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From orogenic to anorogenic environments: evidence from associated magmatic episodes

par *Bernard Bonin*[1]

Abstract

In the present Alpine-Mediterranean belt, the transition from late-Variscan events to early Alpine episodes is well illustrated by magmatic formations emplaced during Permo-Triassic times:

- during the eo-Permian, calc-alkaline and anatectic plutonic and volcanic products are widespread in the Alpine belt itself as well as in its foreland; calc-alkaline activity takes place in a distensive regime accompanying large dextral shear zones and may be caused by earlier subduction processes during the Carboniferous.
- the Middle Permian is a critical period with a sharp magmatic discontinuity marked by the emplacement of the first alkaline complexes, at the same places as previous calc-alkaline formations; they are associated with large sinistral shear zones and originate from undepleted mantle primary liquids.
- at the Permian-Triassic boundary, under an incipient rifting regime, numerous alkaline ring-complexes are emplaced all along the Alpine belt, especially at the sites of subsequent Jurassic continental disruption and, in some places, transitional complexes are also present.
- the Triassic is marked by a large rift system and the emplacement, in the external zones, of alkaline massifs and, in transform fault zones, of tholeiitic massifs.

At the end of Triassic times, oceanic spreading can operate, separating previously cognate alkaline plutonic-volcanic ring-complexes.

Keywords: magmatic activity, calc-alkaline series, alkaline complexes, tectonic activity, late Variscan, Alpine belt.

Résumé

Dans la chaîne alpine actuelle, la transition depuis les événements tardi-hercyniens jusqu'aux épisodes précoces alpins est bien illustrée par les associations magmatiques du Permo-Trias:

- au début du Permien, les formations plutoniques et volcaniques calco-alcalines et anatectiques sont répandues dans la future chaîne alpine et son avant-pays. L'activité calco-alcaline est contemporaine d'un régime distensif accompagnant de grandes zones de cisaillement dextre mais peut avoir été provoquée par les processus antérieurs de subduction au cours du Carbonifère.
- le Permien Moyen constitue une période critique avec une nette discontinuité magmatique, marquée par la mise en place des premiers complexes alcalins, aux mêmes endroits que les formations calco-alcalines précédentes. Les massifs alcalins sont associés à de grandes zones de cisaillement sénestres et proviennent de liquides primaires issus d'un manteau non appauvri.
- à la limite Permien-Trias, au cours d'un épisode de rifting débutant, de nombreux complexes annulaires alcalins se mettent en place dans la chaîne alpine, en particulier là où aura lieu au Jurassique la déchirure continentale. Dans certains cas, des complexes transitionnels sont aussi présents.
- le Trias est marqué par un régime de rift et la mise en place dans les zones externes de massifs alcalins et dans les zones évoluant postérieurement en transformantes de massifs tholéïtiques.

A la fin du Trias, l'expansion océanique prend place et sépare les complexes annulaires alcalins plutoniques-volcaniques qui étaient précédemment voisins et liés.

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In the South European block, the Permo-Triassic appears to be a critical period as it corresponds to the end of the Variscan orogenic episodes as well as the beginning of the Alpine orogenic cycle. Geologically, it is marked by molassic sedimentary deposition in basins created in a pull-apart regime, large shear zones related to microplate relative motions and by huge magmatic formations characterized by typical K-rich red ignimbritic flows. The ignimbritic rhyolites are ascribed to contrasting suites, i.e. Lower Permian calc-alkaline and / or anatectic suites followed by Middle to Upper Permian alkaline ones.

Alkaline magmatic provinces are classically considered as *anorogenic*, i.e. "unrelated to orogenic disturbance" (BATES and JACKSON, 1980). The anorogenic character has been used to typify *A-granites* (LOISELLE and WONES, 1979; WHALEN et al., 1987). Little attention has been paid in the past to the characteristics of late- to post-orogenic alkaline massifs compared with the classical non-orogenic ones.

In South Europe, many Permian alkaline provinces display ambiguous features as they are emplaced in Variscan areas at times when orogenic events are not yet completed. The Alpine-Mediterranean belt includes an exceptional alkaline magmatic province (BONIN, 1980; BONIN et al., 1987), emplaced just after the Variscan orogenic episode and just before the subsequent continental disruption and oceanic basin opening, related to the first Alpine events.

In this paper, we shall focus on the magmatic sequence in the Permo-Triassic, illustrating a shift from a typical orogenic context to an anorogenic context.

