Post-Eocene calcalkaline activity and basin opening in the western and central Mediterranean region: implications for magma source metasomatism linked to Hercynian orogeny

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ABSTRACT

Distinct, short-lived extension pulses formed the Balearic, Bavilov and Marsili basins at ~22-16, ~8-6 and ~1.9-1.5 Ma. Basin opening was accompanied by migration of arc magmatism from southeastern France to the Aeolian-southeast Tyrrhenian region which is subducted by the Ionian Sea oceanic lithosphere. Formation of the Balearic basin occurred amidst the Oligo-Miocene calcalkaline (orogenic) cycle which affected the Hercynian European lithosphere between Sardinia-Corsica and southeastern France. By contrast, two distinct short-lived periods of formation of oceanic crust in the basins of Bavilov and Marsili predated the adjacent calcalkaline arc volcanism. Chrono-petrological evidence and the adopted geodynamic setting suggest different ages for the calcalkaline volcanism and the subduction-related, metasomatic modifications of its magma source(s) in the area of study. Unlike the calcalkaline activity of the Aeolian arc (~1-0 Ma), that of Sardinia (~33-14 Ma) may reflect a previous metasomatic event probably coinciding with the older Hercynian orogeny.

KEY WORDS: Central-western Mediterranean, «back-arc» basins, arc volcanism migration, Hercynian metasomatism, subduction.

INTRODUCTION

The calcalkaline igneous products are characterized by geochemical signatures such as the high LIL/HFS (large ion lithophile elements/high field strength elements) ratios that are thought to originate from magma sources the composition of which has been modified by addition of materials brought down to depth during, contemporaneous and previous, subduction processes. Similarly to the extensive Quaternary calcalkaline (orogenic) volcanic associations of the earth convergent margins which overlie slabs of oceanic lithosphere, subduction of the Ionian Sea oceanic lithosphere beneath the SE Tyrrhenian Sea indicates that eruptive activity and metasomatic imprinting of the magma sources are temporally associated. A constant dip to the west of the Ionian-Adria lower plate is a conventionally accepted notion for generation of the post-33 Ma magmatic activity extending from SE France to the Aeolian arc and implies a synchronism of subduction and orogenic volcanism through time. Notwithstanding that subduction and orogenic volcanism are coeval events during the recent geological periods, there are geological evidences indicative of diachronism between old calcalkaline magmatic associations and metasomatic processes in the past (e.g.: DUDÁS et alii, 1987, 1991; KEMPSON et alii, 1991; WEAVER, 1991; COX, 1992; HAWKESWORTH et alii, 1992; STOREY et alii, 1992; UTO et alii, 1992; TOMMASINI et alii, 1995; MORRIS & HOOPER, 1997; WENZEL et alii, 1997; COMIN-CHIARAMONTI et alii, 1999; PECCELLERO, 1999; FROST et alii, 2000; LUFTIN & FURNES, 2000; MORRIS et alii, 2000; SAVELLI, 2000; 2002; SMITHIES & CHAMPION, 2000; FEELY, 2003; LINDSAY & FEELY, 2003; GHEZZO, 2004). In the light of time-space distribution of volcanic activity in a portion of the west Mediterranean and adjacent orogens, this paper aims to evaluate whether the calcalkaline event of the Sardinia-southeastern France region (~33-14 Ma) has been subsequent to the enrichment processes of the relative magma sources or not. A diachronism would require the existence of an old subduction beneath Sardinia the polarity of which was most likely different from that linked to the Aeolian Quaternary arc volcanism, with significant implications for the late Cenozoic tectonic and magmatic evolution of the western and central Mediterranean. This area is controlled by a west-directed subduction process akin to those of the «classical» marginal basins at the western rim of the Pacific ocean (see, e.g., KARI, 1975; SARTORI, 1980; 1981; DOGLIONI et alii, 1999 and references therein).
GEOLOGICAL SETTING

