The Distribution of Alpidic ore Districts in the Western Part of the Mediterranean Sea in Relation to Plate Tectonic

By YVES A. FUCHS*)

Résumé

On envisage l'étude des gîtes de la Méditerranée occidentale du point de vue de l'évolution géodynamique de cette zone. L'importance des phénomènes magmatiques et hydrothermaux du Carbonifère supérieur et du Permien est miseen évidence et leur rôle quant à un apport important en métaux est souligné. Cette période est caractérisée comme celle d'une phase initiale du cycle alpin plutôt que comme un phénomène tardif du cycle hercynien.

On insiste, en ce qui concerne le Tertiaire, sur les différences de comportement des bordures des plaques eurasiennes et africaines. L'existence sur la marge de la plaque africaine de phénomènes de coulissement (dilacération de la microplaque d'Alboran) et de zones de subduction crustales paraissent responsables de la présence d'un magmatisme calco-alcalin et de la formation de gîtes hydrothermaux (veines polymétalliques et/ou gîtes volcanogéniques) en Italie et au Maghreb.

Zusammenfassung

Die Bildung der Erzlagerstätten und Erzvorkommen im westlichen Mittelmeerraum steht in enger Beziehung zu den verschiedenen Entwicklungsphasen der Plattentektonik. Wichtig sind die magmatischen und hydrothermalen Ereignisse während des Obersten Karbon und des Perm. Sie spielen eine besondere Rolle für die Metallzufuhr. Dieser Zeitraum stellt mehr eine initiale Phase des Alpidischen Zyklus als eine späte Phase des Variszikum dar.

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*) Laboratoire de Géochimie & Metallogénie – Université Paris VI. Tour 16–5e E., 4, place Jussieu – 75230 Paris Cédex 05.

Während des Tertiärs spielen die Ränder der Afrikanischen und Europäischen Platten sehr verschiedene Rollen. Am Rand der Afrikanischen Platte sind es die lateralen Bewegungen, die zum Zerreißen der Alboran Mikroplatte führen; die aktiven Subduktionszonen sind verantwortlich für einen kalk-alkalinen Magmatismus sowie für die Bildung hydrothermaler Lagerstätten (polymetallischer Gänge und/ oder vulkanogener Lagerstätten) in Italien und in Nordafrika.

Numerous ore occurrences or economic deposits of the Western part of the Mediterranean Sea show an evident relationship with particular events of the Alpine Orogenesis. The geochemistry as well as the morphology of these deposits are of quite different types. However it seems that the most important periods for the formation of ore deposits were related to some major events in the evolution of plate tectonics in the western part of the Mediterranean Sea.

The Initial Period

The rifting process began very early, probably during the late Carboniferous and Lower Permian period. Oceanization phenomena were not present during this time, but a distensive tectonic movement was an important fore-runner of the opening of the Téthys. In the French Massif Central during Stephanian time, the main tectonic trend was of compressive type. Important shearing zones with a N 20 E direction were active. In some areas, pull-apart phenomena induced the formation of intermontane subsiding coal basins. These areas were restricted. Therefore, some crustal anatexis, related to these basins, and a silico-aluminous potassium rich magmatism originated. It belongs to the type of "topaz rhyolites" described in the western part of the USA by D. Burt and Sheridan (1980), or to the type of hypovolcanics called ongonites by Kovalenko (1976).

Uranium, tungsten (as scheelite in tuffs), fluorite, tin, . . . occurences are associated to this type of volcanism (Badia et al., 1984). Later during Lower Permian, the distensive phenomenon became the most important. Large graben type basins were developping in the western part of Europe. A dominantly calc-alkaline magmatism was related to this geodynamic evolution (Badia et al., 1984). This magmatism is important all over western Europe (North Italy, Maures, Estérel, Alps, Massif Central and Vosges in France, Sarre-Nahe Basin and Northern Germany in FRG, North Sea, . . .). Its characteristics (petrological, geochemical and isotopes) show that this could be the result of an evolution in a continental plate, particularly along deep seated fault zones, where mantle influence can also be observed. This distensive geodynamic evolution is dominant during the Permian all over Western Europe whereas in some places it began during Stephanian, as the age of 285 My for the ignimbrites of Novazza has shown (S. Philippe, 1984, U-Pb method of zircons). It must be emphasized that the development of hydrothermal convective systems seems related to this magmatic activity. Ore deposits like Novazza in North Italy (uranium with some zinc and molybdenum in ignimbrites), Val Vedello in the same region (uranium in the boundary fault of a graben basin) and minor occurrences like

