CAUSE OF EAST-WEST EARTH ASYMMETRY
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Introduction. Many efforts to explain some asymmetric characteristics of our globe and of the global tectonics have been made (Bostrom, 1971; Stevenson and Turner, 1977; Marotta and Mongelli, 1998; Doglioni et al., 1999; Carminati and Doglioni, 2012) most of them using the implicit or explicit assumptions of plate tectonics geodynamics.

A non exhaustive list of asymmetries of the Earth is: The magnetic polarity (Gilbert, 1600); The land-hemisphere and the water-hemisphere; southern tips of the continents (Bacon, 1620; Mantovani, 1909; Barnett, 1969; Carey, 1996; among others); Larger extension of expanding mid-oceanic ridges on the southern hemisphere. South-eastward trend of younger ages in the long Pacific seafloor volcanic chains; A larger width of the seafloor isochrones bands on the Nazca region; A pear-shaped Earth; etc. Many other additional asymmetries have been described [see for a review: Carey (1959, 1963)].

It is a few decades that the different slopes of the Wadati-Benioff zones oriented towards the east and west has been enclosed in the list of asymmetries of the Earth. Namely, the alleged subductions under the Americas have an angle of about 30°, while under the east Pacific coasts (Asia, Japan) the angle is steeper (Luyendyk, 1970; Isaacks and Barazangi, 1977; Riguzzi et al., 2010; and many others). The cause of this difference has been identified by main stream in the tidal drag that would cause a global shift of the lithosphere towards west (the so called “westward drift”).

The Coriolis inertial effect. The unavoidable existence of the Coriolis fictitious force on a rotating Earth (Gerkema and Gostiaux, 2012; Gerkema et al., 2008) has inspired several authors to search for the possible effects of this solicitation on the surface observable tectonic features (Van Bemmelen, 1971; Rance, 1967; Howell, 1970; Kane, 1972; Hughes, 1973; Storetvedt, 1992; Pan,1993; Donescu and Munteanu, 2011). In the opposite party was Jeffreys (1928) and many others up to our days (Jordan, 1974; Ranalli, 2000; Ricard, 2007; Doglioni et al., 2011), whose main argument is the extremely large viscosities of mantle, and the consequent assumption that the inertial terms in the Navier-Stokes equations are negligible.
In a Coriolis-effect-free Earth’s mantle, the westward drift of tidal origin of the lithosphere has been adopted by main stream (Bostrom, 1971; Doglioni et al., 2011; among others) as explanation of the East-West asymmetry of the Wadati-Benioff zones, with additional assumptions. But the same argument of high viscosity can be used to reject the westward drift because the negligible value of tidal force in comparison to viscous friction (Jordan, 1974; Ranalli, 2000; Caputo and Caputo, 2012).

In the first years of plate tectonics the hypothesis was proposed that the plates could be decoupled from underlying mantle at level of asthenosphere, but Jordan (1974) proved that the depths of oceanic and continental lithospheres are very different and that the roots of continents can be detected up to 350 km. The consequent undulations of the ideal surface that defines the roots of oceans and continents do not allow for a tidal westward drift on it. Plate tectonicists have resolved the problem by hypothesizing a thin low viscosity layer at the depth of about 400 km, immediately upon the transition zone but still not observed by seismology (Caputo and Caputo, 2012). Besides the lacking of evidence in favor of this thin layer, evidence exist of regional upwelling of the 400 km discontinuity (Scalera et al., 1981; Piromallo and Morelli, 2003). The evidence of strong undulations of transition zone produces consequent problems in the hypothesized thin low viscosity layer, which could be uplifted by the upwelling transition zone or cutted and interrupted by it – a difficulty for the horizontal motion of the plates in the explanation of the E-W asymmetry without Coriolis effect.

