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RECENT/PRESENT TECTONICS IN ITALY: INSIGHTS FROM THE NEOGENIC MEDITERRANEAN DEFORMATION PATTERN*

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RIASSUNTO - *Tettonica recente/attuale in Italia: conoscenze a partire dal quadro deformazionale neogenico nell'area mediterranea* - Il Quaternario *Italian Journal of Quaternary Sciences,* **10**(2), 1997, 299-304 - L'analisi delle deformazioni neogeniche nell'area mediterranea centro-orientale ha fornito importanti vincoli sulla natura dei meccanismi dinamici e sui processi tettonici che hanno controllato l'evoluzione strutturale di questa zona di collisione continentale. Sulla base di queste indicazioni è possibile prevedere un'assetto tettonico/cinematico quaternario che può rendere conto delle principali evidenze neotettoniche e delle caratteristiche dell'attività sismica nella regione italiana.

Parole chiave: Evoluzione recente, neotettonica, Catena Appenninica, Italia
Key words: Recent evolution, neotectonics, the Apennines, Italy

1. LEARNING FROM NEOGENIC DEFORMATIONS: EXAMPLES OF "MINIMUM WORK" KINEMATIC/ TECTONIC SETTINGS

The analysis of the physical implications of the time-space distribution of Neogenic deformations in the Mediterranean area led us to develop some ideas on the "controlling factors" of geodynamic processes in this region (Mantovani *et al.*, 1997). Horizontal stresses induced by the convergence between the Africa-Arabia and Eurasia plates are the main driving mechanism. The shortening required by this convergence has been accommodated by a succession of consuming processes, mainly involving the African and Adriatic lithosphere, the locations of which and their time durations have been controlled by the basic physical requirement of minimizing the total work of horizontal forces against the forces resisting the lithosphere shortening at all consuming boundaries.

Lithosphere shortening develops through two distinct, even if closely connected, processes: the first consists in the generation of fractures in the upper brittle buoyant crust and the consequent imbrication of the resulting crustal slivers. The second consists in the gravitational sinking of the lower lithosphere, that, once mechanically decoupled from the upper buoyant crust, presents a negative density contrast with respect to the underlying mantle. The first process is resisted by frictional forces in the upper crust that contrast fracturing and by gravitational forces that contrast the uplift of crustal slivers by reverse movements along crustal faults. The second process, on the contrary, does not require any work since it is driven by gravitational forces, which cause the sinking of the lower non-buoyant lithosphere. However, this last process might involve the forced transportation to depth of light buoyant crustal material, which is resisted by buoyancy forces. A given distribution of consuming processes in the whole system may persist as long as it represents the solution of "minimum work", in the sense described above. As soon as the resisting forces at some consuming boundary increase for any reason (by the arrival of a thicker crust at the trench zone, for instance), the system may find it more "convenient" to stop the ongoing consuming process and then activate other shortening processes at different boundaries where a lower work of horizontal forces is involved.

The shift of maximum horizontal stresses from the suturing border to the boundaries under activation is generally achieved by lateral escapes of crustal wedges (Tapponier, 1977; Mantovani *et al.*, 1996,1997). To understand this "choice" of the system one must consider that the horizontal displacement of masses is not (or poorly) resisted by gravitational forces and that, furthermore, this phenomenon mostly involves orogenic bodies which are characterized by a very poor mechanical coupling with the underlying structure (Mantovani *et al.*, 1997).

The most evident example of "minimum work solution" is represented by the upper Miocene lateral extrusion of Anatolia in response to the cessation of the lithosphere consuming process at the northern edge of the Arabian indenter (McKenzie, 1972; Tapponier, 1977; Dewey & Sengor, 1979; Mantovani *et al.*, 1997). This lateral escape allowed to attenuate horizontal stresses at the sutured Arabia-Eurasia collisional boundary and to increase stresses at the southern (Hellenic trench) and western (preApulian zone) borders of the Anatolian-Aegean-Balkan extruding system where new consuming