1. Eo-Permian calc-alkaline magmatic activity

During Stephanian-Autunian times, widespread volcanic-plutonic activity occurred in the more or less consolidated Variscan fold belt (MOSSAKOVSKY, 1970). Rapid uplift and erosion are evidenced by deep unroofing of the Carboniferous batholiths and by arkose-type deposition in molassic basins emplaced in the foreland of the mountains.

In West Corsica, a fissural volcanic activity has produced in the Lower Permian a complete calc-alkaline suite (VELLUTINI, 1977). The basal andesitic flows lie unconformably on Stephanian coal-bearing layers and some cineritic beds have yielded Autunian Cordaites. The volcanic suite is made up of andesitic pyroclastic flows, dacitic pyroclastic flows, ignimbritic dacites and rhyodacites, and rhyolitic ignimbritic flows. Dyke swarms, trending N 60–70°, are particulary abundant in the vicinity of the volcanic plateaus and are therefore considered as the feeders of the lava piles. No central volcanic structure has been described so far, all the units display fissural characteristics.

The same types of volcanic formations are described during the Early and Lower Permian in the southern margin of Europe, from Galicia (in Spain) through the Alpine belt to the Pamirs (in the U.S.S.R.) (MOSSAKOVSKY, 1970). In the North African part of the Variscan fold belt, calc-alkaline Permian volcanic activity is also recorded (BEAUCHAMP, 1983).

The interpretation of the calc-alkaline volcanic events in terms of plate tectonics is a matter of world-wide debate. As far as the European Variscan fold belt is concerned, ZIEGLER (1983) has proposed a satisfying synthesis in which the continental collision between the Gondwana shelf and the Laurasian block has played a major role. In this scheme, the convergence between the two blocks apparently changed during the Westphalian-Stephanian boundary and was subsequently accompanied by the development of large dextral shear zones between the Appalachians and the Urals (ARTHAUD and MATTE, 1977). The change of stress field directions caused initiation and development of a complex pattern of conjugate shear faults and related pull-apart structures, which transected the consolidated Variscan fold belt as well as its foreland. The fault system remained active from Stephanian to Autunian (ARTHAUD and MATTE, 1975).

Deep crustal fracturing triggered widespread magmatic activity. However, the chemistry of the magmatic products is highly variable (Fig. 1). Calc-alkaline formations are recognized in the Variscan fold belt itself whereas the north European foreland is the site of markedly alkaline magmatic activity (Scotland, Oslo Graben). This implies that the magmatic sources were quite different even if the tectonic environment was nearly identical.

In his numerous papers on granite settings (for a review, see PITCHER, 1987), PITCHER has claimed that caution is needed when interpreting calc-alkaline formations in terms of sub-

