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Roots of modern geodynamical views in Schiaparelli's thought

The volcano-seismic correlation events on the Andes

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Abstract. The reflections of Schiaparelli in the branch of astronomy more extensively involved with the geophysics and geology was influential on the progress of Earth sciences, contributing to unprejudiced forms of reasoning about the evolution of our planet. Today some new factual evidence and interpretations of the phenomena linked to a volcano-seismic correlation and to a progressive shift of the Earth's rotation poles through geological time find their roots in the geoedynamical examples published in 1893 and 1891 by Schiaparelli. If a possible synchronicity of a volcano-seismic correlation – peculiar for the South American Pacific Margin – with features of the Markowitz oscillation of the secular Polar Motion will be confirmed by comparison of a longer series of Polar Motion data and volcano-seismic events (average return period of 40-50 years), we would reasonably be in the presence of a phenomenon that puts in communication the Earth's surface with its deeper interior (core-mantle boundary) and that should be directly linked to a slow asymmetrical expansion of the Earth.

Key words. Geodynamics – Volcano-seismic correlation – Asymmetrical Earth's expansion – Polar Motion – True Polar Wander

1. Introduction

The origin of modern geodynamics can be traced back to Isaac Newton – who speculated that the Earth might be flattened at the poles due to its rotation – and already in 1666 Placet hypothesized, in a little known theological treatise, movements and clashes of islands that would form the New American World. Possible relative movements of land and sea can be found in Greek authors (Placet 1666), but greater awareness were gradually gained within the young science of geology, thanks to the discussions around the issue of marine fossils. An increasing credit was conceded to the organic origin of the fossils along with an upward transport by tectonic processes. Geology begins his own systematization through the observations of Leonardo da Vinci on the diversity of fossils passing from one layer to another, and the term "geology" begins to be used on the second half of the '600 when Niels Steensen (Steno) (1638-1686) sets out the principles of stratigraphy. The nineteenth century was a fertile period of hypotheses on geodynamics, all precursors of those most familiar today such as continental drift, geosynclines,

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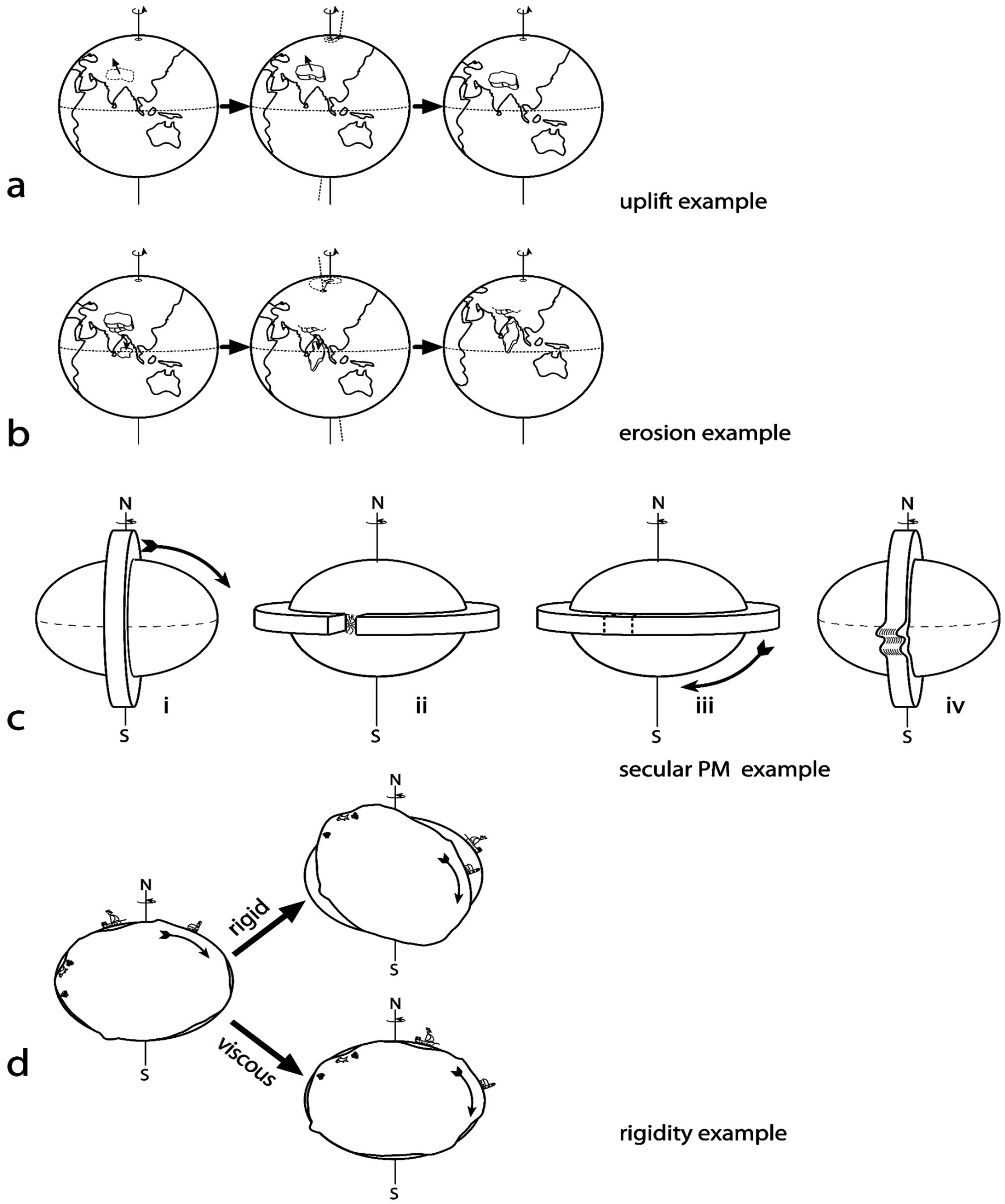

