The Apennines: Geo-tectonic evolution and metallogeny – An overview

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With 6 Figures

Zusammenfassung

Der Apennin ist ein relativ einheitliches Orogen zwischen dem Golf von Genua und Sizilien; nur Calabrien und Sardinien-Corsica bilden eine ältere variscische Einheit. Die wechselnden Phasen von Krustenausdehnung und Kompression vom Perm bis in die Gegenwart bestimmten die Metallogenese. Es wird bezweifelt, daß der Ozean zwischen der Adriatischen Platte und Afrika die vielfach angenommene Breite gehabt hat. Herzynische und praeherzynische Vererzung fehlt im Apennin, wenngleich die Isotopenzusammensetzung einiger Erze in der Trias auf ältere Mineralvorkommen im Paläozoikum hindeutet. Dem Öffnungsstadium der Tethys entsprechen die berühmten jurassischen Ofiolith-gebundenen Lagerstätten von Monte Catini. Die kretazischen Bauxite in den Abruzzen und in Apulien sind allochthon und werden von vulkanischen Aschen aus Afrika hergeleitet (Bardossy). Dem miozänen Kollisionsmagmatismus sind die Kontaktlagerstätten von Elba zu verdanken. Hg, Sb und Leuzit sind ökonomisch wichtige Produkte des jüngsten nach-tektonischen Vulkanismus in der Toskana.

1. Definition of the area

On the geographical point of view, the Apennines are the mountain chain stretching all along the Italian Peninsula, in continuation of the Marittime Alps: the geographic boundary between Alps and Apennines is located in the Western

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section of the Genua gulf (along a line connecting Noli Head with the Cadibona Pass).

On the geological stand point the boundary Alps-Apennines is displaced 40–80 km eastwards; the first figure (a) refers to the ancient literarure, the second (b) to the most recent authors. In fact, till the 70's it was usual to establish that boundary along the "Sestri-Voltaggio line" (just West of Genua), whilst at present the "Levan-to-Ottone line" (West of Spezia) is supported. These two North-South lineaments enconpass a montainous region, in which the formational-structural characters are (at yet) controversial, so far as they have to be considered dominantly of Alpidic or Apenninic style.

Moreover, on the geological point of view, Sicily can be considered as a continuation of the Apennines, exception made for the most Southern section of the Apennines (from the Sangineto line due South) and the Northern corner of Sicily (from the Taormina line due North), which, togheter, make up the "Calabrian-Peloritanian Arc". The latter is a province having geological, geodynamic and metallogenic characters clearly different from the other sections of the Apennins and Sicily and rather similar to the ones of the Alps and of Sardinia.

As a consequence, the present paper deals with the Apennines plus Sicily, excluding the Calabrian-Peloritanian Arc, which is the topic of another paper in this same volume: from now on the term "Apennines" will concern the above defined area (Fig. 1).

2. General Geological and Metallogenic outline

The Apennines are a part of the Alpidic orogenic belt comprising also the Tunisian Magrebids, Southern Alps, Dinarides, Hellenides. This elongated chain resulted by deformation of a continuous Mesozoic continental margin developed on the Southern part of the spreading Tethys, alongside the African promotory or Adria.

Like other parts of this fold belt sharing the Adriatic stable area as a common foreland, the Apennines area was affected by upper Permian to Middle Triassic intracontinental rifting, by Jurassic to Middle Cretaceous oceanic rifting and spreading and, finally, by closure, collision and post-collision deformations in Late Cretaceous to Recent times.

An outstanding character of the Apenninic geology is the scantiness of Hercynian/Pre-Hercynian outcropping/sub-outcropping terranes, the absence (at least the lack of known evidences) of the Hercynian plutonism and thermo-metamorphism and hydrothermalism. Anticipating what will be said later on in detail, the known Hercynian/pre-Hercynian stock-metal is practically nil, even if there are some good reasons supporting that it should not be so. This is quite a difference from the Alps, from Sardinia, from the Calabrian-Peloritanian Arc where the Hercynian/pre-Hercynian stock-metal is important.

The main ore/industrial mineral accumulations in the Apennines took place in Permo-Triassic (mainly pyrite), in Jura (Cu, pyrite of the ophiolites), in Cretaceous-