Pomayrols in France (uranium in dacitic dyke) or Ellweiler in Germany (uranium with some mercury and copper in a permian volcanic complex), seem to be directly related to hydrothermal circulation. The circulating fluids were particularly rich in magnesium and sodium penetrating into a hydrothermally altered zone, and leading to the formation of minerals, such as magnesian chlorite and dravite (BADIA et al., 1985). J. LEROY (1978) in his study on the uranium district of Limousin (France) has noticed that the granites show an age of 350–360 My (Rb-Sr), but that towards 285 My, a lamprophyric magmatism related to a fault tectonism took place. A heat flow was associated to this magmatism. It caused a heating up of the cold water which impregnated the granites and then formed convective circulating hydrothermal systems. The fluids caused the episyenitization of the granite and this phenomen was followed by the deposition of pitchblende and pyrite (275 My) (LEROY, 1978). Not only uranium is affected by these hydrothermal processes. BREVANT et al. (1982) studied the isotopic ratios of lead in galena of the southern part of the French Massif Central. They have shown (Fig. 4) that the isotopes of lead in galena were distributed in two groups, one with $17.76 < 206$ Pb/204 Pb < 17.94 and the other one with $18.25 < 206$ Pb/204 Pb < 18.63. They concluded that, after a mantle evolution until 3 By the lead was incorporated in a part of the crust. Afterwards the less radiogenic group was associated to the carbonate rocks of the Cambrian. The second group seems to be related to the hercynian granitoids or more exactly to the hydrothermal systems of the late evolution of the hercynian period.

It can be discussed whether these major hydrothermal events were related to the end of the Hercynian orogenesis, or to the beginning development of the Alpine system. Following H. WOPFNER (1984) who investigated the Permian deposits between Val Camonica and the Karawanken, one can assume that the development of a complex rift system during the Permian initiated the alpidic sedimentation. Equally, this tectonic and magmatic environment was favourable for an important metal supply during this initial phase of the alpidic evolution.

Part of this metal supply is directly connected with the transportation by hydrotherms. An other part in the continental and epicontinental domain is provided by the weathering of the old basement and another important part by the weathering of recently vented volcanics. ZIELINSKY (1982) has shown the importance of the weathering of volcanic glasses as a source for metal supply in the supergene cycle. It can be a major source for stratiform deposits and occurrences of uranium located in strata of Permian age (France, Italy, . . .) but also extending up to the Triassic in Austria (PETRASCHECK et al., 1974).

During Triassic, the opening is continuing. In the Western Mediterranean Sea, one can clearly characterize two domains. In basins with Germanic facies, lead-zinc deposits (Maubach and Mechernich in FRG, Saint Avold and Largentières in France, J. Tebagha in Tunisia) are hosted in sandstones. In the other domain of sedimentation, important economic deposits (Bleiberg in Austria, Raibl, Salafossa, Gorno in Italy and in S-W Spain) are related to carbonate rocks deposited on an epicontinental platform. The palynspastic map (Fig. 1) shows that the most important deposits are located in the vicinity of deep seated structures of major importance. It is impossible to conclude that these structures represented the source of the metal

