IS LARGE SCALE SUBDUCTION MADE UNLIKELY BY THE MEDITERRANEAN DEEP SEISMICITY?

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Abstract: The deep seismicity in the Mediterranean region does not have the pattern that the alleged convergence of Africa and Eurasia should produce. Often, where subduction slabs and Wadati-Benioff zones should be present – showing intermediate and deep hypocenters – only shallow intracrustal seismicity is detected. Most geoscientists admit, without a valid explanation, that in this region subduction occurs largely aseismically.

Inspection of South Tyrrhenian, Aegean and South Carpathian deep foci zones makes clear that these isolated narrow plumes (or clusters, filaments) of hypocentres cannot be sites of active subduction but that they are related to uplift of deep mantle material. Their presence under actively rising part of orogens – besides many additional clues coming from a number of different fields – leads to a unified interpretation of the involved phenomena, and to a new interpretation of the orogenic processes and fold belt building. The evidence points to vertical displacements of materials as the main process responsible for deep earthquakes, volcanic phenomena and orogenesis.

Several tens of km of overthrusts and underthrusts should not be mistaken for large-scale subduction, and the limit of 50-70 km (the roots of an orogen) should be considered the maximum depth of occurrence of metamorphism. Into these limits of depth, the nonlithostatic overpressures due to the surfaceward mantle flow, the association of fluids, extreme magnitude earthquakes and deviatoric stress can be the causes both of those metamorphosed facies (until now presumed to come from depth up to 200 km) and of a shallower than supposed synthesis of biogenic and abiogenic hydrocarbons.

Keywords: *Wadati-Benioff zones, Mediterranean deep earthquakes, vertical displacements, orogenic processes, mantle phase changes, HP and UHP metamorphism, expanding Earth.*

The Mediterranean deep seismicity

A typical clustering of deep seismicity has been revealed in the circum-Pacific active margins, which has shown a very different image of the Wadati-Benioff zones from the traditional ones (Scalera, 2006c, 2007b & 2008). The hypocentres do not arrange themselves along inclined planes or spoon like surfaces, but display series of elongated clusters or filaments that taper toward greater depths. Along the South American Pacific margin the extreme magnitude earthquakes (1835, 1868, 1906 & 1960) are correlated with an increased yearly rate of volcanic eruptions (Scalera, 2007b & 2008). Few clusters of hypocenters with depth up to 300 km are present under the Western and Eastern Himalayan Syntaxial zones, presenting the problem of the existence of solitary isolated filaments. Isolated filaments of hypocenters also exist in the Mediterranean region, investigation of which can strengthen conclusions already reached (Scalera, 2007b & 2008) about the possibility of ruling out large scale subduction and allowing only the occurrence of few tens of km of over thrusts, supported by much observational evidence.

It is already known that the deep seismicity in the Mediterranean zone is not distributed as the alleged convergence of Africa and Eurasia should produce. Very often, where subduction slabs and Wadati-Benioff zones should be present – showing intermediate and deep hypocenters – only shallow seismicity is detected. A few small zones show hypocenters reaching depths of about 200 km, and only one zone has foci deeper than 500 km. This situation has forced most geoscientists to admit − without a valid explanation − that in the Mediterranean region the alleged subduction occurs largely aseismically.

Apennines and South Tyrrhenian deep seismicity

In Italy, the inhomogeneity of the distribution of hypocentres is revealed along the Apennines, where the hypocentral depths exceed 50 km only in rare case (Chiarabba et al., 2005). A festoon pattern of the hypocentres is recognizable. Since the axis of the mountain belt is at the present time in a state of collapse – as indicated by the focal mechanisms, by geodetic measurements (Serpelloni et al., 2006) and other evidence (Salustri Galli et al., 2002) – the festoons of crustal earthquakes are most probably associated with mechanical processes leading to intrusions of wedges of deeper materials. The alleged presence of a subducing slab is at odds with this kind of hypocentral distribution, which instead is a signal of a more general process of mantle materials movements and of a typical clustered pattern that hypocenters tend to follows at a larger scale. Geodetic surveys (Devoti et al., 2002) confirm that convergence of Africa and Europe cannot be considered the mechanism of the generation of the Apenninic seismicity.