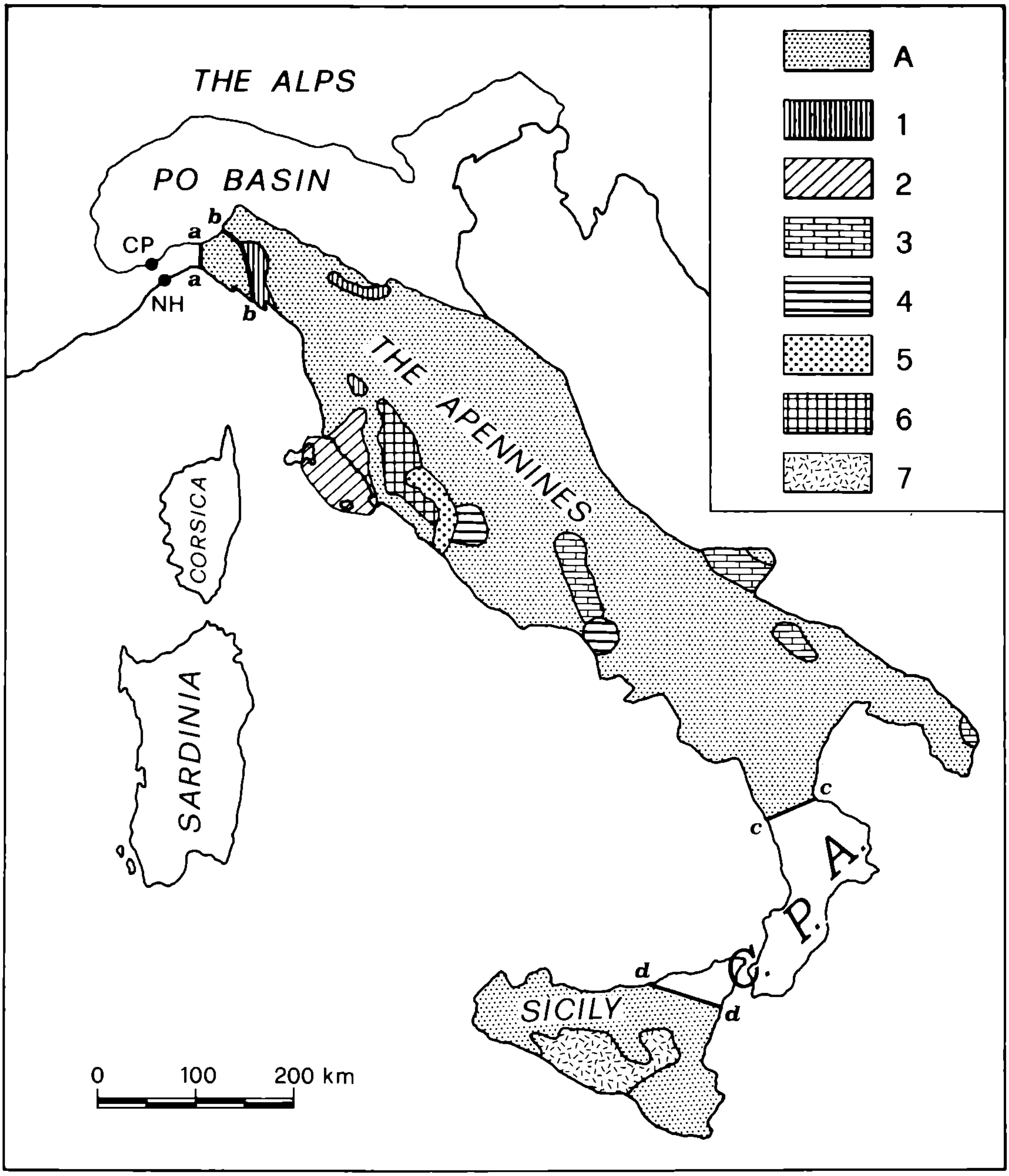

Fig. 1. Location map of the area dealt with in this paper (Apennines plus Sicily excluding the Calabrian-Peloritanian Arc) and of the main mining districts in it. — NH: Noli Head; CP: Cadipona Pass; a—a: Sestri-Voltaggio Line; b—b: Levanto-Ottone Line; c—c: Sangineto Line; d—d: Taormina Line; C. P. A.: Calabrian-Peloritanian Arc; A: Area dealt with in this paper. District n°: 1: Cu, Pyr; 2: Pyr, (Mixed sulfides), Fe_2O_3; 3: Bauxite; 4: Leucite; 5: Hg, Sb; 6: F, Ba; 7: Na, K, S.

Paleogene (bauxite), in Upper Miocene (evaporites and S), in Pleistocene (mainly Hg, Sb, F, leucite).

This metallogenic outline characterizes the Apennines and makes them different from the other Italian geological-metallogenic provinces.

3. Geo-tectonic evolution

3.1. Paleozoic: traces of Hercynian orogenesis

The Paleozoic basement of the Apennines crops out only in Tuscany, where field work and boreholes for mining and/or geothermal investigations evidenced a severely tectonized and partly metamorphosed Ordovician-Devonian sequence affected by the Sudetian and Asturian phases of the Hercynian orogenesis. Large scale thrusting within the basement occurred during the first phase, whilst the Asturian compressional movements were soon followed by crustal extension causing in Tuscany the formation of intramontane troughs where Coalmeasure type sediments (S. Lorenzo Group) deposited (BAGNOLI, et al., 1980).

The main effect of the subsequent Saalian phase, at the end of Lower Permian, was the uplift of large crustal blocks. To the same phase has been related also the acidic magmatism of the Red Porphyries which are a part of the "Asciano Group". Both mentioned groups may be interpreted as late-Hercynian molasses, corresponding to the progressive erosion of the chain and to the subsequent post-orogenic volcanism (CASSINIS et al., 1980).

Upper Permian was characterized in Tuscany by a vast peneplain and the area was no longer site of accumulation. Exception is made locally for the fine-grained red sandstones of the Castelnuovo Fmt., tentatively correlated with the "Arenarie di Val Gardena" of the Southern Alps.

3.2. Triassic

Northern and Southern Apennines show different evolution during Triassic, in the frame however of a general "intracontinental platform" paleotectonic stage ("intracontinental basin" in the Lagonegro domain).

The early sedimentary assemblages resting on the Late-Hercynian molasse in the Northern Apennines are terrigenous sediments of continental to deltaic and shallow marine environment ("Verrucano"), somewhere with interbedded carbonate bodies and prasinites (Punta Bianca). During Late Triassic, large evaporitic and carbonate platform sedimentary environments spread over the whole area. Sedimentary units of this age are represented by: sulphate rocks interbedded with dolostones (Burano Anhydrite); gypsiferous limestones or dolostones, soon transformed in vuggy complex ("Calcare cavernoso") by leaching of gypsum; dolostones (prevailing in the Grezzoni Fmt. of the Apuane Alps, in the Filettino units of Northern Latium and in other scattered outcrops or boreholes in the Latium-Abruzzi carbonate platform); shales, marls, limestones (in the Rhaetavicula contorta beds and in the Portòro Fmt.).

On the whole, during Norian, it is possible to recognize in Central-Northern Apennines a general paleogeography characterized mainly by a wide evaporitic area and a carbonate belt around it (CIARAPICA & PASSERI, 1981). No evidence of pelagic sediments was found up to now.

In the Southern Apennines quite different sedimentary associations are recognizable. In the Lagonegro Basin sequence, the terrigenous, shallow marine argillites and sandstones with interbedded basalt flows, pillow breccias, somewhere channelled bioclastic limestones, of the M. Facito Fmt. occur at the base. They are followed by pelagic cherty limestones.

Phyllites, with interbedded coralgal carbonates and prasinites („Campotenese-Lungro Phyllites"), are present at the base of the Campania-Lucania carbonate platform sequence. They are covered by back-reef and supratidal dolomites and evaporites.

Upper Triassic carbonates and evaporites show very high rates of sedimentation (up to more than 100 m/m. y.). They were deposited on what had formerly been continental crust of normal thickness (D'ARGENIO & ALVAREZ, 1980) with its surface approximately at sea level; they progressively overlapped all possible source area of terrigenous clastics, so that only cherty limestones and marls could deposit, even in the basins.

This does not explain however the absolute lack of terrigenous clastics along such a wide area from Late Triassic until the deposition of the early Alpine flysch. In fact, passive continental margins, undergoing such strong subsidence, commonly develop thick wedges of clastic sediments transported from the continents interior. In order to have pure carbonate deposition, a continental margin must be really isolated from the influxes of rivers or other sources of clastics. As D'ARGENIO & ALVAREZ pointed out, this is most likely to occur where the rifting, leading progressively to the sea-floor spreading, has blocked out a large sector of continental crust, as it was the case both in the Adriatic promontory and in the Florida-Bahamas region.

Subsidence was very probably an isostatic response to crustal thinning during the rifting and spreading phases. Calculations based on Apennine sequences indicate a thinning of the Italian continental crust for the whole Mesozoic by approximately 40% beneath pelagic basins and 20% beneath carbonate platforms (D'ARGENIO & ALVAREZ, 1980).