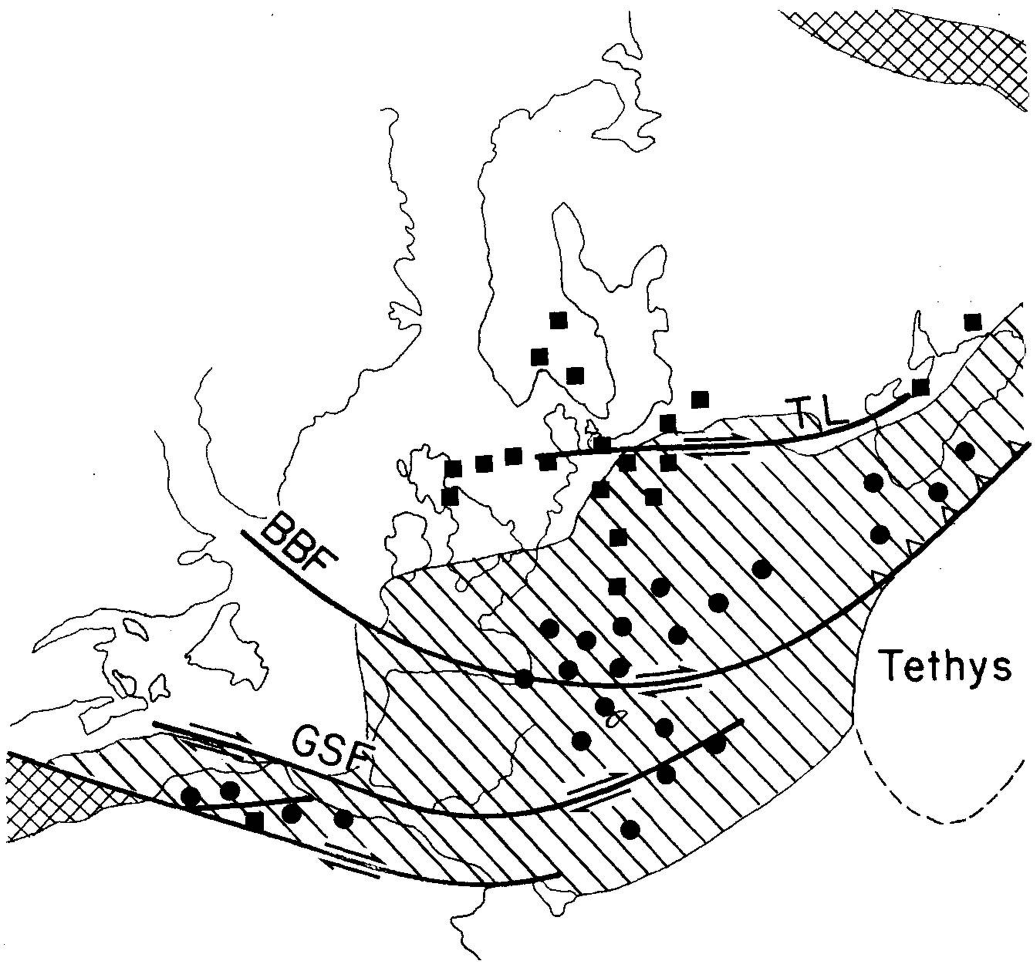

Fig. 1 Sketch map of Europe and North Africa during Stephanian-Autunian times.
Diagonal lines: inactive fold belt, cross-hatched area: active fold belt, squares: alkaline igneous centres, dots: calc-alkaline igneous centres.
BBF - Bay of Biscay Fault Zone, GSF - Gibraltar Strait Fault Zone, TL - Tornquist Line.

duction-type magmatism. This author has proposed several types of calc-alkaline magmatic massifs, among which:

- Andinotype, with tonalites, granodiorites and minor associated gabbros, emplaced in volcanic formations and constituting huge intrusive batholiths, acting as feeders of andesitic volcanoes. The Peruvian Coastal Batholith is a well-known example (PITCHER et al., 1985).
- Caledonian-type, characterized by high-K calc-alkaline rock types and emplaced as diapiric or permitted plutons intruding volcanic plateaus and calderas. Glen Coe is a classical example (CLOUGH et al., 1909). The environment is marked by rapid uplift, adiabatic decompression of the crystalline basement and subsequent erosion.

The Stephanian-Autunian volcanic and hypabyssal formations are clearly related to the Caledonian-type and unrelated to the Andinotype. They are characterized by high K contents and by a large development of felsic products, which imply a high rate of differentiation in crustal magma chambers.

2. Lower Permian anatectic magmatic activity

In the southernmost part of the Variscan fold belt, anatectic magmatic formations are recorded from Morocco through Algeria to Calabria. Other anatectic massifs of the same Permian age are known in the French Massif Central (Velay, Lodève and Rodez basins). They may constitute typical diapiric leucogranitic plutons (e.g. Morocco, Kabylie in Algeria), large peraluminous granitic massifs (e.g. Calabria), and even peraluminous volcanic formations (Lodève and Rodez basins).

They differ from the leucogranitic belt trending from Brittany to Vosges and Schwarzwald (LAMEYRE and AUTRAN, 1980), as they are a little younger (290 to 270 Ma. instead of around 300 Ma. for the leucogranitic belt) and less clearly related to large-scale overthrusting events.

They are composed of rock types evolving from cordierite-bearing leucotonalites to leucogranites, in which Al-rich minerals (two micas, garnet, sillimanite, andalusite) and volatile-rich minerals (tourmaline, topaz, fluorite, beryl) are well represented. Generally, they intrude the calc-alkaline granites and may form composite plutons (Calabria, Morocco). At some places, anatectic topaz-bearing rhyodacitic and rhyolitic ignimbrites constitute their volcanic equivalents and closely resemble present anatectic volcanic formations, known elsewhere as "ongonites", "topaz rhyolites" and "macusanites" (PICHAVANT, 1987). Different rates of batch-melting of the continental crust are substantiated by rock types varying from intermediate to felsic ones.

