragments and of their paleopole sets. The reconstructions are not then filtered by rotation-pole tables which are available in the literature.

Many hypotheses about Earth expansion are possible, and notable among them is the slow expansion framework without subduction (Hilgenberg, 1933, 1965, 1974) or with subduction of Owen (1981, 1983a,b, 1992) which, in his Atlas (Owen, 1983b), opened the way to

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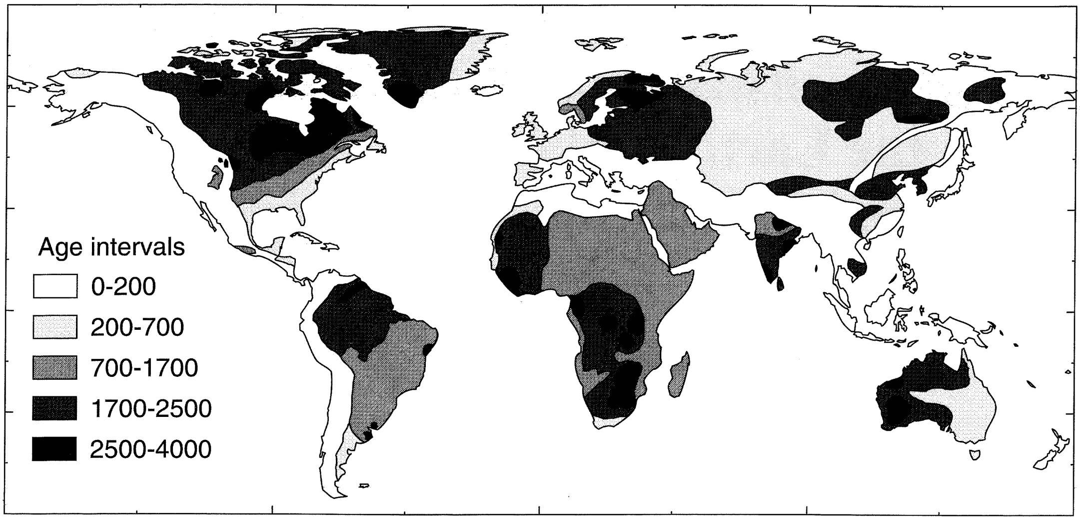


Fig. 1. The approximate ages (in million of years) of the continental crust.

precise variable radius cartography. Davidson (1983, 1997) prefers a view that reconciles pulsating Earth dilatation to plate tectonics, admitting subduction. Chudinov (1998) advocates «eduction», a process which could be considered opposite to subduction: a slow extrusion of the oceanic crust at the trench-arc zones. I have preferred to test in this paper my personal view of a model of «subduction» so limited, that only a few tens or very few hundreds of kilometers of oceanic crust are underthrust and reworked under the arcs (Scalera, 1993b, 1998). This model needs modification to be applied to nonsubductive zones. My idea of Earth dilatation is near to the conception of Carey (1975, 1976), except for the admitted very limited amount of underthrusts, and I accept also pulsation in the progress of expansion because pulsation is now unambiguously detected in recent ocean floors half spreading maps (see fig. 5.19 of McElhinny and McFadden, 2000 – based on Müller *et al.*, 1997), from which we can see that the expansion pulse is now at a minimum.

I have used only the files of perimetral contours of the continental fragments, their coasts (only to help the visual recognition), the Paleozoic shield perimeters, and the positions of the main volcanic rocks. I have taken into account also a map of the continental crust ages (fig. 1). Today, the updated Global Paleomagnetic Database (GPMDB) is not provided in ASCII format and I have used the facility of extraction from the database which is active on the Web Site of the Norge Geologiske Undersøkelse NGU (The Geological Survey of Norway; http://www.ngu.no/). In these extractions, the quality criteria are not the same as in the software I have already created (Scalera *et al.*, 1993, 1996). A selection has been made, checking the data individually and leaving open the criteria of acceptance of the data in the case of fragments which are poorly known.

2. Radius

A review of the data of the Deep Sea Drilling Project indicates that oceans were shallower than today during the Paleozoic and the Mesozoic (Dickins *et al.*, 1992), leading to the conclusion that oceanic depths (that we observe today) should be restricted to geosynclinal bands. According to my expansion hypothesis, during the Triassic period the oceans seen today had not yet opened, or were only narrow shallow seas which were subsequently underthrust with a possible mechanism described in Scalera (1993b, 1998).

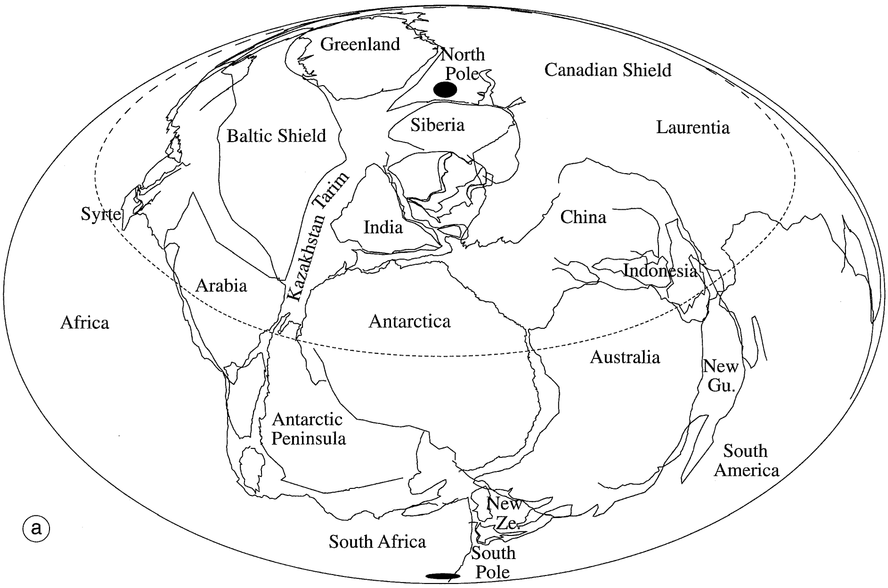
The main uncertainty in the initial production of the reconstructions was the choice of the correct mean Triassic Earth's radius. This difficulty is linked to the strong indication which has arisen in the course of the reconstruction, of a reduced size of the continental fragments. Some continental pairs of fragments have indeed found a correct mutual position, but only if a considerable band of coastal terranes became superimposed. It was soon recognized that only the elimination of part of the terranes external to the Paleozoic shields allows of a correct positioning of the fragment, taking into account the boundary conditions of the paleopoles. The case of Australia and South America is a typical example of this, in which large parts of East Australia and the southern part of South America came into superimposition along a zone in which no shield is present, and both the continents present a number of dispersed units of «Gondwana facies». The same happens in the Mediterranean area, between Europe and Africa. This problem, which is not present in the slow expansion hypothesis (Owen, 1981, 1983a,b, 1992), become ineluctable in my version of fast expansion framework, and has been resolved heuristically accepting that the continents have also undergone strong tensile extensions (lesser with respect to oceanic expansion). Traces of this are especially evident along all the orogenic belts, although many other kinds of geological areas could be considered to show the working of tensile forces. Clearly, compressions are concomitant – or compression alternate to extension – but the net balance favours the extensions. In general, not only the oceanic terranes younger than the Period of the reconstruction have to be eliminated but also the younger continental ones, following the indications of a map of the approximate crustal age (fig. 1). The white area in the map of fig.1 should not be considered completely free from small fragments of older crust, which are effectively observed and constitute terrains detached from the main older shield in the course of the process of continental extension. The light grey area (200-700 My) should also be considered to participate in the continental extension, as well as the intermediate grey area (700-1700 My). For example, the African Cretaceous west and central rift system, with the Gao, Benue, Ngaondéré, Ténéré, Sudan, Syrte rifts and the dextral displacement along the reactivated Ngaondéré-Birao-Khartoum are not represented in the map of fig.1, which should be considered only a rough approximation. After a few global tests, and discussions with experts on the field, the radius of the Triassic reconstruction was fixed at 3300 km. With this choice all of the oceanic areas (in the modern meaning of the word) are eliminated, with the exception of a small area of the North Eastern Pacific. In fig. 2a,b the final reconstructions are shown.