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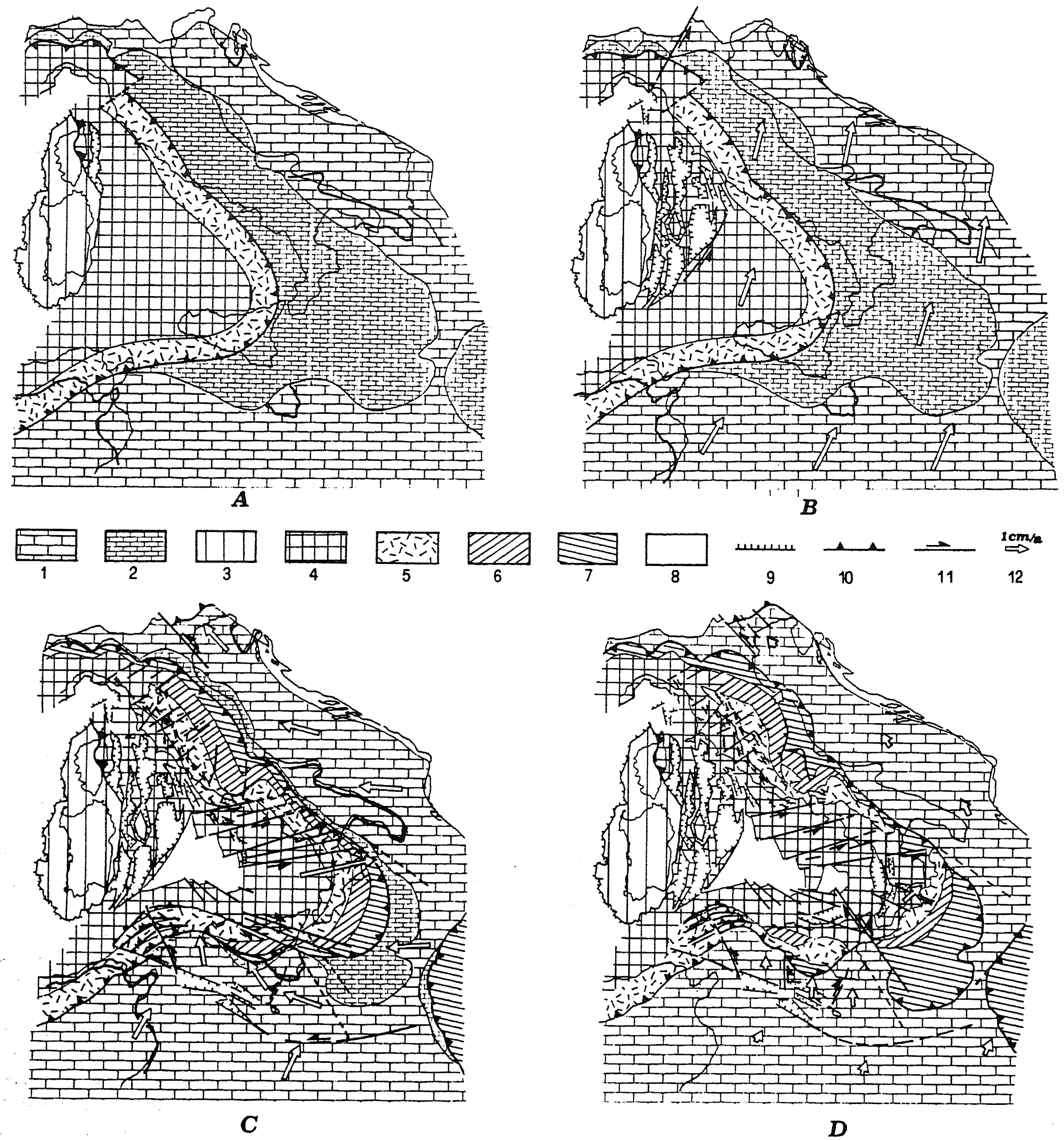

Fig.1 - Tentative reconstructions of the central Mediterranean tectonic setting in the Late Tortonian (A), Early Messinian (B), Late Pliocene (C) and Present (D). 1) Present extent of the Africa-Adriatic foreland; 2) Africa-Adriatic margin consumed during the evolution; 3) Corsica-Sardinia massif; 4) Alpine-Apenninic pre-Tortonian belt; 5,6,7) Tortonian, Messinian and post-Messinian accretionary belts; 8) Extensional areas; 9,10,11) Tensional, compressional and transcurrent features; 12) Tentative motion vectors of major structural elements with respect to Eurasia. Present geographycal contours and the paleopositions of some geographycal key zones are also reported for reference.

Ricostruzioni schematiche dell'assetto tettonico del Mediterraneo centrale alla fine del Tortoniano (A), all' inizio del Messiniano (B), nel Pliocene terminale (C) ed attualmente (D). 1) Configurazione attuale dell'avampaese Africa-Adriatico; 2) Margine Africano-Adriatico consumato durante l'evoluzione; 3) Massiccio Sardo-Corso; 4) Catene Alpino-Appenniniche formate prima del Tortoniano; 5,6,7) Catene di accrescimento Tortoniana, Messiniana e post-Messiniana; 8) Aree che hanno subito assottigliamento crostale; 9,10,11) Strutture estensionali, compressive e trascorrenti; 12) Velocità e direzione indicative dei movimenti rispetto all'Eurasia dei principali elementi strutturali. I contorni geografici attuali e le paleoposizioni di alcune zone geografiche chiave sono riportate per riferimento.

processes were activated at the expense of the thinned African and Adriatic lithosphere (see Mantovani *et al.*, 1997).

