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The Earth expansion theory and its transition from scientific hypothesis to pseudoscientific belief

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Abstract. During the first half of 20th century, the dominant global tectonics model based on Earth contraction had increasing problems accommodating new geological evidence, with the result that alternative geodynamic theories were investigated. Due to the level of scientific knowledge and the limited amount of data available in many scientific disciplines at the time, not only was contractionism considered a valid scientific theory but the debate also included expansionism, mobilism on a fixed-dimension planet, or various combinations of these geodynamic hypotheses. Geologists and physicists generally accepted that planets could change their dimensions, although the change of volume was generally believed to happen because of a contraction, not an expansion. Constant generation of new matter in the universe was a possibility accepted by science, as it was the variation in the cosmological constants. Continental drift, instead, was a more heterodox theory, requiring a larger effort from the geoscientists to be accepted.

The new geological data collected in the following decades, an improved knowledge of the physical processes, the increased resolution and penetration of geophysical tools, and the sensitivity of measurements in physics decreased the uncertainty level in many fields of science. Theorists now had less freedom for speculation because their theories had to accommodate more data, and more limiting conditions to respect. This explains the rapid replacement of contracting Earth, expanding Earth, and continental drift theories by plate tectonics once the symmetrical oceanic magnetic striping was discovered, because none of the previous models could explain and incorporate the new oceanographic and geophysical data.

Expansionism could survive after the introduction of plate tectonics because its proponents have increasingly detached their theory from reality by systematically rejecting or overlooking any contrary evidence, and selectively picking only the data that support expansion. Moreover, the proponents continue to suggest imaginative physical mechanisms to explain expansion, claiming that scientific knowledge is partial, and the many inconsistencies of their theory are just minor problems in the face of the plain evidence of expansion. According to the expansionists, scientists should just wait for some revolutionary discovery in fundamental physics that will explain all the unsolved mysteries of Earth expansion.

The history of the expanding-Earth theory is an example of how falsified scientific hypotheses can survive their own failure, gradually shifting towards and beyond the limits of scientific investigation until they become merely pseudoscientific beliefs.

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1 Introduction

At the beginning of 20th century, the contracting-Earth theory had been the dominant geodynamic model (Suess, 1904; Wilson, 1959; Billings, 1960) for more than 50 years (Dana, 1863), supported by authoritative scientists, and in line with the accepted ideas on the origin of the solar system (Kelvin, 1864). Planetary contraction was so deeply integrated in geologists' vision that mobilism appeared barely scientific (Simpson, 1943) and continental drift remained a marginal and largely controversial hypothesis for over 50 years (for a discussion on the subject, see Ruse, 1978; Hallam, 1983; Frankel, 1987; Oreskes, 1988).

Indeed, the experimental data available to geoscientists, especially those deriving from geophysical tools that could provide penetration and accuracy in the investigation of the planet, was very limited or non-existent; therefore any geodynamic hypothesis could only be largely speculative, although promising. Once new geophysical tools became available, integrated with an increasing amount of traditional geological information, the validity of Earth contraction started to be challenged. After the discovery of radioactivity, and that radioactive decay generated heat inside the planet, a slower cooling rate had to be assumed for our planet (Joly, 1909), implying that Earth was not contracting at all or the contraction was too small to generate the observed tectonic structures. Furthermore, the radiometric age determinations (Holmes, 1913; Badash, 1989) were essential in determining a reliable timeframe for the geological events that contributed to the undermining of the contraction theory (Stinner, 2002). Finally, paleomagnetic studies were showing that diverging apparent polar wandering paths on different continents confirmed the change of reciprocal continents' position through time (Runcorn, 1956; Carey, 1958; Collinson and Runcorn, 1960).

The problems faced by the contraction theory stimulated the investigation of alternative geodynamic models, including expanding Earth (Lindemann, 1927; Furon, 1935, 1941; Carey, 1958; Heezen, 1959; Wilson, 1960), pulsating Earth (Joly, 1908, 1925; Haarmann, 1930), and fixist–mobilist hybrids (Van Bemmelen, 1966). Although geologists were clearly open to new ideas, Ruse (1978), Hallam (1983), Frankel (1987) and Oreskes (1988) showed that the large majority of Earth scientists rejected mobilism and favored the fixist alternatives. It was only the discovery of the seafloor magnetic striping that finally led to the abandonment of fixist geodynamic models through the development of plate tectonics (Vine and Matthews, 1963; Wilson, 1963; Vine and Wilson, 1965; Vine, 1966; Dickson et al., 1968; Heirtzler et al., 1968). However, the new plate tectonics theory had only a superficial similarity with continental drift, because all previous mobilist and fixist geodynamic theories became obsolete after the revolutionary advances that occurred in geophysics occurred during the 1960s. Plate tectonics quickly became the fundamental framework for Earth sciences, considered valid at least since 3–3.5 Ga (Condie and Kröner, 2008; Næraa et al., 2012). In its more than 50 years of existence plate tectonics has amply proved its ability to explain within a single context the most diverse geological phenomena, and it is supported by a great deal of evidence.

However, expansionism has not vanished at all in the Earth sciences community. Expansionist papers have been published in scientific journals, and sessions at the 30th International Geological Congress, Beijing (Dickins, 1996; Hongzhen et al., 1997), 32nd International Geological Congress, Florence (Anonymous, 2004), and 34th International Geological Congress, Brisbane (Anonymous, 2012; Choi and Storetvedt, 2012a, b) were dedicated to the expanding-Earth theory. Earth expansion has been the subject of specific symposia organized by major scientific institutions (Carey, 1983a; McKenna, 1983; Scalera et al., 2012). Finally, the Earth expansion theory has found some credit among biogeographers (Ager, 1966; Glasby, 1999; McCarthy, 2003, 2005a, b, 2007; McCarthy et al., 2007) because of some intriguing biogeographic transpacific correlations.