The magmatic suite defines the Hercynotype of PITCHER (1987), in which migmatites are remobilized as anatectic granitic melts, emplaced diapirically during the earliest phases of an oblique continent-continent collision or subduction. No evidence of a continent-continent collision of Himalayan-type has been afforded for the Lower Permian in the Variscan fold belt. Thus, we favour the hypothesis of intra-continental subduction during late orogenic stages, as proposed and documented in the peri-Pacific Coastal Ranges (AUBOUIN et al., 1986).

In the N. African part of the Variscan fold belt as well as in the Apulian Promontory, such intra-continental subduction is inferred (BOSSIÈRE, 1985) and may have resulted in the large-scale transcurrent faults located at the boundaries between the stable African continental plate and the future Alpine mobile belt.

3. The 270 Ma critical period

Several alkaline complexes have been emplaced during the Middle Permian. Present stratigraphic and structural syntheses (VERGELY, 1984; FABRE, 1988) have substantiated the continental character of the crust throughout the entire inactive Variscan fold belt.

According to VERGELY (1984), the continental area between Europe and Africa stable blocks is subjected after the Middle Permian to a large-scale sinistral movement. A change in stress field directions has caused, initiated and/or remobilized a pattern of conjugate shear faults which are closely associated with two major dislocation zones: the Bay of Biscay Fault Zone (BBF) and the Gibraltar Strait Fault Zone (GSF) (Fig. 2). The major fact in this scheme is the complete reversal of stress field: large-scale east-west trending dextral shear zones in Autunian times are replaced by large-scale east-west trending sinistral shear zones in the Middle Permian. This new regime is governed by incipient rifting and extension in the site of the future central Atlantic basin.

Late-Variscan faults are remobilized with an opposite sense of movement, named the *"harpoon effect"* by BLACK et al. (1985). A reversal in the sense of movement of a pre-existing fault system may trigger or enhance partial melting in the mantle. As a result, magmatic activity began by formation of early volcanic lava plateaus (Estérel, Lugano area, Bolzano area), some lying conformably on previous calc-alkaline volcanic formations (VELLUTINI, 1977; BULETTI, 1986). Subsequent caldera volcanoes and underlying ring-complexes intrude the Variscan basement as well as the Permian volcanic plateaus.

The dated 270 Ma. old alkaline complexes are emplaced:

- in Morocco: Azegour and W. Rehamna complexes (MABKHOUT, 1987), and the slightly older Bou-Mia (ROSE, 1987),
- in Corsica: Pastricciola, Tana-Peloso, (BONIN et al., 1987), Ota acid-basic association (VAN TELLINGEN, personal communication, 1986),
- in the Alps: Baveno pink granite (CAIRONI, 1985), Combeynot massif (COSTARELLA, 1987), and Lugano area (BULETTI, 1986; NIGGLI, personal communication, 1987),
- in N. Vosges: Kagenfels, Raon-L'Etape and Grands-Brûlés (REVE, 1985).

This alkaline suite constitutes two large-scale magmatic alignments:

- a first one, prelude to the Western Mediterranean alkaline magmatic province, from Morocco to Alps, with complexes located in Morocco, Corsica and Alps,

- a second one, trending south-north, from the French Alps to Norway, with complexes located in the French Alps, N. Vosges, alkaline volcanic products discovered in deep drillholes in the N. Germany plain, and the Oslo Graben association (BONIN et al., 1987).

The two magmatic alignments define a Y-shaped fault system along which alkaline complexes are emplaced. The north-south trending part constitutes the failed arm, whereas the Western Mediterranean part remained active till the end of the Triassic.

All the complexes are characterized by scarce basic lavas, numerous K-rich red ignimbritic flows, and by associated pink to red subsolvus biotite granites, displaying a two feldspar mineralogy, Mg-rich biotites evolving to Al-rich siderophyllites, and early Fe-Ti oxides, suggesting a water-rich and oxidizing environment (REVE, 1985; POUPON, 1986; MABKHOUT, 1987). Hypersolvus granites are notably lacking.

The tectonic context and the crustal environment during the Middle Permian are not very different but the magmatic sources of the alkaline complexes differ significantly from those of the K-rich calc-alkaline magmatic formations, implying that these contrasting sources all lie below the continental crust (BONIN et al., 1987).

4. Upper Permian to Triassic magmatic activity

Following the 270 Ma period, continuous magmatic activities of various anorogenic affinities are recorded before the Jurassic throughout the Alpine mobile belt. The majority of the igneous centres are made up of alkaline rock types, with minor transitional and tholeiitic rock types.

