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Lithosphere tectonic context of the carbonatite-melilitite rocks of Italy

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ABSTRACT. — The occurrence in Italy of Quaternary carbonatite-melilitite rocks, belonging to the Intra-mountain Ultra-alkaline Province (IUP), is considered in order to discuss a likely geodynamic environment for the Tyrrhenian-Appennine system. The IUP tectonic setting is described at the crustal and lithospheric scale and compared with the HK-series of the Roman Co-magmatic Province. It is concluded that a suitable mantle source for the IUP and HKS melts products (e.g. a radiogenic source with a phlogopite-bearing carbonate peridotite composition) does not need either the westward subduction of the Adriatic continental lithosphere or a mantle plume. The IUP and HKS geochemistry, as well as the deformation history of the Tyrrhenian-Appennine system, is explained in the frame of a substantially passive intra-continental rift context. The peculiar metasomatism and high radiogenic content of the HKS and IUP mantle source is attributed to fluids directly deriving from the lower mantle.

RIASSUNTO. — L'inquadramento geodinamico del sistema Mar Tirreno-Appennini è stato riconsiderato alla luce della recente scoperta in Italia di una serie di rocce carbonatitico-melilititiche di età quaternaria appartenenti alla Provincia Ultra-alkalina Intramontana (IUP). Il contesto tettonico di IUP, e delle contigue serie alte in potassio (HKS) della Provincia Comagmatica Romana (RCP), è stato esaminato sia alla scala crostale sia a quella litosferica. Le sorgenti dei magmi IUP e HKS sono rappresentate da una peridotite radiogenica a flogopite e carbonato. L'ipotesi di un arricchimento isotopico della sorgente per azione di fluidi

provenienti da uno slab in subduzione è insufficiente, in quanto la posizione di alcuni centri (es. area del Vulture) non è compatibile con quella di un possibile piano di subduzione ovest immergente; inoltre, non è necessaria, in quanto valori isotopici di Sr e Nd, simili a quelli delle rocce italiane, sono stati riscontrati in altre aree geodinamiche in distensione o intra-continentali. Si può escludere anche l'attività di un *plume* astenosferico, poiché non si osservano i fenomeni tipici di questo tipo di ambiente (*doming* crostale, elevate temperature astenosferiche, attività magmatica che predata quella tettonica, forti valori di assottigliamento litosferico contro bassi valori di estensione litosferica). La geochimica delle rocce IUP ed HKS e l'evoluzione geodinamica del sistema Tirreno-Appennini può essere, invece, ben inquadrata in un contesto di rift passivo intra-continentale, che ha determinato forti estensioni litosferiche con conseguente sollevamento di una astenosfera arricchita in fluidi metasomatici e radiogenici. Questi fluidi potrebbero essere direttamente risaliti dal *boundary layer* localizzato ad una profondità di circa 670 km, al limite tra mantello superiore ed inferiore.

KEY WORDS: *carbonatites; lithosphere; passive rift; metasomatism; Apennines; Italy*

INTRODUCTION

Present knowledge on the geometry and tectonic setting of the lithosphere-asthenosphere system in Italy, as well as of the

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associated magmatism, is strongly conditioned by the popular geodynamic interpretation of the area in the frame of a subduction-related geodynamic scenario (SERRI, 1997; PECCERILLO, 1999; DOGLIONI *et al.*, 1999; FACCENNA *et al.*, 2001). Some authors consider an alternative geodynamic context in order to explain the evolution of the Tyrrhenian-Apennines system and the associated

magmatism (LOCARDI, 1982; CUNDARI, 1994; VANOSI *et al.*, 1994; LAVECCHIA, 1988; LAVECCHIA *et al.*, 1995). In their view, the compression is subordinated to the extension and the opening of the Tyrrhenian basin has driven the development of the Apennine fold-and-thrust belt system. Strong support for this point of view comes from geochemical and petrological data concerning the occurrence of