2 The expanding-Earth theory before and after plate tectonics

Like contractionism and continental drift,the expanding-Earth theory also has a long history, dating back to the 19th century; however, it remained a marginal idea until the beginning of the 20th century, when some geologists suggested the possibility of Earth expansion (Carey, 1975; Scalera, 2003a, b). While continental drift gained little consensus because of the scientists' problem in accepting planet-wide migration of continents (see Ruse, 1978; Hallam, 1983; Frankel, 1987; Oreskes, 1988), the expanding-Earth theory had the merit of explaining with a fixist model the evidence of ancient continental connections, suggesting that continents fragmented and dispersed not because of lateral displacement but because of radial expansion while the planet was inflating (Heezen, 1959). Indeed, because of the very schematic knowledge about the structure of the planet available at the time, there are some interesting parallels between Earth expansion and Wegener's theory. Wegener (1929) did not consider crustal subduction or mantle convection; he connected India to both Africa and Asia in his Paleozoic paleogeographic maps, and believed that continental crust floored the Tethys Sea. Moreover, some expansionists accepted, like Wegener (1929), that the Pacific Ocean was older than the Atlantic and Indian oceans, because they believed the planet expanded following a linear trend. Therefore, the images of Earth in expansionist and mobilist views were not so radically different at the time. This also explains the existence of mobilist–expansionist hybrid hypotheses and some geologists' shifts of opinion from mobilism to expansionism and vice versa (Carey, 1975, 1988).

The main argument for Earth expansion is the questionable claim that continental profiles have a perfect reciprocal fit on a smaller Earth, while mobilist reconstructions leave open gaps. To test this hypothesis, expansionists worked with tridimensional physical models of the planet, scaled at different sizes to verify the quality of the geometrical fit between continents on an increasingly small Earth (Carey, 1958, 1975; Creer, 1965; Barnett, 1969; Scalera, 2003b). The experimenters apparently failed to note that the process worked like a reversal of the contraction theory. Therefore, if the modern lithosphere had to adjust to a smaller Earth this would not just decrease intercontinental distances but also increase the deformation of the continents. What expansionists were also unable to provide was a valid mechanism increasing Earth's size, although the speculations of eminent astrophysicists and physicists provided some support to the possibility of planetary expansion. Hoyle (1948) proposed the steady-state cosmologic model, postulating the continuous creation of new matter in the universe, and Dirac (1937, 1938) published the large numbers hypothesis, which implied a change of the universal gravitational constant with time and the creation of new matter (Shneiderov, 1943; Jordan, 1966, 1973).

The discovery of the magnetic stripes on the bottom of the oceans was the crucial evidence that oceans were expanding, disproving the contraction theory, but expansionists could also present the initial, localized evidence of oceanic expansion as proof of planetary expansion. The persisting appeal of expansionist theories, or the difficulty to adopt mobilism, is confirmed by the several papers combining moderate expansion with limited drifting (Holmes, 1965; Hospers and Van Andel, 1967; Van Hilten, 1968; Owen, 1976; Steine, 1977) that were published during the transition years towards the widely accepted plate tectonics. However, improved and expanded geophysical data removed the reasons and uncertainties that initially motivated support for planetary expansion. Moreover, plate tectonics succeeded in integrating preexisting geodynamic hypotheses, like mantle convection (Holmes, 1929, 1931; Hess, 1962) and subduction (Wadati, 1935; Benioff, 1954, 1955; White et al., 1970; Schellart and Rawlinson, 2010), and support for Earth expansion rapidly vanished. Finally, the only supporters of expansion remained the radical expansionists that rejected any subduction (Carey, 1975, 1988; Vogel, 1994; Scalera, 1998, 2005a, 2006; Maxlow, 2002, 2012).

The sea-floor magnetic stripes ensure an excellent degree of confidence on post-Triassic oceanic crustal accretion rates and radical expansionists immediately converted the ocean expansion to the Earth inflation rate. The resulting Early Jurassic Earth diameter was 6600 km (Vogel, 1994; Scalera, 1998, 2005b, 2006; Maxlow, 2002, 2012), meaning that our planet had almost doubled its diameter in about 200 Myr (Figs. 2, 3). If the same rate of expansion (6600 km in 200 Myr) were linearly extrapolated backwards in time, the whole planet would not have existed before the Devonian (Fig. 3). Therefore, the various opinions among expansionists about the growth rate of the planet abandoned the option of a linear expansion in order to converge on the idea that Earth inflation followed an exponential trend.

Indeed, the pattern of the sea-floor magnetic striping provides the most striking evidence disproving Earth inflation (Fig. 1). Magnetic anomalies (Bird et al., 2007; Korhonen et al., 2007) and age (Heezen and Fornari, 1975; Mueller et al., 1993) maps of the ocean floors show that the ocean basins generated by the fragmentation of Pangea (Atlantic, Indian, and Southern oceans) are axially symmetrical. Every Mid-Ocean Ridge (MOR) runs along the geographical mid-ocean line, and divides two symmetrical sequences of parallel magnetic stripes of gradually increasing age from the MOR to the continent–ocean transition. Theoretically the symmetrical oceanic expansion could, of course, agree with both a constant-size planet, given that older crust is removed when new crust is added, and an inflating planet if subduction does not happen.