The presence during the Permo-Triassic in the Variscan basement of the Alpine mobile belt of anorogenic magmatic activity and its alkaline nature were first discovered in Corsica (BONIN, 1972; BONIN et al., 1972). Subsequently, numerous alkaline formations were described elsewhere (Fig. 2).

The Upper to Late Permian time is a major period of intense magmatic activity. All the magmatic complexes that have been recognized so far in a continental environment are markedly alkaline:

- in the European continental crust: Carinthia (Austria) (MORAUF, 1980), Err and Julier-Bernina Decke (Switzerland) (TRÜMPY, 1975; BÜHLER, 1983; RAGETH, 1984), Penninic domain (THÉLIN and AYRTON, 1983), Estérel (BOUCARUT, 1971), Corsica (BONIN, 1972, 1982, 1986; VELLUTINI, 1977), Sardinia (VELLUTINI, 1977), Badajoz Province (Spain) (DUPONT and BONIN, 1981),
- in the Apulian Promontory: Bolzano area (VELLUTINI, 1977), Lugano area (BULETTI, 1986; NIGGLI, personal communication, 1987).

All the dated complexes have yielded ages from 270 to 235 Ma. with a peak at 245 Ma. (BONIN et al., 1987). Volcanic rock types are represented by basaltic lava flows, scarce trachytic lava flows, numerous rhyolitic ignimbrites and associated pyroclastic formations. Plutonic rock types are represented by scarce gabbros, monzogabbros and monzonites, and by abundant alkaline granites.

Triassic igneous centres have been described in the same areas. They display, however, a greater variety in terms of magmatic suites:

- in the African block and the Apulian Promontory, the alkaline series is represented in the Monzoni-Predazzo plutonic-volcanic association (FERRARA and INNOCENTI, 1974), the Central Alps, Italy (FIORENTINI POTENZA et al., 1975), whereas, in Morocco, tholeiitic volcanic products are present as well, they preceed the spectacular tholeiitic dolerite Jurassic dyke swarms which accompany the Atlantic oceanic basin spreading.
- in the European continental crust, the alkaline series is well developed in Corsica and in the Internal Alps, in the Briançonnais and Acceglio zones for instance, whereas tholeiitic dyke swarms with spillitic affinities and associated volcanic formations are widespread in the External Alps. In transform fault zones, tholeiitic magmatic suites are also well developed (Pyrénées, Spain, Portugal) (VERGELY, 1984).

During the Upper Permian-Triassic period, basic and intermediate alkaline rock types are poorly represented: gabbros as cumulate rocks as well as net-veined complexes (PLATEVOET et al., 1988), monzonites in very subordinate amounts, with the exception of the *locus typicus* Monzoni (DEL MONTE et al., 1967). Accordingly, basalts and intermediate volcanic rocks are not well represented. On the contrary, rhyo-