From Fig. 1a and b it is possible to infer the progressive improvement of the catalogues of the South Tyrrhenian deep seismicity. The Engdahl et al. (1998) catalogue has superseded the old USGS global seismicity catalogue, but in the Italian region it has been overtaken by the CSI-INGV catalogue (Italian Seismic Catalogue of INGV). The CSI is more complete, especially regarding intermediate seismicity, making possible more accurate investigations (Frepoli et al., 1996; Chiarabba et al. 2005) with respect to older studies (Caputo et al., 1970; Giardini and Velonà, 1991; among others). Evidence is growing that the South Tyrrhenian is not associated to the so-called 'slab pull' and 'roll back' that need a tensional state of the slab (Frepoli et al., 1996). Hollenstein et al. (2003) has shown using GPS data that the 1994-2001 trajectories of crustal motion of Calabrian-Sicilian arc are completely at odds with the surface movements forecast by 'roll back'. More recent investigations (Argnani et al., 2007; among others) have reached analogous results. In the light of these new geodetic evidence, subduction can hardly be invoked as the cause of deep earthquakes.

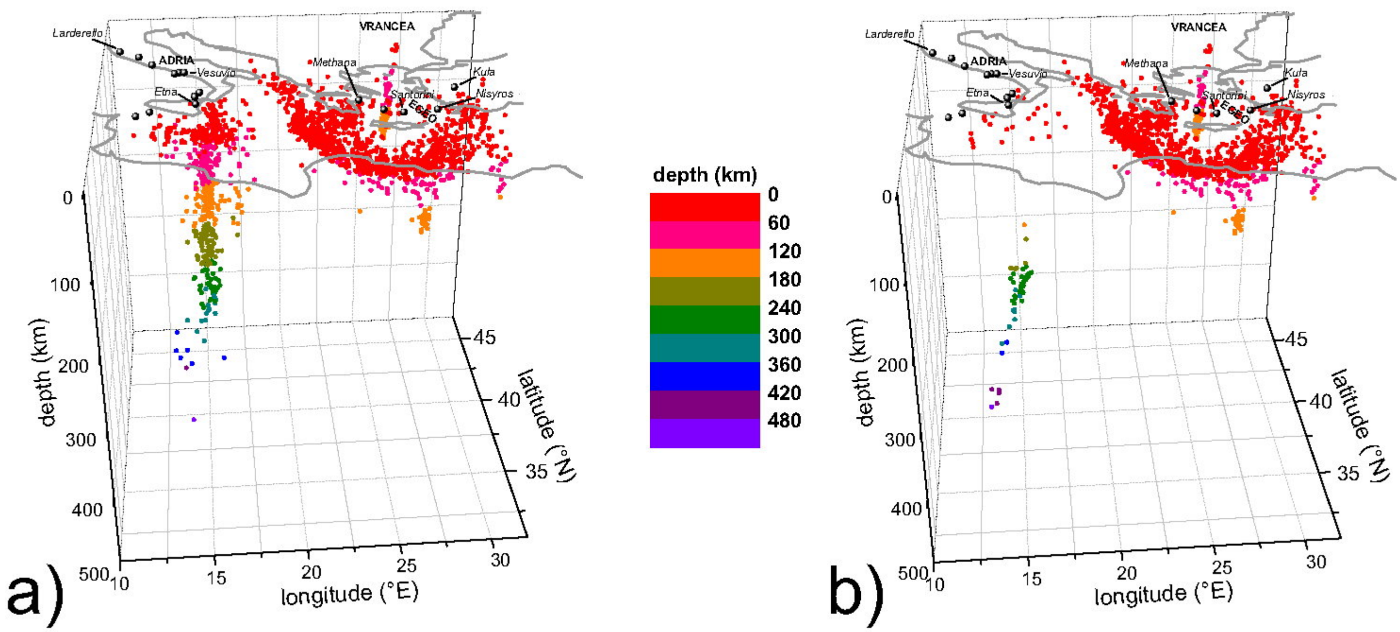

Fig. 1 – The Mediterranean is characterised by four deep earthquake spots: South Tyrrhenian, Aegean, West Turkey, Vrancea. The geographical position of the four deep foci clusters, their narrowness and azimuth are not compatible with mechanical processes linked to a very long front of subduction between Africa and Eurasia. The black circles on the surface represent the volcanoes that have erupted in historical time. a) Tyrrhenian foci from CSI-INGV catalogue and Aegeum and Vrancea from Engdahl Global Catalogue of relocated Hypocentres. b) All hypocentres from the Engdahl Global Catalogue of Relocated Hypocentres.