Furthermore, in the Pacific Ocean the MOR is the symmetrical spreading axis of two opposite sequences of magnetic stripes, so much so that the first magnetic profiles from the southern Pacific Ocean (Pitman and Heirtzler, 1966; Herzilier et al., 1968) were the most strikingly symmetrical ever recorded worldwide. However, the opposite continental margins of the Pacific Ocean do not fit together, although the complex arrangement of archipelagos, islands and peninsulas along the Asian coast can give plenty of opportunities for ad hoc adjustments (Fig. 1). Moreover, the East Pacific MOR runs very close to the American coast, terminating against the North American continental margin. The Chile Ridge forms a triple junction with the East Pacific Ridge, and terminates against the coast of South America. Finally, the MOR between Cocos and Nazca plates ends against Central America. If Earth were expanding, the abrupt terminations of ocean ridges against the continental margins would not be possible, because they should instead cross another transversely spreading ridge. For this reason, Carey (1983b, 1988) stated that mountain ranges are a different type of expanding ridge. Moreover, oceanic crust older than 50 Ma is missing along the American side of the Pacific Ocean, while along the Asian coast ocean crust dating to 180 Ma is largely preserved. Plate tectonics explains the missing oceanic crust through destruction via subduction at convergent plate boundaries, the asymmetric magnetic bands offshore California, and the ridge truncations (Anderson, 1971). The expansion theory is instead unable to explain how new oceanic crust could preferentially accrete along only one side of a MOR, or how expanding ridges could terminate against convergent margins.

Another characteristic feature of oceanic plates is the transform faults running from the MOR to the continental margins, parallel to the spreading direction (Menard, 1969). These structures have a dominantly vertical displacement, although they might also have a lateral component along strike and allow the rigid lithospheric plates to adjust to the

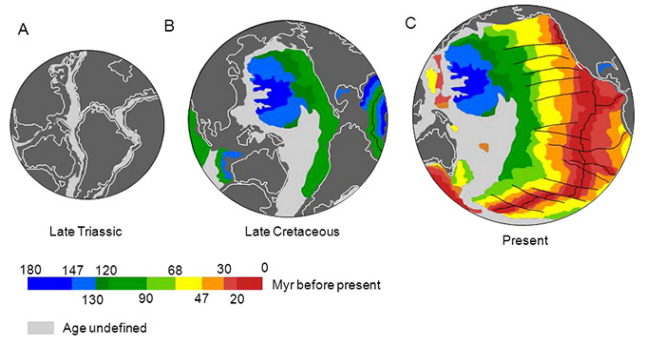

Figure 1. Planetary expansion, Pacific Ocean view, redrawn from McCarthey (2003, 2005b). **(A)** Late Triassic "dwarf Earth". Following expansionist reconstructions all the world oceans, including the Pacific Ocean, are closed, and opposite continental shelves are in direct connection on a whole-continental-crust planet. The light-grey areas of undefined age may be deep-water seas, although the central Atlantic did not exist in the Triassic. South America nests inside the Gulf of Mexico, distorting the Florida peninsula and removing the Yucatan to achieve a proper fit. It should be noted that according to Scalera (2007a) the restoration presented by McCarthey (2003, 2005b) is inconsistent. **(B)** Late Cretaceous dwarf Earth. The one-sided spreading of the Pacific Ocean is evident, with the spreading ridge supposedly coincident with the Pacific coast of the Americas. On the right is visible a section of the central Atlantic, showing a symmetrical spreading. The wide expanse of Jurassic Pacific Ocean (blue shades) implies that until the Cretaceous, North America and Asia drifted away from each other while South America remained connected to Australia and Siberia to Alaska. **(C)** Present-day Earth, showing the general asymmetry of the Pacific Ocean. McCarthey (2003, 2005b) does not provide his estimate for the radius of the Triassic dwarf Earth, but if it is scaled to the present-day Earth, its radius was 67 % of its actual length, significantly larger than estimates from other expansionists.

spherical surface of Earth, isolating adjacent sections with different spreading rates within the same oceanic plate (Wilson, 1965; Morgan 1968). As Carey (1983b) explained, if Earth were expanding, the crust should break with a radial pattern while the surface inflates, generating an arrangement of equidimensional plates resembling shrinkage cracks, or polygonal soils. Transform faults are weak lineaments within the plates, and they would be preferential areas where distension should act if the crust stretches under the push of the inflating Earth and plate margins radially recede from each other. Therefore, on an expanding planet, where the distensional component would largely dominate, a rift would develop instead of a transform fault, creating a network of expanding ridges connected by triple junctions (Fig. 4).

3 Physical consequences of an expanding planet

If Earth were expanding, there would be dramatic physical consequences: if the mass of the planet increased with its volume, a way to increase the mass must be found; if the mass remained constant while the volume increased, then there is the problem of explaining the consequent density change. Of course, variations in volume, mass and density will also change the planet's gravitational acceleration at its surface, with effects on atmosphere, hydrosphere and biosphere, and on other objects in space, the most affected being the Moon.

If Earth's mass has remained constant, and it was compressed in a planet with half of Earth's radius (Table 1), the average density would be nearly 40 g cm^{-3}. Moreover, the Archean volume of an expanding Earth should have been even smaller than the one at 200 Myr. As mentioned before, expansionists mainly support an exponential trend of Earth expansion. Estimates for the post-Triassic time use the oceans' spreading rates derived from ocean floor magnetic anomalies, but those for the preceding 98 % of Earth's history depend on accretion rates of the continental crust. The decreasing resolution of radiometric dating with increasing rock age and problems of the preservation of ancient rocks and accessibility due to erosion, metamorphic recycling and burial would of course complicate the restoration. If the simple assumption is made that Earth's radius has doubled every 200 Myr, primordial Earth at its formation, 4.5 Gyr ago, would have had a radius of just a few meters. Therefore, the expansionists had to find an initial planetary size that could fit the supposed exponential trend without giving too unrealistic outcomes. Maxlow (2002, 2012) used a global map of the world to calculate the size of Archean Earth, removing continental sediments and crystalline rocks of increasing age. Although this is a largely questionable approach, because it groups, in the same cluster, rocks formed during time intervals spanning about 2 Gyr, Maxlow (2002, 2012) estimates an initial Earth radius of 1700 km, almost equivalent to the radius of the Moon or slightly larger than Earth's inner core (Fig. 2). This is the smaller primordial-Earth radius proposed by the expansionists and, because of the supposed exponential expansion trend, lasted for 3.5 Gyr, until the Neoproterozoic. In the case of the 1700 km Archean radius of Maxlow (2002, 2012), Earth's density would have been 290 g cm^{-3}.