In both figs. 2a and 2b of the Triassic reconstructions, the extensions of epicontinental seas, in some cases shallow seas covering very large extensions of the Western Europe and Asia (map 29 of Smith *et al*, 1994), have not been drawn.

3. India

The Triassic paleopoles of Antarctica are practically absent, but the positioning by Jurassic and Early Cretaceous results is sufficient for this purpose, leaving Antarctica connected to the southern margins of Australia. As a consequence, all the space enclosed in the 30°S parallel is, in this reconstruction (fig. 2a,b), filled by African and South American terranes with the boundary between them (future Atlantic opening) running along a meridian.

Because of this, India cannot find a proper position on the 30°S parallel as it does in the conventional constant radius paleogeography. This fragment, after assuming its north paleopole (Indian Trias data used here in: Wensink, 1968; Bhalla and Verma, 1969; Klootwijk *et al.*, 1983; all data refers to primary magnetization) as being the south, finds two possible positions, both in the interior of the area occupied today by Asia. A reason for this can be found in the fact that Asia is a mosaic of blocks which have mutually moved leaving as traces of these movements several areas of ocean-like terranes (Burrett, 1974; Stöcklin, 1981, 1984; Crawford,



Triassic - Radius 3300 km

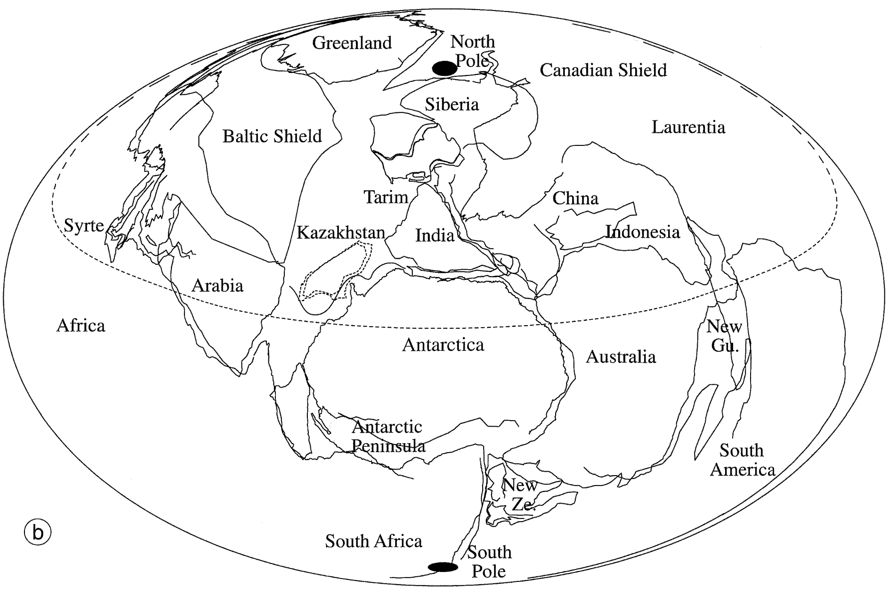


Fig. 2a,b. a) This possible reconstruction of India has some geological difficulties. The main problem is the too short distance between India and the Urals. b) The preferred reconstruction of Triassic. This second possible position of India can reconcile several needs for terranes proximity advocated by paleontology, and leaving an adequate space to the Trans-Uralian terranes as Kazakhstan and Tarim. An alternative position of Madagascar, which deserves to be carefully screened, is drawn in a dotted line.

1983). These terranes should be eliminated in expanding Earth paleogeography if reconstruction of times older then their ages are produced.

A first position of India is with its actual west coast connected to the Antarctica Dronning Maud land, and its east coast running from 30°N to 60°N and facing towards the Siberian plateau (fig. 2a). This position is too near to the Uralian belts leaving insufficient space for the Siberian sedimentary basin, and for Kazakhstan and Tarim. Although this Indian position is in agreement with the paleontological data referred to below, it is more difficult to explain the pattern of the ocean floor ages younger towards south for the west side of the Ninetyeast ridge and older towards south for the east side of the same ridge (see the maps of Larson *et al.*, 1985 and Müller *et al.*, 1997).

A second paleoposition of India (figs. 2b and 3a) could be geologically and paleontologically consistent with Earth expansion. This second position is with West India in contact with the next polygonal side of Antarctica (the Mc Robertson land facing the Cooperation Sea) with its southern tip and Ceylon touching the Australian Naturalist plateau, and with the modern North Indian boundary (Himalaya) in contact with the Siberian Traps, and leaving more space for the trans-Uralian terranes, Kazakhstan and Tarim (fig. 2b). This position could give a kinematic sense also to the opening of the Siberian Traps, and could be considered geologically more realistic giving a easy explanation of the above mentioned problem of the ocean floor geochronology to the west and east of the Ninetyeast ridge (see map 34 in Owen, 1983b). A further geologic argument is the solution, in this reconstruction, of severe geologic incompatibility arising from the impossibility to find a continuation of the Himalayan belt in Antarctica or Southern Western Australia (Dickins and Shah, 1987).

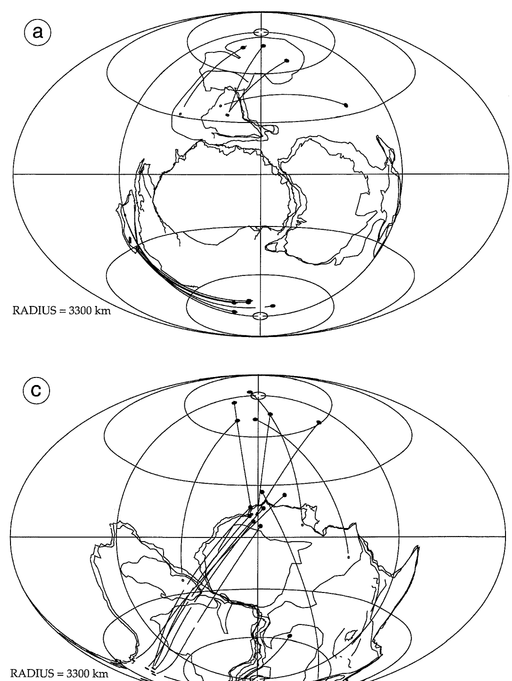


Fig. 3a-c. a) The Triassic poles of India, Madagascar, and the position of their continental fragments in the paleogeographical reconstruction. b) The Triassic poles of Siberia and Australia. c) The Triassic poles of South America and Africa and their position in the paleogeographical reconstruction. Both the continents present highly displaced southern poles in comparison to those of northern sampling sites. This is the effect of the interaction of the two continents with their boundary terranes of Antarctica and Australia, and of the opening and development of the Paleozoic, Mesozoic and Cenozoic African rift zones, the Nazca-Cocos expanding plates, and the Andean rifts.

