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6° Convegno Nazionale

THE GEODYNAMIC MEANING OF THE WADATI-BENIOFF ZONE EARTHQUAKES: FROM APENNINES TO A GLOBAL PERSPECTIVE FOR MOUNTAIN-BUILDING

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The Italian earthquakes are not uniformly distributed (Fig. 1ab) either along the mountain belt or in depth. The zones in which the deeper earthquakes are originated are shown, and it is scrutinized their context both regional and global. It is inspected if the characteristic inhomogeneous pattern recognizable on global scale is also recognizable in the Italian region as whether relic or actual phases of tectonic processes. A possible link with non-collisional orogenetic processes is proposed.

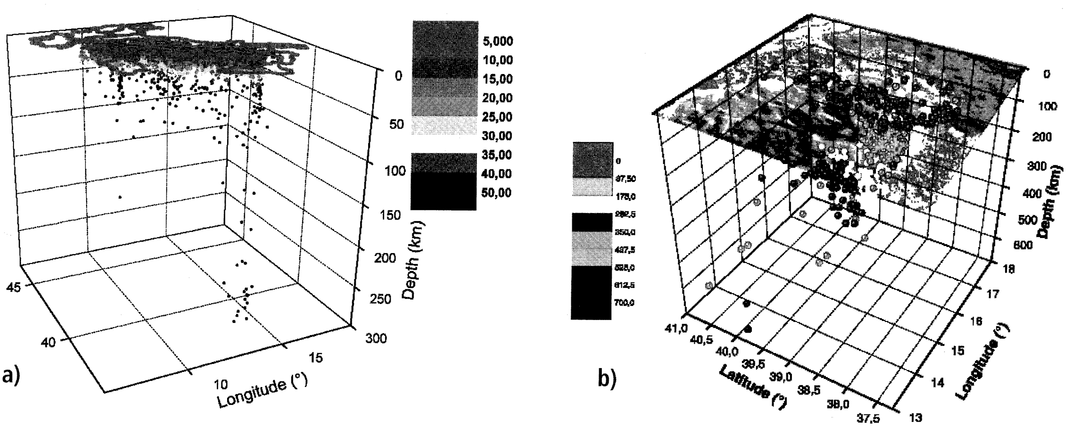

Fig. 1 – Non uniform distribution of Italian seismicity along the Apennines and Calabrian-Sicilian arc (data from Italian catalogue of earthquakes. http://www.ingv.it/CSI/). In a) The hypocenters show zones of higher density at depth of 50 km below North Apennines (Garfagnana), Central Apennines (Umbria), Southern Apennines (Irpinia). In b) the deep earthquake zone under the Calabrian arc reaches the depth of 500 km, starting as a near vertical column up to 200 km depth and then tapering along a lower slope. This 'single-filament' typical pattern is similar to many other 'multi-filamentous' structure that are observable in most Wadati-Benioff zones around the world.

Mediterranean

The Mediterranean is characterised by two well-defined regions of deep earthquakes (Berckhemer and Hsü, 1982; Cadet and Funiciello, 2004; Vannucci et al., 2004; Scalera 2005a). The hypocenters do not exceed the depth of 200 km beneath the Aegean region, while they reach more than 400 km under the southern Tyrrhenian region (Fig. 1b). Minor spots of intermediate-depth earthquakes are present beneath the northern Apennines (Fig. 1a; hypocentral depth max 60 km), around the Gibraltar region (max 60 km) and under the narrow, near-vertical focal volume (depths 60 - 220 km) in the Vrancea region, Romania. This is a non-uniform pattern of Mediterranean hypocenters, which should link with an analogous non-uniform state of strain and stress along the Tethyan furrow.

There is common consensus that the cause of the deep seismicity can be ascribed to a subductive process, albeit some doubt is raised in the case of the Vrancea chimney of hypocenters, which is judged the relic stage of a former wider Wadati-Benioff zone.

Because it is possible carefully to reconstruct the Pangea mosaic (Bullard et al., 1965; Owen, 1983; other references in Scalera and Jacob, 2003) this is a guarantee of little deformation through geologic time of plates. Then it is unlikely that such non-uniform pattern of deep hypocenters is generated by the Africa-Eurasia interaction through uniform motion of the two plates. Moreover, in this region a consistent amount of evidence of extensional processes at odds with the alleged Africa-Europe convergence livens up the discussion (Michard, 2006; among others) or allows new interpretations (Scalera, 2005a; Lavecchia and Scalera, 2006).

Global overview of Wadati-Benioff zones

The real Wadati-Benioff zones do not correspond to what is prescribed by plate tectonic theory, and to what we expect to see having in mind the narrow hypocenter sections of the classical iconography. In these classical narrow vertical sections – perpendicular to the trenches and arcs – fairly aligned hypocenters are shown dipping with a slope around 45°.