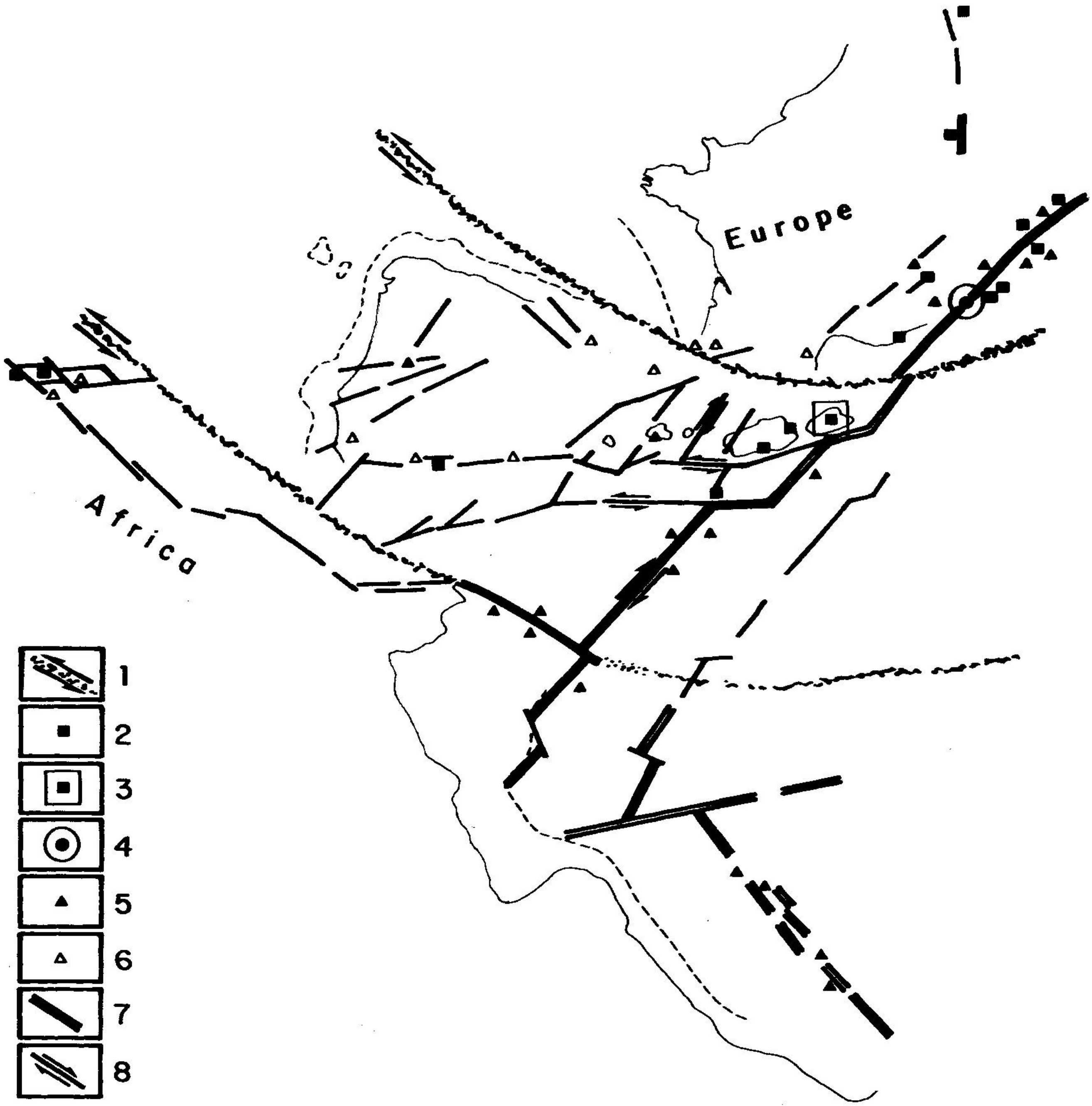

Fig. 2 Sketch map of Mediterranean regions during Late Permian and Triassic periods.
1. major shear zones, 2. Permian alkaline centres, 3. Corsican alkaline province, 4. Matterhorn transitional province, 5. Triassic alkaline centres, 6. Triassic tholeiitic centres, 7. lines of continental fragmentation and subsequent oceanic opening, 8. transcurrent fault with indication of their sense of movement.

litic ignimbrites and granites always predominate.

In one single complex, hypersolvus, transsolvus and subsolvus granites (TUTTLE and BOWEN, 1958; MARTIN and BONIN, 1976) display contrasting mineralogical and chemical characteristics:

- metaluminous hypersolvus (a single mesoperthitic alkali feldspar) granites show a complete crystallization sequence with fayalite, hedenbergite, Fe-rich amphibole and Fe-rich biotite.

- aluminous granites are Fe-rich biotite-bearing and can be hypersolvus (a single mesoperthitic alkali feldspar), transsolvus (early mesoperthitic alkali feldspar mantled by K-feldspar, and albite as a discrete phase in the groundmass), or subsolvus (K-feldspar and albite). In each case where intrusive relationships have been observed, early hypersolvus granite is intruded by late subsolvus granite, which may develop a transsolvus chilled margin. This has been explained by large-scale influx of water percolating into a cooling water-undersaturated magma chamber (MARTIN and BONIN, 1976). Influx of water at temperatures above the "wet" granite solidus would result in nearly complete remelting of the early crystallized hypersolvus granitoids and the production of water-saturated granitic melts. Late subsolvus granites are the result of the crystallization of these liquids. Isotopic crustal signatures are expected as waters involved in the system are remobilized in a crustal convective geothermal field (BONIN et al., 1987).