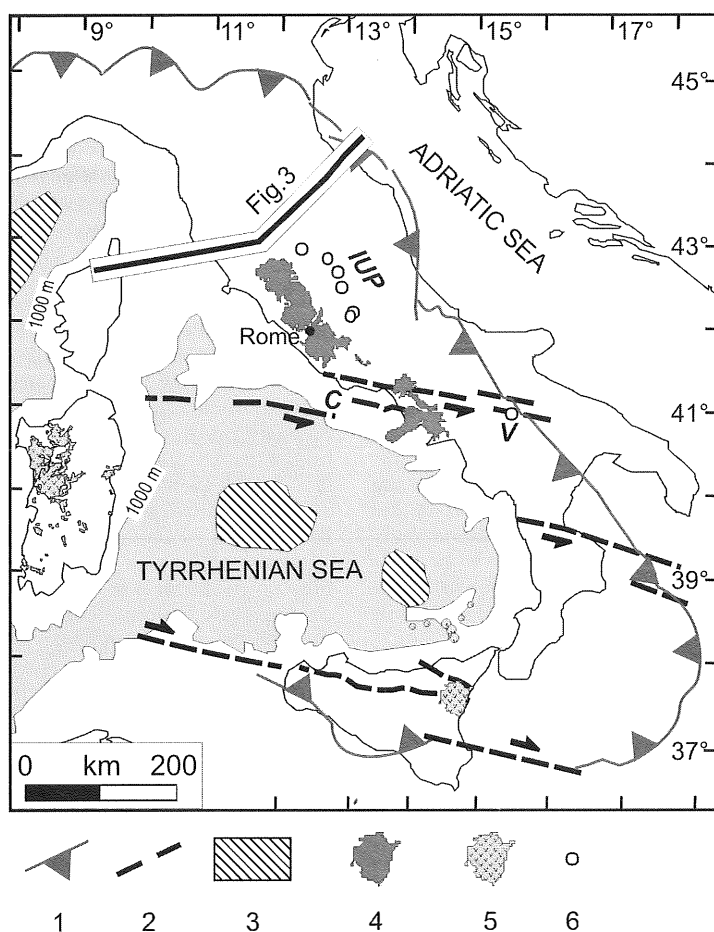


Fig. 1 – Schematic map of the Tyrrhenian-Apennine system with trace of the section in Fig. 3. CV = Circeo-Vulture line. 1) outer front of the Apennine fold-and-thrust belt system; 2) lithospheric-scale transfer fault zone; 3) ultra-thinned continental crust (<10 km); 4) igneous centres of the Roman Co-magmatic Province (RCP); 5) Mt. Etna and Plio-Pleistocene magmatic occurrences in Sardinia; 6) igneous centres of the Ultra-alkaline Province (IUP).

Ca-carbonatites and melilitites in the Apennines of Italy (LAVECCHIA and STOPPA, 1996; STOPPA and WOOLLEY, 1997). World wide, these rocks are most commonly related to melts from the mantle and are typical of extensional environments (WOOLLEY, 1989).

IUP TECTONIC CRUSTAL SETTING

The Italian Ca-carbonatites and melilitites are middle Pleistocene in age (~0.64 to ~0.26 Ma) and constitute a magmatic province, named Intra-mountain Ultra-alkaline Province (IUP) (Fig. 1). The IUP extends from Umbria (Colle Fabbri, San Venanzò-Pian di Celle, Polino), to Latium (Cupaello), Abruzzo (Grotta del Cervo, Oricola-Camerata Nuova) and Basilicata (Monticchio and Masseria Boccaglie at Mt. Vulture) (LAVECCHIA *et al.*, 2002 and references therein).

The IUP occurrences of central Italy lie along the inner side of the Apennine mountain chain, within a narrow area (less than 20 km wide), which extends in the NNW-SSE direction for a length of ~110 km. This narrow zone is positioned ~50 km to the east of the axis of the co-axial Roman Co-magmatic Province (RCP). The IUP centres are located in a zone of widespread Plio-Quaternary extensional tectonics with typical NNW-SSE striking horst-and-graben structures. The faults bordering the grabens control, at upper crust level, the location of the IUP centres.

The IUP occurrences of southern Italy are located within the Vulture volcano, which lies at the outer border of the southern Apennine mountain chain, ~100 km eastward of Vesuvius. Vulture is located just behind the NNW-SSE striking frontal ramp of the Campania-Lucania thrust belt and on a regional N105°E-striking left-lateral fault system, named Circeo-Vulture (CV) line. The line represents the landward expression of a major tectonic E-W lineament, known as the «41st Parallel» fault system. The «41st Parallel» and the «Circeo-Vulture» lineaments have been interpreted as a left-lateral

lithosphere transfer zone which allows a larger extension of the southern Tyrrhenian sector compared to the northern sector (LAVECCHIA, 1988). This transfer zone also appears to have controlled the tectonic position of Vesuvius and Vulture: the two igneous centres lie along the transfer zone itself and are placed more than 50 km eastward compared with the northernmost RCP and IUP occurrences, respectively.