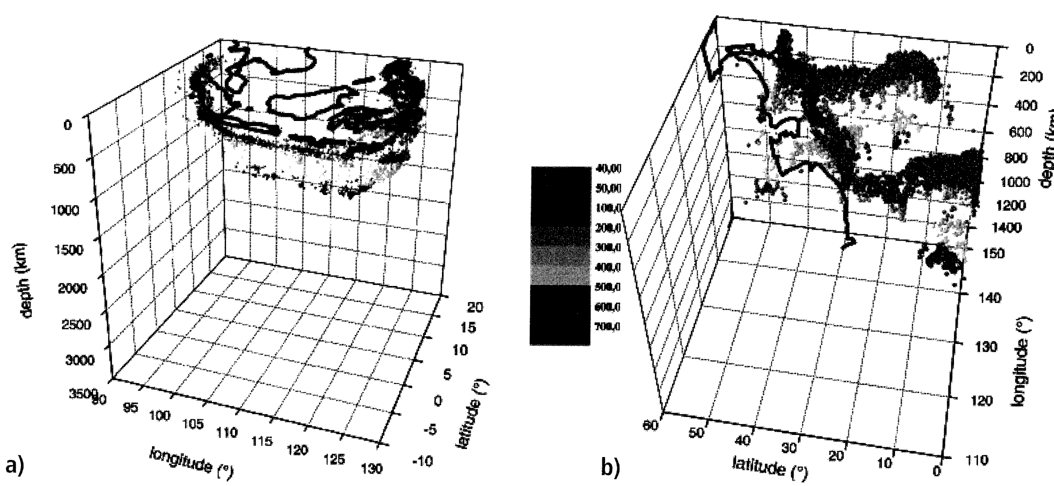

Fig. 2 - Most classical iconography of the 'subduction zones' is taken from vertical sections perpendicular to the circum-Pacific arcs. The reality is somewhat different. Plotting the entire Wadati-Benioff zones in 3D, using a larger scale, a filamentous structure of the subduction zones is highlighted. In a) the Sunda arc (from Sumatra to Andaman islands) shows hypocenters not deeper than 250-300 km. Deepest seismicity is present under Java up to New Guinea, with focal sources up to 700 km. Here the hypocenters have the tendency to group in large columnar zones of which the islands are the capitals. In b) the filamentous pattern of the East Asian Wadati-Benioff zones (from 60°N to equator) is plotted. 'Subduction' is an improbable process as cause of this kind of uneven patterns. (data from the 'Centennial Catalogue' by Engdahl et al.1998)

Abandoning the classical iconography, if 3-D plots of the hypocenters of very large areas are drawn, filaments of hypocentres are recognizable (Fig. 2ab) in the catalogue of the relocated events (Engdahl et al. 1998), instead of a regular pattern. These filaments are real characteristics of the hypocenters distribution because their separation can easily reach the order of magnitude of degrees (Fig. 2ab). The filaments have the tendency to taper to depth, leading to the idea of a narrow region of origin of a disturbance, which propagates – becoming progressively larger – toward the surface. Instead of recalling to the mind the downgoing subduction, they evoke the image of trees, or smoke coming out of chimneys. If those filaments were taken as basic features to be taken into consideration in constructing new schemata for the Wadati-Benioff zones, it would almost be necessary to build a mechanism in which little place can have a downgoing slab. It seems more credible that an upward transmigration of matter or energy (wide sense) could be involved in these zones.

Moreover

A preliminary analysis of seismic and eruption data on the arcs of Indonesia and western South America (Smithsonian Institution, 2006). have shown that a correlation between extreme magnitude earthquakes (USGS, 2006) exists for the Cordilleran region (Fig. 3). Seismic and volcanic phenomena seem to be related in a cause-effect chain. This correlation – and the lack of similar demonstrable correlation on Indonesian arcs – has some links with a general view of the global geodynamic processes (Scalera, 2006) in an expanding Earth framework (see several papers on Earth expansion and alternative views in: Scalera and Jacob, 2003; Lavecchia and Scalera, 2006).

