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ALPINE MAGMATIC-METALLOGENIC FORMATIONS OF THE NORTHWESTERN AND CENTRAL DINARIDES*

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In the paper are presented basic geological, petrological, geochemical and mineral deposit data for five main magmatic-metallogenic formations of the northwestern and central Dinarides: (1) The Permo-Triassic rifting related andesite-diorite formations; (2) The Jurassic-Lower Cretaceous accretionary (ophiolite) formations; (3) The Upper Cretaceous-Paleogene subduction related basalt-rhyolite formations; (4) The Paleogene collisional granite formations, and (5) The Oligocene-Neogene postsubduction andesite formations.

All these magmatic-metallogenic formations originated in different geotectonic settings during the Alpine evolution of the Dinaridic parts of the Tethys and the postorogenic evolution of the Paratethys and the Pannonian Basin, respectively.

Ključne riječi: magmatsko-metalogene formacije, geologija, petrologija, geokemija, rudna ležišta, Dinaridi

U članku su prikazani osnovni geološki, petrološki, geokemijski i rudnoležišni podaci za pet glavnih magmatsko-metalogenetskih formacija sjeverozapadnih i središnjih Dinarida: (1) permo-trijaske andezitsko-dioritske riftne formacije; (2) jursko-donjokredne akrecione (ofiolitske) formacije; (3) gornjokredno-paleogene subdukcijske bazalt-riolitne formacije; (4) paleogene kolizijske granitne formacije, i (5) oligocensko-neogene postsubdukcijske andezitske formacije.

Sve te magmatsko-metalogene formacije stvarane su u različitim geotektonskim ambijentima za vrijeme alpinotipne evolucije dinarskih dijelova Tetisa i postorogene evolucije Paratetisa, odnosno bazena Panona.

Introduction

The Dinarides represent a typical orogenic belt located along the northeastern flank of the Adriatic microplate (Dewey et al., 1973) or the Apulia (Dercourt et al., 1993). In this large area, genetically different formations which originated during the Alpine Wilson cycle in the Dinaridic parts of the Tethys, and the pre-Alpine basement rocks are found.

The Dinarides represent a complex, fold, thrust and imbricate belt characterized by a regular pattern in the spatial distribution of the characteristic lithologies (**fig. 1**). From the southwest to the northeast, the following main lithological units can be distinguished: (1) The Adriatic-Dinaridic carbonate platform of the Alpine passive continental margin (the External Dinarides); (2) The carbonate-clastic formations of the Alpine passive continental margin; (3) The ophiolite formations related to the open Tethyan area, and (4) The sedimentary magmatic-metamorphic formations of the Alpine active continental margin (Pamić, 1993). The last three units are included in the Internal Dinarides, i.e. the Supradinaricum (Herak, 1986).

These internal units are thrust by the Palaeozoic-Triassic nappe (Pamić & Jurković, in press) which stretches along the central Dinarides with its southwestern frontal parts thrusted over the Adriatic-Dinaridic carbonate platform. The Palaeozoic-Triassic nappe represents, in fact, the southeastern prolongation of the Sava nappe (Mioč, 1984) and the Southern Alps, in the northwest whereas it goes on without a break towards the southeast into the Hellenides (the Korab zone in West Mazedonia?).

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The generation of all these large lithofacies complexes is the result of long-lasting sedimentary evolution of the Dinaridic parts of the Tethys. It was accompanied by magmatic activity which gave rise to the origin of different magmatic formations in which many kinds of numerous mineral deposits and occurrences are included.

The aim of this paper is to present the Alpine magmatic-metallogenic formations (**MMF**) of the northwestern and central Dinarides and the South Pannonian Basin and their basic geological, petrological, geochemical and mineral deposit characteristics.

Alpine magmatic-metallogenic formations

In the northwestern and central Dinarides five main groups of the Alpine MMFs can be distinguished: (1) **The Permo-Triassic rifting related andesite-diorite formations; (2) The Jurassic-Lower Cretaceous accretionary (ophiolite) formations; (3) The Upper Cretaceous-Paleogene subduction related basalt-rhyolite formation; (4) The Paleogene collisional granite formations, and (5) The Oligocene-Neogene postsubduction andesite formations.**

1. Permo-Triassic rifting related andesite-diorite formations

Geology. Magmatic activity was related to rifting processes which took place on the Variscan basement of the Pangea during the period of about 40 Ma. The rifting magmatism accompanied first stages of the evolution of the carbonate platform and preceded the opening of the Dinaridic part of the Tethys. The MMFs are found in Late Palaeozoic-Triassic autochtonous (the External Dinarides) and allochtonous (the Internal Dinarides) metasedimentary and sedimentary complexes (Pamić, 1984).