Earth's surface gravity would also be higher if the planet's mass were compacted into a smaller volume: if Earth's mass were concentrated in half of its present diameter, the surface gravitational acceleration 200 Myr ago would have been 36.6 m s^{-2}. The surface gravity of a 1700 km radius Earth would be 138 m s^{-2}. Even expansionists find these figures unlikely, so they claim that, when Earth was smaller, its mass was also lower and somehow increased together with the increasing volume. This could have happened following two very different patterns: Earth's mass has increased with size but the average density has remained constant, and therefore the surface gravity has increased, or the average density of the planet decreased while its mass increased and the surface gravity remained constant (Table 1, Fig. 3).

If a planet has the same density as Earth but only half its radius (Fig. 3), the surface gravitational acceleration would be only 5 m s^{-2}, slightly higher than those of Mars or Mercury,

Table 1. Physical parameters of Earth (first line) compared to the Moon, the internal planets of the solar system, and different scenarios of "dwarf Earth", with one of the planetary parameters (in brackets) maintained equal to present-day Earth values through the hypothetical planetary expansion. J1, J2, J3: Early Jurassic dwarf Earth with 6600 km diameter, where mass, density and surface gravity, respectively, have been kept constant. A1, A2 and A3: Archean (4500 Ma) dwarf Earth with size according to Maxlow (2001, 2002, 2012), where mass, density and surface gravity, respectively, have been kept constant. In brackets are the planetary parameters left constant in each scenario. Although Mercury's size comparable to Mars and the Moon, its average density is close to that of Venus and Earth because of the large size of its metallic core.

	Diameter km	Surface area $\times 10^{12}$ m^2	Volume $\times 10^{19}$ m^3	Mass $\times 10^{22}$ kg	Density g cm^{-3}	Surface gravity m s^{-2}
Earth	12 742	510	108	597	5.5	9.8
Mercury	4880	75	6	33	5.4	3.9
Venus	12 102	460	93	487	5.2	8.8
Mars	6800	145	16	64	3.9	3.9
Moon	3476	38	2	7	3.3	1.6
J1	6600	137	15	[597]	39.7	36.6
J2	6600	137	15	83	[5.5]	5.1
J3	6600	137	15	160	10.6	[9.8]
A1	3400	36	2	[597]	290.4	138.0
A2	3400	36	2	11	[5.5]	2.6
A3	3400	36	2	42	20.7	[9.8]

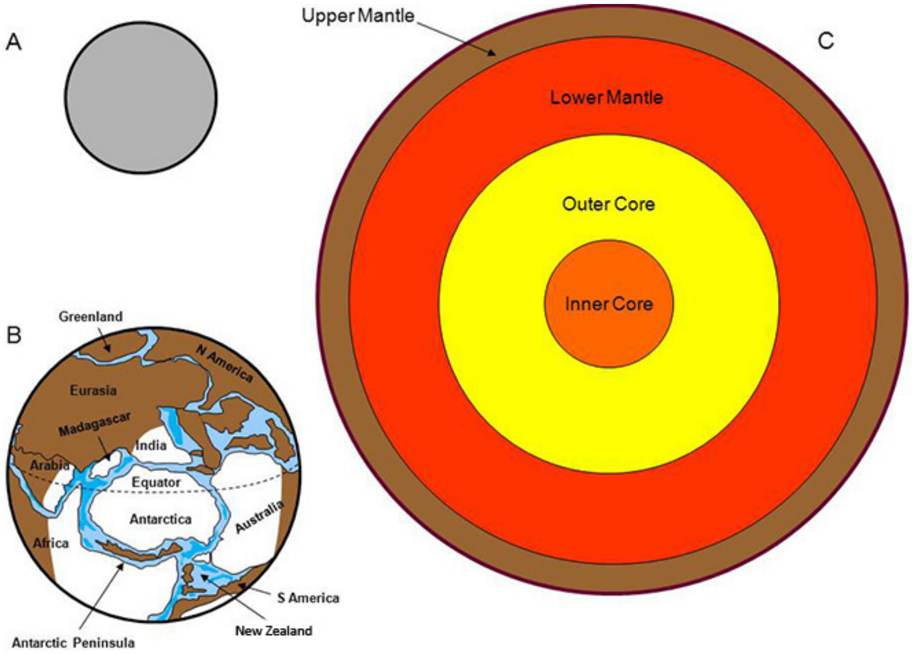

Figure 2. **(A)** 1700 km radius Archean dwarf Earth of Maxlow (2002, 2012). **(B)** 3300 km radius Late Triassic dwarf Earth from Maxlow (2002, 2011, 2012) and Scalera (2003b, 2005b, 2006, 2007a). **(C)** The internal structure of Earth. All planets are drawn at the same scale. The paleogeographic restoration in **(B)** is based on Scalera (2006, 2005b, 2007a). Scalera (2006, 2007a) does not provide a color scheme, but brown most likely indicates emerged areas, light blue shallow seas, and dark blue deep water. The white areas, which are not in the original images of Scalera (2006, 2007a) and Maxlow (2011, 2012), indicate the areas covered by the Permo-Carbonifeorus ice cap in standard paleogeographic maps. New Zealand and the Antarctic Peninsula were free of ice cover because they were submerged or outside of the glaciated areas. The ice cap also did not reach the western side of South America. If the expansionist interpretation were correct, the ice cap would have extended across the Equator, unless the whole planet had shifted its rotational axis from the Carboniferous to the Triassic. Moreover, if Pangea completely enveloped the planet, remains of a second ice cap should exist on land masses on the opposite pole. Extension of epicontinental seas notoriously varied in Earth's history, but during the Permo-Triassic they covered a limited fraction of Pangea; therefore, the expansionist dwarf Earth in the Late Triassic should have been mainly emerged, with isolated sea basins, as it is also shown in Scalera (2006, 2007a).

