Geological Quarterly, Vol. 38, No. 4, 1994, p. 609–616

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Metallogenic evolution of organogenic metamorphics in NW Bulgaria: genetic types of gold and gold-polymetallic mineralizations*

The metallogenic evolution of the organogenic Lower Palaeozoic rocks in the West Balkanides is divided into six stages, each generating different types of gold deposits: (1) volcanogenic-sedimentary gold-copper pyrite deposits; (2) sedimentary-diagenetic gold-pyrite deposits in carbon-rich sediments; (3) postmetamorphic-hydrothermal quartz-gold-silver deposits; (4) skarn gold deposits; (5) postmagmatic-hydrothermal gold-polymetallic deposits; (6) gold placers. In some areas the superposition of different mobilization, generation and re-generation processes in time and space lead to the formation of more complex polygenic and polychronous gold-bearing deposits. The proposed evolutionary model may be used to prognosticate gold deposits of the above six genetic types.

INTRODUCTION

The present study is an attempt to analyze some aspects of the metallogenic evolution of the Lower Palaeozoic organogenic metamorphic rocks in the West Balkan structural-metallogenic zone. The aim is to derive a complex (polygenic-polychronous) geologic-genetic model for gold mineralization which combines diverse sedimentary, metamorphic, metallogenic, geotectonic and other factors favouring the origin of several basic industrial types of gold deposits.

Some regional aspects of these problems are treated in the works of Bulgarian geologists (N. Obretenov, I. Peev, 1969; V. Velchev, 1983; N. Obretenov *et al.*, 1985; S. Stoyanov, I. Stoyanov, 1989; T. Todorov, R. Yaneva, 1989). Analogous problems are discussed by B.

*Articles marked by an asterisk were presented at "Mineralization in Black Shales" Conference.

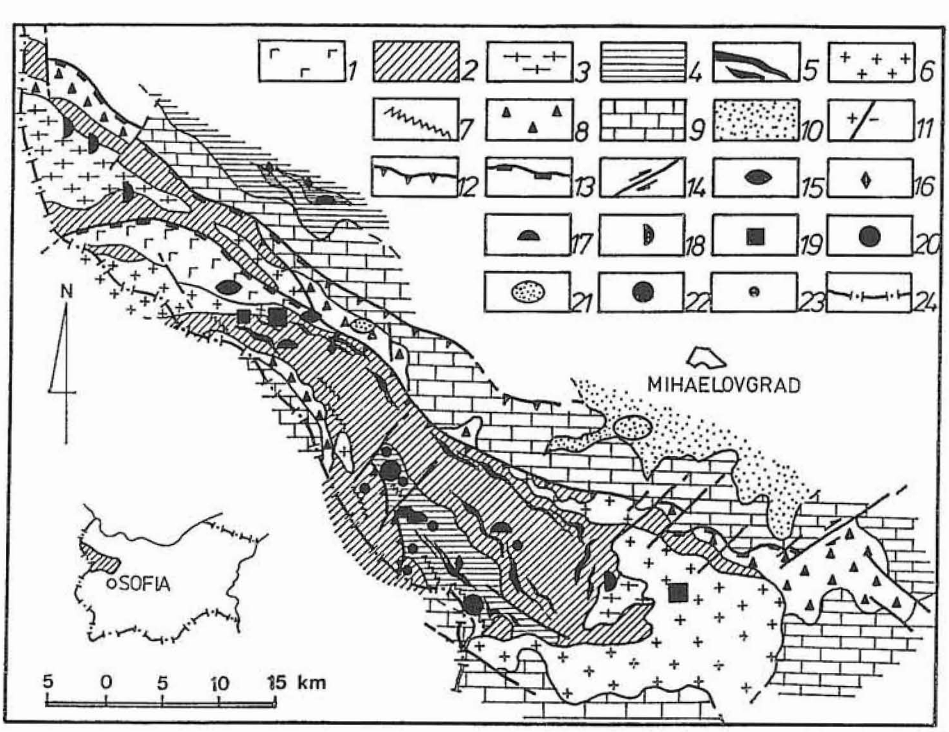

Fig. 1. Scheme showing distribution of the polygenic and polychronous gold mineralizations in the West Balkan metallogenic zone

Structural complexes and geological formations: Caledonian complex: 1 — Chernivrah unit; 2–3 — Berkovitsa unit: 2 — spilite-keratophyre, marble-tuff schist, graphite schist and gabbro-diorite-plagiogranite formations, 3 — gneiss-granite formation; 4 — Dalgidyal unit (conglomerate-sandstone-shale formation); 5 — outcrops of carbon-rich lithostratigraphic horizons; Hercynian complex: 6 — granodiorite-granite formation, 7 — bodies and dykes of the basalt-andesite-dacite formation, 8 — sandstone-breccia-conglomerate formation; 9 — Mesozoic complex (dolomite-limestone, sandstone and other geological formations); 10 — Cenozoic complex; 11 — normal fault; 12 — thrust; 13 — nappe; 14 — strike-slip fault; geologic-genetic types of gold deposits and mineralizations: 15 — volcanogenic-sedimentary gold-copper-pyrite, 16 — sedimentary-diagenetic and fine dispersed gold-pyrite deposits in "black slate" lithostratigraphic horizons, 17 — postmetamorphic-hydrothermal gold-polymetallic (greenschist facies), 18 — postmetamorphic-hydrothermal quartz-gold-silver (amphibolite facies), 19 — gold-skarn, 20 — postmagmatic-hydrothermal gold-polymetallic, 21 — placer; size of ore deposits: 22 — deposit, 23 — ore mineralization; 24 — state frontier