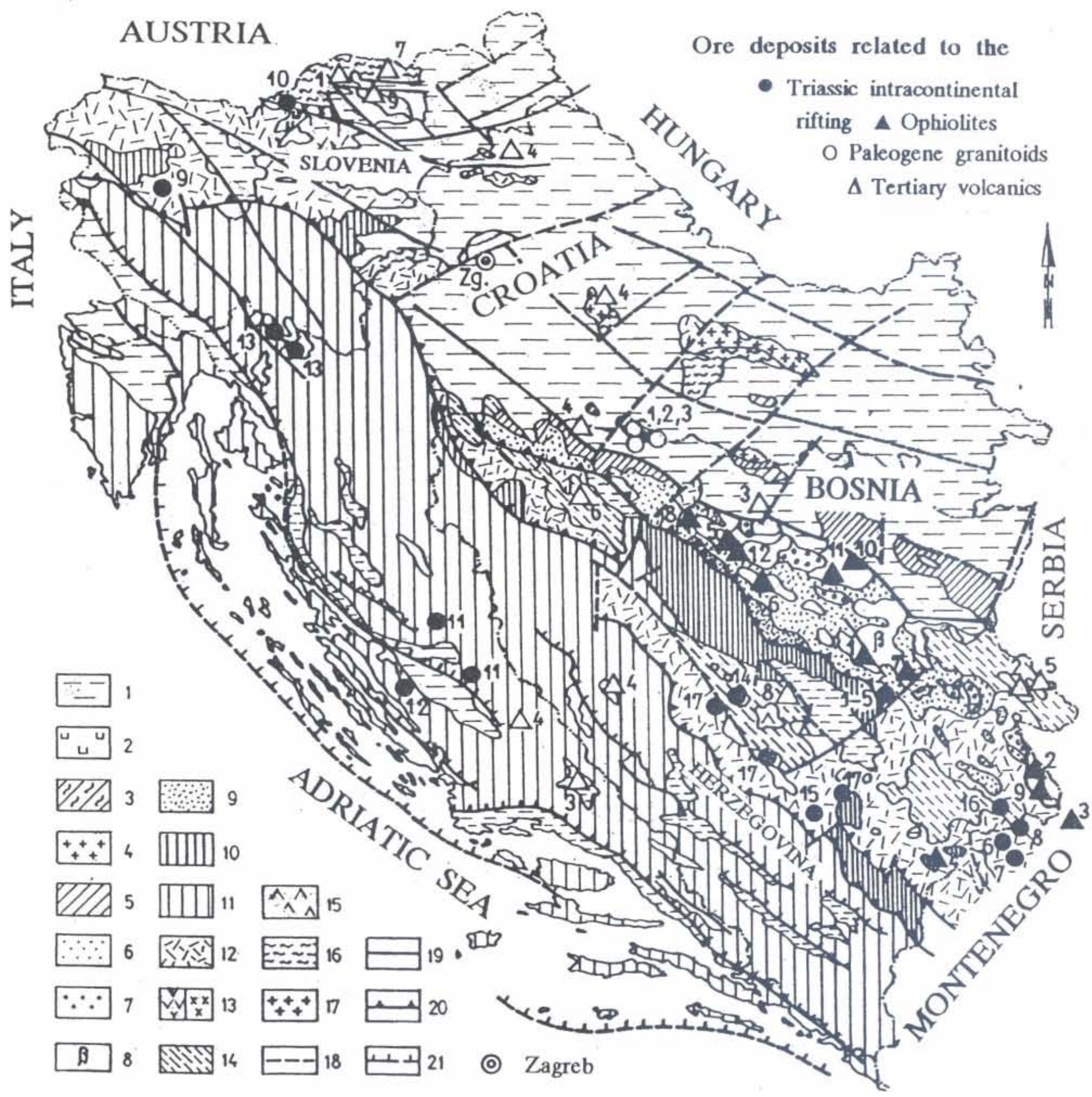


Fig. 1. Geological map of the northwestern and central Dinarides showing positions of main Alpine mineral deposits (Pamić & Jurković, in press; Mioč, 1984)

Legend: 1 Tertiary and Quaternary sediments; 2 Tertiary volcanics; 2 Paleogene metamorphic rocks; 4 Paleogene granitoids; 5 Upper Cretaceous-Paleogene flysch (active continental margin); 6 Dinaridic Ophiolite zone, mostly mélange; 7 Lower to Upper Cretaceous sequences unconformably overlying ophiolites; 8 larger ultramafic massifs; 9 radiolarites; 10 Jurassic to Upper Cretaceous sequences of the passive continental margin; 11 Adriatic-Dinaridic carbonate platform; 12 allochthonous Triassic sequences; 13 larger bodies of Triassic volcanic (a) and plutonic (b) rocks; 14 allochthonous Palaeozoic sequences; 15 larger bodies of Palaeozoic volcanics; 16 Palaeozoic metamorphic rocks of the Eastern Alps and Tisia; 17 Palaeozoic granitoids and migmatites; 18 normal fault; 197 strike-slip fault; 20 interterrane thrust; 21 intra-terrane thrust; klipe or window. Numbers mark mineral deposits described in the paper.

The magmatism gave intrusive and extrusive rocks. The intrusive rocks occur in form of small plutons (up to 50 km^2), stocks and veins in Upper Palaeozoic to Anisian sediments; their K-Ar crystallization ages vary from 262 to 216 Ma. More abundant volcanics, commonly accompanied with pyroclastic rocks, are interlayered with marine Upper Permian and Scythian mostly clastic sediments and Anisian to Norian mostly carbonate sediments alternating with shales, cherts, »pietra verde« and subordinate sandstones. Main and the most intense volcanic activity took place during the Ladinian and it gave large volcanic flows up to 1000 m thick. No traces of magmatic activity have been observed in the late Upper Triassic, when long-lived carbonate platform sedimentation was initiated over a large area.