Fig. 1. Four examples described by Schiaparelli (1883, 1891). For explanations, see text.

geotumors, expanding Earth and plate tectonics. Among others, it should be remembered the book (Celestial Scenery; 1838) by the Scot Thomas Dick (Goodacre 1991), in which clear ideas were stated about moving continents, followed in 1854 by the classic book by Antonio Snider-Pellegrini (1858) which in addition to the concept of a supercontinent fracture, also inaugurated the concept of wide variations in volume of the planet (in this case contraction; see Scalera 1999). Same surface fracturing of an uniform crust with volume expansion was defended by the Italian Roberto Mantovani (Parma 1854 - Paris 1933) (Scalera 1997, 2009), and in 1888 by the Polish-born Russian Ivan Osipovich Yarkovski (Scalera 1999; Beekman 2006).

How influential was astronomy on the success of mobilism in Earth science? It is sufficient to recall that frequently in the past duties of astronomy, meteorology, geomagnetism, seismology at Observatories were combined. The ideas circulated among insiders not as specialized as today: the work of Schiaparelli was ranging from mathematics to astronomy, geophysics and the history of science, the latter built on deep knowledge of ancient linguistics (Celoria 1910; Gabba 1947). In the nineteenth century astronomy was the only real source of instrumental data on which to base arguments about global geodynamics (Mulholland & Carter 1982). For most of the XIXth century, the scattered data about the variation of latitude of individual stations, lead to hypothesize subtle tangential displacements either of large tectonic units, or of whole continents, or of the entire Earth's crust. Vito Volterra studied the possibility of a polar motion (PM) influenced by steady state currents of materials on the surface or in the deep Earth's body, corresponding also with Schiaparelli (Guerraggio 1984). Given the need to separate all these possibilities, methods were devised for detection and data reduction using a set of stations nearly-uniformly distributed all around the same parallel (Cecchini 1928; Proverbio 1996).