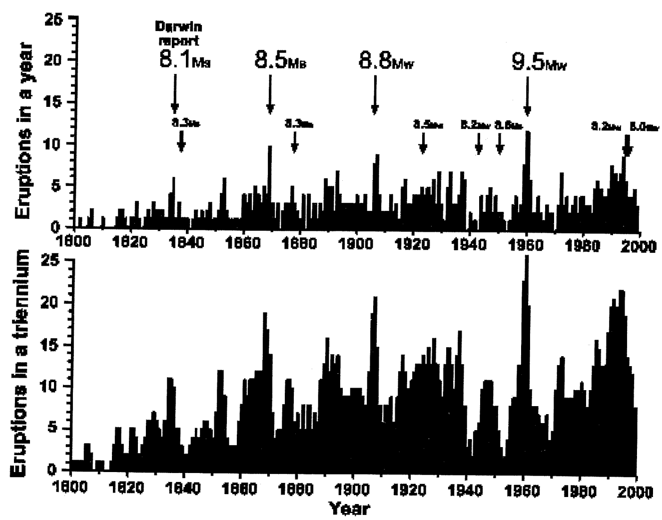

Fig. 3 - The data of the global Smithsonian catalogue of volcanic eruption for the South American Andean volcanoes which have erupted from 1800 to 1999 (Smithsonian Institution, 2006). The number of volcanic eruptions in a year and the number of volcanic eruptions in a triennium are plotted. The earthquake data are from Engdahl et al. (1998; the Centennial Catalogue) and from USGS (2006). Albeit the possibility that the observations and reports of occurred eruptions could increase in the occasion of great earthquakes (increased compulsion in search for correlation between seismology and volcanology in these occasions), the peaks of the number of eruptions seem neat and well evident with respect to the normal background-noise when some M>8.4 earthquakes occur. Especially neat is the cluster of eruptions which matches the great Chilean earthquake of 1960 (M=9.5, the greatest magnitude ever recorded). An analogous good correlation cannot be recognizable in the data of the global Smithsonian catalogue of volcanic eruption for the Indonesian zone and in particular for the great Sumatran earthquake of December 2004. This presence (in the Nazca region) and lacking (far from Nazca region) of the eruptions-earthquakes correlation could be put in relation to a global tectonic and geodynamic view of an asymmetrically expanding Earth (Scalera 2006).

A new model of orogenic evolution

As a consequence of the above considerations, and keeping in mind the evidence that come from the presence of water in the mantle at considerable depth (recall the existence of the LVZ – depth 60-150 km – and the revealed seismic anisotropy similarly ascribable to water circulation or trapping under the orogens) a heuristic model of evolution of an idealised orogen is proposed, which does not resort to large scale subduction (Fig.4). It can also explain the occurrence of seismically activated zones of hypocenters in the form of filaments, by irregular and episodic activation of mass and energy transmigration in a laterally non homogeneous mantle as that concerns thermal distribution, stress, strain, and composition. The model – with the right modifications for the local different situations – could apply to the evolution of the Italian orogens.

An undisturbed layer situation is the starting situation. Tension is supposed to act and a stretching of the lithosphere is envisaged to gradually develop. The trough evolve increasing its depth, the crust grows thin, and similar symmetrical geometrical change occurs at the lithosphere and upper mantle bottoms, with development of an uplift of the layer interfaces (Fig. 4). The isostasy make the inverted troughs at the mantle interfaces and their evolution more pronounced that the superficial ones. The furrow of the stretched crust is eventually filled with meteoric and/or sea water, preconstituting the conditions for an early interaction of pre-metamorphic protoliths with water, in agreement with observations (Fig.4).

In a situation in which both an horizontal tensional state persists and no crystal lattice rearrangement of the upward moving and deforming materials is supposed possible, it were impossible an eventual uplifting of the topographic surface. But if to the persistent tensional state, an unpacking of the crystal lattice towards more open and voluminous figures is associated (Green and Ringwood, 1970; Ringwood, 1991), then the resulting grown of volume can lead to the updoming of the topography, starting a process whose evolution can lead to truly orogenetic processes. It is possible to speech of phase changes driven by isostatic deep uplift (Fig.4).

This additional uplift of materials driven by phase changes (with increasing volume along all the isostatically raising column) could be cause of seismicity (superficial, intermediate and deep) which pattern of hypocentres can appear distributed along Wadati-Benioff zones, as much as the starting