Petrology-geochemistry. Plutonic rocks are mostly diorite and albite syenite with subordinate gabbro, albite granite and granite-granodiorite, mostly all of them also represented by hypabyssal equivalents. Volcanic rocks are andesite, dacite and basalt mostly tranformed into metabasalt, metaandesite and metadacite, all of them amygdaloidal and accompanied by volcanic breccia and tuff. The association as a whole is of calc-alkaline to slightly tholeiitic affinity.

Four main MMFs can be distinguished: **(1) The basalt-spilite formation** of the Mounts Zelengora–Treskavica–Igman–Zvijezda, the area of Hrvatsko Zagorje and SE Slovenia; **(2) The andesite-dacite and quartz keratophyre formation** of the Sava nappe in Slovenia with granitoids of Mt. Karavanke; here, the andesite-dacite-quartz keratophyre subprovince of northern Montenegro can be included: **(3) The spilite-andesite formation** of the External Dinarides, Adriatic islands and Hrvatsko Zagorje and **(4) The basalt-spilite-andesite-quartz keratophyre formation** of the Jablanica–Prozor–Vakuf–Ključ zone in which the largest plutonic bodies are included (Pamić, 1984).

Predominant andesite and diorite are correlative in major- and trace-element contents with orogenic high-K andesite but with distinct differences in barium, strontium, and copper. Trace element discrimination diagrams suggest within-plate origin.

The great variation trend is probably caused by partial melting of crustal rocks as indicated by high $^{87}Sr/^{86}Sr$ ratio. Each solidification level had its own features reflected in some compositional peculiarities. The primary composition of volcanics was affected by contamination and late- and post-magmatic alterations shown in albitization, adularization and zeolitization.

Mineral deposits. Economically, the Triassic MMFs include the most important mineral deposits of the Alpine Wilson cycle of the Dinarides. The deposits are located in hypabyssal intrusive and volcanic-sedimentary formations or in adjacent rocks composed of Upper Palaeozoic and Scythian and Anisian sediments. It is probable that most of the Triassic deposits belongs to the group of aborted rifts.

Geochemically, in the deposits, iron, manganese, barium, mercury, lead and zine predominate over quite subordinate copper and fluorine. Most of the metals are of crustal origin as indicated by lead isotopic composition. Numerous small-sized vein and replacement barite deposits, located in Lower and Middle Triassic clastic and carbonate rocks are characterized by average values of $\delta^{34}S$ = +21–23‰, T_h<200 °C, and low salinity (Šiftar, 1988, Jurković & Palinkaš, 1994, 1996, Jurković et al., 1994).

Triassic mineral deposits are included into four main magmatic formations as follows:

1) The basalt-spilite formation of the central Bosnia includes: a) the Čevljanovići primary stratiform **manganese deposits** (marked with symbol ●1 on the fig. 1) with braunite, cryptomelane, romanechite, hausmannite and manganite as primary ore minerals (Vujanović, 1968); b) the Vareš (●2), big submarine stratiform hydrothermal **siderite** (barite-bearing) – **hematite deposits** (Smreka, Droškovac, Brezik, Pržići) underlain by shales enriched in copper, iron, zinc and lead sulphides (Petković, 1960; Bodulić, 1979); c) the Gornja and Donja Borovica, Rupice, Brestić, Juraševac, Rid (●3) and Srednje (Maine) (●3a) stratiform or stratabound volcanogenic-sedimentary **barite deposits** with different proportions of iron, lead, zinc±copper, antimony, arsenic-sulphides. In this group of deposit belong also the Veovača and Selište (●4) intraformational ore breccias and conglomerates in adjacent Triassic dolomites (Ramović et al., 1976) and d) the Draževići (●5) stratabound disseminated **cinnabar deposits** (Ramović et al., 1979) **(fig. 2).**

2a) The andesite-dacite and quartz keratophyre formation of Montenegro includes: a) the Šuplja Stijena (●6) volcanic-hydrothermal vein and disseminated **lead-zinc-iron sulphide deposits** (Janković, 1953); b) the Brskovo (●7) volcanic ± volcanogenic-sedimentary hydrothermal massive **zinc-lead-iron sulphide deposit** (Janković, 1982, 1987); and c) small vein and metasomatic **barite deposits** ± mercury, antimony and iron sulphides on Mt. Kovač Mountain (●8) (Kulenović, 1987; Jurković & Palinkaš, 1996).