IUP MANTLE SETTING

Regional information on the thickness of the Italian lithosphere may be found in PANZA and SUHADOLC (1990). Details on the depth of the Lithosphere-Asthenosphere Boundary (LAB) beneath the IUP and the RCP may be found in LAVECCHIA *et al.* (2002). These authors have computed the thickness of the thermal lithosphere, considering that the LAB is given by the depth at which the geotherm intersects the horizontal isotherm of the convective asthenosphere (adiabat). They have chosen an asthenosphere potential temperature (T_p) of 1280°C and have calculated two steady-state geotherms, assuming average heat flow values of 100 and 60 mW/m² for the RCP and IUP, respectively (Fig. 2). The adiabatic curve corresponding to a T_p of 1280°C intersects the RCP and the IUP geotherms at depths of 45-50 and 85-90 km, respectively. The difference in regional heat flow between the RCP and the IUP substantially corresponds to a sharp LAB deepening in central Italy, moving from the thinned Tuscan lithosphere to the unthinned Apennine-Adriatic lithosphere. Also BAILEY and COLLIER (2000), through the use of global tomography, evidence a marked contrast in the velocity structure below the Tuscan region, where low velocity overlies high velocity mantle, and the Apenninic region, where the opposite condition is observed, with a consequent strong lateral step/discontinuity between the RCP and the IUP.

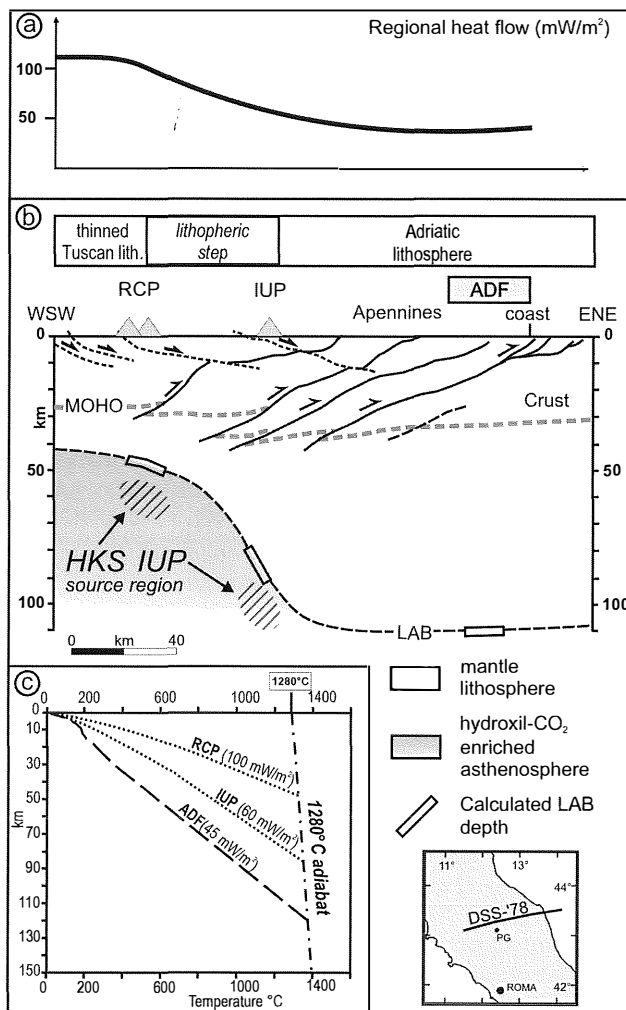


Fig. 2 – a) Regional heat flow profile along the section of fig. 2b (data from PASQUALE *et al.*, 1997); b) Lithospheric section along the trace of the Deep Seismic Sounding profile Piombino-Ancona (DSS '78): the thickness and deformation style of the crust is from LAVECCHIA *et al.*, 2002; the depth of the Lithosphere-Asthenosphere Boundary (LAB) beneath the RCP, the IUP and the ADF (Adriatic Foredeep) corresponds with the depth of the intersection between the geotherm and the 1280 $^{\circ}\text{C}$ adiabat; the depth of the LAB beneath Tuscany is from PANZA & SUHADOLC, 1990. c) Temperature-depth profiles: IUP and RCP geotherms from LAVECCHIA *et al.*, 2002; ADF geotherm from PASQUALE *et al.*, 1997.