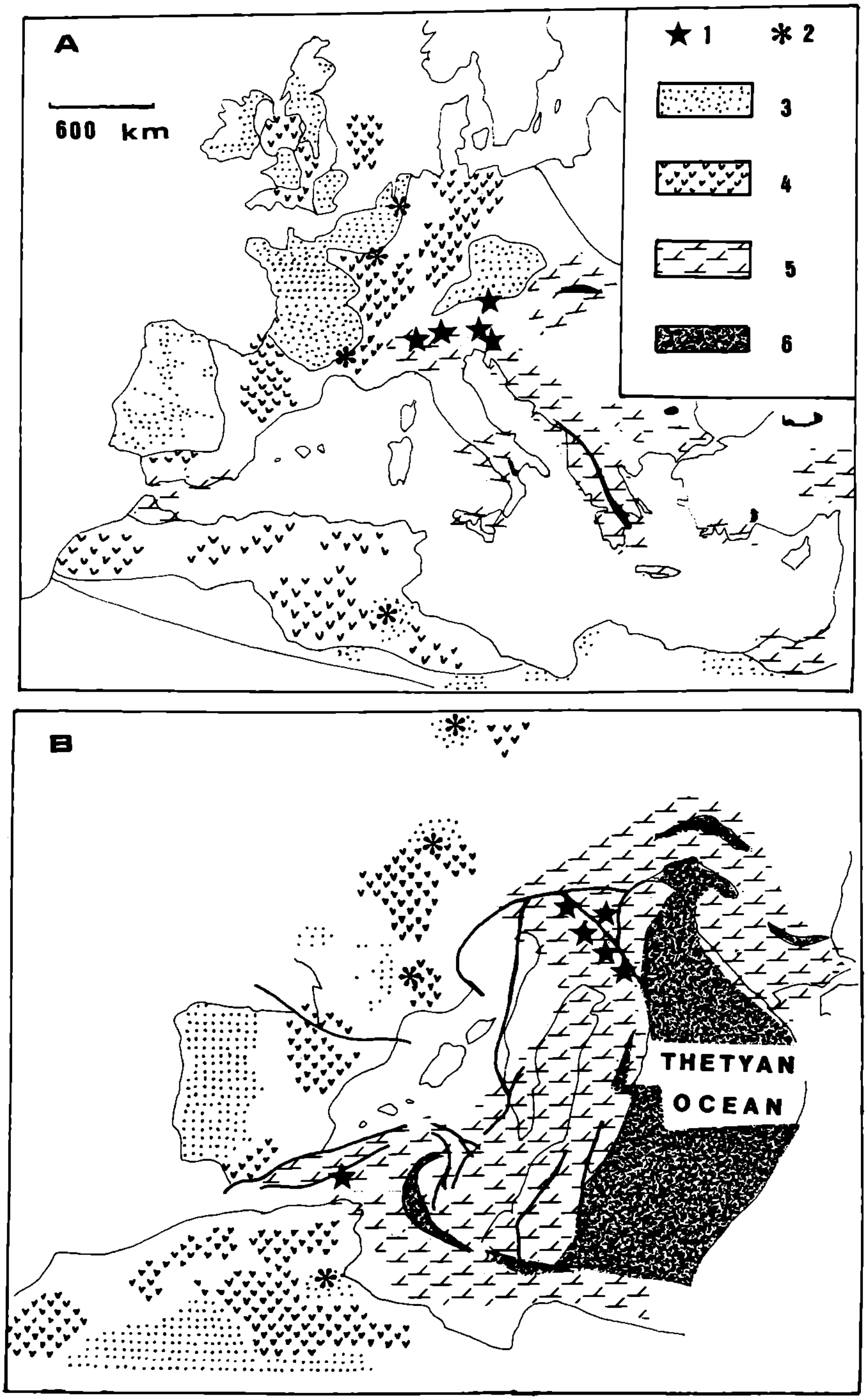

Fig. 1. Repartition map (A) and palynspastic map (B) of Triassic sediments and of related Pb-Zn deposits. 1 = carbonate hosted Pb-Zn deposits; 2 = sandstone hosted Pb-Zn deposits; 3 = sandstone facies; 4 = evaporitic facies; 5 = carbonate platform facies; 6 = oceanic crust.

supply. The discussion remains open. Many geological observations agree with an exogenous source of supply. Nevertheless, these structures induced unstable sedimentation conditions in the neighbouring areas and induced the formation of sedimentary traps (emersion surfaces, karst, unconformities, reef facies, lagoonal facies, slumping, . . .).

Regarding the stratiform pyritic deposits of Southern Tuscany, the presence of evaporites and basic volcanics (TANELLI et LATTANZI, 1983) indicates an environment with volcanogenic supply and a trend to rifting or initial ocean floor spreading. This point of view matches with the palynspastic map (Fig. 1).