Almost contemporaneously, the Adriatic plate, in response to the stop of the consuming process in the Western Alps (see Dal Piaz, 1995 and references therein), decoupled from main Eurasia through the activation of the left lateral Giudicarie fault system and started moving roughly NE (Fig. 1A,B). This drifting implied a divergence between the Adriatic block and the already fixed Corsica-Sardinia massif, causing crustal stretching in the northern Tyrrhenian zone. This interpretation may explain the lack (or the relative quiescence) of orogenic activity in the Apennines during the opening of the northern Tyrrhenian basin (*e.g.* Vai, 1987; Castellarin *et al.*, 1992).

The convergence between the Adriatic domain and the Anatolian-Aegean-Balkan system (Mantovani *et al.*, 1997) was accommodated by the consumption of the preApulian zone. This kinematic/tectonic pattern lasted until the Messinian, when the forces resisting the consumption of the preApulian foreland underwent a considerable increase. In response to this increase, the system found it more convenient to suture the preApulian border (see, *e.g.*, Mercier *et al.*, 1989) and to activate the consumption of the western Adriatic margin, where large areas with thin lithosphere were still present (see, *e.g.*, Patacca *et al.*, 1993). This tectonic reorganization was mainly achieved by a significant change in the kinematic pattern of the Adriatic block, which began to rotate clockwise in response to the westward pushing of the Aegean-Balkan system (Fig. 1C).

This new kinematics emphasized horizontal compressional stresses in the Tyrrhenian-Apennines region, which were accommodated partly by the consumption of the western Adriatic thinned margin and partly by lateral escapes of crustal wedges. One of these wedges, the Iblean-Ventura buoyant continental fragment, decoupled from Africa by a left lateral shear zone in the Sicily channel and extruded roughly NNW to NWward. Other wedges, in the southern Apenninic Arc extruded roughly eastward, at the expense of the adjacent Adriatic foreland. The right lateral decoupling between opposite lateral extrusions of the Iblean and Calabrian blocks was allowed by a system of SE-NW trascurrent faults, as the Taormina one. The fact that transcurrent movements in the Sicily channel were accompanied by formation of troughs has been interpreted as a consequence of internal deformation in the Iblean-Ventura block (Mantovani *et al.*, 1996, 1997).

In the wake of the eastward extruding wedges in the southern Apenninic Arc, crustal stretching occurred in the central Tyrrhenian zone (Magnaghi-Vavilov basin). The convergent motion between the eastward extruding Apenninic wedges and the Adriatic plate was accommodated by the imbrication of Adriatic upper crustal units, forming the Pliocenic Apenninic accretionary belt, and by sinking of the lower lithosphere into the underlying mantle (roll back). During this phase, the central part of the Apenninic belt, the Abruzzi-Latium segment (A.L.) behaved as hinge zone between the northern and southern Apenninic Arcs. This hypothesis is suggested by the poor deformation this zone underwent and by the fact that the northwestern (Ancona-Anzio) and southeastern (Ortona-Roccamonfina) boundaries of A.L. behaved as lateral ramps for the outward displacements of the northern and southern Apenninic Arcs with respect to A.L. The greater migration rate and the counterclockwise rotation of the southern Apenninic Arc with respect to the northern Arc (Fig. 1C) caused a considerable distortion of the belt with respect to its previous configuration (Fig. 1B).

A new significant change of tectonic style occurred around the late Pliocene-early Pleistocene, in response to the cessation of the lithosphere consuming process beneath the southern Apennines, well documented by geological data (Mostardini & Merlini, 1986; Patacca & Scandone, 1989). As in previous cases, the disactivation of a consuming border required the reorganization of the deformation pattern in the whole zone, in order to favour the consumption of the thinnest zones which were left in the surrounding regions. At this stage (beginning of the Quaternary) thin lithosphere was only left in the Ionian basin and in the northern Adriatic zone. Given this context and with considering the "minimum work" principle, one could expect an acceleration of outward extrusion of the belt segments which were facing the Ionian and northern Adriatic zones, *i.e.* the Calabrian and northern Apenninic Arcs, which is indeed documented by neotectonic data (*e.g.*, Westaway, 1993; Bartole, 1995).

Another important effect which was induced by the suture of southern Apennines was the acceleration of uplift in the whole Apenninic belt, with particular regard to southern Italy which was more directly stressed by the Africa-Adriatic convergence. A similar effect had previously occurred in eastern Anatolia, in response to the cessation of the lithosphere consuming process at the northern edge of the Arabian indenter (see, *e.g.*, Dewey & Sengor, 1979), where uplift of more than 2 km are suggested by geologic data.