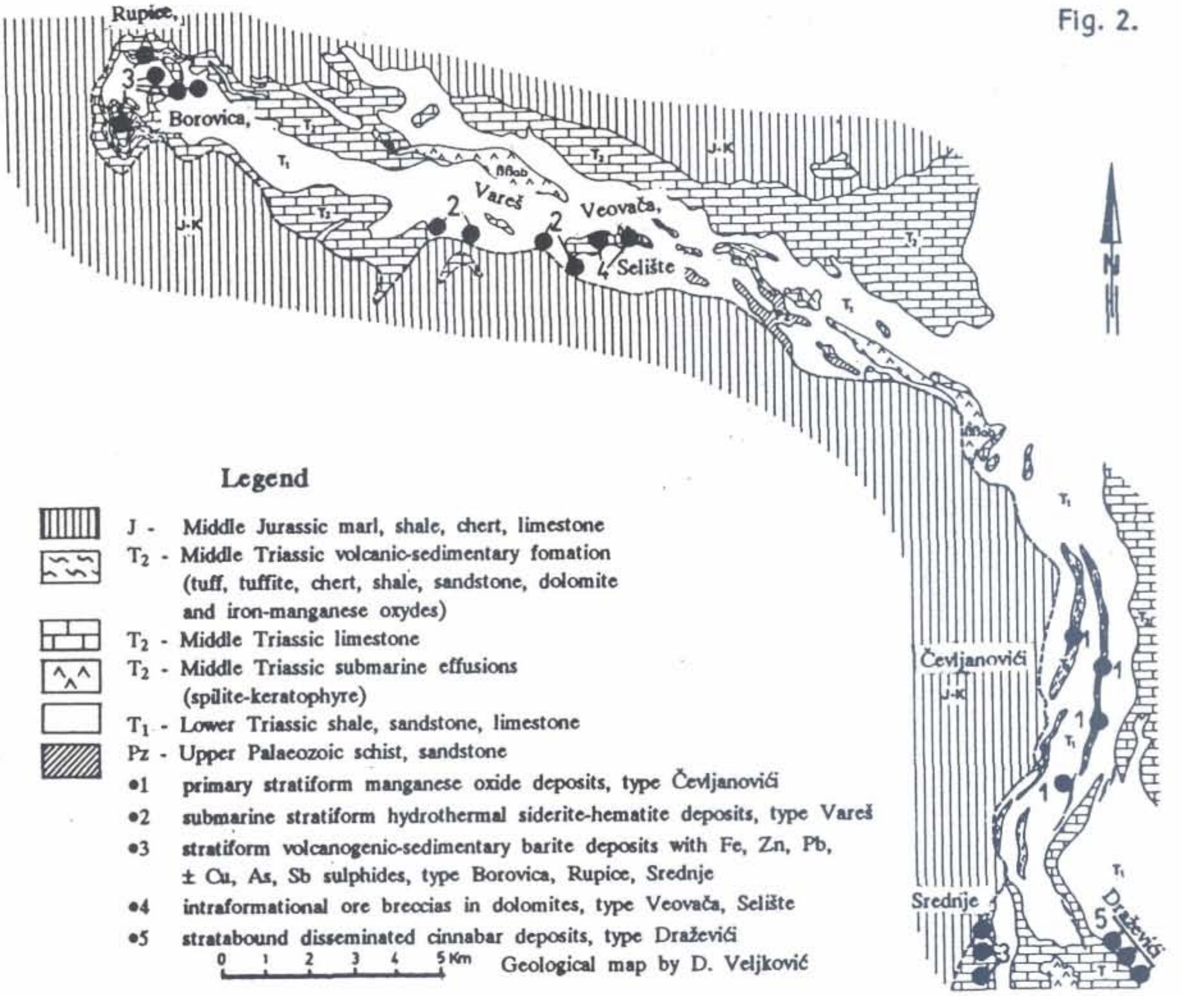
2b) The andesite-dacite and quartz keratophyre formation of Slovenia includes: a) two largest Alpine deposits of the Dinarides: α) The Idrija (●9) and Podljubelj **cinnabar deposits** originated from low-temperature, highly differentiated upper mantle fluids. Sulphide sulphur isotopic composition suggests a heterogeneous origin of sulphur (both magmatic and biogenic) (Mlakar & Drovenik, 1971; Drovenik et al., 1989; Štrucl, 1984, Drovenik et al., 1990); β) The Mežice **lead-zinc deposits** (●10) which are similar to the Bleiberg and Raibler deposits, with very small proportions of molybdenum, iron, arsenic and fluorine, which might have originated by remobilization of older deposits during Triassic rifting magmatism as indicated by unusually high lead ages. However, sulphide sulphur isotopic composition indicates biogenic influence ($\delta^{34}S$ = –1.7 to –20.9‰ (Dolenec et al., 1993a, 1993c).

3) The spilite-andesite formation of the External Dinarides includes mostly occurrences and small deposits: a) the marine **oolithic iron-deposits** at Pribudić (Gračac, Lika) and at Pađene (Knin, Dalmatia) (●11) (Jurković, 1962; Šinkovec, 1975); b) the bentonite deposits (●12) originated by alteration of tuffs which are interlayered in Ladinian sediments (Braun, 1991), and c) the bimineralic **pyrite-barite deposits of the Sabkha-type** (●13) (Jurković, 1962; Palinkaš et al., 1993).