A great number of diverse ore deposits is hosted in the sedimentary rocks of Jurassic age in the Western Mediterranean area. These carbonate rocks belong to the epicontinental platform type. The ore deposits consist of lead-zinc ores, but also fluorite and barite (Les Malines in France, Touissit in Morocco, El Abed in Algeria are lead-zinc deposits; Pierre-Perthuis in France is a fluorite deposit; Chaillac and Pessens in France are barite deposits). Bou Grine, Jebel Ajered in Tunisia, Kharzet Youssef in Algeria, Reocin in Spain are lead-zinc deposits hosted in platform carbonate rocks of Lower Cretaceous age.

The controlling features of these ore deposits are mainly related to sedimentary or diagenetic structures. The supply of metals to the platform epicontinental environment is connected mainly with leaching out of weathered sections on merged areas. The stratigraphical control of the occurrences and deposits was a function of epirogenic movements, causing the leaching of pedogenetic concentrations, formed on the continent during periods of stability. The main controlling factors of these types of deposits are of climatological and sedimentological type, but the permanent instability controls the localization of the ores in time (supply) and space (palaeogeographical traps). On the other hand it is possible that some heath flows occured and induced remobilization of ore (SUREAU et al., 1981).

The Orogenic Events and the Closing of the Tethys

The first closing event occured in the internal part of the Alpine system during the Lower Cretaceous (Albian mainly). The evolution of this phenomenon is confusing. Many geological features were overprinted by the later development of the orogenesis. A predominant dynamic metamorphism (except in the Pyrenées) was active from about 110 My (Schistes lustrés from Liguria, Piémont and Calabria) (DURAND-DELGA et FONTBOTE, 1980). The apparent age of the pitchblende from Val Vedello (Bergamasc Alps, Italy) 115 My (S. PHILIPPE, 1984) could be related to a remobilization and rejuvenation connected to this event.

Nevertheless, the most important geodynamic events occured during the Tertiary. At the beginning of the Miocene, the Mediterranean Sea was formed by the collapse of continental blocks. At the same time the crust thinned out and the Alboran Sea developed. An other basin, the Basin of Provence was formed through a 30 to 55° rotation of the Corsican-Sardinian microcontinent. The Algerian basin opened through the movement of the Kabylian Massif above a subduction zone, dipping

North during the Miocene which is now situated behind these massifs. The formation of the Tyrrhenian basin is related to a subduction zone situated outside of the Sicilian-Calabrian-Apenninic Arc. This evolution was still proceeding as a dextral movement by tearing the microplate of Alboran into two pieces. (J. ANDRIEUX et al., 1971). Again during the same period a shortening happened between the Eurasian and the African Plate. This shortening is related to the activity of two crustal subduction zones symmetrically dipping on both sides of the mesomediterranean plate. In the Maghrebides the geological units were overthrusted towards the South, in the Betides, towards the North. In the Apennin, it is assumed that a southwest dipping subduction zone could have induced the forward movement of the internal Ligurian zones above the external ones. This subduction zone could be the prolongation in this direction of the Maghrebide subduction zone.

Only is this Southern and Eastern part of the Western Mediterranean area (Betide, Maghrebide, Apennins), a calc-alkaline magmatism developped during this period (Tuskany, Tunisia, Algeria) and some hydrothermal events were associated with this magmatism. The difference in the geodynamic and magmatic evolution on the Eurasian and African plate in the Western Mediterranean Sea induces some differences in the domain of genesis of ore deposits. During Tertiary time, the ore deposits which were formed on the Eurasian plate, were related to supergene phenomena. So are uranium deposits in the sedimentary cover like Coutras in Gironde (France), Saint Pierre du Cantal (France) or the roll type deposits of the Lauraguais (France). On the other hand, on the African plate and at its boundaries on the Southern and Eastern banks of the Western Mediterranean Sea, some ore deposits are connected with magmatism and the associated heat flow and hydrothermal systems.