Further evidence can be extracted by inspection of the ocean floor isochron map (Müller *et al.*, 1997) which shows an absence of interpreted data just in the region of Cooperation Sea adjacent to Mc Robertson land, Antarctica, in which the Indian first impulse of rotation should have occurred. The inspection of the high resolution gravity field map of the Southern Ocean (longitude from ≈ 50 to ≈ 120 in McAdoo and Marks, 1992) confirms the highly disordered nature of the same region, in comparison to the more ordered morphology of the neighbouring oceanic terranes around Antarctica. In particular, the neighbouring oceanic terranes immediately to the east (longitude from ≈ 140 to ≈ 180 in McAdoo and Marks, 1992) show a unambiguous trace of a left transtensional process which splitted Australia from Antarctica, and this is just the indication provided by my Triassic map in fig. 2b.

The problem of the Indian paleoposition is strongly linked to the more general problem of the inconsistency of many palaeontologic results and constraints (see many papers in the book edited by Mc Kerrow and Scotese, 1990), which claim land connection (impossible in reconstructions in which a modern radius is adopted) between Eurasia and Gondwana, and at a global level between the opposite Pacific coast (Shields, 1979, 1983, 1996, 1998; La Greca, 1989; Sluys, 1994). The trans-Pacific presence of some species of earthworm (in East Asia and West Laurentia) has been explained exhuming the hypothesis of the ancient continent «Pacifica» (Sluys, 1994), which fragmented into several parts, at the same time as the break-up of Pangea, colliding with Asia and Laurentia. But this unsatisfactory explanation can be avoided by discarding the existence of a Carboniferous Pacific, and admitting an expanding Earth (La Greca, 1989).

In a paper on the Late Palaeozoic, Nie Shangyou, Rowley and Ziegler (1990) say: «It is of particular interest that the Cathaysian floras also existed in northern parts of Gondwana, an important fact not often recognized. [... ...] Land connections were required [... ...] between the Cathaysian microcontinents and those of Gondwana, while many of them appear to have had separate tectonic histories. The nature and location of these 'land-bridges' are not now understood and remain as a major challenge to the Palaeozoic palaeogeographic reconstructions.» At the same time, geological constraints led Stöcklin (1981) to claim: «[... ...] repeated rifting and compression along old lineaments, with repeated opening and closing of narrow, Red Sea type oceanic troughs between rigid continental blocks may have been the fundamental mechanism in the tectonic evolution of Iran – rather than long-distance continental migration with subduction and consumption of gigantic volumes of oceanic crust as assumed in most current plate tectonic models for the Middle-East». The same, in my opinion, should be valid for most of Asia, and also for other regions. No need for land-bridges to exist and a fair agreement with the Stöcklin requirements is possible with the choice of a proper smaller radius of the Earth. The same proper radius choice can resolve the analogous implication of the review of Dickins *et al.* (1993) and Teichert (1971) about the Permian marine invertebrate fauna.

Many links of the antarctic flora have been found in the course of the exploration of this continent with the flora of the Northern Hemisphere from the Paleozoic to the Mesozoic (Truswell, 1991) and a greater Gondwana is suggested by Burrett *et al.* (1990) on the basis of similarities among Palaeozoic faunas of China and Australia. Numerous antarctic pollens and flora are similar to some European and North American ones, and a strong affinity exists in the Jurassic flora with India and Europe. Middle Jurassic bivalves from Ellsworth land, Antarctica, show European or cosmopolitan affinities (Quilty, 1982, 1983; Thomson, 1991), and Palaeozoic, Devonian, fishes with unambiguous European affinity, are recorded in Antarctica (Young, 1991), all facts which could find a significance considering the initial Triassic position, and subsequent kinematics, of Antarctica and Antarctic Peninsula in my reconstructions.

Very important is the paradox of the Cretaceous flora, fossil forests, which show indisputable signs of long growing seasons, equability of light and frost-free conditions, typical of temperate or low latitudes (Truswell, 1991), a fact incompatible with the classic Pangea reconstruction and with the paleomagnetic data. In a paleogeography based on an expanding Earth (see the sections on the reconstructions) the paradox disappears, with Antarctica located on intermediate latitudes. The Antarctica luxuriant Mesozoic vegetation (Truswell, 1991) can be also due to the combined effect of both the non existence of the thermal insulation due to the circumpolar deepwater circulation (Lawver *et al.*, 1992), and of the effect of expansion described in fig. 7.

The Upper Paleozoic glacial strata of India, traditionally considered as a Gondwana and Southern Hemisphere marker, could be in this framework ascribed to a Northern Hemisphere position of India on a smaller Earth ($R \approx 0.5 \cdot R_{modern}$).

The Siberian fragment finds its location with paleopoles at right angles and distance (fig. 2a,b and fig. 3b). The position of Siberia is with its modern northern boundary in contact with the modern Northern Indian margin. Siberia appears to be rotated more than 100°, and the shape and the geochronological pattern of the opening of its basaltic traps (Larson *et al.*, 1985) is in agreement with a clockwise rotation of the Siberian craton from the Paleozoic to the Mesozoic; a rotation drawn by similar geodynamic forces as those which have driven the Indian craton.