Crustal thinning, high subsidence, carbonate or cherty sedimentation everywhere, elimination of any possible cratonic influx in sedimentation and, above all, the early phases of the subsequent Tethyan spreading led to important variations in the paleotectonic regime at the end of Triassic. The Apennine sector of the African continental margin changed in fact at this time, from intracontinental to epioceanic platform/basin stage.

3.3. Jurassic—Lower Cretaceous

The cycle of Triassic rifting ended with deposition of evaporites, shallow water carbonates, deep water cherty limestones. During Early Jurassic time, the Central North Atlantic ocean began to open, a new cycle of rifting began and fragmentation of the Western Tethyan region accelerated, with creation of new rift basins. In Middle Jurassic time, rifting and transform faulting created deep-water corridors, linked the early Atlantic to the Tethyan Ocean and isolated new lithospheric plates in what had formerly been a coherent block (BIJU-DUVAL et al., 1977). According to some authors, the Adria itself became a separate plate. The Troodos ophiolite assemblage in Cyprus has been interpreted as related to an oceanic basin opened between the African and the Adriatic plates. It has however to be said, that against this and similar other hypotheses postulating more or less wide oceanic areas between Africa and Adria, there are a lot of valid arguments (see for a review, CHANNELL et al., 1979).

The age of the earliest appearance of oceanic crust in the new rift system has not been satisfactorily ascertained; the following factual observations are important at this concern: in Sicily, pillow lavas are interlayered in sediments of Late Liassic and Late Bajocian ages. Allochthonous ophiolites of Northern Apennines show radiometric age of 160 to 185 m. y. (Sinemurian to Bathonian; BORTOLOTTI & GIANELLI, 1976).

In the Northern Apennines, basin areas originated in Middle Liassic time by tectonic "drowning" of large sectors of Liassic-Triassic shallow-water carbonate domains, mainly represented by the Calcare Massiccio Fmt. These basins, westwards connected to the newly formed oceanic area of the socalled "Liguride domain", were shaped throughout the Jurassic, by seamounts characterized by very condensed sedimentation. Middle Liassic tensional faulting caused sudden facies variations, neptunian dykes, brecciation, slumping along the slopes.

Liassic platform carbonates pass abruptly upwards to the cherty-marly limestones of the basinal sequence. Limited traces of alkali-olivine basaltic volcanism at this time were detected in Southern Tuscany (BOCCALETTI & MANETTI, 1972). Local emersions, preceding the final drowning, have been recognized in many parts of Tuscany and Umbria.

The above mentioned "Liguride domain" shows the most significant evidences of the Jurassic oceanic rifting/spreading. It is an outstanding paleographic feature in the outline of the Alpidic "geo-syncline", and occurs, fairly continuously, all along the Apenninic chain.

The sedimentary evolution of this sequence is, up to now, controversial, because the terranes, by which it is made up, are known only in allochthonous positions.

Since the 60's (DECANDIA & ELTER, 1969) the Liguride domain is interpreted as an oceanic hiatus connected to a rifting/spreading cycle; in a few words, it is thought to be an oceanic area located between the Paleo-European and the Paleo-African cratons, divided in two (Eastern and Western) sections by a paleo-wrinkle ridge (the so-called Bracco wrinkle) that can be considered as a middle-oceanic ridge.

As a matter of fact the Bracco wrinkle is a vast complex made of mafic/ultramafic crust (peridotites-lherzolites, harzburgites and gabbroes), suffering—in middle to upper Jurassic—from metamorphism of green-schist or amfibolite facies (CORTESOGNO et al., 1975). It was dissected, since the Malm, by normal synsedimentary

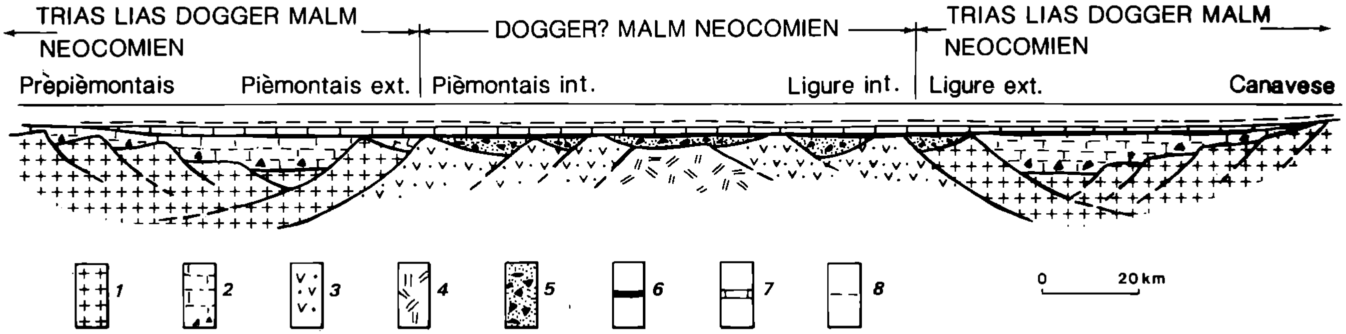

Fig. 2. Palaeogeographic reconstruction of the Liguride Domain in Jura-Lower Cretaceous (from GRANDJACQUET & HACCARD, 1977, simplified). – 1 = Continental Crust; 2 = Trias-Giura; 3 = Lherzolites of the Liguride Domain; 4 = Peridotites and Gabbros of the Liguride Domain; 5 = Pillow lavas and ophiolite breccias; 6 = Radiolarite; 7 = Calpionella Limestone; 8 = Palombini shales.

faults (GRANDJACQUET & HACCARD, 1977), delimitating horst-and-graben systems; the latters, in turn, controlled the depths and localizations of the overlying vulcano-detrital sediments and radiolarites (see Fig. 2 and 3).

The origin of the "ophicalcites" is also debated: according to GRANDJACQUET & HACCARD (1977) they should be related to tectonic accidents, and be generated by carbonate matter filling tension fractures and breccias. FOLK & MCBRIDE (1976), instead, support a pedogenic origin, in connection to paleotopographic highs with subaerial exposition of (ultra)-mafic rocks, prior to radiolarite deposition (Fig. 3). Mainly pelagic facies sediments overlied the radiolarites in Neocomian: namely the Calpionella limestones (Berriasian) and the Palombini shales.