LINKS BETWEEN THE IUP AND THE HK-SERIES OF THE RCP

The IUP shares important geological and petrological aspects with the more abundant, almost coeval, leucite lavas (so-called *High-*

Potassium Series, HKS) of the Roman Comagmatic Province. The HKS and the IUP carbonatite-melilitite rocks are derived from mantle sources with the same composition (radiogenic carbonate/phlogopite-bearing peridotite), but different depths (LAVECCHIA

and STOPPA, 1996). Based on thermobarometric data and considerations (PECCERILLO and MANETTI, 1985; CUNDARI and FERGUSON, 1991), their mantle source region would be located at depths corresponding to 22-24 kb and 28-30 kb, respectively. Comparing these depths (about 60-70 km for the HKS, about 90-100 for the IUP) with the thickness of the lithosphere in central Italy, it is evident that both mantle sources, are located beneath the LAB, within the uppermost mantle asthenosphere (Fig. 2b). It is also evident that the surface position of the HKS and IUP products is controlled by the shape of the lithosphere (BAILEY and COLLIER, 2000). In central Italy, the strong lateral density contrast between the upwelled Tuscan asthenosphere and the unthinned Apennine-Adriatic lithosphere may favour stress release processes along the lithospheric step zone, thus controlling the uprising from the asthenosphere of the HKS- and IUP- parental melts. In southern Italy, the focusing of the IUP magmatic activity into one well defined site (Vulture) can be explained hypothesising that the parental melt source region is sited at the intersection between the NNW-SSE striking lithospheric step and the N105° Circeo-Vulture strike-slip lithosphere discontinuity.

IUP GEODYNAMIC CONTEXT

A suitable mantle source for the IUP melts, as well as for the HKS products (e.g. a source with a phlogopite-bearing carbonate peridotite composition), does not necessarily need either the eastward subduction of the Adriatic continental lithosphere, or contamination with the upper crust. In fact:

1) The IUP shares geochemical features (major- and trace-element) and volcanic style (shape and dimensions of centres) with most famous carbonatite provinces, such as the SW Uganda (Fort Portal) and Gregory Rift ones, which are rather typical of intra-continental tectonic settings (BAILEY and COLLIER, 2000). In these areas, carbonates are certainly not present in the basement rocks and subduction

processes are not active since at least 500 ± 150 Ma (ASHWAL and BURKE, 1989).

2) The IUP Sr and Nd isotopic ratios ($^{87}\text{Sr}/^{86}\text{Sr} \sim 0.7100$ to 0.7111 and $^{143}\text{Nd}/^{144}\text{Nd}$ from 0.5119 to 0.5121) (CASTORINA *et al.*, 2000) are similar to those of the micaceous kimberlites and lamproites from West Australia and South Africa, which are considered to reflect an enriched mantle source and not a crustal contamination (MITCHELL and BERGMAN, 1991).

3) The peculiar metasomatism of the IUP mantle source cannot be associated to fluids deriving from a subducting slab, because some of the IUP centres (the ones in the Vulture area) are sited in the rear of the hypothesised Adriatic subduction plane.

4) A contamination by upper crustal material (PECCERILLO, 1999) cannot be considered in order to justify the radiogenic isotope composition, because the sedimentary limestones hosting the Polino occurrence are different from the carbonatites in their much lower Sr isotope ratio (CASTORINA *et al.*, 2000).

5) The very low percentage of mantle partial melting commonly associated with the carbonatitic melts (<1%) is not compatible with the higher degree of partial melting (> 1%) that we would expect above a subduction plane.