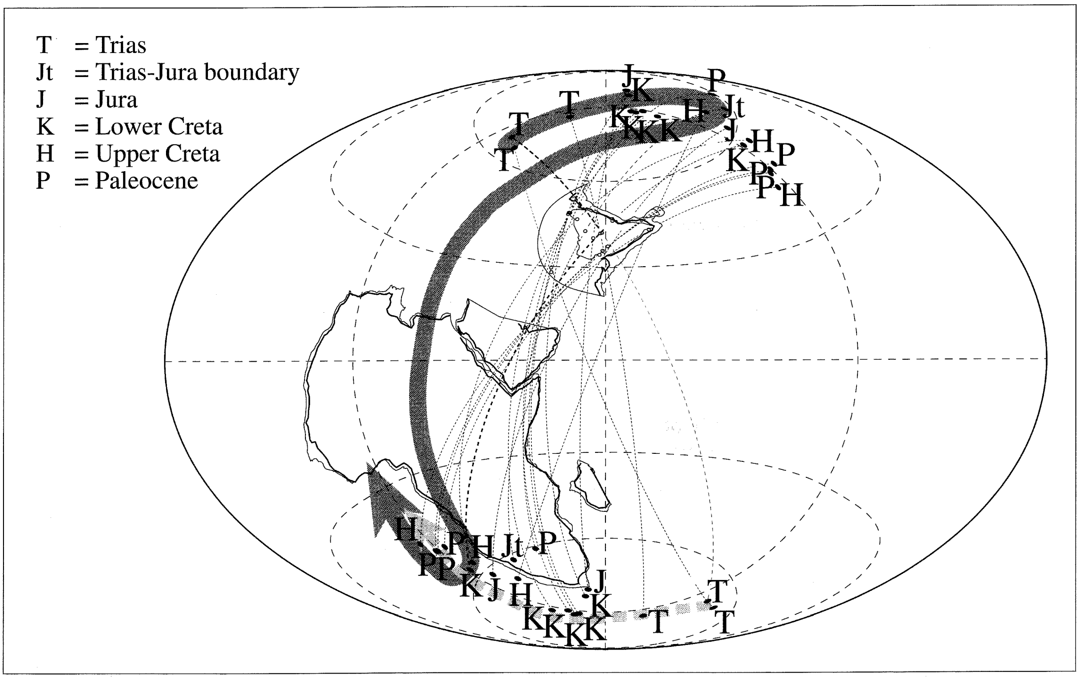


Fig. 4. The Indian plate has been conventionally traced on a globe of radius 4800 km, a value intermediate between the Trias (3300 km) and the modern radius (6370 km). Its plotted position has been chosen to facilitate the visual understanding of the Indian rotation problem. With the same aim, each paleopole from Trias to Paleocene has been traced together with its antipole. Two ways to interpret the Apparent Polar Wander Paths (APWP) are possible. The first APWP is traced as a dotted gray arrow and it is the generally accepted way to interpret the Indian drift as a long trip from the Southern Hemisphere to the northern one (path in the series in fig. 5a). The second APWP is traced as a bold deep gray arrow and is the new possibility examined in this paper as the proper one in the Earth's dilatation framework: the Indian plate performs a strong clockwise rotation from Jurassic to Cretaceous (path in the series in fig. 5b), moving away from the Eurasian plate, but conserving the geologic contact, and paleontologic and climatic links.

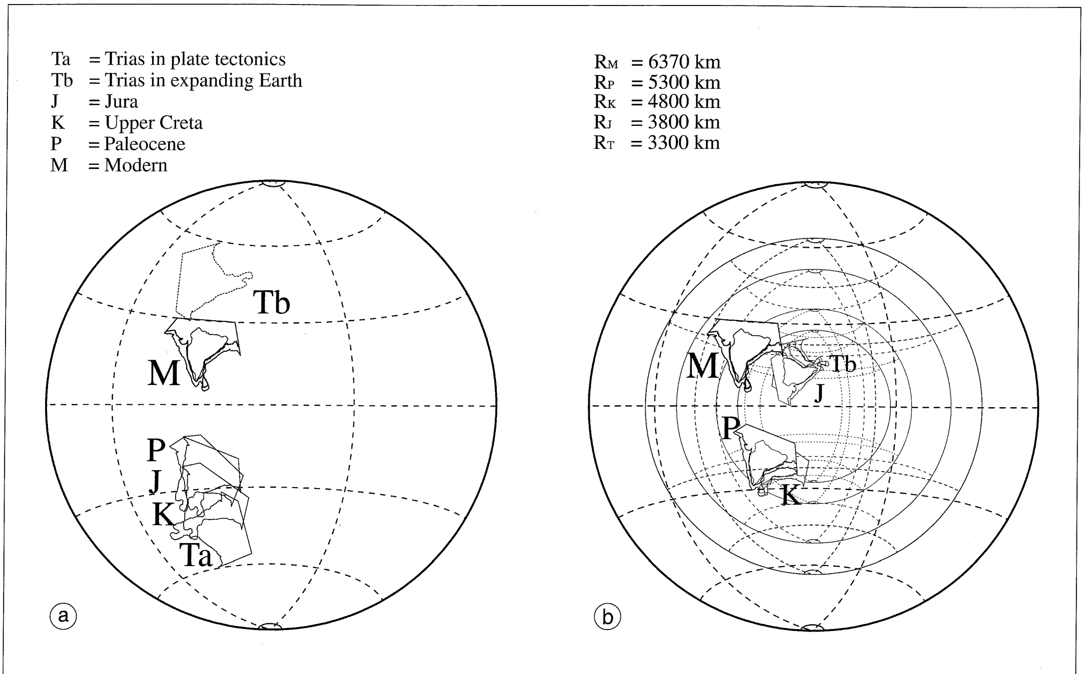


Fig. 5a,b. a) The path of the Indian plate has been conventionally traced on a globe of modern size. The Indian plate drift is, in the plate tectonics hypothesis, a long trip from the Southern Hemisphere to the northern one. As a reference, the alternative Triassic position in the expanding Earth framework Tb is plotted in a dotted line. The distance in kilometers to be travelled by India from Triassic in this constant radius representation is ≈ 8000 km, near 1/5 of the Earth's great circle, and the separation of India from Eurasia, followed by their convergence which has created the Himalayas and the Tibetan plateau, is a nearly forced choice. b) The path of the Indian plate in the hypothesis of the dilatation of the Earth is plotted in a pseudo hyperspheric perspective. A different Jurassic paleopole has been chosen in this expanding representation. The Indian plate performs a strong clockwise rotation (more than 150°) from Jurassic to Cretaceous. The kilometric amplitude of the Indian oscillation, from north to south and north again, is only of nearly 4000 km, which is easier to explain as containing a component of global reorientation of the lithosphere, namely a component of secular polar motion. The Jurassic-Cretaceous strong rotation occurs on a pivot (the modern Pakistan-Afganistan) which remains near to the initial J and final K position. In this case, the geological contact with Eurasia is never lost and a narrow Tethys Sea is possible on the Eastern Indian coasts. The projection used is the Lambert azimuthal equivalent, and the perspective effect has been obtained using a 90% metric unity in the older geologic time with respect to the younger preceding one.

This completely new position of India is able to resolve several paradoxes which are present in the plate tectonic constant radius reconstructions (Chatterjee, 1984, 1987; Sahni, 1984; Chatterjee and Hotton, 1986; La Greca, 1989). In these conventional reconstructions, India has to migrate nearly 8000 km from a southern latitude position to its actual modern position, impinging on Asia – a trip difficult to imagine. In my reconstruction, India performs a strong clockwise rotation from the Jurassic to the Early Cretaceous (figs. 4 and 5a,b), more than 150°, pivoting on the (modern) Pakistan and Afghanistan region. The seeming amplitude of the Indian oscillation, from north to south and north again, is now of nearly 4000 km, but this is not completely real and no subduction of 4000 km of oceanic crust is involved because India – due to the effect of the increasing radius and length of geographic degree, and dilatation of the

Asiatic continent – never separates from Asia, except for repeated rifting and compression and opening and closing of narrow shallow seas, or Red Sea-type oceanic troughs (Stöcklin, 1981, 1984, 1989).

Some workers have already advocated a clockwise rotation of India. Storetvedt (1990) proposed a rotation of ≈ 135° at the Cretaceous-Tertiary boundary, but others proposed different solutions with clockwise and anticlockwise rotations at different times (Wensink, 1973). In Wensink (1973, see his fig. 6, in which there is a question mark near India), the position of India in the Upper Carboniferous is drawn rotated clockwise 90° with respect to its conventional position near Somalia and a counterclockwise 90° post-Carboniferous rotation is postulated. Instead, the position of India in Wensink's fig. 6 is exactly what is to be expected in my dilatational Earth if the Carboniferous Southern Indian pole (in Wensink figure) is assumed to be the Northern Pole.