2. Schiaparelli conjectures

Schiaparelli's conjectures on the causes and consequences of the motion of the pole are at least four. The first shows the motions of the pole of rotation caused by geological processes (Schiaparelli 1883, 1891; Gribaudi 1902). In the sequence in Fig. 1a the lifting of the Tibet plateau and of the Himalayan belt causes a separation between the principal axis of inertia [dashed], and the rotation axis, which initially coincide. The intersection of the axis of inertia with the surface of the northern hemisphere goes away from the lifting area and begins spiraling in a retrograde sense with a period of 14 months around the rotation axis until returning to coincide with it, with the result of shifting the Asian continent towards the equator. The geological process continues with the gradual planation and destruction by erosion of the plateau and the transport of sediments on the bottom of the Indian Ocean near the equator (Fig. 1b). This horizontal movement causes the intersection of the principal axis of inertia with the surface of northern hemisphere to go nearer (about 30 meters) to the zone of sediment deposition and then to spiral until it comes back to coincide with the axis of rotation. The latitudes of Asia increase. The displacements and their time rates shown in Figure 1ab are exaggerated.

Schiaparelli ascribed great importance also to the role of the phenomenon of the secular PM in determining tectonic and geodynamic processes. In an additional example, he considers an ideal crustal belt that surrounds the Earth along a complete meridian (Schiaparelli 1883, 1891; Gribaudi 1902)), this will be about 1/600 shorter than a similar equatorial circle. If the secular PM produces a rotation of 90 degrees of the Earth's crust carrying the aforementioned belt along the equator, this ideal crown will fracture, and the gap will be filled with material derived from the interior of the planet (Fig. 1c,i,ii,iii). If, subsequently, the process reverses or continues in the same direction, and the equatorial belt goes back to cross the poles, it must fold to fit a smaller length (Fig. 1c,iii,iv). Following Schiaparelli, this mechanism could put in direct communication the internal geological world with the surface phenomena (Schiaparelli 1883, 1891) and be the cause of the birth of mountain chains. Earthquakes and volcanism and their global distribution might be related to these major crustal movements and fracturing.

A third example on the consequences of the secular polar motion is related to changes in sea level. On a ellipsoidal and rigid Earth, again a strong reorientation of the whole Earth's crust leads the polar continental areas to approach the equator. Because of a hypothetical perfect rigidity they would keep constant their old polar distance from the center of

Earth – about 20 km less with respect to the equatorial radius – and consequently would be completely submerged by sea-water (Fig. 1d). Schiaparelli evaluated the effect of this extreme rigidity on the Italian regions, which would end in 10My under a 5000 meters thick liquid layer. Finally, in a last example — a corollary about climatic effects of the secular PM (roughly estimated at the end of '800 to be few tens of meters per century; today we know it is about 12 m/century) — Schiaparelli writes that PM would have worrying consequences on the climate of the Italian peninsula, which will approach the equatorial areas, reaching in 10My a climate similar to that of Senegal.

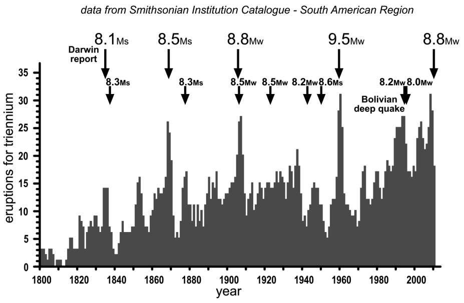

Fig. 2. Using the complete Smithsonian catalog of eruption data of the Andean belt from 1800 to 2010, the triennial number of eruptions along the time axis has been plotted. All the non-discredited data have been used. Cusps of eruptions coinciding with the occurrence of great-magnitude earthquakes are confirmed, and an additional peak is correlated to the 2010 Maule quake (M=8.8). At the moment no explanation exists for all the large fluctuations and marked minima in the eruption rate. But it must be stressed that a number of strong seismic events exist that does not correlate with peaks of the triennial rate of eruption, leading to the conclusion that different processes can cause strong earthquakes, but only a sub-set of them can cause the volcano-seismic events. In 1994, the occurrence of very deep and strong seismic event in Bolivia (M=8.2; depth=641 km, data USGS, 2007) is preceded by a decennium of increased rate of eruptions.