Although the mutual importance of all the forces acting on the mantle materials must first be assessed, it is important to note that the observable facts seem to indicate a non-negligible action...
of the inertial Coriolis effect triggered by the Earth’s rotation. Indeed, the Earth is rotating from West toward East and consequently each vertical motion directed from the depths towards the surface should be deviated away from the perfect verticality by a sufficiently strong Coriolis force, undergoing a bending toward west (Fig. 2b). Obviously, the extrusion of mantle materials would not occur along perfectly vertical tracks, but following already existing discontinuity lines. For example the emerging flows adjacent to the western continental margins must have born already with a bending to west, and a more pronounced bending will be the result of the long time of action of the inertial force. If, on the contrary, the flows are near the eastern continental margins, starting already with an eastward bending, the Coriolis force will make them more vertical. The Pacific ocean-floor volcanism is more developed on the western side of the median ridge, and also this can be argued as caused by the prolonged westward action of the Coriolis force that possibly is able to detach “macro-drops” of rising materials and to lead them along more west directed bending paths.

Also the asymmetric topography across the rift zones, the compositional, thermal and density asymmetries (Doglioni et al., 2011), could find an integrated explanation in which the first cause is the Earth’s rotation and the consequent inertial forces. In the same way that the gravity force operates as a sort of filter that drives the lighter compounds towards the surface and the heavier ones towards the geocenter, the Coriolis force could constitute an “E-W filter”. It could drive the heavier minerals towards west, where they appear as constituting a “fertile mantle”, while a “depleted mantle” is the result to east.

In the present short note, before to deal with the Coriolis effect, a reflection has to be made about the possibility of motion of the mantle as a fluid, namely of convective motion in the mantle.

The Reynold Number. In fluid mechanics, the Reynolds number \( N_{Rey} \) is a dimensionless number that gives a measure of the ratio of inertial forces to viscous forces and consequently quantifies the relative importance of these two types of forces for given flow conditions:

\[
N_{Rey} = \frac{V \cdot L}{\nu}
\]

where \( V \) is the mean velocity of the fluid, \( L \) is the characteristic length of the geometry (motions of mantle materials on length of undreds of kilometers), and \( \nu \) is the kinematic viscosity. The higher the Reynolds number is, the more turbulent the flow will be: If \( N_{Rey} < 2000 \) the flow is laminar; If 2000 < \( N_{Rey} \) < 4000 it is called transition flow; If \( N_{Rey} > 4000 \) the flow is turbulent.

Recalling that kinematic viscosity \( \nu \) is the ratio of dynamic viscosity to density \( \nu = \mu/\rho \), we take the following values: \( V = 1 \text{ cm/yr} \approx 6.34 \cdot 10^{-10} \text{ m/s} \); \( L = 10^5 \text{ m} \); \( \mu_{UM} \approx 10 \cdot 10^{19} \text{ Pa s,} \)

\( \rho = 3.3 \text{ g/cm}^3 = 3.3 \cdot 10^3 \text{ kg/m}^3 \). Consequently the Reynolds number for the Earth’s upper mantle is \( N_{Rey} = 2.1 \cdot 10^{-21} \) which is a very little value indicating a slow laminar flow. However, all the researches on the mantle convection assume as starting point a layered non-expanding Earth, which may be a model far from reality.

The Rossby Number. It is also important to know if the role of Coriolis effect is important with respect to other inertial forces. It is sufficient to evaluate the Rossby number:

\[
N_{Rossby} = \frac{V}{L \cdot f}
\]

with \( V \) = typical velocity of the involved material; \( L \) = typical length on which the phenomenon develops; \( f = 2\omega \cdot \sin \phi \) = Coriolis parameter (\( \phi \) = latitude). The value of \( N_{Rossby} \) must be very littler than 1.0 to assure that Coriolis effect is important. In the case of motions of mantle materials on length of hundreds of kilometers we can assume \( \omega = 10^{-5} \text{ rad/s} \), \( L = 10^5 \text{ m} \), \( V = 1 \text{ cm/yr} \approx 6.34 \cdot 10^{-10} \text{ m/s} \). With the same values for \( L \) and \( V \) adopted in the preceding Reynold number and \( \omega = 10^{-5} \text{ rad/s} \) it results:
a value ever extremely little, except very near to the equator. Because we are not treating
aeronomical problems (which have material motions tangential to the Earth’s surface) but we
are mainly interested to radial displacements, the \( \phi \) must be taken as the colatitude, and the
value overcome the unity only near the poles. Then the Coriolis effects are dominant on other
inertial forces, but our judgment should not be hasty about their real importance, because the
existence of strong viscous friction can mitigate or make them negligible.