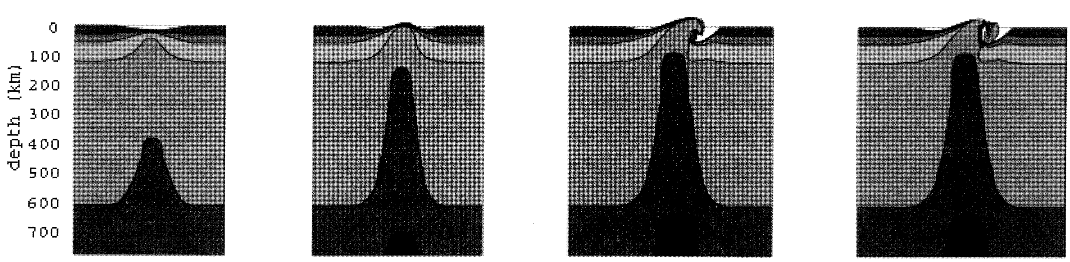

Fig. 4 – The proposed new model of mountain building. Starting from left, a tensional situation produces a stretching of crust, lithosphere and mantle. Due to the necessity of isostatic compensation (no more than a tenth of kilometres of depth can be attained on earth surface. See e.g. Hilgenberg, 1974) the greater effect of the stretching appears as a strong uplift of the lithospheric and mantle strata. On this uplifting column an excess of room become necessary because the mantle material must undergo phase changes toward more unpacked crystal structures (Green and Ringwood, 1970; Ringwood, 1991). This surplus of increasing volume of the decompressed material is sufficient not only to fill the space between the vertically split lithosphere and mantle, but it can also produce updoming of the crust, and subsequent relatively quick (centimetres for year) uplift. Then the created true orogen can undergo erosion, summital collapse and gravitational spreading, with final denudation of metamorphosed crustal material previously buried by gravity nappes, together with several kinds of mantle facies. Different rates of rifting – and evolution of the rate through geological time – can lead to different kind of orogens from continental to mid oceanic ridges ones.

of warping of crustal layers, exposition of the top of the doming zone to the action of gravitational spreading and erosion.

A possible asymmetrical unilateral outpouring of the exceeding material drives the gravitational nappes to overthrust the sediments of the pre-existing trough, forcing them on a burial path which emulate the subduction process, but without reaching depths greater than 50-70 km.

At the boundary between uplifting material and down-pushed crust and lithosphere, phenomenon like metamorphism, mixing, migmization, upward transport of fragments of the buried lithosphere ecc. are possible.

The crustal, intermediate and deep (up to 700 km) seismicity of the Earth could be explained – following Ritsema (1970) – by the direct and indirect effects of phase transformations (propagation of strain and of instability conditions). My conclusion is that these phase transformations happen along the isostatic uplift path, and not along a downgoing subduction path.

Conclusion

The Italian and Mediterranean situation, with small circumscribed regions – Tyrrhenian, Aegean, Vrancea – of deep and intermediate seismicity, can be explained assuming also in this region the presence of few zones of unstable mantle. This instability can be due to differences in the state of deformation, depressurization, composition (all linked each other). The 3-D pattern of intermediate and deep hypocenters – especially the 'filament' beneath the Messina Street (Fig.1b) – is analogous to the filamentous distribution of foci in the Circum-Pacific Wadati-Benioff zones (Fig. 2ab). No subductive process can produce such a characteristic pattern, which can be more easily ascribed to an upward transport of matter and energy *sensu lato* (Scalera, 2005b).

Searching for an orogenetic model that could be in harmony with an upward transport of mass, it is possible to envisage the suitable mechanism of mountain building in the framework of an expanding Earth. High velocity anomalies revealed by means of seismic tomographies – regional and global – of Wadati-Benioff zones (Van der Voo et al., 1999; Fukao et al., 2001; Piromallo and Morelli, 2003; Spakman and Wortel, 2004; Cimini and Marchetti, 2006; among others) can be interpreted as revealing uplifting column of denser mantle material, which episodic transformation to less close-packed crystal structure is linked to the intermediate and deep earthquake occurrence. The increasing volume of the isostatically upwelling material is the cause of the outpouring of materials that are involved in the mountain building and its subsequent disruption by erosion and gravitational spreading (Fig.4).

The Italian along chain geological and stress-strain situation (Valensise and Pantosti, 1992; Lavecchia et al., 2003; Calamita et al., 2004; Cucci, 2004; Scalera, 2005a; Serpelloni et al., 2006; among many others) can be put in agreement with the above proposed model. This model can be considered the first causal explanation – linked to deep mineralogical phases, isostasy and expanding Earth – of an already existing class of orogenetic non-collisional models (Ollier and Pain, 2000; Ollier, 2003) that derive their evidence above all from surface geology and morphology – or hypothesizing an under-crustal or intracrustal creation (by solidus-solidus phase transformation) of the granite (Sanchez Cela, 2004) – and never have been definitively discarded by classical geology (see chap. VIII in Aubouin, 1988).

Finally it must be stressed the practical implications of this kind of researches. To made the probabilistic forecasting of earthquakes (still very far is the deterministic one) more effective, it should be noted that changing our view from an envisaged seismogenic downward movement, e.g., of the African plate in Southern Tyrrhenian Sea toward a more unpredictable causal chain that depends from unobservable and non-directly testable processes of phase change in an only largely hypothetical geochemical, hydrothermal, and strain-state deep mantle environment, can imply a more severe 'project earthquake' upon which to found our possibilities to realize important buildings in zones of already very high seismic risk. This additional awareness of possible alternative geodynamical scenarios should be assessed besides already existing (Guerricchio and Ponte, 2006) geological arguments that advise for greater prudence.

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