According to ABBATE et al. (1980) the main part of the features of the structural environment in which ophiolites generated in Northern Apennines, can be explained by assuming that most of those ophiolites originated in a narrow ocean, subjected to East-West transcurrent movements, between Africa and Europe, with protrusion of (ultra)-mafic diapirs along the related transform fault zones. A narrow transitional zone, probably characterized by continental crust of reduced thickness, was interposed between the oceanic and the external areas. It corresponds to the Subliguride (or Sicilide) domain, another paleogeographic feature occurring now as allochthonous masses (usually non-ofiolithiferous flysch type) all along the Apennine chain, especially in Sicily.

In Central and Southern Apennines the well-differentiated Triassic sedimentary pattern, already characterized by a carbonate platform-basin system, persisted without important variations. New basins however developed across former carbonate platforms at the expense of pre-existing platform margins. Back-reef

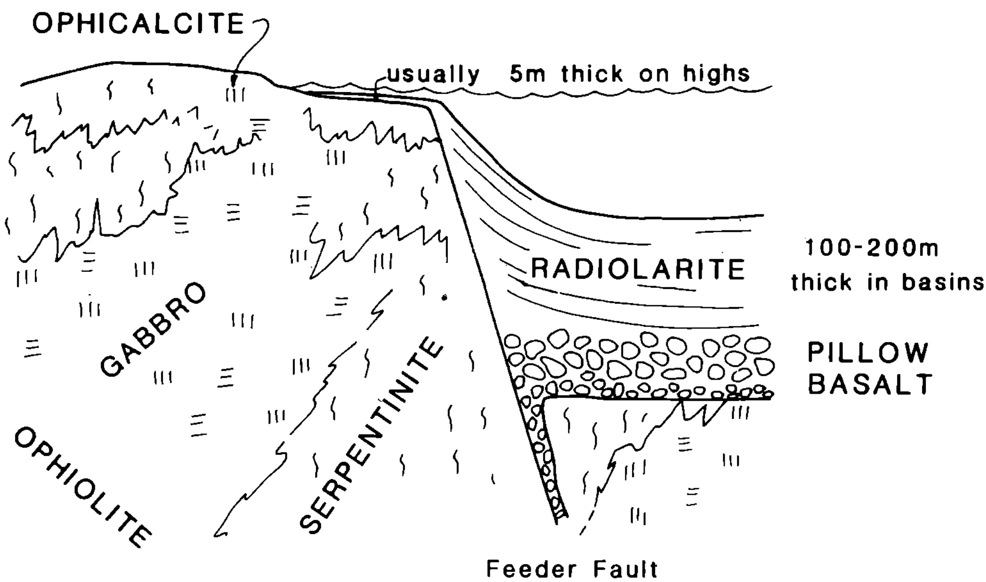

Fig. 3. Geologic relationships of ophicalcite and radiolarite (from FOLK & MCBRIDE, 1976).

lagoon sedimentation of Bahamian type was typical of the persistent carbonate platforms (Latium-Abruzzi pl., Campania-Lucania pl., Gargano-Murge pl. and minor Sicilian representatives), where very thick carbonate sequences accumulated. Intervening basinshaped areas were dominated by siliceous-marly sedimentation, often with thick bioclastic intercalations supplied by the nearby platforms. True radiolarites are sometimes present.

3.4. Middle-Upper Cretaceous

Evidenc of the closing movements occurring at this time in the Tethys are not directly detectable. Subsidence of the platforms was however dramatically reduced to less than 10 m/m. y.; there was an evident reduction of platform domains due to synsedimentary faulting; local basaltic volcanism occurred in the Southern areas; a large part of the carbonate platforms emerged for some m. y. in late Albian—Cenomanian, gaving rise to bauxite formation (BARDOSSY et al., 1977). Only in the innermost zones (Liguride domain) the first flysch facies of the Apennines testify the tectonic crisis occurring in the Tethys.

So far as beginning of the closure is concerned, GRANJACQUET and HACCARD (1977) support that clear symptoms of the first reduction of the Tethyan oceanic area are recognizable in Northern Apennines since the end of Lower Cretaceous and during Middle Cretaceous.

In fact, they postulate the overthrusting of the Liguride domain upon the European craton; intensive syn-sedimentary tectonics consequently took place on the surface: f. i. slumpings and olistostromes; these features are particularly frequent in the terrigenous flysch units, known as "Basal Complexes" in the current literature.

According to ABBATE et al. (1980), the ophiolitic detritus, interbedded in the Basal Complexes, was provided from the paleo-highs located in connection with former transform zones or at the contact between transform zones and normal oceanic crust.

The above mentioned early compressional phase should have played a rôle on the paleogeography of the Liguride domain, controlling in turn, the distribution of the huge turbidite complexes which have been formed from Upper Cretaceous to Paleocene. It is the case of the Helminthoid flysch, calcareous turbidites (M. Antola, M. Cassio, M. Caio, etc.) and of arenaceous turbidites (M. Gottero and M. Casanova); many authors, in the last twenty years, proposed various, often opposite ideas about their correlations: this fact derives (at least in part) from the factual difficulties related to their allochthonous positions.

Some (relatively) ancient studies (ELTER G. et al., 1966; ELTER P. and PERTUSATI, 1973), integrated and/or modified by recent stratigraphic-sedimentologic analyses, deserve still fundamental interest on this topic. According to the synthesis proposed by SAGRI and MARRI (1980), the Apenninic "geo-syncline" has been fed with huge amounts of terrigenous materials from the Sardo-Corsican Massif. The coarser ones deposited close to the continental margin and built up a series of deep-sea fans (Gottero Sandstones, Macinaggio and Elba flysch) (Fig. 4).