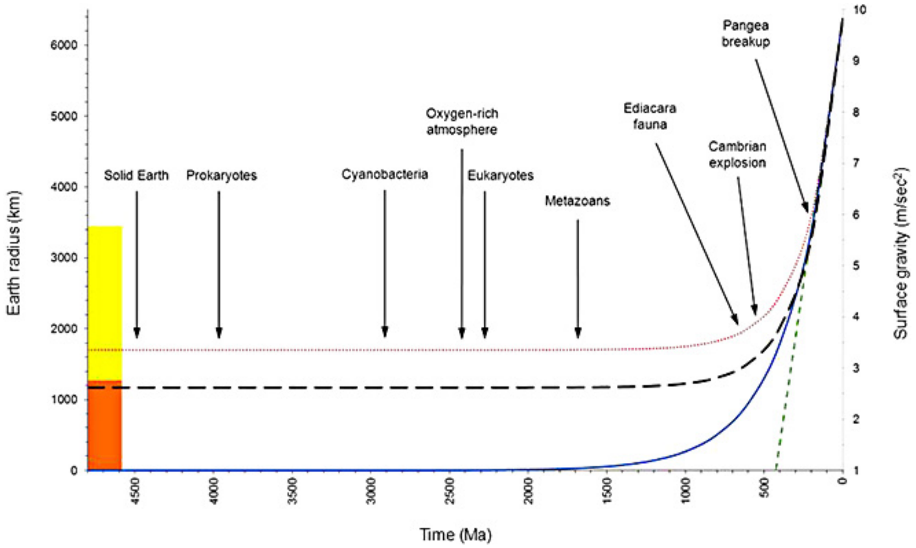

Figure 3. Variations in the planetary radius and surface gravity of an Earth expanding its size through time according to different scenarios. Major events in Earth's history are indicated at the relative time of occurrence. The orange and yellow blocks on left-hand side correspond to the radial extensions of Earth's inner core and outer core, respectively. Short-dashed line: linear trend of planetary expansion extrapolated by post-Triassic oceanic expansion (3300 km/200 Myr). Solid line: exponential trend of planetary expansion extrapolated by halving Earth's diameter every 200 Myr. Dotted line: exponential trend of planetary expansion calculated using the formula from Maxlow (2012). Long-dashed line: Earth's surface gravitational acceleration with increasing planetary radius following the exponential trend of Maxlow (2012) if a constant average density of 5.5 g cm^{-3} during expansion is hypothesized. Crucial events in Earth's history should have happened in reduced gravity, similar to the gravity of Mercury or Mars.

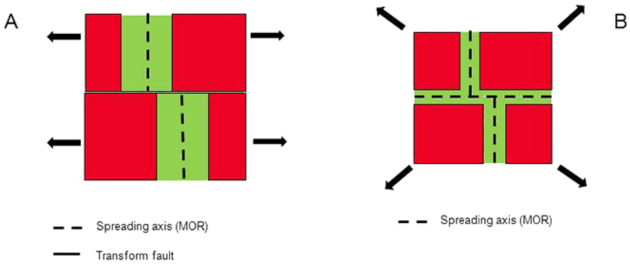

Figure 4. (A) Transform faults on a constant-size planet divide adjacent sections of the same oceanic plate expanding at different speeds. **(B)** On an expanding planet, every plate recedes from the adjacent ones, increasing the distance by moving radially. Therefore, no transform fault is needed to accommodate differential spreading rates, and a network of triple junctions and connecting spreading ridges would surround equidimensional plates.

which have an extremely thin atmosphere and no liquid water (Lammer et al., 2008). The 1700 km radius Archean Earth of Maxlow (2002, 2012) has almost the same size of the Moon, and its gravity would be about 2.6 m s^{-2}: the possibility that such a small gravitational force could retain any atmosphere at all is negligible and clearly disproved by analogue objects in the solar system. It is also very unlikely that the Moon would have orbited Earth if our planet had such a low gravity. Moreover, following the trend of Maxlow (2012), the 1700 km radius Earth lasted until the Neoproterozoic (1 Ga) and the "dwarf Earth" did not reach the size of Mercury, and a surface gravity of 3.8 m s^{-2}, before the Devonian. Then, if a constant density is postulated through the supposed Earth inflation, conditions were of extremely reduced gravity and there was only a minimal atmosphere for at least 90 % of the planet's existence. However, crucial events in Earth's history, like the formation and retention of the atmosphere, the accumulation of liquid water on surface, the evolution of life, of the eukaryotic cells, the development of metazoans and vertebrates, and many geological data require physical conditions similar to those of the present day to have persisted for almost the entire history of our planet (Margulis and Lovelock, 1974; Kasting, 1993; Allègre and Schneider, 1994; Mojzsis et al., 1996; Anbar et al., 2001; Wilde et al., 2001; Fedonkin, 2003; Lunine, 2006; Netman et al., 2007; Schopf et al., 2007; Nystuen et al., 2008; El Albani et al., 2010; Hickman and Van Kranendonk, 2012; Van Kranendonk et al., 2012). Therefore the hypothetical dwarf Earth should have maintained almost the same surface gravity as present-day Earth.