Because it is evidently very difficult to distinguish the exact time window in which India performed its rotation, I have joined the paleopole analysis to the sea-floor magnetic anomalies analysis. The simple inspection of the Indian Ocean magnetic anomalies map of Owen (1983b, map 34) has revealed that the second paleoposition (fig. 2b) of India is strongly indicated by the magnetic anomalies which, on the contrary, exclude with certainty the first paleo-

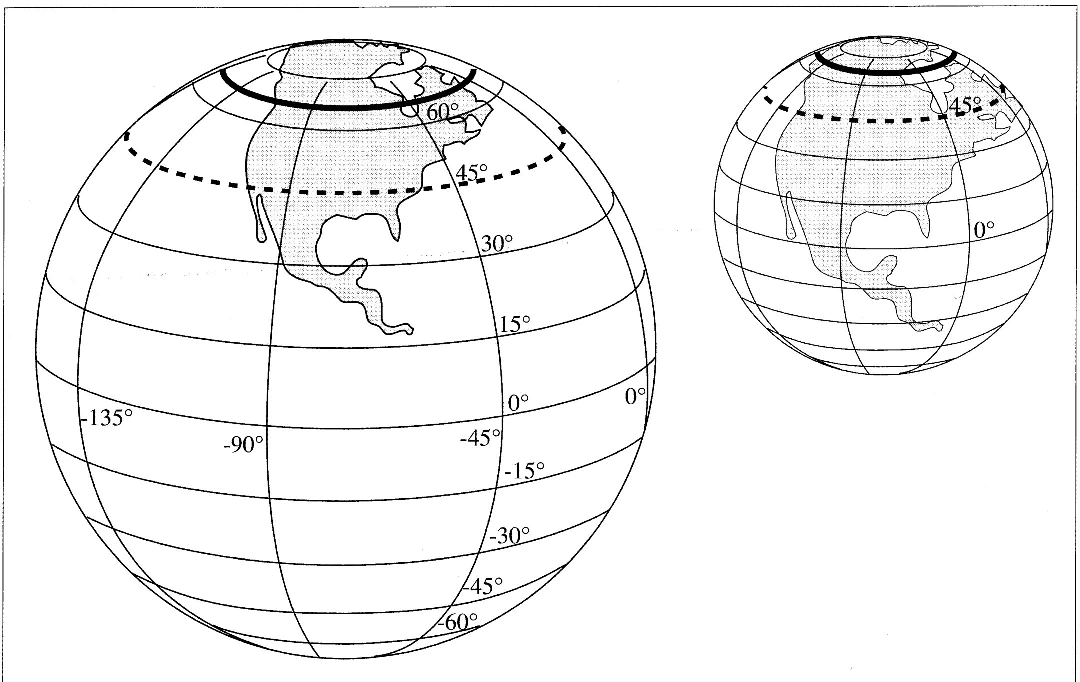


Fig. 6. The influence of the Earth dilatation on our judgement of the ancient climate. On a half radius Earth, a parallel or the polar circle encloses an area nearly a fourth of the modern area. As a consequence, the polar circle or a glaciation with ice reaching intermediate latitudes, ≈ 45°, occupy a lesser continental area (≈ 1/4) on a half radius Earth. If people erroneously assume the radius of the Earth to be constant, the climate of the old epochs can be judged abnormally mild, presenting fossils of non-glacial flora and fauna enclosed in a modern size polar circle. The Antarctica luxuriance Mesozoic vegetation can also be an effect both of the non existence of the thermal insulation due to the circumpolar deepwater circulation, and of the effect described in this figure.

position (fig. 2a). The east margin of India is in fair contact with the Broken and Diamantina ridges (which can be considered further traces of the Indian paleoposition), and its strong rotation happens essentially during the time window from the end of Jurassic to the Cretaceous magnetic quiet zone (110 My - 87 My). The absence of a paleopole up to now supporting this rotation could be due to a rapid rotation which gives rise to averages in the data analysis with too high dispersion parameters. Curiously, the choice of this time window is strongly supported not by data but by «absence of data», namely the absence of linear magnetic anomalies in the Cooperation Sea, south of the Kerguelen plateau (Müller *et al.*, 1997), because these anomalies have been distorted and confused by the rapid Indian rotation. It may be that a specific search for a «non linear pattern» of magnetic anomalies in the Cooperation Sea (also by reevaluation of the already existing oceanic survey data) could provide further evidence of a quick rotation of the Indian continental fragment.

India rotation evolved with the Eastern Indian margin shifting along the fixed «buoy» constituted by the intersection of the Broken-Diamantina ridge and the Ninetyeast ridge. Then, from the time of anomaly 33 (77 My) up to the Recent, the kinematics of India became similar to that prescribed by plate tectonics, with the exception of a constant contact with Asia due to the smaller Earth dimension.

The distribution of vertebrates is in agreement with my new Triassic Indian position. This conclusion, from different points of view is reached by Ahmad (1983), Chatterjee (1984, 1987), Sahni (1984), Chatterjee and Hotton (1986), Sahni *et al.* (1987), Tripathi and Singh (1987), Smith (1988) and Patterson and Owen (1991), concerning also the northern and western boundary of India. Madagascar and India are found to have tetrapod faunas with predominant northern relationship. A similar situation occurs in Indochina and, more generally, for north Gondwana of the Mesozoic age, which are paleontologically linked to Central and Northern Asia and Europe, suggesting an active interchange across a very narrow Tethys Sea (Buffetaut, 1989a,b; Buffetaut *et al.*, 1989; Astibia *et al.*, 1990). Ager (1986) developed analogous reasoning especially using the distribution of brachiopods, and Stöcklin (1984, 1989) reached the same conclusion for the Afghanistan-Pamir-Pakistan region on the basis of geological evidence.

It is noteworthy that the banded iron formation of the Proterozoic (1900-2100 My) of Northern Europe (UNESCO, 1976) can be settled, on a nearly half size Earth, in correspondence with the analogous conspicuous iron formation in India.

All the quoted papers are in conflict both with the long and isolated journey of India (fig. 5a) before its hypothesized collision with Laurasia, and with the large extension of the Tethys Sea which are both the result of paleogeographical reconstructions performed on an Earth of constant radius.

The relationship of India with Eurasia through time is reinforced in the Jurassic (Chatterjee and Hotton, 1986, 1992; Patterson and Owen, 1991), in particular for the affinity of the Indian and Eurasian flora (Smiley, 1976, 1992). In the Cretaceous, a further continuation of these ties persists (Briggs, 1996). In the slow expansion atlas (Owen, 1983b), the distance of India from Asia from the Jurassic to Recent is already reduced in size, allowing these ties to persists, and in my reconstructions (Scalera 1994, 1995, 1998) the Asian-Indian contact is stronger and the Tethys region can be constituted only by very narrow seas.

The problem of the eastern margin of India from the Paleozoic to the Tertiary has not found a definitive solution as to whether this margin was open or not to the sea. But marine sediments containing warm to tropical Tethyan marine faunas have been found along the Indian eastern coast starting from the Permian and extending during the Mesozoic. On this basis, Chatterjee (1984) concludes that the data from geology does not provide evidence that the eastern margin of India was once in contact with Australia or Antarctica and that it was open to the sea. Dickins and Shah (1987) deny the possibility, from the paleontologic and geologic point of view, of an India placed adjacent to Western Australia in the Permian. Other workers, such as Carey (1975, 1976) and Owen

(1983a,b, 1992), advocate, on palaeontological or structural geology grounds, the Australia or Antarctica contact respectively. The position of India in my Triassic reconstruction (fig. 2b) can reconcile the Chatterjee, Dickins, Carey and Owen positions, also taking into account the evidence of proximity between Australia and China (Burrett *et al.*, 1990). My solution for Indian paleoposition is similar, but not coincident for the Australia rotation, to that proposed in the constant radius framework by Ridd (1971), on the basis of geologic evidence.