The suture of southern Apennines also caused a considerable reduction of the mobility of the Adriatic plate. The Quaternary kinematics of this block (confined to few mm/y) has been also influenced by the reactivation of shortenings at its eastern border, *i.e.* southern Dinarides and Hellenides (Mercier *et al.*, 1989).

2. SEISMOTECTONIC INTERPRETATION

Most of the tectonic processes which were activated in response to the suture of the southern Apennines are still going on (Fig. 1D) and are now responsible for present deformations and related seismic activity.

In the southern Alps, deformations and seismic activity are connected with the shortening processes at the collisional boundary between the Adriatic block and Eurasia, as clearly indicated by geological and seismological evidence (see, *e.g.*, Slejko *et al.*, 1989), which suggests a dominant SE-NW to SSE-NNW compressional regime.

In the northern Apennines, deformations are connected with the progressive outward bending of the Arc, driven by a compressional regime roughly parallel to the main trend of the belt (SE-NW). This bending develops through relative rotations (Speranza *et al.*, 1997) and lateral escapes of crustal wedges, favoured by transcurrent fault system transversal to the chain (see, *e.g.*, Boccaletti *et al.*, 1985). The proposed mechanism may account for the occurrence of compressional deformations on the external fronts of the chain and contemporaneous tensional/transtensional features in the internal zones, as indicated by geological and seismological observations (Elter *et al.*, 1975; Boccaletti *et al.*, 1985; Castellarin & Vai, 1986; Bartole, 1995). The outward migration of wedges in the northern Apennines occurs at the espense of the adjacent Adriatic foreland, which consequently undergoes downward flexure. This mechanism might be connected with the occurrence of subcrustal earthquakes beneath this zone (Amato *et al.*, 1993).

In the central Apennines, deformations and seismic activity are mainly related with strike-slip tectonics, due to the left lateral motion of the outer parts of the belt, moving in connection with the Adriatic plate, with respect to the internal zones, characterized by a more stable "Tyrrhenian" kinematic behavior (Fig. 1D). This hypothesis is coherent with the interpretations of neotectonic data in this zone proposed by some authors (see, *e.g.*, Cello *et al.*, 1995).

In the southern Apennines, the belt is sutured to the Adriatic foreland and thus no, or very poor, Quaternary compressional deformations are recorded at the external fronts (see, *e.g.*, Cinque *et al.*, 1993). Recent deformations and seismic activity in this region seem to be mainly associated to a tensional stress field oriented SW-NE (Cinque *et al.*, 1993; Hippolyte *et al.*, 1995; Montone *et al.*, 1997). Neotectonic data also indicate uplift and eastward tilt of the central-eastern part of the chain and of the adjacent Bradanic trough (Cinque *et al.*, 1993; Patacca *et al.*, 1997). These deformations and the seismic activations of normal faults, with downward movement of the Adriatic side, might be consequences of the Quaternary reactivation of the underthrusting of the southern Adriatic platform beneath the southern Dinarides and Hellenides (see, *e.g.*, Mercier *et al.*, 1989). This phenomenon is probably responsible for the relaxation of flexure (unbending) in the southern Adriatic, indicated by the analysis of the foredeep basins (Kruse & Royden, 1994), and could also explain the activation of normal faults in the belt. This tectonic interpretation may also account for the fact that in the last two centuries strong earthquakes in the southern Apennines, mainly associated to the above mentioned normal faults, have been regularly preceded by the most intense releases of seismic energy at the opposite Adriatic border, in the southern Dinarides-Albania (Mantovani & Albarello, 1997).

In Calabria and Sicily, tectonic activity is related with the lateral escapes of crustal wedges in response to the Africa-Adriatic convergence (Fig. 1D). The Calabrian wedges move roughly eastward, at the expense of the adjacent Ionian lithosphere. This causes compressional deformations in the external Calabrian Arc (*e.g.*, Rossi & Sartori, 1981; Del Ben, 1993) and tensional features in the internal side, mostly concentrated in the Crati and Mesima troughs (Westaway, 1993). The fact that present deformation rates are much stronger in southern Calabria with respect to the northern part of this zone, is a consequence of the considerable slowdown of northern Calabria after the middle Pleistocene collision of this sector with the Apulian structural high (Barone *et al.*, 1982). The considerations and arguments reported in this note are necessarily very sinthetic. A detailed description and illustration of the evidence considered and of the proposed geodynamic interpretation is given by Babbucci *et al.* (1997) and Mantovani *et al.* (1997).

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