4) The most differentiated basalt-andesite and spilite-quartz-keratophyre formation of the Middle and South-eastern Bosnia with the largest plutonic bodies includes hypabyssal magmatic deposits: a) the **endometamorphic magnetite-hematite skarns** (●14) of the Mt. Radovan diorite (Jurković, 1957; Janković & Zarić, 1978; Bodulić, 1979; Šarac & Pamić, 1981) and Tovarnica (●15) **exometamorphic magnetite-garnet-epidote skarns** with subordinate pyrrhotite and pyrite and accessory copper, lead, zinc, bismuth and arsenic

Triassic ore deposits in the area of central Bosnia, related to the intracontinental rifting

Fig. 2.



minerals (Čelebić, 1967; Bodulić, 1979; Šarac & Pamić, 1981); b) the (Podhrusanj–Čajniče) high temperature **hydrothermal magnetite and/or hematite or pyrrhotite deposits** which are zonaly arranged around intrusive bodies (●16) (Kulenović, 1987; Jurković & Palinkaš, 1996), and d) numerous but small stratiform **hematite and manganese-oxide deposits** (± siderite) located in the Ladinian volcanic-sedimentary formation (●17) of the Konjic–Prozor–Bugojno area, Central Bosnia (Jurković, 1957; Čelebić, 1967; Bodulić, 1979).

2. Jurassic-Lower Cretaceous accretionary (ophiolite) formations

Geology. Ophiolites, found in the Dinaride Ophiolite zone, represent fragments of the Tethyan Mesozoic oceanic crust originated during the period of about 80 Ma. The ophiolites are associated with: a) Upper Triassic to Lower Cretaceous radiolarites interlayered with basalts; b) Ophiolite mélange of olistostrome origin, subsequently tectonized (Dimitrijević & Dimitrijević, 1973). It consists of shaly-silty matrix in which are included fragments, cm-dcm-m-dm-hm-km in size, of predominant native graywacke+basalt, tuff, diabase, gabbro, peridotite, shale, radiolarite+exotic blocks of Middle Triassic to Lower Cretaceous limestones. The mélange is of a presumed Jurassic to Lower Cretaceous age but its tectonization terminated by Eocene/Oligocene main deformational event (Pamić, 1982). Sm-Nd isochron age of 136 Ma on lherzolites and K-Ar ages of 189–160 Ma on amphibolites were obtained (Lugović et al., 1991; Lanphere et al., 1975; Majer, 1975). c) Lower to Upper Cretaceous overstep sequences underlain by the ophiolite mélange.

Larger ultramafic bodies (100–500 km^2) represent faulted sheets, up to 2000 m thick, which are thrusted onto the ophiolite mélange, and are conformably underlain by amphibolites, locally associated with eclogites. Gabbros and massive or sheeted diabases occur as small to large (20 km^2) masses into the mélange. Basalts occur at the top of the preserved ophiolite sequences or interlayered with shales and graywackes, and radiolarites or as fragments in the mélange.

Petrology-geochemistry. Four main ophiolitic MMFs can be distingusihed: **a) The tectonite peridotite formation** represented by lherzolite and rare harzburgite and dunite serpentinized to various degrees; **b) The cumulate peridotite-gabbro formation** composed of strongly serpentinized peridotite and gabbro varieties, commonly with modal and compositional layering; **c) The diabase formation** with subordinate dolerite and ophitic gabbro, partly affected by ocean-floor metamorphism. **d) The basalt formation** mostly albitized and zeolitized and altered into metabasalts (spilites). These rocks are associated with rare and small masses of M-type granitoids.

Predominant ultramafic tectonites are mainly fertile spinel lherzolites which are correlative in chemical composition with peridotites of subcontinental and normal oceanic environments and thus are not directly arc-related. They significantly differ from the peridotites of typical ophiolite complexes as indicated by extremely strong depletion of LREE (Lugović et al., 1991).

Diabases have high Mg-values (70) and high nickel and chromium contents indicating a low degree of differentation. Sm-Nd isotopic data suggest their upper mantle origin whereas their normalized element concentration patterns are similar to those of E-type MORBs or BABTs.

The fertile character of lherzolites and the chemical features of associated mafic rocks suggest origin within a back-arc spreading centre (Lugović et al., 1991).

Mineral deposits can be divided into several genetical groups and subgroups:

(A) Primary ore deposits:

1a) Podiform refractory chromite deposits related to tectonite peridotites are represented by small ore zones (200×20–30 m) averaging 10–15% of low-quality refractory chromite in the Duboštica (▲1) (Vareš area) (Sunarić–Pamić & Olujić, 1968). High-quality small-sized or medium sized chromite deposits related to the Zlatibor massif (▲2) are built up of harzburgite and lherzolite and minor dunite. Bigger chromite deposits have been exploited in the Đakovica, Orahovac and Brezovica massifs (▲3) built up of harzburgite, minor dunite ± pyroxenite and gabbro in the Kosovo area and NW Mazedonia. Total reserves of chromite ore are 1×10^6t. (Grafenauer, 1977., Janković, 1990). **1b) Other** small mineral **occurrences** (Rastište, ▲4) are represented by titanomagnetite, pyrrhotite, chalcopyrite segregates and platinum flakes (Terzić & Zarić, 1970; Rakić, 1963).

2) Cu-Ni deposits related to the diabase formation:

a) Liquid-magmatic pyrrhotite-chalcopyrite-pentlandite lenses and vein-stockworks with subordinate cubanite, chalcopyrrhotite, bravoite and millerite in Mt. Čavka, northern Bosnia (▲5), (Đurić & Kubat, 1962) **b) Hydrothermal** Cu-veins and stockworks composed of quartz, chalcopyrite, pyrite and arse-nopyrite (Đurić & Kubat, 1962).