It should be clear that a fundamental test for my reconstruction is the comparison of Triassic and Pre-Triassic fossils of West India with those of the Antarctic zone which in my map appears in contact with the Western Indian margins. A reconsideration and new search for possible similarities between Triassic faunas and floras of Eastern India and Northern Siberia (before the opening of the Siberian traps), of which some evidence already exists (Nie Shangyou *et al.*, 1990) should also be made. The same should be made for the common boundary between Madagascar and Antarctica.

Finally, I want to note that in this new Pangea a persistent problem is still the position of the Madagascar fragment. While the volcanic provinces of India and Madagascar are similar, Chatterjee and Hotton (1986) claim that there is no evidence, geological or paleontological, of a link between India and Madagascar. This contraddiction should be resolved in agreement with the above interpretation of the paleopole data, which locate the two fragments separated. And I, from some paleontologic clues (Battail *et al.*, 1987; Wright and Askin, 1987), can indistinctly see that Madagascar may also have undergone a strong rotation, similar to that of India, leaving completely free the contact between Antarctica (and the Antarctic Peninsula) with Africa. A careful screening of this hypothesis (sketched in broken line in fig. 2b) deserves consideration.

4. Mediterranean

The Indian plate is now near to the eastern wedge of the European Paleozoic shield, with its northern boundary, the modern Himalayan belt, now disposed essentially along a meridian (fig. 2b). This proximity, and some problems it can produce, can be only slightly mitigated by taking into account the Tertiary Rhine-Bresse Graben, which could mean a palinspastic contraction of the European shield by a few tens of kilometers. Due to this position of India, the European shield has to be displaced to the west, and the Caledonian belt will be in contact and continuation of the Appalachian belt. In this configuration, the Mediterranean region appears completely closed, with the Arabian plate slightly displaced to the west. To do this, the Ityopiya Somalia Corner has to follow the Arabian plate eliminating the East African rift zone for a few tens of kilometers of extension (Morley, 1999). Some terranes in Egypt have to be eliminated in the reconstruction, and this can be achieved considering firstly the field data of a continuous migration of the Egyptian paleodeltas northwards and eastwards, accompanied by a concomitant deposition of new limestones plateaus (Issawi *et al.*, 1999). Also the Cretaceous west and central rift system of Africa (Keller *et al.*, 1995), which could have contributed to an enlargement of the Syrte Gulf (see the map in Keller *et al.*, 1995), and the dextral displacement with narrow extension along Cretaceous reactivation of the Pan-African Ngaondéré-Birao-Khartoum transform fault zone, should also be considered.

The Syrte Gulf then contains the precursor terranes of the Adriatic peninsula, Adriatic plate and Aegean area, and its Cretaceous enlargement could be related to the events which originated Carpathian orogenesis. The first opening of the Eastern Mediterranean happened in Jurassic time and is related to the opening of the Wharton basin, the Western Pacific, and the oceanic area now represented by the Ophiolite belt in the Himalayas.

The clockwise rotation of India, more than 150° in the time window ≈ 110-85 My, should not be judged as too rapid, because it has the same rotation rate as other small plates, *e.g.*, Iberia and Corsica-Sardinia and Japan (Gueguen *et al.*, 1998; Jolivet *et al.*, 1995). This analogy can be extended if we note that there is a correspondence and symmetry between the counterclockwise rotation of Spain and Sardinia-Corsica block to the west of Eurasia, and the clockwise rotation of India and Siberia to the east, both rotations driven by a flux of mantle material directed from east and from west towards the centre of Mediterranean Sea. These fluxes should be thought of as caused by the very slow increasing of the distance between Africa and Eurasia. A clue to the existence of these sublithospheric fluxes is the existence of the two Mediterranean back arc basins, Tyrrhenian and Aegean, which cannot be easily explained in the plate tectonics framework because the two Benioff zones, and the hypothesized subductions, are directed towards two not compatible azimuths. Then the need for a revision of the concepts about the zones of trench arc and back arc becomes stronger because of the Mediterranean geologic situation, and while the role of the subducting slab becomes weaker, the role of the advection of mantle material in the back arc expansion appears more important. In agreement with this interpretation is also the progressive protrusion of Anatolia towards the Aegean Sea, as documented by the dextral strike focal mechanisms along the great Northern Anatolian fault.

The recent analysis of GPS data in the Mediterranean region (Anzidei *et al.*, 2001) has shown that a discrepancy exists among the African-European convergent kinematics resulting from the Novel-1 model and the new processing of the geodetic data. Although we have to be very prudent because of very few data (only two stations on the African continent but in orogenic zones) the plotting of the displacement vectors in a European reference frame shows a motion of the African plate that can be interpreted as diverging (very few millimeters for years) from Europe. The same analysis (Anzidei *et al.*, 2001) shows that the two Iberian stations are in a state of mutual counterclockwise rotation, which leads to an interpretation of the modern state of motion of Iberia as a prolongation of the Cretaceous counterclockwise rotation, which opened the Biscay Gulf.

The complete closure of the Mediterranean region in the Triassic does not mean the complete absence of sea ways, because a number of these Eurasian epicontinental seas are well documented (map 29 of Smith *et al.*, 1994).

5. South America and Australia

The South American pole (fig. 3c) sampled in Central Andes appears inconsistent in comparison with the African and Laurentian poles, because of a strong clockwise rotation and a southern dislocation (near 60°). This fact can be explained by the action of a push exerted by the Pacific midoceanic ridge, especially after the start of the expansion of the Nazca plate. Only one pole, sampled north of the Amazon river, in Suriname, is compatible with the African ones, and one pole sampled in the Central Andes points towards the South Pole. All Andean belt palaeomagnetics have to be treated with great caution due to Cretaceous and Cenozoic thrusting and rotations.

The sampling sites of the Australian Triassic poles now appear dislocated towards the inner modern eastern coast of South America, and different solutions can be proposed for this. The most plausible explanation is that most South American terranes and bedrock, south and west of the Paleozoic shields, are of Mesozoic or younger ages. It is then possible that both these terranes and the Falkland plateau developed their elongation toward the south in post-Triassic time, leaving in the Trias the place for the Australian Triassic sampling sites to be correctly located without superimpositions with American continental terranes. To mitigate this problem a slight shortening of the Australian continent is postulated in the Triassic reconstruction. While no attempt has been made to locate unambiguously on the final plot the New Zealand terranes, because of insufficient paleopole data, this problem could be solved in a way strictly related to that of the Australia-South America mutual position. The problem is considered a minor one and has deliberately been left open.

6. Africa

The need to eliminate a large band of terranes of the East African rift, suggests the further necessity to take into account all post-Triassic rifts. The apparent geometrical inconsistency of the superimposition of the pairing Australia-Antarctica to the southern part of the pair Africa-South America and Falkland plateau can be resolved in this way.

To perform the paleogeographical reconstruction I have used only the Northern African Triassic poles, because the southern ones are discordant from the former. This fact is further evidence of an active post-Triassic rifting of the continent.