3. Modern geodynamical conjectures and data

The argument of the fracturing of the crust displaced from a polar ellipse to the equator circle remains valid. The modern subjects require the same changes in radius and curvature proposed by Schiaparelli a century earlier. Especially in an asymmetrically expanding Earth framework (Hilgenberg 1974; Carey 1976; Owen 1976; Scalera 2003, 2006, 2010a among many others) we have to expect a region where the lithospheric tissue more intensely underwent the process envisaged in Fig. 1c,ii,iii where a communication between deep interior and surface of the planet is established. Because the maps of the expansion rates of the oceans (Larson et al. 1985; McElhinny & McFadden 2000) show a maximum expansion rate on the Nazca region, we should expect that eventual peculiar phenomena related to this planetary expanding side would be observable on the Pacific margin of South America.

During his trip on the Beagle, Charles Darwin (1840) wrote about the eruptions associated to the Conception earthquake of 1835. Lorenzo Casertano's survey (1962) following the 1960 great Chilean earthquake found some unclear evidence of a link between eruptions and the seismic event. Scalera (2008) using the data available in 2006 in the Smithsonian Institution Catalog of volcanic eruptions revealed grounded evidence that South-American Wadati-Benioff zone earthquakes with magnitude greater than 8.4 are associated to an enhanced rate of volcanic eruptions, but still it was impossible to determine the causal chain between the two phenomena. An average return period of about 45 years was deducible from the data for the time window 1800-2010. After 2006, the Smithsonian Institution has greatly increased the completeness of the catalog (Siebert et al. 2011) adding the new eruptions for the 2000-2010 interval, but also adding 60% new entries in the list of the Andean volcanoes. The occurrence of the Chilean Maule earthquake of 27 February 2010 (M=8.8) – occurred at five decades from the 1960 one – has been the occasion to rework all the data in searching for additional clues able to indicate a preferred causal direction eruptions-earthquakes or earthquakes-eruptions or from a third more general cause (e.g. mantle movements) to both eruptions and earthquakes.

A series of papers deal with the triggering of eruptions by earthquakes at different distances from the hypocentral region (Uffen and Jessop 1963; Latter 1971; Carr 1977; Barrientos 1994; Linde & Sacks 1998; Hill et al. 2002; Manga & Brodsky 2006; Walter 2007). The possibility of a triggering of earthquakes by volcanic activity has been proposed by a scant group of people (Critikos 1946; Kimura 1976; Acharya 1982, among others), and the mutual influence of volcanic activity on great earthquakes occurrence and viceversa by Coulomb stress time variations has been investigated by Nostro et al. (1998) on Southern Italian region.

Interaction between volcanoes and earthquakes has been hypothesized carried by at least three physical phenomenons: static stress variations, viscoelastic relaxation, dynamic stress induced by seismic body waves and surface waves. These physics interaction processes are considered as the "final steps" and the earthquakes and volcanoes are credited to be mutually linked through their action (Nostro et al. 1998; Hill et al. 2002).

An alternative conception deserving to be scrutinized is the non-compressional framework of mountain building (Scalera 2007b, 2008). An isostatic uplift of mantle material in a distensional environment is the key concept that can contemporaneously provide explanation of a wide number of geological phenomena. An advantage of this schema is the possibility to explain the great shallow earthquakes not as subhorizontal slip of a subducting lithosphere but as sudden vertical movements – along the complementary perpendicular fault plane of the focal mechanism (Scalera 2007c) – under the forearc. This alternative interpretation framed in an asymmetrically expanding planet can allow a common secular process involving the complete South American Pacific margin. The Polar Motion is explained by plate tectonics hypothesizing a subtraction of mass due to the melting of the ice cap in the Northern Hemisphere on the Canadian Shield. This slow deglaciation cannot be extrapolated to more than 1My in the past, while we need