In Tuscany, the autochtonous basement consists of units from Paleozoïc up to Oligocene. These units are overlain by allochtonous liguride and subliguride units. The whole geological succession up to the Calcare Massicio was intruded by quartz-monzonites (5.7 My old; BORSI et al., 1967). A mostly thermic metamorphism (500° C and < kb) was associated with these intrusions. Then, a volcanic activity (about 4.7 My) began. It showed vented volcanics and porphyry dykes. The dykes are intensively transformed through a potassium rich hydrothermal alteration. Copper-lead-zinc sulfide ores (Campiglia Maritima) are associated with this magmatism. Recent publications (particularly by F. CORSINI et al., 1980; G. CORTECCI et al., 1983) on the base of sulfur isotope data, conclude that the formation took place at low depth and temperatures in the range of 250 to 400° C. The involved hydrothermal fluids could have removed a metal content wich existed in the autochtonous units. An other type of deposit like the Gavorrano pyritic ore body have resulted from contact metamorphism of intrusives with a preexisting deposit (BENCINI et al., 1980).

Ore deposits or occurrences associated with Tertiary magmatism are also important in the Maghrebides. Some of them are directly related to volcanic activity like Oued el Kebir (TOUAHRI et FUCHS, this vol.). In Oued el Kebir area, near Jijel, the first unit consists of vented volcanics forming trachytic domes, breccias and tuffs. After deposition of these effusives, the center of the area collapsed and a caldera was formed. Within the caldera, marine sediments were deposited. This very

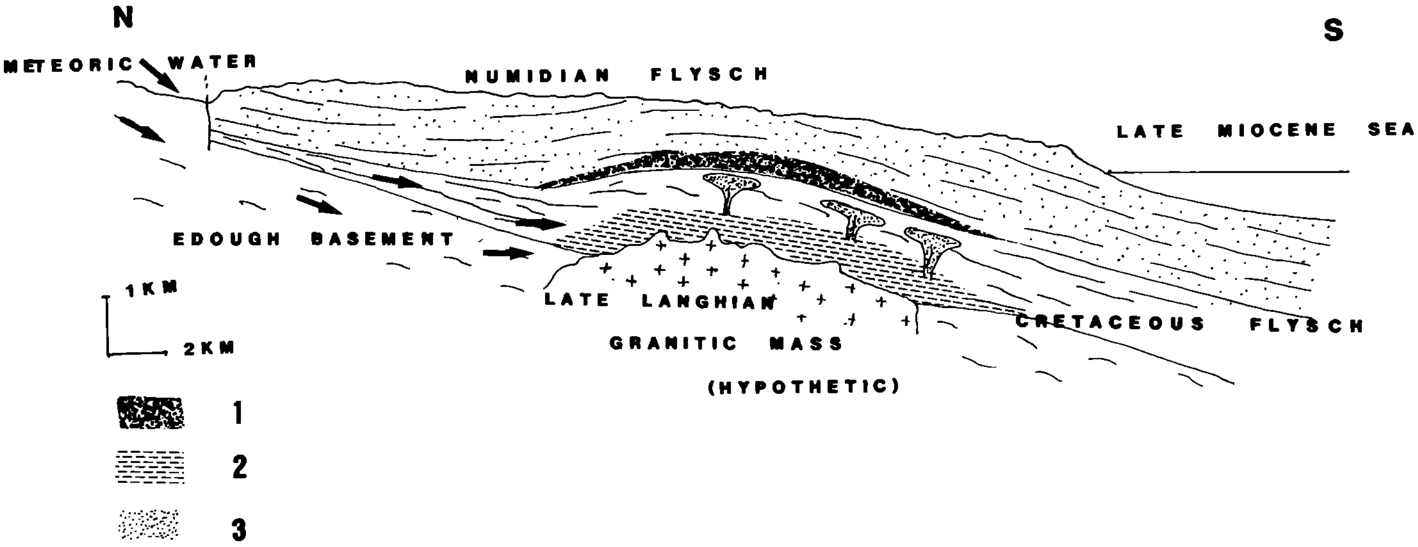

Fig. 2. A possible cross-section of the Aïn Barbar geothermal field at the end of Langhian times (in Marignac, 1983). 1 = silicifications in the Numidian cap rock; 2 = hornfelses with adinolite/solite/ plagioclase; 3 = Ca-Al Silicates in the Maestrichtian aquifer.