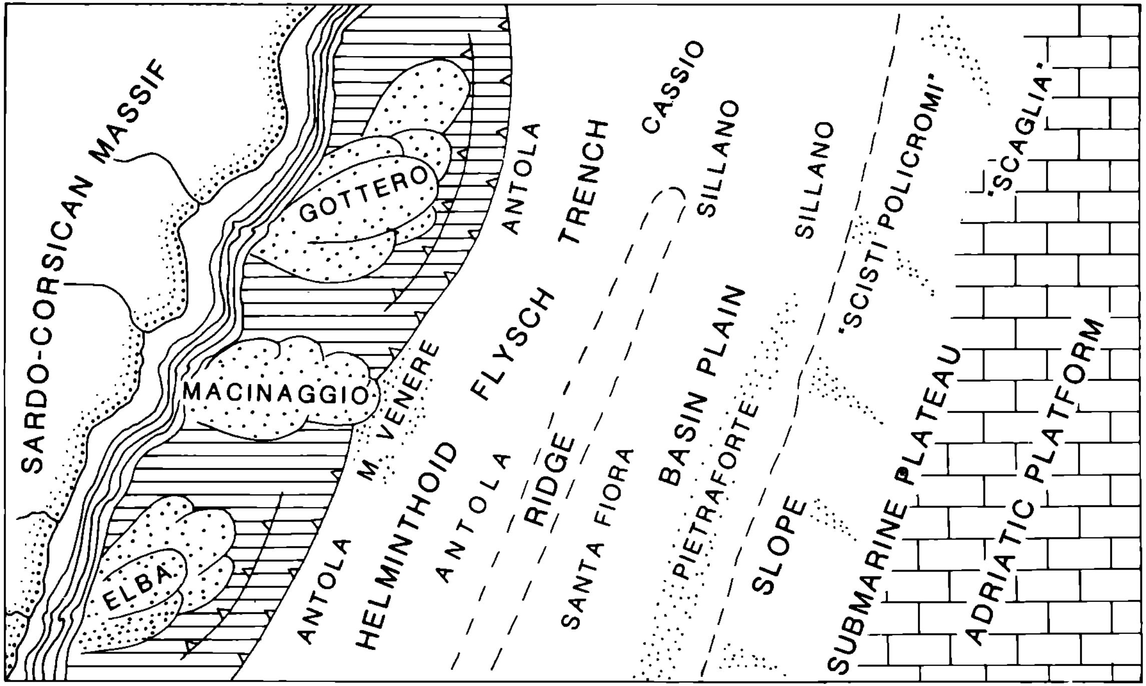

Fig. 4. Palaeogeographic setting of the Liguride Domain in the middle-upper Cretaceous (from SAGRI & MARRI, 1980).

Huge masses of Helminthoid flysch, instead, accumulated eastwards, on a basinal plain, located below the carbonate compensation level; the noteworthy quantities of calcareous muds accumulated in the Helminthoid flysch trough may be related to the high productivity of micro-organisms, that lasted during Cretaceous, in connection with the widespread transgressions which affected the main part of the continental margins (JENKINS, 1980).

Specific studies on the sedimentary facies (ABBATE, personal communication) pointed out that the turbidites of the Gottero sandstones were deposited as a small deep-sea fan in a trench slope basin; they contain foraminifers which indicate deposition at bathial depths and pinch out into and are overlain by, basin plain turbidites.

The Casanova Unit shows peculiar characters in the above defined outline; in fact, according to CASNEDI (1982), the slope and the basin-plain deposits are well represented in this unit, but fans are absent. This is due to the quick activation of a slope along the margin of a major ophiolitic ridge, related to the prosecution of the aforesaid early compressional phase.

At the end of the Cretaceous, all main carbonate platforms emerged. They were affected by a general marine ingression only during Lower-Middle Miocene, whilst sedimentation of the "Scaglia" type (thin bedded varicoloured—dominantly reddish—pelites with marls) persisted continuously in the basins.

In sharp contrast with what happened during Middle Cretaceous, no traces of this long emersion are recognizable. Karst, residual sediments, hard-grounds, erosion, etc. are absolutely absent. Only a very thin stylolitic surface marks the paraconformity between Mesozoic and Miocene.

3.5. Collisional and post-collisional events

During the Cretaceous, the opening of North Atlantic occurred with a greater spreading rate compared with the South Atlantic. This fact, coupled with a strong North-South component in the relative motion between Africa and Europe, squeezed out the Central Tethys, until a continent-continent collision, that mainly occurred in Late Cretaceous-Eocene time, gave rise to the most outstanding part of the Alpine Chain. The Apennines were deformed later, during Mio-Pliocene. Their history was complicated by the opening of small oceanic basins, while orogenetic movements were still going on, in particular the Ligurian and the Tyrrhenian ones, interpreted as back-arc spread marginal basins, with basic magmatism on the floor. The Southern Tyrrhenian should have been related to an arc-trench system with intensive, still active, subduction in corrispondence with the Calabrian-Peloritanian Arc.

The opening of the Tyrrhenian sea started about 7,5 m. y. ago as it is proved by absolute age dating of bathyal plain basalts (BARBERI et al., 1978); the history of the Tyrrhenian area has been connected strictly with folding, faulting, magmatic and metallogenic activity, neotectonics and seismicity of the Apennines.

The Neogene-Quaternary post-collisional evolution has been reinterpreted, in a fairly new way, by BOCCALETTI et al. (1982); these authors suggest a regmatic system consisting of two main conjugated shear trends, according to NE-SW and