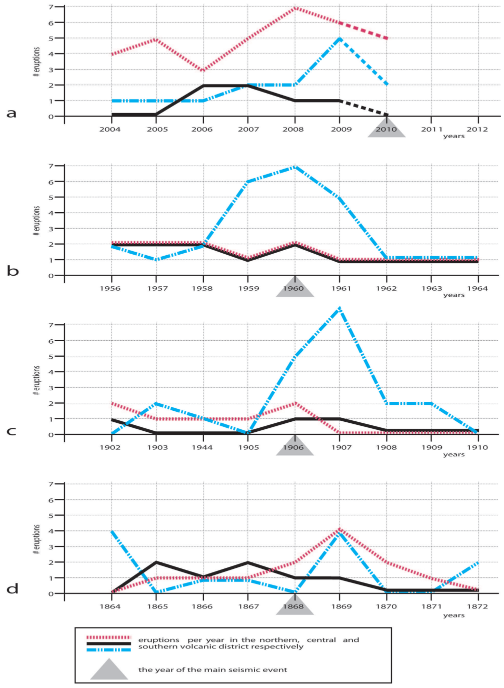

Fig. 3. Rate of eruptions for year on the three volcanic districts of the Andean Pacific margin for the events of a) 2010, b) 1960, c) 1906 and d) 1868. Passing from the oldest volcano-seismic correlation event of 1868 to the recent one of 2010, the maxima migrate from a position on the time axis following the earthquake to a position preceding the seismic event. This can be caused by uncertain information about the date of onset of the eruptions in historical times. The precursory increasing rate of eruption must be confirmed with future occurrence of correlation events.

to reconnect it to the very ancient True Polar Wander (TPW). TPW is ascribed to advections of mass related to geoidal shape, which pattern we cannot know in the deep past (Steinberg & O'Connel 1997). The anomaly can be resolved in the expanding Earth schema by assuming an emplacement of mass – extruded from the interior – in the Southern Hemisphere on a migrating Nazca region (Scalera 2006). In this interpretation the TPW path through geological time – with its stasis at 50 My and subsequent inversion of sense (Besse & Courtillot 2002) – is naturally linked to the North-to-South migrating position of the region of maximum planetary expansion and unbalanced emplacement of mass in the global paleogeography of the expanding Earth framework (Scalera 2006). The crossing of the equator at about 50 My causes the observed stasis in the TPW path.

Passing from the older coincidence events to the 2010 one (Fig. 2 and Fig. 3), it is clear the trend – as soon as the data have become more precisely located on the time axis – of an enhanced rate of eruptions before the main seismic event.

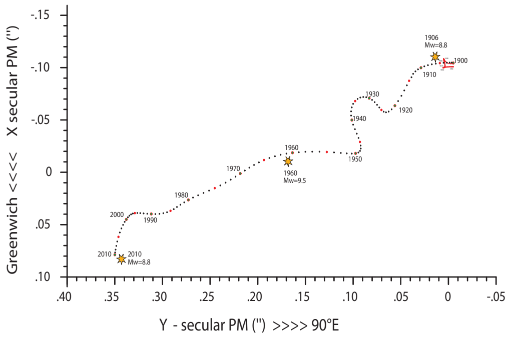

Fig. 4. The secular Polar Motion (PM) from 1846 to 2009. The data 1846-1899 are not omogeneos with the 1900-2009 series and their loop cannot be interpreted. The path is the result of the application of running averages on the PM data. Both the volcano-seismic correlation events of 1960 and the recent one of 2010, occur after ten years from a five-year period of stasis of the secular PM (1945-1950 and 1995-2000). This possible synchronicity must be confirmed or confuted by next centuries of data.

The 1868 event – In this case (Fig. 3d) we have no data characterizing the 1835 event, and in 1868 no aerial data were available for surveying the Andean volcanoes. The news was collected only by visual witness by either inhabitant of localities nearest the volcanic apparatuses or people passing for a direct inspection. The dates of the eruptions were possibly confused with the observation dates, displacing the events many months ahead and possibly one or more years ahead. This could be the case of a small group of eruptions of uncertain date grouped in 1869. The peaks of eruptions after the quake, in Fig. 3d can be an artifact.

The 1906 event – This event (Fig. 3c) is indeed a pair of great earthquakes (Ecuador, January 31, M=8.8, Lat=01.0N, Lont=81.5W; Chile, August 16, M=8.4, Lat=33.0S, Lon=72.0W) that occurred on the same year separated by a very long distance (3500 km). In Fig. 3 only the southern district appears to have a peak of eruptions correlated to the earthquakes. This time the maximum is one year after the seismic event but the growing of the eruptions amount starts in the same year of the quake. Then the real distribution on the time axis can be different and considering the reasons explained above in the preceding 1868 case, it may be that some of the real onsets have occurred many months before and also one year before.