From the discussion above it is clear that a dwarf Earth could have the same surface gravity as the actual Earth only if it is denser than our planet (Table 1). For a 3300 km radius Earth the minimum average density is close to 11 g cm^{-3}. Exoplanets of similar or higher density are currently modeled and have possibly been detected (Seager et al., 2007), but this dwarf Earth would entirely consist of the metallic core, without any silicates to form the crust and mantle. Such a Mars-size, full-metal object has no equivalent in the entire solar system, although Mercury could represent the closest example of a planet largely consisting of metal, because its iron core makes up a large part of its volume and mass (Harder and Schubert, 2001). However, this is unusual compared to other terrestrial planets and it is not believed that Mercury originally formed with a higher metallic component, but that it has lost a large fraction of its original mantle because of collisional erosion (Rubie et al., 2007). Of course, it should be considered that the 3300 km radius dwarf Earth is only an intermediate step from an even smaller dwarf Earth. The 1700 km radius Earth of Maxlow (2002, 2012), which should have lasted for about 80 % of Earth's history, would require an average density of 21 g cm^{-3}, higher than the density of Earth's inner core, to have the same surface gravity of Earth. Moreover, the inexplicable average density transition from 21 to 5.5 g cm^{-3} should have been fine-tuned in relation to the size change to maintain a constant gravity. Finally, it should be considered that even if the dwarf Earth had the same surface gravity of the actual Earth, this does not mean that the gravitational force is the same for the two planets because, although denser, the dwarf Earth has a much lower mass than the real Earth and therefore generates a lower gravitational force. This means that the Moon could not have maintained its orbit around Earth.

The physical parameters of a dwarf Earth also conflict with our knowledge of Earth's internal structure. Like all other planets, Earth consists of concentric layers characterized by different density, composition and physical state. Below the thin outer shell of the crust, the solid silicate mantle is further divided into layers of different mineralogical composition because different minerals are stable at different pressures and temperatures (Fig. 2). The inner core is solid, but consisting of an iron alloy with nickel and some lighter elements, while the outer core is liquid because its temperature is higher than the melting point for the same iron alloy at the pressure existing at that depth. This internal structure of Earth formed because the energy released by impacts with other planetoids partially melted the undifferentiated Earth. Immiscible liquids segregated in the molten mass and the liquid iron accumulated towards the bottom of the lava ocean, and then moving further down towards the center of the planet, displacing the lighter elements that migrated towards the surface, finally forming separate concentric layers via gravitational differentiation (Rubie et al., 2007).

Assuming that the supposed dwarf Earth developed as Earth evolved, from the aggregation of planetesimals followed by partial melting due to impacts and finally internal differentiation, the existence of the outer liquid core is problematic. As mentioned above, the Archean dwarf Earth of Maxlow (2002, 2012) is only a little larger than Earth's inner core, while the Late Triassic dwarf Earth is slightly larger than Earth's outer core. If the Archean dwarf Earth already had a liquid outer core, this must have opportunely increased its thickness and internal radius while the planet inflated, although it is questionable whether an iron alloy could exist in a liquid phase in a high-density object like the dwarf Earth. On the other hand, if the original dwarf Earth had no liquid outer core, this must have appeared at some stage of the planet's expansion, possibly after the dwarf Earth had reached a size larger than the one of Earth's core. Given the timing of the planetary inflation suggested by the expansionists, the liquid outer core must have suddenly appeared or rapidly expanded within just a few million years. At the same time, the mantle mineralogical layering should have also rapidly formed and radially expanded or shifted while the planetary size and mass increased. This rapid planetary differentiation and evolution is contradicted by our understanding of Earth's interior. Integration of seismic data, thermodynamic models, laboratory experiments, and analysis of xenoliths and xenocrystals provide an increasingly accurate picture of the deep Earth, its physical and temperature conditions, internal dynamics, chemical composition and stability phases at different depths (Saxena, 2010). Although different models could fit the same set of data, the range of variations is strictly constrained and leaves no room for a smooth (i.e., non-catastrophic) planetary expansion.

The expansionist hypothesis also has implications conflicting with Earth's thermal history. Although the decay of radioactive elements increases Earth's internal temperature, and short-lived radioactive elements might have been an important source of internal heat, the impacts were the major contributor to the internal thermal energy of the planet (England et al., 2007; Rubie et al., 2007). Therefore, if the expansionist dwarf Earth formed as the actual Earth did, the initial thermal energy accumulated by the smaller mass planet would have been lower than that of the full-sized Earth, and it would have largely dissipated during the extensive length of time the dwarf Earth maintained an almost constant size (Fig. 3). A different source of internal heat, able to increase the internal temperature of the inflating planet to the point of melting the outer core, must be found. This heat source must have also not been active until the planet had appreciably increased its size, or the dwarf Earth would have probably never solidified.

4 Exotic physics for an expanding planet

Several different mechanisms have been proposed over the years to explain the supposed planetary expansion, but even Carey (1975), listing the existing expansion theories, commented that none of them was convincing, and expansionists are still discussing the same wide range of solutions today (Scalera, 2003b; Maxlow, 2012). Expansionists have not been deterred by their inability to offer a plausible expanding mechanism; instead their failure in finding an explanation within the accepted physical laws had the effect of increasing their reliance on pseudoscientific solutions.

Possible mechanisms suggested for the growth of planetary volume and mass are the aggregation of material from space, or the generation of new material inside the planet. The accretion of cosmic material might seem at first a reasonable hypothesis for planetary mass growth. All bodies in the solar system formed by the aggregation of gas and dust in the primitive solar nebula, and extraterrestrial material is constantly falling on Earth (Bland et al., 1996; Peucker-Ehrenbrink, 1996; Karner et al., 2003; Yada et al., 2004; Zolensky, 2006), sometimes with very dramatic effects (Alvarez et al., 1980; French, 1998; Chapman, 2004). However, during the formation of the solar system, the growing planets cleaned their orbits of residual material and, when the Sun reached the necessary mass to trigger nuclear fusion reactions, the solar wind expelled what remained of the original cloud (Taylor, 2001; Righter and O'Brien, 2011). Clearly, the bulk of mass growth of the Sun and the planets must have occurred early in the life of the solar system, leaving only little material for further accretion, in striking contrast with the possibility of an exponential growth. Moreover, since the material rains down from space like a snowfall, the Jurassic crust should be buried below thousands of kilometers of younger rocks.