- peralkaline granites are poorly developed: Sierra Vieja in Badajoz Province (Spain) (DUPONT and BONIN, 1981), Evisa-Calasima, Cauro-Bastelica and Bonifatto in Corsica (VELLUTINI, 1977; BONIN, 1982, 1988). They consist of hypersolvus arfvedsonite granites and of albitic arfvedsonite-aegirine granites, with associated fenitization processes (BONIN and PLATEVOET, 1988). In Corsica, the emplacement of peralkaline complexes occurred during a short time interval, from 250 to 230 Ma., and in restricted areas, when compared with widespread aluminous biotite granite complexes. Peralkaline fluids yield a mantle signature (Sr isotopic ratios as low as 0.703, BONIN et al., 1978), suggesting the system has evolved as a closed system with no interaction with the surrounding crustal formations. The reason for such restriction remains unclear and the petrological problem is not yet solved (BONIN, 1988).

The ages of the alkaline igneous activity are clustered around 250 Ma., beginning at 270 Ma., and ending at around 200 Ma. They evidence a large thermal event, substantiated by isotopic overprinting in the mineral ages of the Variscan basement (FERRARA and INNOCENTI, 1974; MALUSKI, 1977). BONIN et al. (1987) have proposed for the alkaline complexes of nearly the same age and characteristics the name of *Western Mediterranean Magmatic Province*.

As the thermal event is distinctly different from the latest Variscan tectonic and metamorphic episodes as well as from the early phases of the Alpine cycle, several authors (FERRARA and INNOCENTI, 1974; VELLUTINI, 1977; BONIN, 1972, 1980; BONIN et al., 1987) have pointed out that it corresponds to a moment shortly preceding the breakup and fragmentation of the Pangean continental block, and the formation of oceanic basins ("Tethys of the Reconquest", AUBOUIN, 1977).

A special mention must be made of the Matterhorn - Mont Collon - Dents de Bertol magmatic suite (DAL PIAZ et al., 1977). The layered gabbros and the associated granitic dykes display transitional characters and yield an age of 250 Ma. This magmatic suite has equivalents in the Eocene transitional ring-complexes in N. Scotland (Ardnamurchan, Mull) (RICHEY, 1932). It has been suggested that incipient oceanization processes into a continental cratonic area would result in the magmatic sequence: alkaline → transitional → tholeiitic series (GIRET, 1983). In the case of the Matterhorn transitional suite, the transition from alkaline to transitional series was already achieved at the Permo-Triassic boundary.

Ophiolitic suites in the Alpine mobile belt are considered to be remnants of oceanic crust formed between Europe, Africa, and other continental blocks. Tholeiitic differentiates, that have been dated so far, are lower Jurassic in age (180-135 Ma.) (OHNENSTETTER et al., 1981), and post-date the latest alkaline magmatic episodes by a 20 Ma. time interval. However, in the present state of knowledge, older (Triassic and even Permian) ophiolitic suites cannot be precluded.

5. Discussion: magmatic sources and tectonic control

Permo-Triassic times appear as a major period during which the transition from orogenic regimes to anorogenic ones has been completed. Magmatic evidence is particularly abundant.

5.1. OROGENIC REGIMES DURING THE EO- TO LOWER-PERMIAN

A first (Stephanian-Autunian) K-rich calc-alkaline fissural volcanic activity, with an associated peraluminous anatectic event, is a good marker of late orogenic stages, respectively of "Caledonian-type" and of "Hercynotype" contexts (PITCHER, 1987). Shear fault zones control the site of emplacement of the magmatic provinces. Pressure release and / or water supply caused by fracturing enhance and/or induce partial melting in deep zones in the thickened orogenic crust (anatectic melts) and in the underlying hybrid mantle (calc-alkaline primary melts).

The late- to post-orogenic high-K calc-alkaline magmatic provinces cannot be considered as directly subduction-related. Isotopic data indicate, however, that source rocks for high-K calc-alkaline magmas are likely to lie in a subduction-related lithospheric unit (LIEGEOIS and BLACK, 1984). Presently, no completely satisfying experimental data have been obtained to constrain the thermodynamic conditions necessary to produce calc-alkaline primary liquids during post-collisional uplift processes.

SEKINE and WYLLIE (1982), and WYLLIE (1982) have provided experimental evidence that calc-alkaline magmas originate in an upper mantle hybridized with hydrous siliceous melts generated in the subducted oceanic crust and then reacting with the overlying peridotite to produce wet hybrid olivine-free pyroxenites. Melting of this hybrid pyroxenite, flushed by aqueous fluids rising from the subducted oceanic slab, would yield calc-alkaline magmas. In this scheme, calc-alkaline magmas can be produced as long as hydrous siliceous melts, resembling rhyodacites in composition, can be extracted from the dehydrating subducted oceanic crust.