Aegean deep seismicity

The Aegean deep earthquakes are distributed on a semicircular ring deepening toward the centre of the back-arc with a slope between 30° and 50°, depending on the zone and the depth. As a whole the foci appear to be distributed on an irregular conical surface, generally not exceeding 60 km in depth. The hypocenters can be found at a greater depth (up to 180 km) only on two isolated clusters, the first under the eastern tip of Crete, and the second more easterly under southern Anatolia, where ideally the Hellenic and Cyprus arcs meet in a cusp.

Recent seismic tomographies (Widiyantoro et al., 2004) show under the Aegean a "more complex trajectory of mantle flow than hitherto thought", confirming the global tendency of the high velocity anomaly to have a horizontal segment into the transition zone (Fukao et al., 2001). Additional large masses of high velocity anomaly material are 'trapped' under the 660 km discontinuity, leading to considerations about the excessive amount of lithospheric material that would have been absorbed into this small arc-backarc system. Indeed, already in 1997 the characteristics of the Hellenic arc seismicity lead Papadopoulos (1997) to find at least two main strong contradictions within the traditional subductive interpretation. He writes: "1) the tomographic lithospheric slab penetrates down to at least 400 km which doubles the maximum depth of the Benioff zone seismicity; 2) the resulting minimum time estimates for the subduction process duration at least doubles the seismotectonically calculated maximum time of 13 Ma for the subduction initiation" (Papadopoulos, 1997).

Further contradictions arise from the attempts to reconcile the relatively quick southwestward motion of the western Anatolia – geodetically determined– with the tensional state of stress of the Aegean Sea crust shown by focal mechanisms (McClusky et al., 2000; England, 2003; Serpelloni et al., 2007; among others). The impinging of Arabian block into Anatolia appears to be a clumsy solution if it is accepted that recent investigations on the Levant Rift system (Jordan Rift, Lebanese Splay, El Gharb Rift) indicate it is a result of continental breakup evolving towards an emerging oceanic spreading centre (Mart et al. 2005).

A possibly better cause for both the west Anatolia' kinematics and the rifting state of Aegean could be a flow of material from the mantle in response to the progressive detachment of Africa from Eurasia. This southwestward flow could be considered the twin-flow of the southeastward Tyrrhenian flow, both flows being an expected consequence of the slow opening of the Mediterranean (Scalera, 2005a and 2006a).

Vrancea deep foci

The nearly tubular and vertical distribution of deep foci in Vrancea (Romania) under the Southern Carpathian arc (Fig. 1) has always been an outstanding problem for the geosciences. The tomographic images of the Vrancea region (van der Hoeven et al., 2004; Weidle et al., 2005) show an extraordinary similarity with the Calabrian arc tomography (Cimini and Marchetti, 2006). The Vrancea high velocity anomaly extends nearly vertically up to the transition zone, but the hypocentral cluster does not exceed 180 km in depth. The seismicity of Vrancea is generally interpreted to be the final stage of subduction, slab roll-back and plate boundary retreat (Weidle et al., 2005; Tomek and PANCARDI Team, 2006), but all the evidence – immediately over the deep hypocentres – is of an uplift of the crustal layers, with dramatic inversions of the stratigraphic orders, with older strata thrust over younger ones – a sign of extrusion of the deep crust (see Fig. 3 in Knapp et al., 2005). Subduction is neither presumed nor needed in either the results of the seismic refraction line VRANCEA'99 (Raileanu et al., 2005) or in the associated density model that fits the observed Bouguer anomaly profile (Nicolescu and Rosca, 1992; Raileanu et al., 2005).

Moreover, the map of the metamorphic facies of the Pannonian Basin and Carpathians (Strutinski et al., 2006) shows a complete absence of metamorphic rocks at the surface in a large region centered on Vrancea, leading to hypothesizing a still ongoing process – linked to deep seismicity – of exhumation of these facies.

Conclusions and an additional topic

Besides the regions where the clusters of deep hypocenters are distributed on long belts – namely on the circum-Pacific active margins – in the 'land hemisphere' the filaments of foci have a propensity to be located under the region of maximum curvature of the mountain belts. The main examples are the Western and Eastern Himalayan Syntaxial zones, the Southern Carpathian 'syntaxial' zone, the Southern Apennines (Calabrian arc) 'syntaxial' zone, and the Aegean arc. The lack of a plume of deep hypocentres under the Western Alps should be considered a strange gap. But the presence there of one of the few deep crustal exposures in the world – the Ivrea Zone – is further evidence of the link of these plumes to phenomena of uplift of deep materials. The possible extinction of this kind of plume under the Western Alps – while it is still not extinct under Vrancea – can be a clue to a relatively rapid variation through geologic time. In Vrancea, mantle upwelling and earthquakes seem to cooperate, producing and surfaceward transporting the still buried metamorphism. Then the isolated spot of deep hypocentres of Vrancea can be interpreted as the last stages of exhumation on the surface of deep materials – a process that is still to be completed with the cooperation of erosion.