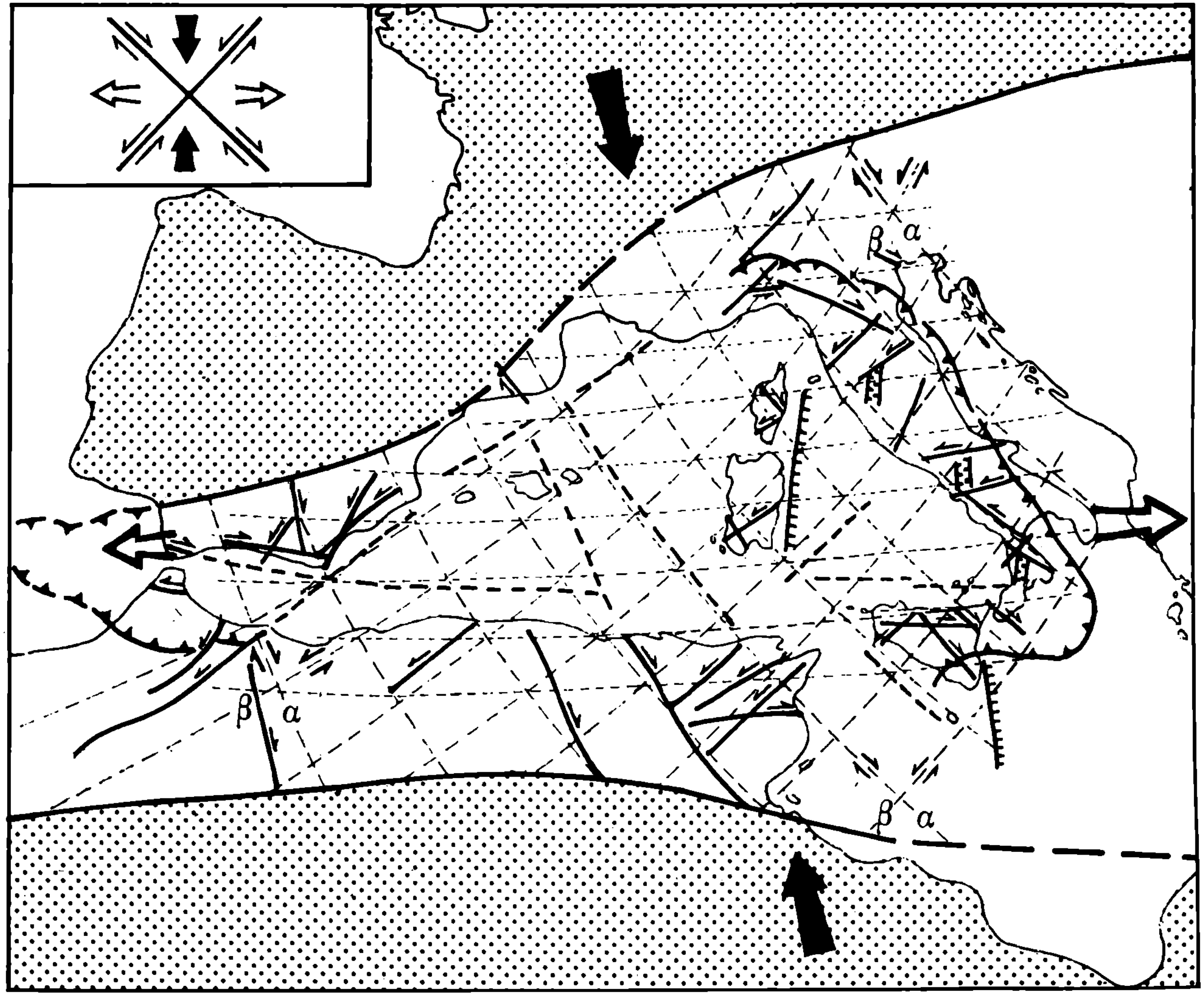

Fig. 5. Actual main shear faults of the Western Mediterranean area compared with the slip-line field developing between the two oblique converging African and European rigid blocks (from BOCCALETTI et al., 1982).

NW-SE, associated with a mostly shearing E-W trend and a mostly tensional N-S trend (see Fig. 5).

This rather complicated system could explain not only the mechanism of crustal extension, that was responsible for the opening of the Western Mediterranean basin, but also the mechanism of formation of several Neogene—Quaternary basins of the Apenninic chain.

A special significance in this scheme, is attached to some triangular basins occurring in external position relative to the Apennine folded belt: they should represent "pincer" features, generated by converging folds, connected to the two major conjugated shear trends (see Fig. 6).

The so-called "Messinian salinity crisis" (HSÜ et al., 1973), has to be located in a rather debated paleogeographic and structural outline, which—so far as the Apenninic domain is considered—should have been controlled by compressional phases in the external part of the chain and by distensional movements in its Tyrrhenian side.

Messinian evaporitic deposits were well known since a long time in a number of outcrops in the coastal Mediterranean countries (such as Sicily, and on both sides of the Apenninic chain). The researches carried out by the Deep Sea Drilling Project, since 1970, found Messinian evaporites both in the rises and in the sub-marine plains. They are underlain by euxinic sediments (including diatomites) and are overlain by Pliocene marine beds; their total thickness is estimated 2000 meters or even more.

Various evaporitic facies are recorded; in fact some deposits have sabkha, ephemeral lake, or not very deep lagoon characters, being made of selenitic gypsum, nodular and/or chickenwire anhydrite, finely laminated gypsum and anhydrite, halite; others are clastic and/or turbiditic, thus suggesting probable sub-acqueous deposition at various depths.

In any case there exist various associated types of facies, with such faunistic contents and such structural characters, as to justify the contrasting theories, that have been proposed for their interpretation.

In short, these theories are based on the contrast between the supporters of the "closed barrier at Gibraltar", with consequent general desiccation of the basin, and the supportes of the "open barrier" hypothesis.

The Messinian evaporites have been involved, in their syn-/ and post-depositional stages, by the compressive and/or distensional tectonics respectively along both the Adriatic-Padanian and the Tyrrhenian sides of the Apenninic chain.

They have been consequently moulded, at places, in complex structures; among them, the diapires, recognized by seismic profiles of the Mediterranean basins (particularly in the Balearic one), deserve special attention.

3.6. The geo-tectonic evolution of the Apennines and of the Tyrrhenian sea, on one hand, and the petrographic composition and localization of the volcanic complexes, on the other hand, are strictly linked.

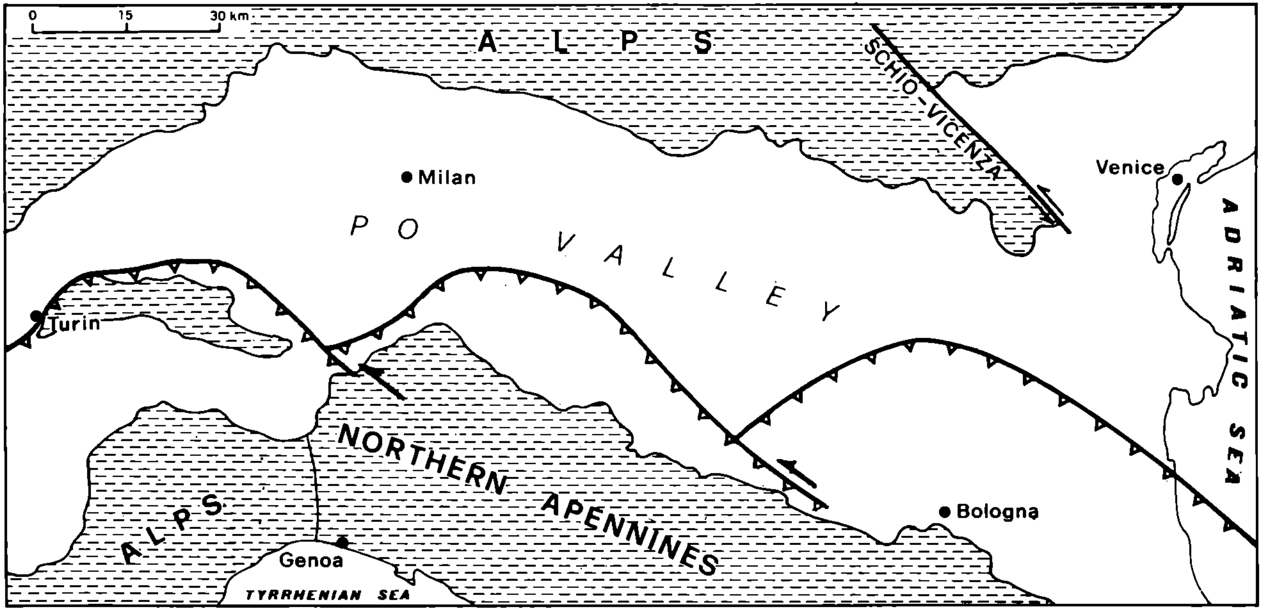

Fig. 6. Scheme of formation of triangular “pincer” basins on the Northern Apennines external front.