The alternative hypothesis is that new mass is continuously generated inside the planet (Carey, 1988; Edwards, 2006; Betelev, 2009). This idea could find support in the hypothesis of Hoyle (1948) and Hoyle et al. (1993) that new matter is being created in the universe to sustain the model of a steady-state universe. Not only has evidence of this process never been found but the cosmic microwave background radiation discovered by Penzias and Wilson (1965) is considered crucial proof against a steady-state universe (Smoot, 2006). However, even if the hypothesis of Hoyle (1948) and Hoyle et al. (1993) were confirmed, further problems would arise. Any new matter generated in the universe must be in the form of elementary particles: as Hoyle (1948) explained, magnetic neutrality of the universe requires that newly generated particles be neutrons; therefore the neutrons must somehow combine to generate the various elements. However, nucleosynthesis of light elements (H, He, Li, Be) occurred within seconds to minutes of the Big Bang at high-temperature, high-density conditions not existing anywhere in the universe today, while the nucleosynthesis of heavier elements can only happen inside stars and during supernova explosions through processes requiring physical conditions not existing inside planets (Wallerstein et al., 1997). Moreover, even if newly created neutrons could possibly emerge inside Earth, they would soon decay to protons and electrons with emission of antineutrinos. If the neutrons were captured by preexisting elements, the resulting unstable isotopes would also decay, emitting antineutrinos. The geoneutrino flux is currently measured in various underground laboratories worldwide with the aim of measuring the amount and distribution of heat-producing radioactive elements, and the results of these experiments agree with a reference Earth model based on standard geophysical theories (Dye et al., 2008; Huang et al., 2013). According to Scalera (2003b) the rate of new matter generated inside Earth since the Early Jurassic is 1.37×10^{16} kg yr^{-1}, while, according to Betelev (2009), the rate of mass increase is 5×10^{15} kg yr^{-1}, and the bulk of this mass will emit antineutrinos within a very short time of its appearance. Huang et al. (2013), in their reference model of heat-producing elements, estimate the amount of U, Th and K radioactive isotopes in the planet to be 5×10^{15} kg. Considering the half-life of U, Th and K, only a fraction of this mass decays every year, emitting antineutrinos. Undoubtedly, the geoneutrino flux emitted by the supposed annual increment of Earth's mass would largely exceed the flux due to the decay of radioactive elements, and the geoneutrino detectors would not have missed this contribution.

Expansionists also suggest that the gravitational constant decreased over time (Shneiderov, 1943; Jordan, 1966, 1973; Blake 1978; Yabushita, 1982; Scalera, 2003b; Völgyesi, 2006), an idea already proposed by Dirac (1937, 1938). Therefore, even if Earth has increased in mass over time, the gravitational force would remain almost constant. This was a likely assumption before the discovery of the ocean magnetic striping and the large-scale magnetostratigraphic correlations, when expansionists still favored a slow and linear Earth expansion. As mentioned above, the systematic determinations of the oceans crustal ages, and the magnetic striping correlations at the oceanic scale, clearly indicate that no in situ oceanic crust older than the Early Jurassic is preserved; therefore the expansionists faced the possibility that the planet's radius rapidly extended by 3300 km in about 200 Myr and the idea of an exponential expansion was introduced. Apart from the inconvenience that, despite the large number of measurements made, evidence of any change of the gravitational constant has not been found, the variation of the gravitational constant should have followed the same exponential trend of the planet size, and this would have had detectable effects on the entire universe.

5 Biogeographical correlations and geological lineaments

The idea of planetary expansion is not restricted to a limited group of heterodox Earth scientists, because it has won the support of at least some biogeographers. According to Ager (1986), Glasby (1999), McCarthy (2003, 2005a, b, 2006, 2007), McCarthy et al. (2007) and Scalera (2007a), a direct connection between the opposite American and Asian coasts could explain some cross-Pacific biogeographical correlations. Removing the Tethys Ocean in a smaller planet should also solve uncertainties about the size and position of India during the Mesozoic and explain evidence of faunal connections between continents divided by the Tethys (Patterson and Owen, 1991; McCarthy, 2005a, b). These biogeographical problems have been addressed using various traditional approaches (Hallam, 1986; Stanley, 1994; Holloway and Hall, 1998; Briggs, 1989; Sanmartín and Ronquist, 2004; Sanmartín et al., 2006; Ali and Aitchison, 2008; Noonan and Sites, 2010; Goswami et al., 2011; van Hinsbergen et al., 2012), and the expansionist claims have been already refuted in various papers (Thewissen and McKenna, 1992; Briggs, 2004, 2006; Ali, 2006; Ali and Aitchison, 2008). However, this case probably merits some further consideration because, as expansionists like to remember, although biogeographic correlations were probably the clearest evidence supporting ancient continental connections (Wegener, 1924), contemporary geologists and paleontologists still persisted in denying mobilism. Once more it appears that expansionists tend to concentrate on small discrepancies, which seem to be solved by the expansionist solution, but fail to see the much larger consequences generated by their explanation.