The zones I have described above increase the doubts about the existence of a large-scale subduction (hundreds of km and more). However, the argument I feel is decisive to exclude an ongoing (at least since Jurassic) subductive process in the Mediterranean region is the simple inspection of the 3D map in Fig. 1. No mechanical underthrust process caused by the alleged collision of Africa and Eurasia can produce such a remarkable pattern of few isolated and welldefined plumes of foci, leaving the long margin of interaction between the two continents completely free from deep foci – from the Rif to Atlas, to Adriatic, to Dinarides and to Anatolia. The slopes and the directions of the four deep plumes clearly distinguishable in Fig. 1 are completely different. Their nature as isolated spots, like similar patterns around the circum-Pacific margins (Scalera, 2007, 2008), supports the idea of disturbances having their origin at depth. The isolated Mediterranean deep hypocentral clusters lead to the idea of their association with vertical displacement of material more clearly than in the opposite hemisphere. This rising material is thought to be involved in the building of the overlying fold belts and basins.

A model explaining the conclusions described above has been developed, and published in this and other Journals (Scalera, 2006c, 2007a, 2007b, 2007c & 2008). Here I summarize the main characteristics of the model and a new aspect (the vth item) not made explicit in the previous papers:

i) - A rifting of the crust and lithosphere causes a stretching of the crust and an opening of a depositional sedimentary basin.
ii) - The space left between the two edges of the rift is essentially filled from below by an isostatic rising of mantle material.
iii) - The rising material changes its mineral phase toward a more open-packed lattice, but a time of permanence in a metastable state can be possible.
iv) - The changes of phase (Green and Ringwood, 1970; Ringwood, 1991) produce a surplus of volume, which must find space. The material can be extruded on the surface. The efficiency of the extrusion is in inverse relation to the rifting rate. Deep earthquakes are linked to the phase changes and the occurrence at great depth of a transition from a metastable state to the transformed one starts the uplift of a column and a series of earthquakes.
v) - The efficiency of the extrusion can have an inverse relation with the global rate of expansion of the Earth. In Fig. 2, the 'Half Spreading Map of the Oceans' (Müller et al., 1997; McElhinny and McFadden, 2000; Müller et al., 2008) shows three minima (in Recent, Late Cretaceous, Late Jurassic) and the Recent minimum is correlated to the so-called 'Neotectonic Period' (Ollier, 2003; Ollier and Pain, 2000) – the last few million year time window – in which most fold-thrust belts have a renewed folding and thrusting. If the global rifting activity – driven by a global expansion – stops, the metastable states of the uplifted material continue to convert to lighter and bulkier phases, extruding on the surface and giving all the appearance of a time-coordination among far and unrelated fold belts. If this coincidence between Neotectonic Period and Half Spreading Recent minimum is real, other 'Neotectonic Periods' should be found in the geological past, eventually in time-windows covering the Late Cretaceous and Late Jurassic minima of the Half Spreading Rate (Fig. 2). This possibility, still without a definitive assessment, deserves to be investigated.
vi) - The extrusion process and the extruded material actively form the fold belt. The over-thrusts and the gravity spreading are helped by the 'piston' of the extruding material. Indeed, gravity spreading alone is not sufficient to build the observed overthrusts (Viti et al., 2006).
vii) - The HP and UHP metamorphism can have their origin in the 'forge' of the orogen where high nonlithostatic overpressures can be generated at the boundary between the rising mantle material and the old lithosphere and by great earthquakes (Mancktelow, 1995; Mancktelow and Gerya, 2008) at depth not exceeding the orogenic roots (50-70 km).
viii) - The same overpressures, together with the higher temperatures available in this model at shallower depth, can bear a relation with the synthesis of biogenic and abiogenic hydrocarbons.