3) Garnet and corundum related to amphibolites:

a) Garnet occurs unevenly included as a major mineral in larger amphibolite zones (10–20×5 km), conformably overlain by larger peridotite bodies; the amhibolite containing 10–30% of pyrope-enriched garnet include small eclogite bodies. The richest localities are in the Skatavica (Banja Luka), Borja and Manjača Mts., and the southern parts of the Krivaja Konjuh massif (▲6) (Pamić, 1976.) **b) Corundum** occurs at the village Vijaka (Vareš) (▲7) as a major mineral in esmerald green pargasite schists which form zones 300–600 m long and 10–20 m wide; the lilic corundum grains are up to 2–3 cm in size (Pamić, 1976).

4) Marine primary volcanogenic-sedimentary manganese-oxide deposits in the Uzlomac-Rudo (Banja Luka) area (▲8) (Mijatović, 1979).

B) Secondary ophiolite related deposits:

a) Nickel-chromium-iron deposits Vardište (Višegrad) (▲9), found at the base of Albian-Cenomanian overstep sequences underlain by serpentinites, represent redeposited lateritization products. They are composed of clastic sediments with oolithic ore zones with 15–30 wt.% Fe enriched in Cr (0.6–1.8 wt.%) and Ni (0.6–1.0 wt.%) (Đurić, 1979.)

b) Chrysotile asbestos deposits occur in fault zones of serpentinized peridotites in form of simple or complex vein systems, networks and veinlets, unevenly distributed, commonly with contents of asbestos from 0.5–10%. Their origin is related to hydrothermal solutions derived from M-type granitoids (Vakanjac, 1980). The biggest is the Bosansko Petrovo Selo deposit (▲10).

c) The Bosansko Petrovo Selo (▲11) **talc deposits** impured by breunnerite in form of 1–2 km long and a few hundred metres wide zones, are located along contact between serpentinized lherzolite and small M-type granite intrusions which gave hydrothermal solutions for the mineralization (Sunarić-Pamić et al., 1976).

d) Magnesite deposits occur as single veins and system of veins, lenses, networks, stockworks and irregular bodies located along fault zones, some of them a few kilometer long and a few hundred metres wide in stronlgy serpentinized lherzolites. Oxygen and carbon isotopic compositions indicate that the magnesite originated either by weathering or from metamorphogenic fluids (Ilić & Jelić, 1976; Sunarić-Pamić & Pamić, 1988). The highest quality deposits are in the areas of Banja Luka and Kladanj (▲12), Bosnia.

3. Upper Cretaceous-Paleogene subduction related basalt-rhyolite formation

Geology. In the Prosara–Motajica–Cer–Bukulja zone of the northernmost Dinarides, remnants of Alpine magmatic arc are preserved. They are represented by fossiliferous Upper Cretaceous-Paleogene flysch formation (with blueschist olistolits) in lower parts of which are interlayered basalt and rhyolite intruded by small granite bodies which might have been generated in adjacent for-arc and trench. The axial parts of the flysch formation probably represent surfacial markers of an ancient subduction zone along which the Mesozoic oceanic crust of the Dinaridic Tethys was consumed. The initiation of the subduction is marked by the first Late Jurassic-Early Cretaceous emplacement of ophiolites which unconformably underlie the Upper Cretaceous-Paleogene flysch formation (Pamić, 1993).

Sr-isochron obtained on rhyolites and cogenetic granites gave an age of 71.5 Ma. K-Ar crystallization ages of 75 to 62 Ma on fresh basalts and 66–54 Ma on diabases were obtained.

Petrology-geochemistry. The bimodal volcanic association is represented by amygdaloidal ophitic basalts, mostly albitized and zeolitized, alkali-feldspar rhyolites with subordinate quartz trachytes and tufs, volcanic breccias and agglomerates. The associated intrusive rocks are A-type alkali-feldspar granites (alaskite) with rare alkali-feldspar syenite, and diabase (Pamić et al., 1990).

Basic rocks are tholeiitic high-Ti primitive basalts commonly enriched in MgO with comparatively high K_2O content and thus correlative with magmatic arc basalts. Increased concentrations of compatible trace elements and low $^{87}Sr/^{86}Sr$ ratio (0.70397–0.70441) indicate their upper mantle origin. Geochemical discrimination diagrams point to ophiolitic island arc tholeiites and back-arc basalts (Pamić et al., in press).

Acidic volcanics are low- to high-silica rhyolites characterized with major and trace element homogeneity. They are enriched in lanthanum, cerium, neodymium, ytterbium and particularly in zirconium averaging 463 ppm. High $^{87}Sr/^{86}Sr$ ratio (0.70800–0.71768) indicates their continental crust origin. Sr and O isotopic compositions and REE patterns of associated A-type granites indicate that they are cogenetic with alkali-feldspar rhyolites.

Consequently, the basalts and rhyolites with A-type granites are not cogenetic and they come from two fundamentally different sources.

Mineral deposits. No mineral deposits to date have been identified in association with the basalt-rhyolite formation. Preliminary geochemical data indicate that **alkali-feldspar rhyolites contain** increased quantities of **gold and silver** (Pamić et al., 1990).