The Cretaceous west and Central rift system, with the Gao, Benue, Ngaondéré, Ténéré, Sudan, Syrte rifts and the dextral diplacement along the reactivated Ngaondéré-Birao-Khartoum transform fault zone (Keller *et al.*, 1995), can help to explain the southern discordant paleopoles and the re-positioning slightly toward the west of the Arabian plate.

7. Some mitigated problems

The well known discrepancy between numerically simulated models and field-data based paleoclimate models, can be mitigated by the percentually increased continental area (near 100% of the total spherical surface in the Trias expanding Earth reconstruction, *versus* ≈ 30% in plate Tectonics). Then, on half size or full size radius Earth, the average global percent (average among warm, normal and glacial periods) of glacial zones remains the same, but occupying, in the half size expanding Earth reconstruction, only a smaller portion (fig. 6) of each continental fragment (only 1/4). As a consequence, the climate should show, in normal climate periods, if a modern radius is assumed, an erroneous large tropical desert, and moderate temperature and moist wet zones, abnormally extended towards the polar zones (fig. 6). All this is in agreement with data from paleoclimatology which assign a smooth and sweet climate (with only two glaciations) from 600 My to 100 My, and the same in the time window 100-50 My, in which the presence in high polar latitude of paleontological records of flora and fauna typical of more moderate latitude is inexplicable.

The paradoxical transformation of the Paleo-Tethys into the Neo-Tethys, from the Carboniferous to the Early Triassic, by the relatively rapid movement of the strip-like Cimmerian terrane from Gondwanaland to Laurasia (Metcalfe, 1993; Briggs, 1996; Yang, 1998), along a half-hemispheric path, is now resolved with the contiguity of Cimmeria both to Gondwana and Asia, in agreement with the conception of a repeated opening and closing of narrow Red Sea-like oceanic troughs (Stöcklin, 1981, 1984). This problem is logically analogous to that of India and its improbable trip from Southern Africa to Central Asia.

The presence of evaporites also on the west margin of Laurentia, South America, West Australia, and the north of Canada and Greenland, could be reconsidered taking into account the possible presence of very narrow seas along these margins, in accord with my Trias global reconstruction (R = 3300 km). The salt deposition mechanism should be considered similar to the post-Trias water trapping mechanism which was active on African and South American facing margins at the time of the opening of the South Atlantic.

8. Global geodynamical pattern

In a recent paper (Scalera, 1998), I have described a model of a trench-arc-backarc zones without the need for the subduction concept: only a limited amount of underthrust is required. The model was initially created aware it was valid only for those zones in which active «subduction» is present, with a well-pronounced Benioff zone; typically the Japanese and Marianna arcs. The main aim was to provide an example of a process which could have the same surface (volcanics, ophiolite, accretion complex) and inner (metamorphism, focal mechanisms) effects as those observable. This model now has an urgent need to be extended to those zones in which an expanding Earth framework, and my paleogeographical constraints, prescribe unilateral opening of the Pacific basin, *e.g.*, Aleutian arc, West Laurentia. A fairly natural extension of the model can be obtained by considering the northern prolongation of the expanding South Pacific rise under California, the Basin and Range province, re-emerging in the Gorda and Juan de Fuca ridges and finally remaining hidden under West Canada and South Alaska. I simply would propose the unification of the geodynamic function of mid oceanic expanding ridges and back-arc zones: both are dilatation zones and can be a prolongation of one in the other. The way to make the model able to transform from «backarc spreading» (already published; Scalera, 1998) to «ridge spreading» is to take into account the real qualities of the Pacific advective flux which is shallow and inclined towards the Asiatic margin to the west, while on the east, under the Nazca triple point, the flux is steeper and vertically connected to the deep origin of the density anomaly (fig. 7), on the core-mantle boundary (Su *et al.*, 1992, 1994). The ocean floor spreading became effective in the North-East Pacific when the flux was able to emerge from the cover of the continental margin, as in the case of the Juan de Fuca segment. In the contrary case, north or south of Juan de Fuca, it continues to act as a dilatational agent applied to the few hundred kilometers inland, as in the Basin and Range province. The backarcs of East Asia are episodically open because no spreading ridge has emerged externally to the arc in order to drive the material advected from the interior onto the ocean floor.

All the advected material has contributed to the extension of the Asiatic and Indonesian marginal basins with a pattern of their sea floor ages (see the Larson *et al.* map, 1985) which is precisely what should be expected for a material flux able to produce a strong clockwise rotation of the Indonesian terranes during the magnetic quiet time of the Early Cretaceous. An analogous flux active also from the Triassic to the Cenozoic could be the cause of the clockwise rotation of India and Siberia, with the extension, still active today at an unexpectedly high rate, of the Chinese region (see Calais *et al.*, 1998, and the attached references), confirmed by the nature of the rift-related and intraplate basalts characteristics of the East Asia, continental China and Baikal regions recent volcanism (Zonenshain *et al.*, 1990). The lack at the present time of significant long and intercommunicating sea of Red Sea-type, in the Asia interior, could be due only to the modern minimum rate of global expansion revealed by the half rate spreading map of the world ocean (fig. 5.19 in McElhinny and McFadden, 2000 – based on Müller *et al.*, 1997). The interaction of this Asiatic extensional terrane against the obstacle constituted by the Indian craton, could be the cause of the morphological evolution of the Himalayan arc with its east and west Syntaxial bends.

The same cause, namely the global minimum expansion rate, could hinder the unambiguous geodetic revelation of global expansion. Also the accuracy with which the geodetic stations (on which to base the search for a radius variation) are selected can influence this. This possibility is supported by an analysis of space tracking data (Gerasimenko, 1993), searching for a change in Earth dimensions, which, using LAGEOS and VLBI data for stable non-orogenic continental regions, indicated an increase in the Earth's radius of + 4.15 ± .27 mm/yr. The need for 14. mm/yr, in my reconstructions, should be regarded only as an average on the window of geological time from the end of the Paleozoic to Recent.

The large superplume (fig. 7) which lies today under the Nazca triple-point (Su *et al.*, 1992, 1994), should be imagined in the Triassic to be located under the Eastern Asia - Indonesia region. The slow displacement of this superplume towards its modern position could explain the initial strong geodynamical activity which rotated India and opened the North-Western Pacific Ocean. Both the pattern and ages of the Western Pacific ocean floor volcanism (UNESCO, 1976) and the Darwin rise, appear as the trace of the slow southeastern displacement of the superplume.