According to expansionism, continents entirely covered the surface of Earth from the Archean to the Late Triassic (Figs. 1 and 2); the Atlantic, Indian and Southern oceans did not exist before the Pangean break up; the Pacific Ocean formed in the Early Jurassic; and the Tethys Ocean was a narrow epicontinental sea. The expansionist paleogeographic reconstruction has radical implications: geologic record indicates that the global sea level was especially low during the Permo-Triassic, continental conditions prevailed across Pangea, and epicontinental seas had limited extension. Therefore, the sea surface in the supposed Permo-Triassic dwarf Earth had lower extension than land areas. It is likely that the sea-to-land ratio in pre-Permian expansionist dwarf Earth was similar to the Permian figure, because although the area covered by epicontinental seas widely changed during Earth's history, most of the sea areas on Earth belong to ocean basins and expansionists claim that no oceans existed before the Early Jurassic. On modern Earth, water covers 70 % of the planet's surface, but submerged continental shelves represent only 10 % of the planet's surface. Removing all oceans, and recalculating the percentages for a whole-continental-crust planet, land would cover 75 % of the surface, leaving only 25 % as sea. A similar arrangement should have provided opportunity for the most extensive homogenization of the terrestrial ecosystems, allowing easy migration pathways for land animals and vegetation. However, against the very limited number of apparently anomalous trans-Pacific connections, the bulk of the fossil record allows ancient biogeographic zones and migration barriers to be identified. On the other hand, if the land areas were more extended than seas, marine biota should have been isolated in unconnected epeiric seas, while the fossil record indicates that there was no such segregation. A low sea / land ratio also has implications for the climate and marine circulation of the dwarf Earth and it is not compatible with current understanding of pre-Permian reciprocal positions of continents (Torsvik et al., 2002; Cocks and Torsvik, 2006).

Once the supposed inflation accelerated the expansion of Earth at the end of the Triassic, the Gondwanan continents broke off from Laurasia and rapidly moved away from each other, but India and Australia remained attached or very close to Asia. Therefore, the present-day narrow link between Southeast Asia and Australia through the Indonesian archipelago would only be the vanishing thread left from a formerly extended connection involving Australia, Southeast Asia, India and South America. However, there is no indication that Australia and Asia ever shared a similar fauna in the past, and today the Wallace Line (Wallace, 1876; Moss and Wilson, 1998) still divides the radically different Asiatic and Australian biogeographic regions. Expansionists might claim that the Tethys epicontinental sea divided India from Asia, preventing faunal and floral exchange, but there are several very well documented examples of long-range migrations between continents isolated by continental seas. The Proboscidea dispersed from Africa to all other continents (Australia, remarkably, not included), the Camelidae dispersed from North America to South America, Eurasia and Africa (again, not Australia until British colonization), and the Equidae repeatedly migrated from North America to Eurasia and Africa. Moreover, the Pleistocene Great American Interchange (Marshall, 1988) shows that rapid and massive migrations can occur across long latitudinal distances and different climatic zones, and the separation of India from surrounding continents did not apparently prevent faunal interchange (Briggs, 1989).

Therefore, to explain the controversial trans-Pacific correlations following the expansionists's approach, biogeographers need not only abandon a well-supported geodynamic model to embrace a theory that violates basic physical laws and rejects traditional explanations that are considered valid in many other occasions, but they must also neglect the existence of the most striking biogeographical boundary on the entire planet dividing regions that, according to the inflation theory, were in direct contact for billions of years. They must also discard all pre-Permian biogeographical data, which could not fit a model where all continents are reciprocally connected and never changed their relative positions.

6 Conclusions

Science is an essentially anarchist enterprise, and many irrational motivations can concur in a theory's success or failure (Feyerabend, 1975). Moreover, regardless of the amount of confirming experiments and observations, a scientific theory can always prove wrong (Popper, 1959). On the other side, the theory's supporters could actually decide that contrasting evidence is not actually disproving the theory but just challenging a subordinate part of it (Lakatos, 1978). The observed anomalous precession of Mercury was not believed to be a good reason to abandon Newtonian general gravitation until Einstein's relativity theory showed that Newtonian laws do not apply under these specific conditions. Regardless of these limitations, when more data are collected, the increasing constraints decrease the freedom for speculation, helping to discriminate and abandon the theories less efficient in explaining the data (Kuhn, 1962; Lakatos, 1978). The geocentric planetary model could prevail on the heliocentric system for about two millennia, with the late addition of Tycho's geoheliocentric compromise, until the new observations performed by Galilei using the telescope allowed for astronomers to select the model providing the best description of the solar system.

After more than 50 years of competition, and occasional reciprocal influence, between contractionist, expansionist and mobilist geodynamic theories, the discovery of the seafloor magnetic stripes led to the introduction and general adoption of plate tectonics. Since this revolution in the Earth sciences, the persistence of expansionism was only possible because of the systematic rejection of any contrasting data, and the selective adoption of those data that could fit the theory. While expansionists fully accept divergent margins, they deny subduction, although the evidence supporting both margin types are based on the same kind and quality of geological data (earthquakes' magnitude and depth of hypocenters, gravimetric and magnetic anomalies, geothermal gradients, GPS measurements, seismic profiling and metamorphic assemblages). Expansionists also fail to appreciate that the pattern of mid-ocean ridges and magnetic striping on the bottom of the Pacific Ocean is incompatible with planetary expansion. Moreover, expansionist paleogeographic reconstructions fail to explain how, during the Paleozoic, portions of modern continents moved around the planet, rearranging themselves in the most unexpected patterns (Burke et al., 1976; Dalziel et al., 1994; Torsvik, 2003; Meert and Torsvik, 2003).

While expansionists claim that Earth scientists dogmatically follow a theory (plate tectonics) falsified by geological data, they promote or incorporate borderline and pseudoscientific ideas, including generation of new matter inside Earth, variation of cosmic constants, and exotic matter transformations, conflicting with accepted physical theories. Several combinations of these largely unorthodox theories are used as possible explanations of the mechanism of planetary inflation. Despite almost a century of speculation on the various possible mechanisms advocated to explain Earth inflation, expansionists are still unable to select at least one of these hypotheses as a promising line for further investigation. They also admit that, according to current science, many solutions are physically impossible. However, they do not infer from this conclusion that the theory itself might be wrong, but rather that our knowledge of fundamental physics is inadequate and a scientific revolution is needed.

Although the extraordinary results achieved by plate tectonics do not mean that this theory could not be further improved, or that a better geodynamic model could not be found, Earth expansion is clearly not a viable candidate to replace plate tectonics.

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