\[ E_k = \frac{\nu}{2L\omega \sin \phi} \]

**Ekman number.** In a fluid, the Ekman number is the ratio of the viscous forces to the Coriolis
fictitious forces. It has different definitions but the classic one is

Assuming for \( L \) and \( \omega \) the same values as in the above discussed Rossby number, and for \( \nu \),
the kinematic viscosity, the same value as in the preceding Reynold number, the resulting value
is \( E_k \approx 10^9 \) which mean an inescapable prevalence of the viscous forces on the Coriolis fictitious
forces. The trajectories that Coriolis force would impose (Figs. 1 and 2) in a non-viscous fluid
(Paldor and Killworth, 1988) cannot be followed because the viscous friction. Then, in the
mantle, at least for motions tangential to the sphere, the effects of the Earth’s rotation can be
neglected.

**Round-trip or one-way tickets.** There are at least three main version of the expanding
Earth concept: i) The first version accepts the hypothesis of subduction and possibly of the
convective flows (Owen, 1983, 1992; Perin, 2012). It is only a question of a non-equilibrium
between the amount of subducted materials and new materials upwelled at the mid oceanic
ridges – the last ones are hypothesized to prevail. ii) The more radical second version does not
admit the existence of the subduction (Carey, 1975, 1976, 1996; Vogel, 1984; Maxlow, 2005).
iii) A third version does not admit the existence of the large scale subduction, but a limited
amount of regional underthrusts and overthrusts [few tens of km: Scalera (2007a, 2010, 2012)]
is admitted, in agreement with geological observations.

In plate tectonics the kinematics of the plates has been completed by a geodynamics that
attributes the cause of continental drift to the convective cycles of the mantle and to other
forces such as slab pull and slab-push. Instead, in the expansion global tectonics the main
flows of the mantle materials are not necessarily moving along closed cycles of convection
cells (Fig. 2a), but can be mainly extrusion flows along surfacewards paths. These non-cyclic
surfaceward directed flows (one-way tickets instead of round-trips) must undergo the laws of
the classical physics of fluid-dynamics. Being the Earth a rotating body, the inertial forces, like
the Coriolis ones, must be present and, if sufficiently strong, should be considered among the
factors influencing the final pattern of the flows.

In an expanding Earth, at least in the upper mantle, the radial flows of mantle materials are
not necessarily slowed by viscous resistances. As explained in other papers (Scalera, 2003,
2010, 2012) the expansion can favor the isostatic rising of very deep material along huge
and deep geofractures, which morphology – revealed by catalogues of relocated hypocenters
(Engdahl et al., 1998) – resembles trees or smoke plumes enlarging and assuming the shape of
great calderas (like the south Tyrrhenian one) towards the surface. Sudden motion, in the upper
mantle, is revealed by earthquakes.

The isostatic rising of these materials can nullify the rising of deep materials due to thermal
convection, in the sense that the progressive enlarging size – triggered and driven by global
expansion – of the ‘room’ in which the rising materials are moving may not allow the onset
of the convective circulation. In this room the velocity of rising is not constant but irregular
and mainly impulsive, the rising episodes coinciding with changing of phase, and its range
can be reasonably assumed as equal to the sliding velocity of the two sides of a fault during an earthquake, \( V \approx 1 \text{ m/s} - 10 \text{ m/s} \). Considering that the Coriolis force is \( F_{\text{Cor}} = 2 \rho \omega V \) \text{Nw/m}^3, in the case of 1.0-10.0 cm/y its value is (Ricard, 2007)

\[
F_{\text{Cor}} = 3.0 \cdot 10^{-5} \cdot 6.34 \cdot 10^{-10} \approx 2.0 \cdot 10^{-13} - 2.0 \cdot 10^{-14} \text{Nw/m}^3.
\]

But I can compute that in the case of impulsive velocities of \( V = 1 \text{ m/s} - 10 \text{ m/s} \)

\[
F_{\text{Cor}} = 3.0 \cdot 10^{-5} \cdot 1.0 = 3.0 \cdot 10^{-5} \text{Nw/m}^3,
\]

which is 9 order of magnitude greater than in the case of the convective slow laminar flow. Then, it cannot be excluded the possibility of a deflection of the vertical sudden flows.