4. Paleogene collisional granite formation

Geology. Deep seated subducted lithospheric blocks being no longer in dynamic equilibrium with subduction, gave rise to its termination. This was followed by collision manifested in the Eocene main deformation and uplift of the Dinarides which, in turn, gave rise to the beginning of destruction of magmatic arc. These geodynamic changes might have caused the heating and generation of energetic flux for the synkinematic metamorphism. In the areas with increased geothermal gradients rocks of the Upper Cretaceous-Paleogene formation were metamorphosed under very low-, low- and medium- grade conditions accompanied by local migmatization and synkinematic granite plutonism which produced small plutons (50–60 km^2) found both at the surface and in the subsurface of the Prosara–Motajica–Cer–Bukulja zone (Pamić, 1993).

In slates and phyllites of the metamorphic sequence Late Cretaceous-Paleogene microflora was determined (Pantić & Jovanović, 1970). K-Ar ages obtained on medium-grade rocks range between 48 and 38 Ma. Two Sr-isochron ages obtained on granitoids gave 55 and 49 Ma (Pamić & Lanphere, 1991).

Petrology-geochemistry. The progression from unmetamorphosed Upper Cretaceous-Paleogene sedimentary rocks to very low- and low-grade schists is evidenced by textural arguments, mineral zonation, vitrinite data, changes in the oxygen isotopic composition and geobarometric data from white mica b_0 (Pamić et al., 1993).

Predominant S-type granitoids are represented mostly by granodiorite and monzogranite, however, in the eastern prolongation of the zone quartz monzonite, quartz diorite and tonalite are also common, and some of them belong to the I-type family as do »tonalites« from the easternmost Periadriatic Zone.

S-type granitoids are of crustal origin ($^{87}Sr/^{86}Sr$ = 0.70645–0.72024) but some of granitoids from the eastern prolongation of the zone originated from mixed upper mantle and crustal melts (Karamata et al., 1990). »Tonalites« from Mt. Pohorje originated by a fractional crystallization from primary upper mantle basalt.

Mineral deposits, genetically related to granites, can be divided in two groups:

1) Primary ore occurrences originated in (a) pegmatite-aplitic phase which gave veins and irregular bodies of **pegmatite** and **aplite**; some of them containt beryl (O1); (b) pneumatolytic phase which gave **greisen zones** with accessory sheelite, molybdenite, orthite, cassiterite, tourmaline, beryl, and locally chalcopyrite and pyrite (O2) (Jelić, 1976), both types are located in Mt. Motajica.

2) Secondary ore occurrences are represented by **kaolinite** mineral deposits (O3) of Mt. Motajica which originated by a combined ascending and descending kaolinization process (Ramović, 1976).

5. Oligocene-Neogene postsubduction andesite formations

Geology. Uplift of the Dinarides gave rise to the separation of the Tethys into the Mediterranean and Paratethys. The Paratethyan evolution started by Oligocene transpression (35–20 Ma) characterized by normal faulting, particularly along the Periadriatic-Vardar fault system and andesite volcanism (Laubscher, 1983). In epidermal parts several generations of transcurrent faults gave rise to extension and subsidence and the sedimentary pile 3000–6000 m thick was accumulated in back–arc environments (Stegena et al., 1975).

Afterwards started evolution of the Pannonian Basin brought about by the upper mantle rise and crustal attenuation (Royden et al., 1983; and others). The sedimentation was accompanied by three phases of volcanic activity which took place at 17–16, 15–12 and 11.5–9.5 Ma. The volcanism took place under subaqueous conditions as shown by interlayering of volcanic flows, pyroclastic rocks and fossiliferous marine sediments. Thickness of the volcanic flows varies but some of them are 1000 m thick (Pamić et al., 1995).

Petrology-geochemistry. Based on reliable geological and petrological data obtained in the area of the Sava–Drava interfluve and their correlation with available data from the southeastern Dinarides, four main Tertiary volcanic formations can be distinguished:

1) The Egerian-Eggenburgian andesite formation with subordinate dacite and rare rhyodacite; **2) The Karpathian trachyandesite (latite) formation; 3) The Badenian basalt-andesite formation** with subordinate dacite and rare rhyolite; **4) The post-Badenian alkalic basalt and basalt formation.**

The volcanic rocks of each age group include lava flows as well as pyroclastic rocks.

Although identical in petrography and similar in some geochemical aspects to subduction related andesite associations, the Tertiary volcanic suites are rather complex in genesis as indicated by stable isotope composition. Increased $^{87}Sr/^{86}Sr$ (0.70564–0.70743) ratios are indicative for collisional arcs with thick continental crust (>30 km) composed of the pre-Mesozoic rocks. The Tertiary volcanic associations display some geochemical variations (Pamić et al., 1995). which indicate different geneses:

1) Major- and trace-element variations of Egerian-Eggenburgian andesites and dacites show positive correlation with the coeval Mt. Pohorje »tonalites« which originated by fractional crystallization of Mg-rich upper mantle tholeiitic basalt.

2) The Karpathian trachyandesites (latites) are correlative in trace element contents to intraplate alkalic rocks. High Mg-values and concentrations of nickel and chromium indicate that the trachyandesites are of the upper mantle origin and that they have undergone little or no fractional crystallization. This also probably holds for the post-Badenian alkalic basalts and basalts.