The geodynamic scenario adopted for the diverse orogenic domains of the area of study is depicted in fig. 1: the Hercynian European lithosphere is located to the west while the younger Alpine/Apenninic belt, to the east, is subducted by west-dipping Ionian oceanic lithosphere. The relict front of the Alpine orogenic wedge testifies pre-late Cretaceous subduction-related collision processes extending from NE Corsica and Pieve S. Stefano, central-northern Apennines; joint tectonic and magmatic processes which started in the Oligocene have accompanied through time thinning and extension of Hercynian and Alpine lithosphere on one side, and roll-back of the Apenninic compression or Sardo-Balearic basin) is bordered by the Hercynian domain of Corsica-Sardinia, to the east, and Provence to the north. By contrast, the Tyrrenhenian Sea rests on stretched Alpine/Apenninic lithosphere.

Fig. 1 - Time-space distribution of six magmatic phases (~33-0 Ma) in the Balearic, Vavilov (Vb), Marsili (Mb) back-arc basins and their peripheral orogens (modified from SAVELLI, 2002). Legend, rock types: 1=tholeiites; 2=medium-K and high-K calcalkaline plutons (circles with dots = ~54-34 Ma old plutons); 3=medium-K and high-K calcalkaline volcanics; 4=shoshonites; 5=ultrapotassic volcanics; 6=lamproites; 7=carbonatites; 8=intraplate volcanics; 9=rocks from intraplate, large central volcanoes; 10=igneous rocks from deep drillings (DSDP & ODP sites, Neapolitan area and Pieve S. Stefano; 11=igneous rocks from deep drillings (DSDP & ODP sites, Neapolitan area and Pieve S. Stefano; 12=igneous rocks from deep drillings (DSDP & ODP sites, Neapolitan area and Pieve S. Stefano; 13=igneous rocks from deep drillings (DSDP & ODP sites, Neapolitan area and Pieve S. Stefano). - Distribuzione spazio-temorale di sei fasi magmatiche (~33-0 Ma) nei bacini retro-arco Balearico, Vavilov (Vb), Marsili (Mb) e negli orogeni adiacenti (modificato da SAVELLI, 2002). Legend, types of rocks: 1=tholeiites; 2=plutons of calcalkaline affinity medium- and high-potassica (circles with dots = ~54-34 Ma old plutons); 3=plutons of calcalkaline medium- and high-potassica; 4=shoshonites; 5=ultrapotassic volcanics; 6=lamproites; 7=carbonatites; 8=volcanics of intraplate affinity; 9=large central volcanoes; 10=igneous rocks from deep drillings (DSDP & ODP sites, Neapolitan area and Pieve S. Stefano; 11=igneous rocks from deep drillings (DSDP & ODP sites, Neapolitan area and Pieve S. Stefano; 12=igneous rocks from deep drillings (DSDP & ODP sites, Neapolitan area and Pieve S. Stefano).
Magmatic rocks of variable age (~33-0 Ma) and composition crop out extensively in the central and western Mediterranean region. In the present study they are tentatively subdivided according to their ages and serial affinities (see, e.g., Savelli, 1984, 2002 and references therein; Kastens et alii, 1986, 1987, 1990; Franchalanci & Manetti, 1994). Inspection of fig. 1 shows the time-space distribution of six igneous phases. They include a large variety of magmatic associations such as, e.g., medium-K calcalkaline, high-K calcalkaline, shoshonitic, ultrapotassic, lamproitic, carbonatitic, tholeitic and Na-alkaline. Basalts with tholeitic affinity were erupted in the central Tyrrenhian oceanic domain as well as in the volcanic arcs of Sardinia and Aeolian area. Also, the silica saturation of magmatic products in the region of study is highly variable ranging from (undersaturated) basic to intermediate and to acidic magma types which were most likely derived from both the mantle and the felsic crust.