short period during the Langhian was followed by a new collapse which induced the formation of an extended unit of breccias. Afterwards, the volcanic activity continued with basaltic and andesitic flows which covered all of the area. In a later stage, monzonitic plugs intruded into the outer part of the complex. The ore deposits (Pb, Zn, Cu, Ba, Ag, Au) include stratiform ore bodies at the bottom of a limited sedimentary sequence and stockwerks in the lower volcanic unit, seated beneath the stratiform ore bodies. Both types of mineralization are characterized by an important pervasive hydrothermal alteration of wall rocks.

An other type of ore deposit of Tertiary age in the Maghrebides is a polymetallic vein type. At Aïn Barbar (Algeria), C. MARIGNAC (1983) the evidence of Tertiary thermal domes has been shown. A paleogeothermal system was active towards the end of Langhian time. An allochtonous cap of Numidian flysch induced the formation of a convective hydrothermal system in the underlying Cretaceous flysch unit (Fig. 2). A zonation of wall rock alteration can be observed (Fig. 3). Paragenetic associations indicate that the temperature was less than 320–330° C and the pressure about 100–130 bars (10–1 M. P. A.).

The boundary of the African Plate from the Betides to the Apennins was subject to an important lateral displacement associated with crustal subduction. For these reasons the magmatic and hydrothermal activities were very well developed, particularly during Miocene. Lead isotope ratios are in full agreement with this assumptions. On the border of the European Plate, lead isotope ratios show the existence of two groups: one related to the Cambrian carbonate rocks, the other one to late Hercynian hydrothermal activity (BREVANT et al., 1982, Fig. 4). These two groups were recognized even in the deposits of the post Permian sedimentary units. On the other hand, P. RAJLICH et al. (1983), in their studies of Moroccon deposits Fig. 5 and V. KÖPPEL (1983), in his studies on deposits of the Eastern and

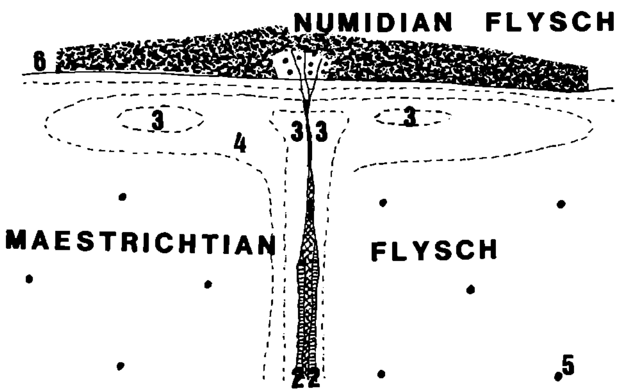

Fig. 3. Diagrammatic scheme showing a possible configuration of the paleoisotherms in the Aïn Barbar geothermal field, with the associated alterations. Note that the model could as well be asymmetrical. 1 = brecciated fault zone; 2 = metasomatic alteration near the ore veins; 3 = epidotic and K-feldspar; 4 = wairakite; 5 = calcite (black dots); 6 = silicification (in Mariguae 1983)

Southern Alps, display a more complex distribution of lead isotope ratios. The results point to the possibility of a remobilization of crustal lead and for a supply of young lead during Tertiary.

Metallogenic, geochemical and isotope ratio data help to correlate the genesis of ore deposits and occurrences in the Western Mediterranean Sea to the main geodynamic events in this area.

Carbonate hosted lead-zinc or fluorite and barite deposits in an epicontinental environment are related both to supergene and tectonic phenomena. It seems however that the initial rifting period and the final closing are the major periods for the supply of metals connected with hydrothermal activity. During the final phase, the boundary of the African Plate suffered lateral displacement and crustal subduction zones played a major part.

The distribution of the elements and therefore the formation of ore provinces are related to major geodynamic events of the initial rifting and of the final stage. Even if within a structural unit, within a particular period, processes which led to the concentration of metals and therefore to the formation of economic deposits were different, the most relevant factors, governing the distribution of provinces, are related to the geodynamic evolution.

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