As a matter of fact, one may distinguish:

a) calc-alkaline and shoshonitic volcanism: it occurs in the Eolian volcanic arc, its age is fairly young (less than 1 m. y.), and is probably to be connected to the most recent compressional phases;

b) intra-crustal acidic anatectic magmatism: the granites/granodiorites of Tuscany (Gavorrano, Elba Island) pertain to this type and were emplaced in a time span from 8.7—4.9 m. y. Subsequently (from 5 m. y. on), some volcanics of the same composition have been emplaced, in a distensional phase that produced a horst-and-graben structure parallel to the main axis of the Apennines. Among them, the M. Amiata volcanic complex, made of rhyodacitic lavas (quartzlatites) and of minor trachites, played an important metallogenic rôle.

c) Quaternary alkali-potassic volcanims: it stretches from Northern Latium to Neaples, mainly along the Tyrrhenian coast. It is emplaced in the same horst-and-graben structures mentioned above and is interesting from the metallogenic stand-point.

d) Continental basaltic volcanism: the first episodes took place in Upper Miocene, but it became important in Pliocene and in Quaternary; it is still going on at present (M. ETNA).

It is related to local tensional zones connected with the complicated game of plate movements and of the consequent stress distribution in the region.

4. Metallogenesis

Five metallogenic main epochs can be distinguished, in the frame of the present paper; namely:

4.1. Hercynian and pre-Hercynian:

no ore/mineral deposits are known in the Hercynian/pre-Hercynian basement.

This is fairly astonishing, taking into account the metallogenic character of the other parts of Italy (specially of Sardinia), in which the best ore/mineral deposits have been generated in this epoch.

It has to be underlined that the Cambrian "Metalliferous"—that holds rich ore/mineral deposits in Sardinia—is not known in the Apennine basement: this fact is obviously a negative (or, at least, not a positive) point for the metallogenic prospects in the Apenninic basement. On the contrary, Ludlovian (Orthoceras dolomites, Graptolite slates, porphyroids) has been recognized (see BAGNOLI et al., 1980 for a synthesis of the knowledges on the Tuscan Paleozoic); it is well known that the latter complex is ore bearing (mixed sulfides and Sb—W—Hg) in many part of Europe, particularly in Sardinia. This fact should be taken into consideration for new and more researches and explorations.

It has also to be pointed out that the "Boccheggiano phyllites Fmt." should not be considered as Pre-Hercynian, as proposed by some authors (BAGNOLI et al., 1980); we incline to date them Post-Hercynian (Upper Carboniferous? Permian?), according to others authors (VIGHI, 1966, COCOZZA et al., 1978), on the basis of the following facts: the "Boccheggiano phyllites Fmt.", is a sequence made of dominant phyllites, quartzites, occasional chloritic and/or grafitic slates, meta-graywackes, meta-basites; lenses of anhydrite and of evaporitic dolomites are fairly frequent in their upper section. Triassic evaporites ("Vuggy Limestone" type) directly overly them, and have the same isotopic composition (C, O, S) of the above-mentioned lenses interbedded in the BOCCHEGGIANO phyllite Fmt. (CORTECCI et al., 1983, 1984).

Moreover, in many cases (Niccioleta, Elba Island) the same stratiform (volcano-sedimentary?) ores occur both in connection with the evaporites held in the Boccheggiano phyllites and at the base of the Triassic Vuggy Limestone.

All these observations, in our opinion, speak for continuous deposition and metallogenesis between the Boccheggiano phyllites and the Vuggy Limestone, and are against a hiatus between them.

4.2. Post-Hercynian/Pre-Tethyan

The involved time span should be from Upper Carboniferous/lower Permian to the end of Triassic. It is not always easy to date exactly the formations pertaining to this epoch; it is easier and more effective, from the metallogenic stand-point, the use of the formational names, even if with some uncertainties about their very ages.

The formations having main metallogenic interest—from bottom to top are: a) the above-mentioned "Boccheggiano phyllite Fmt." and the "basal slates"—at places called "Farma Fmt."—(a Coal-measure type, slaty, graphytic partially flyschoid sequence, with occasional carbonate lenses); b) the "Verrucano"; c) the evaporitic complexes ("Vuggy Limestones", "Grezzoni", "Burano Anhydrites"; "Small Cell Dolomites")*).

The only ore accumulations known till now in the slates are: i) some small and low grade black shale type, mixed sulfide (mainly: pyrite and chalcopyrite) stratiform occurrences (PONTE SAN PIETRO, West of BOLSENA Lake, described in RIVA, 1983); ii) small and low grade karstic, Pb, Ag, Zn (Sb) occurences (S. ANTONIO of PARI, half way between SIENA and GROSSETO, described in GRIONI, in press).

We spoke yet about the pyrite deposits held in the upper section of the Boccheggiano phyllite Fmt., and will recall them shortly after.

Verrucano—in the Apennines—is normally barren; two groups of ore deposits are known in connection to it; namely: i) inside Verrucano: the only rather puzzling case in the BOTTINO district (East of Pisa, described in CHECCACCI, 1984), where small Pb, Ag, Zn (Cu, Sb, As, Bi) stratiform and/or vein deposits are known. ii) in the transition zone between Verrucano and the overlying evaporites (may be a few meters below, a few meters above, normally along the boundary): it is mainly matter of small baryte (and celestite) stratiform (less frequently vein) deposits; at places haematite occurs with economic interest; pyrite (and other sulfides) is a frequent non-recoverable accessory: only in one case (MONTE ARGENTARIO, South-

*) See point 3.1., for details on formation a) and point 3.2. for formations b) and c).

Western Tuscany) the sulfide paragenesis occurs in large—very incompletely explored—quantities. All these deposits have been revised recently by MALANDRINO, 1981; RIVA, 1982; CHECACCI, 1983; DEL FORNO, 1984).

Widespread tourmaline needles and tourmalinites in some Verrucano horizons have to be mentioned, for their possible paleographic significance (see later).

The transition zone between the formations type a) and type c) has paramount importance as metallotect of the major pyrite (with occasional Cu, Zn sulfides) deposits of the Grosseto district(NICCIOLETA, BOCCHEGGIANO p. p., CAMPIANO, p. p.) and the strictly connected haematite-pyrite-pyrrotite Elba Island deposits.

In any case, it is a matter of syn-sedimetary (probably effusive) deposition in evaporitic environment, more or less modified by the Alpidic orogenesis, contact-metamorphism, hydrothermalism (see later on).