A post-33 Ma migration of volcanism from southeastern France to the Aeolian arc was accompanied by successive opening of «back-arc» basins, i.e., the Balearic (~21-16 Ma), the Vavilov (~8-6 Ma) and the Marsili (~1.9-1.5 Ma). The histogram of chronological data of fig. 2 shows the Oligo-Miocene (~33-15 Ma), Pliocene (~6-1.9 Ma) and Quaternary (~1.5-0 Ma) magmatic phases of the southeastern France-Sardinia-Tyrrhenian Sea-western Italy region and their relationships with basin openings. During the first igneous phase (~33-15 Ma), opening of the Balearic basin has been accompanied by the drift of Sardinia-Corsica away from the Provencal margin. Paleomagnetic evidence by Montigny et alii (1981) indicates the short time span of ~20.5-19 Ma for the ~30° anticlockwise rotation of the two islands. Rehault et alii (1984) envisage ~18 Ma as the age of cessation of drifting, whereas ~16/15 Ma are suggested by Vigliotti & Kent (1990), Vigliotti & Langenheim (1995) and Ottaviani-Spella et alii (2001). In Sardinia subalkaline basalts with a tholeiitic tendency group mainly in the middle period (~20-16 Ma, Burdigalian) of the calcalkaline volcanic cycle (Savelli et alii, 1979; Mattioli et alii, 2000).

Besides the Hercynian Europe (i.e., Sardinia, southeastern France, Balearics and Valencia basin) calcalkaline products belonging to the ~33-15 Ma event are widespread also in western regions of the relict Alpine orogen. The Betic cordillera and the Maghrebian chain, between the Alpine and the Apenninic front of subduction were sites of volcanic activity of calcalkaline and tholeitic affinity. This volcanism was accompanied by magmatic emplacement of granitoids with dominant acidic compositions (Bellon, 1981). Intrusive rocks with similar compositions are conspicuously lacking in the European Hercynian region.

In the Apenninic thrust belt and Tyrrenhian margin of the Italian peninsula there is no evidence of exposed, primary Oligo-Miocene «andesitic» volcanic edifices. By contrast, numerous volcanoclastic calcalkaline horizons are interbedded in sediments of Oligo-Miocene age from the Northern and Southern Apennines, the Sicilian Maghrebids and the north African and Betic internal thrusts (e.g.: Selli, 1948; Carmisiano & Spadea, 1973; Borsetti et alii, 1984; Mezzetti et alii, 1991; Baloghi et alii, 1993; Cretelli & Monaco, 1993; Guerrera et alii, 1993; Anelli et alii, 1994; Puglisi, 1994; Montanari et alii, 1995; Amorosi et alii, 1995; Odin et alii, 1997; Cibin et alii, 1998; De Capoa et alii, 2002; Mattioli et alii, 2002). Overall, these volcanoclastics which yielded K/Ar datings ranging from ~32 to ~18 Ma show prevalently intermediate and acidic calcalkaline compositions. An exception to this are the volcanic clasts from the Canetulo unit of the Northern Apennines with prevailingly mafic-intermediate affinity (Mattioli et alii, 2002).
In the Tyrrhenian Sea the short-lived, late Miocene period of activity (~8-6 Ma) was characterized by a pulse of extensional tectonics. The Vavilov basin saw eruption of E-MORB tholeiites (DSDP drilling 373A, Barberi et alii, 1978), while calcalkaline granitoids (islands of Elba, Montecristo and seamount Vercelli), and trachy-dacites and andesites (Caprera island; Borelli et alii, 2003) were emplaced in the north Tyrrhenian Sea region to the north of the 41° parallel structural discontinuity. In this period magmatic activity was conspicuously lacking in all of the peri-Tyrrhenian areas (fig. 2). The regional distribution of the highly different late Miocene products is most likely a consequence of the tectonic framework, in other words the intensity of lithosphere extension and thinning processes may have been much larger in the south than in the north Tyrrhenian (Savelli, 1988; Argnani & Savelli, 2001 and references therein).