The rising material exumed by the superplume (Su *et al.*, 1992,1994) in the Nazca triple-point region could be, at least partially, responsible for the secular variation of the rotation Pole position, whose path is, among many other not-realized possibilities, directed towards the Nazca plate at a rate of more than 10 cm/yr (Dickman, 2000). It should be stressed that only the data set (≈ 1850-2000) of the North Polar Motion is actually known, from the work of the stations of the International Service for the Latitude Variation (all located in the Northern Hemisphere) (Dick *et al.*, 2000). The lack of the South Pole data series and, consequently, of the comparison between the north and south secular variations, impedes the detection of differences

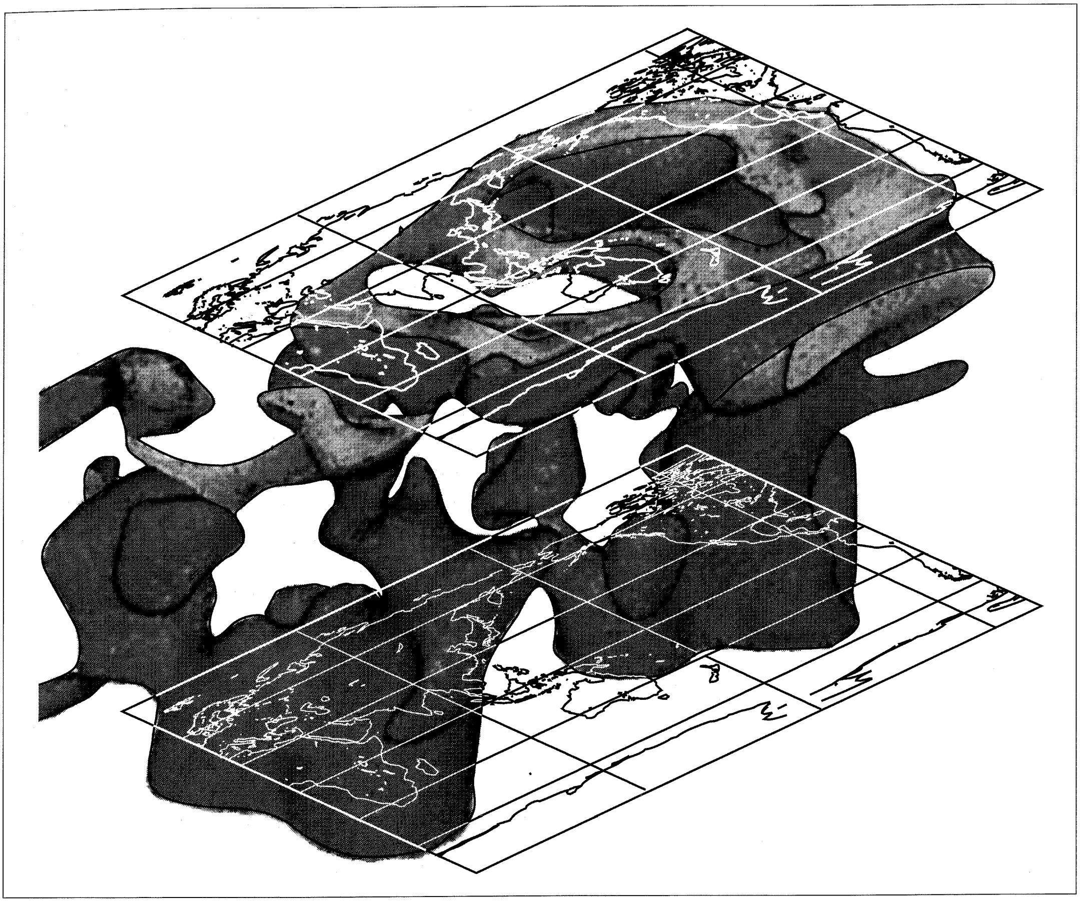


Fig. 7. The great geodynamic engine of South Pacific as revealed by seismic tomography (retraced from Su *et al.*, 1992, 1994, web source). The huge flow of less dense material from the core-mantle boundary has the surface effect of producing, in the region around the Nazca triple point, the maximum heat flow and the maximum ocean floor expansion rate. The reader should imagine the effect of the same dynamic structure from Trias to Creta, when the Earth was smaller than the actual size. The flow was probably located, in Trias ($R \approx 3300$ km), under East Asia and its action, lacking ocean floors, was exerted mainly on continental fragments. Drifting towards south-east the superplume has left the trace of the Pacific volcanism, the Darwin rise, and has favoured fast translations and also fast rotations like that undergone by India.

between the two paths, which are of great importance in supporting a possible asymmetrical expansion of the planet.

Finally it should be stressed that the main «scolio» of the global dilatation is the evidence of a slow deceleration of the Earth rotation, slower than that expected by a planet experiencing a strong variation of inertia moment. In my opinion, this difficulty in not so decisive against expansion because the same persistence of a geomagnetic field through geologic time reflects a mechanism of persistent alimentation of the energy font of the liquid core convective fluxes. The differentiation of the liquid core with a continuous accretion of the metallic solid core, and the consequent release of solidification heat

(Buffett, 1996; Kutzner and Christensen, 2001), could be the cause of the persistent Earth's magnetic field and of a negative contribution to the variation of inertia moment, able to compensate for the positive contribution due to global dilatation. The inversions of the field could properly be linked to the variation of the volume of the liquid core and to the consequent rearranging of the tubular convective cells. An analogous effect of differentiation should be expected at the core-mantle boundary. But other different effects providing a negative contribution to the inertia moment variation may be due to the still unknown physical process leading to expansion.

9. Conclusions

A main point of this work is that the unambiguous choice between a constant radius and an increasing radius geodynamic framework can be made on the basis of the possibility to define the paleoposition and kinematics of India from the Triassic to the Paleocene.

The method chosen in this research has been to ignore, at present, the physical reason for the expansion process, but to search for clues and interconnected compatibility of data in different fields, namely global morphology (Scalera, 1993a), paleomagnetism, sea-floor magnetism, kinematics of plates, geology, tectonics, paleontology, and climatology.

The well known problem of India, finds a new kind of solution, which is robust in that it concerns especially the paleomagnetic evidence and the lack of alternative solution, in the compact Trias plate mosaic in the dilatational framework. Strong evidence is the absence of detected ocean floor magnetic anomalies in the Cooperation Sea, where India has performed its rotation. For the same reason, the lack of a clear paleopole path in the time window of the Indian rotation could be related to a high rotation rate.

Still not completely satisfactory is the Madagascar kinematics, to which problem, deeper and specific study should be dedicated. A better correlation of the assembly of the Indian and Antarctic Triassic and Jurassic data, so far as they concern paleontology and paleomagnetism should be considered of fundamental importance for the present research. Also a reexamination of the magnetic survey data in the Cooperation Sea floor – or new high resolution surveys – should be performed, searching for a curved, non linear, pattern of magnetic anomalies. Finally a question that should be resolved is the overprinting of the Deccan Traps on the magnetizations of the older geologic periods in India. This overprinting could hide a smoother motion and slow rotation of India from the end of Trias to the time of the Deccan emissions. It would then be very interesting to re-sample on the field the complete APWP of India from the Trias to the Paleocene, searching for sampling-sites far from the Deccan Traps.

The paleogeography of the Triassic presented in this paper, while coherent with many data, should not be considered final, but only an initial step on the way to determining the possibility of Earth dilatation and its physical causes.

Acknowledgements

The procedures of extraction of Paleopole data existing on the Web Site of the Norge Geologiske Undersøkelse NGU (The Geological Survey of Norway; http://www.ngu.no/), based on the McElhinny and Lock (1990a,b) Global Paleomagnetic Database Project, have been essential for this work. Many people have read the preliminary manuscript. Among them Samuel Warren Carey sent advice and encouragement, Hugh Owen studied the initial version in depth, sending me corrections, criticisms and advice; John Davidson contributed a long argument and bibliographic references on the paleoposition of New Zealand and encouraged me to increase the number of topics relating to the Indian rotation. The paper has gained greatly in clearness and completeness from the suggestion of all these colleagues, but the responsibility in all the opinions and interpretations here expressed is entirely mine. Finally, an acknowledgement has to be made for the facilities I have taken advantage at the Istituto Nazionale di Geofisica and for the advanced cultural climate favoured by its President Enzo Boschi.

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(received October 20, 1999;
accepted February 15, 2001)