A comparison with the centrifugal force \( F_{\text{Cen}} \) is also useful:

\[
F_{\text{Cen}} = \omega^2 \cdot L \approx 10 - 10 \cdot 10^5 = 10 - 5 \text{Nw/m}^3,
\]

a value in the same order of magnitude of the Coriolis force. The centrifugal force is little but is able to deform the Earth’s shape to an oblate ellipsoid, and this is additionally in favor of the possibility for the Coriolis force to deform the path of the impulsive rising of mantle material. Obviously we cannot expect that the surfaceward motion ever occurs with an impulsive mechanism, but – in the impossibility to know the percent of the path performed in slow or impulsive way – a not negligible contribution of impulsive risings must be assumed.

**Evidence and conclusion.** It is possible to show that changing the assumptions implicit in the adopted geodynamics theory, or in other words, by adopting a different theory of global geodynamics, the role of the fictitious inertial forces can become substantial. In a different framework in which sudden extrusions of mantle materials occur, Coriolis effect value can rise of several magnitude orders, becoming the main cause of the east-west asymmetry of the Wadati-Benioff zones, which might be ascribed entirely to internal causes of the planet (its rotation) and not to external causes (influence of other celestial bodies).

Evidence that the subductive dynamics on the Wadati-Benioff zone (WBZ) is invalid are coming from coseismic phenomena of the recent great and shallow earthquakes [Sumatran quake: Han et al. (2006) and Scalera (2007b); and Honshu quake: Han et al. (2011), among others]. The great Sumatra earthquake has caused a sudden displacement of the instantaneous rotation pole of the Earth (Bianco, 2005). Scalera (2007b, 2012) has evidenced that the rotation axis moved following the meridian of the epicenter, going nearly 3 milliarccsec (\( \approx 10.0 \text{ cm} \)) farther from the epicenter. Rational mechanics rules (Schiaparelli, 1891) make clear that additional mass has been emplaced in the earthquake zone (Scalera, 2007b), following a mechanism of extrusion.

The data of the GRACE satellites (Han et al., 2006) show variations of surface gravity of -15 \( \mu \text{Gal} \) east of the Sunda trench, and a symmetrical anomaly of +15 \( \mu \text{Gal} \) west of the trench. These anomalies does not fit a fault dislocation without a substantial lateral and vertical expansion of the oceanic crust. Their suggestion of local expansion supports the class of models proposed in this paper.

The great earthquake of Honshu Tohoku (March 11, 2011; \( M_w=9.1 \)) has produced similar effects. Instead of a coseismic displacement of the instantaneous rotation pole of 14 cm toward 135°E as forecasted by Gross (see Buis comment, 2012) using the Dahlen (1971) dislocation model, a tendency of a little displacement toward an opposite direction (away from the Honshu hypocentral region) can be deduced (Scalera, 2012). Also in this case an extrusion of material is favored and the gravimetric data have confirmed (Han et al., 2011; Zhou et al., 2012). Similar GRACE results and interpretations have been published for the Maule quake (27 February 2010; \( M_w=8.8 \)) (Heki and Matsuo, 2010).

Already since many years, geodetic GPS networks have given precise indications of what actually takes place on the active margins. The data collected to date for the active margins of Sumatra, Japan, South America and so on, reveal a coseismic deformation of distensional nature (Chlieh et al., 2007; Lee et al., 2008; among others).

The conclusion is that at least two extreme magnitude events have provided astrogeodetic evidence not in agreement with plate tectonics, but more in accord with an expanding and
emitting Earth view. A simplistic evaluation of the regime of the convective motion in the mantle and of the order of magnitude of the involved forces (viscous, buoyancy, inertial) hastily judges as negligible the role of the Coriolis effect in producing the observed slope differences of the Wadati-Benioff regions.

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