3) The Badenian volcanics represent the most differentiated Tertiary association which probably originated by partial melting of different crustal rocks as indicated by trace element data and common occurrences of xenoliths of crustal rocks. Badenian volcanics are frequently affected by hydrothermal metamorphism as shown in spilitization of basalts and propylitization of andesites.

Mineral deposits can be divided in several genetical groups and subgroups:

1) **Primary ore deposits:**

(**a**) The Mala Kropa (Δ1) **magnetite skarn deposit** in Slovenia is located along contact between Oligocene dacites and Upper Cretaceous limestones (Drovenik et al., 1980); (**b**) The Srebrenica (Δ2) **hydrothermal lead-zinc vein deposits** are located in Karpathian trachyandesites and in adjacent Upper Palaeozoic metasediments. The veins are up to 2 km long and a few centimetre to a few metre wide, frequently characterized by branching. Average metal contents: Pb=4.5%, Zn=6.5%, Ag=50–800 g/t, Cd=100–150 g/t. Central parts of same vein systems are enriched in copper, tin, molybdenum and tungsten minerals and strongly tourmalinized and silicified (Ramović, 1963); **c**) **Tuff deposits** (Δ3) are interlayered in Oligocene and Lower Miocene sediments of the south Pannonian Basin (Slovenia, Hrvatsko Zagorje, Slavonija) and intramontane fresh-water basins in Dalmatia and Bosnia: Ploče–Livno, and Piplići (Prnjavor) deposits.

2) **Secondary deposits:**

a) Bentonite deposits (Δ4), also interlayered with Oligocene and Lower Miocene sedimentary and pyroclastic rocks of the Pannonian Basin and intramontane freshwater basins, originated by subaqeous alteration of tuffs and volcanic glass. The most perspective are: Bednja and Poljanska Luka (Hrvatsko Zagorje); Gornja Jelenska (Moslavina), and Maovice (Dalmatia) in Republic Croatia (Braun, 1991); Lješljani (Bosanski Novi) and Grabež (Jajce) in Bosnia (Miladinović, 1976); **b) Kaolinite deposits** Bratunac–Srebrenica (Δ5) (Dangić, 1971) are formed by postmagmatic hydrothermal processes in quartz latite veins located in Palaeozoic metasediments; **c) Oxydization-cementation zones** originated by late Tertiary weathering of Palaeozoic primary iron deposits, Ljubija (Δ6) (Jurković, 1961) or Triassic manganese deposits Čevljanovići (Vujanović, 1968); **d)** the Remšnik (Δ7) lead-zinc-copper-silver deposit in Northern Slovenia, originated by **remobilization from primary Early Palaeozoic deposits,** now located into crushed and fractured parts of metamorphic rocks as supported by D, C, O, Pb, S isotopic compositions (Dolenec et al., 1989, 1993b); **e) Alpine veins** originated by metamorphogenic fluids: quartz-hyalophane veins at Busovača (Δ8) (Bermanec, 1992; Jurković & Slovenec, in press) in Bosnia, and the veins in Mt. Pohorje (Δ9) (Niedermayr et al., 1992).

Discussion

The Alpine MMFs of the northern and central Dinarides originated in different geotectonic settings during long-lasting evolution of the Dinaridic part of the Tethys. The Permo-Triassic MMFs originated by rifting magmatic processes which took place onto the Variscan basement and these processes preceeded the restoration of the carbonate platform. Geological relations and large geochemical differentiation trends both of the magmatic associations and mineral deposits, and their basic geochemical characteristics indicate that the Triassic magmatic and mineralization processes were predisposed by partial melting of the lower crust.

Opening of the Dinaridic Tethys and the generation of the oceanic crust started by the end of the Late Triassic/Early Lias and lasted until the Late Jurassic Early Cretaceous when the processes of subduction started. In the generated Mesozoic oceanic crust all ophiolitic MMFs, which are of the upper mantle origin, are included.

The origin of the Late Cretaceous-Paleogene MMF was related to a presumed magmatic arc and to final stages of subduction, i.e. the termination of the Tethyan evolution. The magmatism was both of the upper mantle (basalts) and lower crustal (A-type melts) origin. The termination of subduction processes was followed by collision and the Paleogene MMF was related to the main Alpine deformation (the Pyrenean phase) which caused uplift of the Dinarides. The synkinematic granite melts and derivative ore fluids are both of the upper mantle (I-type) and crustal (S-type) origin.

The uplift of the Dinarides gave rise to the separation of the Tethys into the Mediterranean and Paratethys in which continued in the Late Oligocene (transpression phase) the dacite-andesite volcanism of the upper mantle origin. It probably represented a prolongation of the collisional magmatic activity under the new geotectonic regime. Afterwards in the southwestern parts of the Paratethys started extensional evolution of the Pannonian Basin brought about by the crustal attenuation and the rise of the upper mantle. Initial Early Miocene stages of the evolution were characterized by synsedimentary volcanism which is both of the upper mantle (the Karpathian trachyandesites and the post-Badenian alkalic basalts) and crustal (the Badenian basalt-andesite-dacite-rhyolite formation) origin.

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