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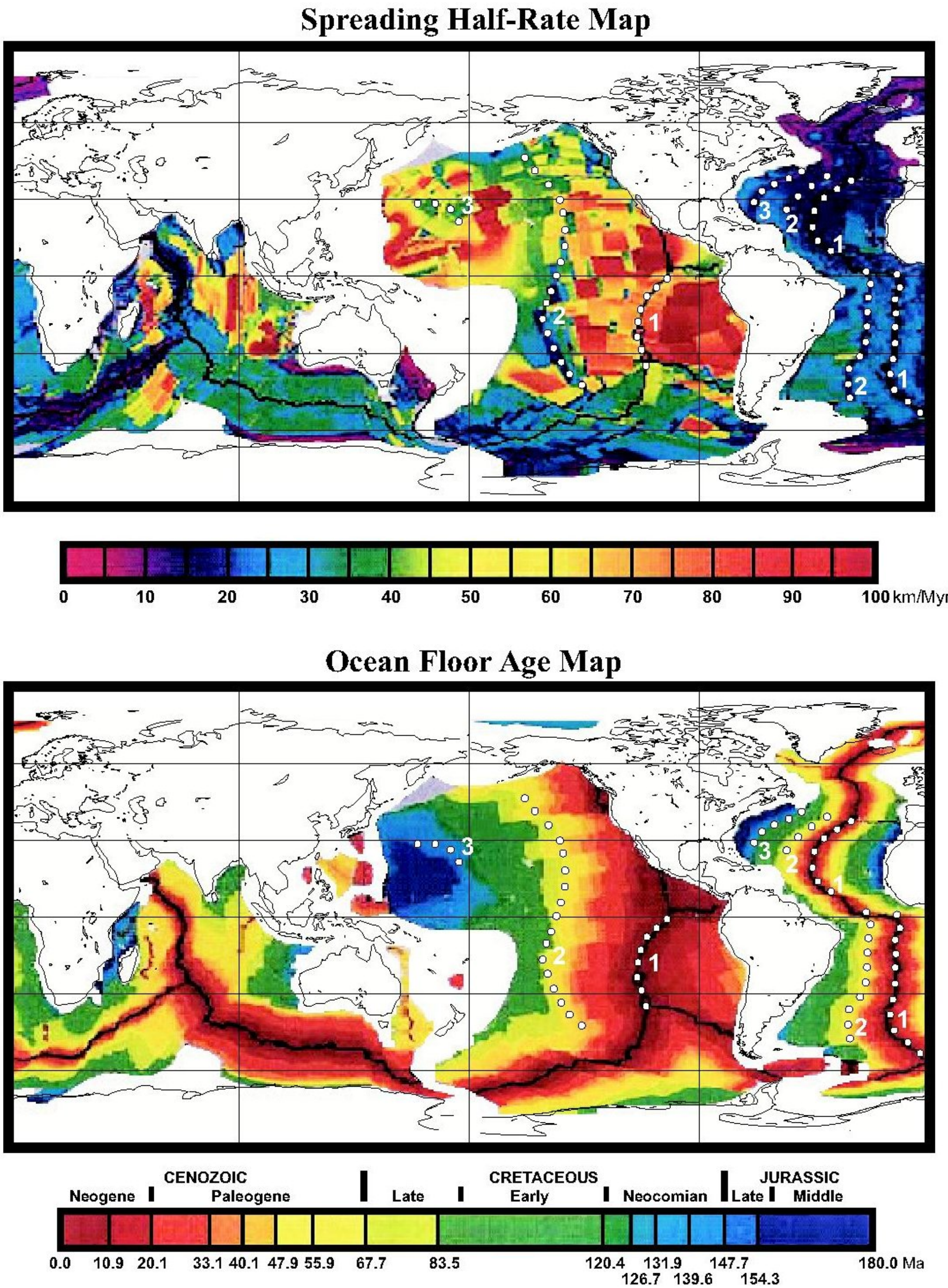

Figure 2. A simple experiment using the Maps of Ocean Floor Ages and of Half Spreading Rates (Müller et al., 1997; McElhinny and McFadden, 2000; Müller et al., 2008), with considerations of the 'Neotectonic Period' (Ollier and Pain, 2000; Ollier, 2003). If the minima of the Half Spreading Rate of Atlantic and Pacific (the white circle series, numbered 1-3 in the upper map) are transferred on the Ocean Floor Age Map below, the ages of the three minima are indicated: Recent, Cretaceous-Cenozoic boundary and Jurassic-Cretaceous boundary. Obviously, the three ages are affected by some uncertainty. In the Recent and in the past time window of about 10 Ma the Neotectonic Period of reactivation and uplifting of orogens is in course. A relation can be hypothesized between the slowing down of the global expansion, the consequent slowing down of the continental rifts, and a mechanism of extrusion of mantle material under the fold belts that can be interpreted as 'Neotectonic Period'. It should be investigated if analogues of the recent 'Neotectonic Period' have occurred during the previous half spreading minima '2' and '3'.

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