The sharp difference in the parageneses and in the industrial importance among the deposits accumulated at the basis of the evaporitic formations, upon the Verrucano or upon the phyllitic sequences cannot be casual: it has probably a paleogeographic significance (distance from the paleo-coast line; basinal energy and related Eh) that can help in the reconstruction of the geological history of the region.

4.3. Tethyan Cycle

For the purpose of the present paper, we shall distinguish the following stages:

4.3.1. Pre-Tethyan rifting:

during this time, the only metallogenic process of a certain interest is the clastic deposition and accumulation of small quantities of cassiterite (MONTE VALERIO, along the Tyrrhenian coast, see VENERANDI-ZUFFARDI, 1983).

The cassiterite source puts problems about the presence at that time of an outcropping basement (the Corso-Sardic massif? A paleo-plate, subsequently sunken in the Tyrrhenian sea?) not so far from the site of accumulation, as it is suggested by the poorly rounded cassiterite grains. This sentence applies also to the tourmaline held in Verrucano described above.

4.3.2. Ophiolitic volcanism:

from the economic stand-point, it had very scanty interest; as a matter of fact the same Cu deposit of MONTECATINI VAL DI CECINA (Tuscany) and the Mn deposits of GAMBATESA (Eastern Liguria), which are the most important ore-bodies of this group, have small tonnages. To complete the list of the deposits related to the ophiolitic Tethyan volcanism, we quote: Libiola (Liguria), Vigonzano, Bisano (Emilia), Rocca Tederighi (Tuscany) for Cu and pyrite; Monte Albareto (Emilia) for talc; Mortale, Terelle (Central Italy) (dubiously) for Mn-oxides; Ziona, Canegreca (Liguria) for (sub-economic) Cr concentrations.

4.3.3. Closure and emersion stages (Middle-Upper Cretaceous):

The deposition of important bauxite masses on the emerging carbonate platform is the major metallogenic event in this stage; the main deposits are widespread in Latium, Abruzzo, Campania, Apulia; the main deposits are S. GIOVANNI ROTONDO and SPINAZZOLA (Apulia).

The studies on these bauxites throw light on the Mediterranean Cretaceous paleogeography: in fact there is general agreement on their allocthonous origin, by alteration of cineritic materials carried by wind from the African plate (BARDOSSY et al., 1977). If this is true, the distances from Africa to the carbonate platforms of the Apennines should have been not so great at those time, probably shorter than now.

4.3.4. Collisional stage:

In the area under investigation (and excluding the Calabrian-Peloritanian Arc) this stage covers the main part of Tertiary and involves the Alpidic orogenesis and plutonism. Bauxite deposition came to end in Paleogene (Southern corner of Apulia) and was followed, at places, by clay accumulation intercalated in flyschoid formations (Neogene of Molise and Apulia).

The Alpidic orogenesis and granitization was characterized, from the metallogenic stand-point, by reworking (metamorphism, recrystallization, selective short distance migration) of pre-existing (pre- and proto-)concentrations.

The following deposits thus originated:

i) high grade, coarse crystalline pyrite (with occasional pyrrhotite) perigranitic masses: GAVORRANO is the main example;

ii) haematite and haematite-magnetite-pyrrhotite-pyrite skarn deposits of Elba Island.

Both i) and ii) accumulations are the result of recrystallization in situ coupled with partial or total oxydation, of pre-existing pyrite masses NICCIOLETA type (see point 4.3.2.).

iii) pyrite and mixed sulfide veins with quartz gangue: BOCCHEGGIANO p. p., CAMPIANO p. p., and others in the GROSSETO district are the main examples.

They are the result of short distance hydrothermal remobilization of pyrite plus mixed sulfide, NICCIOLETA type deposits;

iv) Cu, Zn, Fe, (Pb) skarn deposits: the only example occurs close to CAMPIGLIA (Grosseto district): no evident connection to preconcentrations are known in this case.

The Messinian (Upper Miocene) salinity crisis (see point 3.5.) is the most important metallogenic event (at least from the industrial stand-point) of this time span.

Northern Tuscany (Volterra, Na and alabaster), Eastern Emilia and Marche (gypsum, anhydrite; Perticara, Cabernardi, S); Campania and—specially—Sicily (Cattolica Eraclea, Na; Pasquasia, S. Cataldo, K; Trabonella, Cozzodisi, Gessolungo: gypsum, anhydrite, S) are the interesting areas and the main examples.

4.3.5. Post-collisional stage:

remembering what we pointed out in the first lines of the previous point, this stage starts in Upper Tertiary and includes the not yet terminated post-orogenic volcanism.

Very important ore/mineral accumulations are related to this event, and—particularly—to the volcanics of types b and c, point 3.6.

As a matter of fact, huge Hg deposits (ABBADIA SAN SALVATORE, SIELE, SOLFORATE, etc.) and not negligible Sb deposits (TAFONE, etc.) are, more or less evidently related to the M. Amiata volcanism.

So far as the Quarternary alkali-potassic volcanism is concerned, we may say that enormous potential K—Al reserves are connected with the leucitic lavas; as a matter of fact a few hundreds millions tons of these rocks, holding 20—26% of leucite have been proved; they are waiting for a suitable beneficiation process.

Important fluorite (and baryte) potential reserves, of volcano-sedimetary type, are related to some tuffaceous terranes (Latium: PIANCIANO, etc.); total reserves of about 20 millions tons of run-off, at an average grade of 25% CaF_2 (plus minor quantities of baryte) have been proved. The extreme grain fineness and the intimate mixture with the gangue minerals hinders their economic benefication.

Small deposits of volcanogenic sulfur mixed with marcasite have been partially exploited in the tuffaceous components of these volcanics (Northern Latium).

Small, irregular, generally low grade U occurrences have been recognized, around active or recently extinguished fumaroles of the same area.

Conspicuous high purity clay deposits (bentonites of Ponza Island, etc.) were generated from (mostly hypogene) alterations of perlitic tuffs.

Geo-thermal energy camps are known and exploited in central Tuscany: they are related to a heat dome connected to the M. Amiata volcanic apparatus. Other heat anomalies, at present under active investigation, are located in Latium and in Campania, in connection to the Quaternary alkali-potassic volcanism. Not negligible heavy metal accumulations (Fe, Ti, Zr, Th) are known in the beach sands of the Tyrrhenian coast, in front of the same volcanic apparatus.

Finally it has to be remembered that pyrite deposits, Kuroko type, are generated in the sub-marine areas of the Eolian Arc (HONNOREZ et al., 1970). They have no industrial importance, but represent an interesting metallogenic curiousness.

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