At depths of 100–150 km postulated for the melting zones, water solubilty in silicate liquids can reach 25 wt %. As it is likely that the oceanic crust, even if strongly retromorphosed in the greenschist or in the amphibolite facies, contains less than 25 wt % H_2O, it may be inferred that the formation of each batch of magma results in the dehydration of its source.

In the case of Stephanian-Autunian magmatic suites, the subduction processes had long ceased. This implies that no new hydrous material was carried from above to the depths. Therefore, there cannot be a continuous influx of water in the melting zones. When a continent-continent blocking regime operates, the old already subducted oceanic slab becomes more and more dehydrated and finally unable to produce significant amounts of water-rich siliceous melts. At that point, neither hybridization processes can occur nor calc-alkaline magmas be extracted from the overlying mantle.

At the beginning of the Permian, water was available in sufficient amounts to induce melting of the hybrid mantle as well as the overlying sheared lower crust. Thus, high-K calc-alkaline melts and anatectic liquids are produced and, in some cases, magma mixing can operate and result in composite plutons. It takes 30 to 50 Ma. to significantly dissipate water in lithosphere overlying subducted oceanic crust. Calc-alkaline magmatism can survive during 30–50 Ma. after the end of subduction processes. Magma-continental crust interactions at the magma chamber level result in the typical K-enrichment.

5.2. ANOROGENIC REGIME SINCE MIDDLE PERMIAN

The production of water-rich magmas results in dehydration and strong volume decrease of the sources. The subducted slab and the overlying hybrid mantle, subjected to large-scale disruptions, are replaced by a new LIL-rich asthenosphere beneath the thin overthrusted plate (LIEGEOIS and BLACK, 1984, 1986).

As a result of the melting of this new source, alkaline magmas are produced and collected in magma chambers emplaced in the thickened orogenic crust (BONIN and GIRET, 1984, 1985). As water is available in large amounts at this level, the differentiation processes are complete and yield water-saturated granitic magmas. The earlier magmas are then emplaced either as rhyolitic ignimbrites at the surface or as pink to red subsolvus granites at the subvolcanic level.

A similar dehydration process, at this point, operates at the magma chamber level: the surrounding crustal formations become more and more dehydrated because magmas in the magma chamber are differentiating by fractionation of amphibole, a hydrous mineral. Subsequently, the evolved granitic magmas become water - undersaturated and produce hypersolvus granites. Remobilization of external crustal waters in a convective geothermal field can produce late subsolvus granites (MARTIN and BONIN, 1976).

At this late stage, the petrological processes are not significantly different from those prevailing in non-orogenic environments, like within-plate magmatism (anorogenic Nigerian-type, PITCHER, 1987): hypersolvus granites as well as peralkaline granites in the Western Mediterranean Magmatic Province resemble those in the Niger-Nigeria Younger Granites Province (BOWDEN and TURNER, 1974).

However, in the Western Mediterranean Province, the alkaline magmatic event is rapidly replaced during Triassic times by transitional and tholeiitic magmatic episodes. Incipient oceanic basin openings post-date rifting processes, as a prelude to the Alpine episodes. In within-plate magmatism, rifting processes may occur but do not necessarily lead to oceanization and sea-floor spraeding.

The transition from orogenic to anorogenic regimes, as far as magmatic episodes are considered, is marked by the evolution of the behaviour of water:

- when water is available at the melting zones, calc-alkaline magmas are produced in the hybrid mantle and anatectic liquids in the lower crust,
- when water is unavailable at the melting zones, alkaline primary magmas are produced from a LIL-rich undepleted mantle and are collected into crustal magma chambers in which amphibole fractionation plays a major role. If water is available in great amounts at this level, water-saturated felsic liquids would yield subsolvus granites and associated rhyolitic ignimbrites. If water is present in insufficient amounts to saturate the melts, water-undersaturated felsic liquids would yield hypersolvus granites.
- subsequent rifting episodes can lead to incipient oceanization processes at the sites of previous alkaline magmatic formations.

Ultimately, the Alpine episodes, marked by oceanic closure and continent-continent collision, are responsible for the present convergence of several pieces of the magmatic province, previously genetically linked and emplaced as large magmatic alignments during the Permo-Triassic, and then disrupted during the Jurassic as Europe and Africa blocks are separated. The careful geological and petrological study of magmatic complexes emplaced anorogenically during the Permo-Triassic can therefore be used as a geodynamic tool for the reconstitution of the Alpine "puzzle".

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