The 1960 event – The earthquake occurred (1960, Chile, Lat=38.0S, Lon=72.3W, M=9.5) in the times of more modern scientific instrumentations (seismometry entered in a more advanced status) and surveying facilities (quick transportations, airplanes, helicopters; but difficulties in landing to directly observe the lava flows or debris was already cited by Tazieff 1962). This time (Fig. 3b) the maximum eruption rate is in the same year and the growing of the rate starts before the quake occurrence. We can state that a real jump from two to six eruptions has occurred from 1958 to 1959.

The 2010 event – This time (Fig. 3a) all the onset dates of the eruptive events are known thanks to improvements of satellite, aeronautical and land remote digital surveillance methods. The rate of eruptions occurred in the northern and southern volcanic district increased from one-two erup/year to five in 2009 and we expect that an enhanced rate will be revealed until the end of 2010. The northern volcanic district was particularly active in the interval 2007-2009, while – unexpectedly – the central district with its one or two eruptions/year does not contribute to the constitution of the volcano-seismic correlation event. It is then to be considered as well grounded the statement of a precursory behavior of the northern and southern volcanic activity in this case.

The clue of a possible synchronicity – On the same plot in Fig. 4 I have represented both the secular polar motion (from 1846 to 2009; data of PM from IERS web facilities) and the time of occurrence of the volcano-seismic events of correlations. It is possible to see:

i) – Only three volcano-seismic events can be correlated to the series of PM data 1846-2009, namely the events of 1906, 1960 and 2010 (Fig. 3).

ii) – The PM data preceding 1900 are not homogeneous with the 1900-2009 ones.

iii) – The seismo-volcanic events of 1960 and 2010 occur about 12 years after a five-years window of stasis of the secular PM (a very low velocity, witnessed by the extreme proximity of the annual averaged points in the plot). Albeit the data are not against the same mutual pattern between the event of 1906 and the PM data of the last decade of the XIX century, the non-homogeneity of data do not allow a positive conclusion.

iv) – To ascertain the reality of this further intriguing correlation (or synchronism with the Markowitz oscillation of PM; Poma et al. 1991) a greater amount of volcano-seismic events is needed.

v) – The next expected volcano-seismic correlation will happen within 40-50 years.

4. Conclusions

A crisis of the current tectonic theory is today perceivable (Shields 1987). Plate tectonics appears even more clearly as a compromise between the old academic fixism and a mobilism driven by a slow asymmetrical expansion of the planet Earth. Especially the Mediterranean region – antipodal to the maximum expansion on Nazca – with its characteristics of an extremely low rate of expansion and consequent impossibility to give rise to a fully expressed ocean (Scalera 2005, 2010b), is full of contradictions and paradoxes that the theory have tried to resolve proposing a series of ad hoc hypotetical processes (metamorphism long double trip, roll back, intermittent subduction, slab break out, etc.) very like to the set of deferents and epicycles of Ptolemaic astronomy (Scalera 2010b). In a simpler and unifying manner, the geological evidence can be explained in an asymmetrically expanding Earth framework (Carey 1976; Scalera 2003, 2006, 2010a). The possibility to reveal a number of never suspected integrated phenomena on the side of the maximum asymmetrical expansion of our planet is a further heavy evidence of both the Schiaparelli's envisaged communication between surface and deep geologic realms and a more general evidence in favor of an expanding Earth. However, the planetary expansion schema continues to constitute a formidable challenge to Astronomy and fundamental Physics.

Obviously a part of these arguments (especially the conjecture of synchronicity) claims for a confirmation or confutation by longer time series of data not compatible with a single researcher period of activity. Our scientific posterity – if they will conserve awareness on the relevance of solving these problems – will provide a final judgment on what could be either a new fertile frontier of geosciences or only an expression of the spirit of scientific imagination of Schiaparelli.

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