Also the late Pliocene-early Quaternary period (~1.9-1.5 Ma; fig. 2) saw an extensional pulse which has been accompanied by eruption of basaltic lavas with E-MORB/calcalkaline affinity in the Marsili basin (ODP drilling 650, Beccaluva et alii, 1990). Even though such spreading event was short-lived and restricted to a small area of the southeast Tyrrhenian Sea it appears to have had regional implications since it is arduous to recognize, outside the basin, coeval magmatic products.

The fast openings of the Vavilov and Marsili basins have been followed by the Pliocene and Quaternary igneous phases (~6-1.9 and ~1.0 Ma) which comprise products of Na-alcaline (anorogenic), calcalkaline (orogenic) and tholeiitic serial affinity that reflect emplacement in distinct geodynamic domains (fig. 1). During these periods the Tyrrhenian Sea region saw intra-basinal formation of large seamounts with dominant vertical tectonism (Savelli & Gasparotto, 1994; Faggioni et alii, 1995; Marani & Trua, 2002). Such magmatic and tectonic processes as well as their periodicity can be related to strong pulses alternating with periods of quiescence of roll-back.

Besides the orogenic and tholeiitic volcanism, also the anorogenic (intra-plate) manifestations which erupted mostly in the time span ~5-0.1 Ma are an important source of information on the Mediterranean dynamic processes subsequent to the Vavilov spreading. Differently from the Oligo-Miocene orogenic products, rocks with intra-plate affinity are present in both the western and eastern sectors of the island of Sardinia. Inspection of fig. 1 suggests that, overall, anorogenic volcanics are younger if compared with the age of rocks located at similar distance from the active front of roll-back above the west-dipping subduction of Ionian oceanic lithosphere.

**DISCUSSION**

Inspection of fig. 2 shows that the back-arc spreading of Vavilov and Marsili basins associated to west-dipping subduction predated the Pliocene and the Quaternary (~6-1.9 and ~1.5-0 Ma) volcanic phases. By contrast, the opening of Balearic basin occurred amidst the period of calcalkaline volcanic activity (~33-15 Ma). The emplacement of tholeiitic lavas that is thought to reflect strong extension took place in clearly distinct times with respect to the orogenic products of Sardinia and the Aeolian-southeast Tyrrhenian region (Savelli et alii, 1979; Beccaluva et alii, 1985; Mattioli et alii, 2000). It coincided more or less with the magmatic climax of Sardinia (~21-17 Ma; fig. 2) and it has been a precursor, at ~1 Ma, of the Aeolian volcanism. Regarding the serial character of orogenic products, fig. 3 shows that volcanics of shoshonitic affinity are widespread in the Aeolian arc and scarce in Sardinia. Shoshonite rocks are considered to derive from magma sources which underwent deep-seated metasomatism. Seismicity generated by west-dipping subduction beneath the south Tyrrhenian basin reaches depth of ~500 km. Given a spreading rate of ~4-5 km/My such geo-dynamic scenario is compatible with a setting up of Ionian lithosphere consumption approximately subsequently to the wane of Sardinian orogenic activity and ahead of the Vavilov spreading (i.e., between ~20/15 and ~8 Ma).

With respect to formation of the Alpine orogenic wedge of the study area one can not exclude Hercynian subduction in the European lithosphere, a process which could have provided the metasomatic modification of mantle source(s) of calcalkaline volcanism in Sardinia. Because the orogenic rocks of the first phase (~33-15 Ma) crop out in both Hercynian and Alpine regions (fig. 1; NE Corsica, Betic and Kabylian regions) an open question may be whether the CA metasomatic imprinting of their magma sources took place during or prior to Alpine collision. To begin with, it is considered that the Alpine orogenic wedge was built above a SE-dipping subduction of European lithosphere (see, e.g., Amadio-Morelli et alii, 1976; Doglioni et alii, 1999) which matched the present-day dip of subduction beneath the Alpine chain s.s. In this case the calcalkaline volcanic suite of the Sardinia region should reflect an old metasomatic event which most likely occurred during the previous, Hercynian orogeny as a foreland setting of the island at the times of Alpine collision cannot coincide with a calcalkaline imprinting.