In order to explain the enrichment of the IUP and HKS mantle sources, a mantle plume model might be considered as alternative to the subduction model. In our opinion, also this solution has a number of problems. The presence of a plume would have first produced doming and magmatism and only later, it would have produced rifting. In Italy, by contrast, the volcanism has always post-dated the onset of normal faulting in any given area by up to 2-3 Ma (LAVECCHIA and STOPPA, 1996). Furthermore, plumes typically gave rise to large erupted volumes of mafic magmas, whereas only small amount of alkaline melts are present in Italy. Still, the Tyrrhenian rift zone is characterized by a large extensional strain rate (10^{-15} s^{-1}), which implies that the deformation has occurred mainly isothermally, and in general it does not show evidence of

abnormally high temperature at the lithosphere-asthenosphere boundary (T_p around 1280° C) (CELLA and RAPOLLA 1997). Moreover, the elevated amount of crustal stretching (factor beta up to 3.5-4, LAVECCHIA *et al.*, 1995) and the very high positive gravimetric anomaly cannot be justified considering a plume model (CELLA and RAPOLLA 1997).

FINAL CONSIDERATIONS

1) In absence of both a SW-dipping subduction plane and of a plume how can the peculiar IUP and HKS geochemistry be explained?

In our opinion, the IUP and RCP generations may be explained in the frame of a prevalingly passive rift system, dominated by horizontal tensional forces. These propagated within the Tyrrhenian lithosphere achieving its stretching and thinning, with consequent asthenospheric upwelling and unloading. The HKS and IUP parental melts generated within the uppermost asthenosphere, but their source region was probably fed by deeper hydroxyl-CO₂ rich fluids and volatiles. Global upper-mantle seismic tomography and isotope geochemistry of Cenozoic volcanic rocks suggest the existence of a large low-velocity anomaly (LVA) beneath

the western Mediterranean and western Europe lithosphere down to a depth of about 600-700 km (HOERNIE *et al.*, 1995). In our opinion, this anomaly might have a chemical origin, rather than a thermal origin. It might represent a «wet» mantle region, enriched in metasomatic and radiogenic fluids directly coming from the boundary layer between the asthenosphere and the mesosphere, e.g. from the 670 km discontinuity. In fact, this discontinuity represents a layer isolated from both the upper mantle and the lower mantle convection, where radiogenic fluids may have the opportunity to isotopically evolve in isolation.

2) In absence of both a subduction plane and a plume, what may be the driving force for the strong lithosphere Tyrrhenian thinning and stretching? What may be an explanation for the coeval development of the Apennine compression?

In our opinion, the Tyrrhenian-Apennine deformation history is characterised by the combination and summation of horizontal far-field forces, associated to the north-eastward motion and counter-clockwise rotation of the Adria block (which primarily caused extensive and asymmetric stretching of the Tuscan-Tyrrhenian lithosphere), with local horizontal forces (Tyrrhenian rift push forces) (Fig. 3). The latter may have been generated

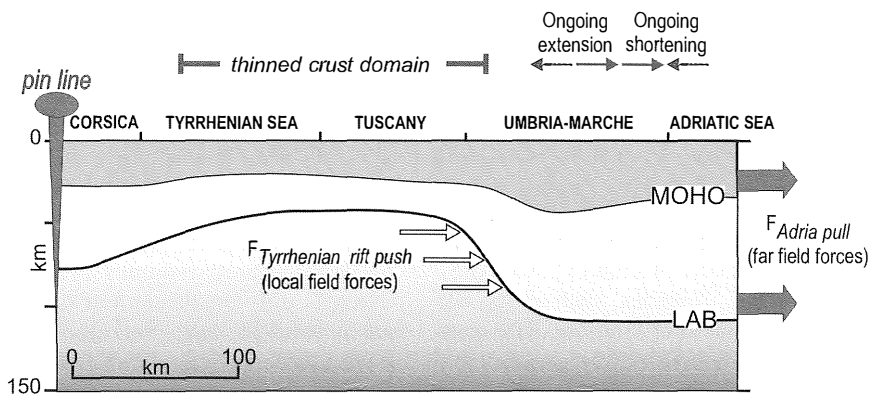


Fig. 3 – Interpretative lithospheric section across the Tyrrhenian-Apennines zone with pattern of the forces involved in the development of the system. Trace of the section in Fig. 1.

at the eastern side of the extending system, as a consequence of the difference in lithostatic pressure between the Tyrrhenian rifted and Adriatic unrifted regions (after TURCOTTE and EMERMAN, 1983). The sum of far field forces plus rift push forces may have determined a velocity in the eastward extending Tyrrhenian domain (V_{rift}) higher than that in the counter clockwise rotating Adriatic domain (V_{Adria}). In turn, this may have achieved a process of lateral material accommodation responsible for the nucleation of the Apennine contractional structures on the Tyrrhenian-Adriatic border.

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