An opposite view contemplates the formation of the Alpine orogenic wedge due to persistent NE- and E-dip-
ping subduction of Africa/Ionian/Adria lithosphere. The high pressure-low temperature (blueschists) facies meta-
morphism of the west-verging core complex of NE Cor-
sica is dated at ~55-40 Ma ago, i.e. prior to the start at
~33 Ma of extension-related calcalkaline activity in Sar-
dinia (JOLIVET et alii, 1998; BRUNET et alii, 2000). Also,
~38-33 Ma is a minimum age estimate of exhumation of
HP/LT metamorphic rocks of the Calabrian orogenic wedge (ROSSETTI et alii, 2002).

The core complex portions exhumed more to the east
in the north Tyrrhenian-Tuscany region exhibit younger
ages of blueschist metamorphism (~30-25 and ~25-20
Ma). The NW vergence of thrusting at the time of severe
Alpine compression and crustal thickening (~55-40 Ma)
argues against concomitant occurrence of a NW-dipping
(synthetic) descent of Adria/Ionian lithosphere producing
metasomatic modification of the mantle beneath Corsica-
Sardinia and Provence. In fact, the main vergence of an
accretionary prism is, overall, antithetic relative to the dip
of subducting lithosphere. Moreover, a long-lasting sub-
duction of Adria-Ionian lithosphere can hardly explain
how the Alpine (synthetic) build up shifted to the Apen-
ninic thrust belt which is a younger antithetic structure
(E-verging thrusting and W-dipping subduction) with
dominant roll-back.

As a consequence, metasomatic modification of mantle
sources of calcalkaline volcanics in Sardinia took most
likely place in concomitance with the Hercynian orogeny
rather than during the Alpine phase of convergence.

CONCLUSIONS

Three distinct, short-lived pulses of extension and
magmatic activity formed the Balearic, Vavilov and
Marsili basins at ~22-16, ~8-6 and ~1.9-1.5 Ma.

Formation of the Balearic basin occurred during the
peak of the Oligo-Miocene calcalkaline (orogenic) activity
which affected the Hercynian European lithosphere
between Sardinia-Corsica and southeastern France. By
contrast, the two short-lived pulses of Vavilov and Marsili
spreading in the Alpine/Apenninic domain of the south
Tyrrhenian Sea region predated the adjacent calcalkaline
arc volcanism.

The Oligo-Miocene calcalkaline phase (~33-14 Ma)
was linked to widespread extensional tectonics and
geothermal rise that affected clearly distinct orogenic
domains, the Hercynian European lithosphere and the
Alpine belt. This igneous phase postdated the HP/LT
metamorphic events of the relic orogenic wedge in the
north Tyrrhenian (~55-40 Ma) and in Calabria (~38-33
Ma).

The joint examination of chrono-petrological data
and adopted geodynamic setting in the area of study sug-
gests the existence of diverse timing between the mag-
matic emplacement of calcalkaline volcanism and the
subduction-related metasomatic modification of its magma
source(s). The metasomatic event appears to predate the
calcalkaline activity of Sardinia-southeastern France and
to be almost contemporaneous to that of the Aeolian-
southeast Tyrrhenian region.

Vavilov and Marsili are proper supra-subduction
back-arc basins. By contrast, the Balearic most likely is
not a similar structure as its formation has not been
accompanied by concomitant foreland lithosphere con-
sumption. In this view, it may be useful to distinguish
better one from the other the two Mediterranean regions
of orogenic activity and basin opening by adopting differ-
ent terms. For the Balearic Sea region a term like internal
basin instead of back-arc basin could be appropriate.

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