Schemat rozmieszczenia poligenicznej i polichronicznej mineralizacji złotonośnej w zachodniobałkańskiej strefie metalogenicznej

Kompleksy strukturalne i formacje geologiczne: kompleks kaledoński: 1 — jednostka Chernivrah; 2–3 — jednostka Berkovitsa: 2 — spilito-keratofiry, łupki marmurowo-tufitowe, łupki grafitowe i formacje gabrowo-diorytowo-plagiogranitowe, 3 — formacja gnejsowo-granitowa; 4 — jednostka Dalgidyal (formacja zlepieńcowo-piaskowcowo-łupkowa); 5 — odsłonięcia poziomów litostratygraficznych wzbogaconych w węgiel; kompleks hercyński: 6 — formacja granodiorytowo-granitowa, 7 — formacja bazaltowo-andezytowo-dacytowych ciał i dajek, 8 — formacja piaskowcowo-brekcjowo-zlepieńcowa; 9 — kompleks mezozoiczny (dolomity-wapienie, piaskowce i inne formacje geologiczne); 10 — kompleks kenozoiczny; 11 — uskok normalny; 12 — nasunięcie; 13 — plaszczowina; 14 — uskok przesuwczy; geologiczno-genetyczne rodzaje złóż złota i mineralizacji rudnych: 15 — wulkanogeniczno-sedymentacyjny typu złoto-miedź-piryt, 16 — sedymentacyjno-diagenetyczny

Buryak (1986), N. Ermolaev, N. Sozinov (1986), G. Phillips *et al.* (1986); R. Hutchinson (1987), B. Blyuman (1988), L. Alavin (1988) and other authors.

EVOLUTION OF THE GEOLOGICAL SETTING

Three regional structural rock complexes (N. Obretenov *et al.*, 1985) are exposed in the West Balkanides.

The oldest, Caledonian complex comprises three contrasting units which at present crop out in the cores of two highly uplifted and eroded anticlinorium structures (I. Haidutov *et al.*, 1985). The rocks were repeatedly affected by regional metamorphism to greenschist and amphibolite facies, accompanied by local migmatization and anatexis.

The lower, Chernivrah unit comprises basic and ultrabasic rocks-elements of obducted oceanic crust (I. Haidutov *et al.*, 1985). The middle, Berkovitsa unit is made up of a volcanogenic-intrusive association related to island-arc type development (marble-tuff-schist, graphite schist and spilite-keratophyre formation). The rocks are intruded by gabbro, gabbro-diorite and other magmatic bodies referred to the gabbro-diorite-plagiogranite formation. The upper, Dalgidyal unit is composed of greenschist terrigenous rocks (conglomerate-sandstone-shale formation) with several carbon-rich horizons (Fig. 1).

The second, Hercynian complex is represented by granodiorite-granite plutons of probable Upper Devonian-Lower Carboniferous age and several unmetamorphosed, dominantly terrigenous geological formations. This complex also includes products of Stephanian-Permian volcanoes of central type, accompanied by numerous dykes and subvolcanic extrusions (basalt-andesite-dacite formation).

The third, Mesozoic complex is composed of Triassic, Jurassic and Lower Cretaceous sediments exposed in the limbs of the anticlinoria. The sedimentary rocks belong to sandstone, dolomite-limestone, breccia-conglomerate and other geological formations.

The main carbon-rich lithological varieties (quartz-graphite formation) in this part of the West Balkanides are concentrated in several horizons related to the Berkovitsa and Dalgidyal units.

GEOLOGIC-GENETIC TYPES OF GOLD MINERALIZATIONS

The evolution of gold mineralizations in the West Balkanides may be related to six metallogenic stages on the basis of specific features in the geodynamic setting as well as spatial, temporal and genetic relationships of hither to established gold mineralizations (geochemical, hydrochemical and concentration anomalies; ore occurrences, deposits and

oraz złoża rozproszonego pirytu złotonośnego w litostratygraficznych poziomach czarnych łupków, 17 — postmetamorficzno-hydrotermalny (w facji zieleńcowej), polimetaliczne złoża złota, 18 — postmetamorficzno-hydrotermalny (w facji amfibolitowej), złoża złoto- i srebronośnego kwarcu, 19 — skarny złotonośne, 20 — pomagmowo-hydrotermalne polimetaliczne złoża złota, 21 — okruchowe złoża złota; w i e l k o ś ć z ł ó ż r u d : 22 — złoże, 23 — mineralizacja rudna; 24 — granica państwa

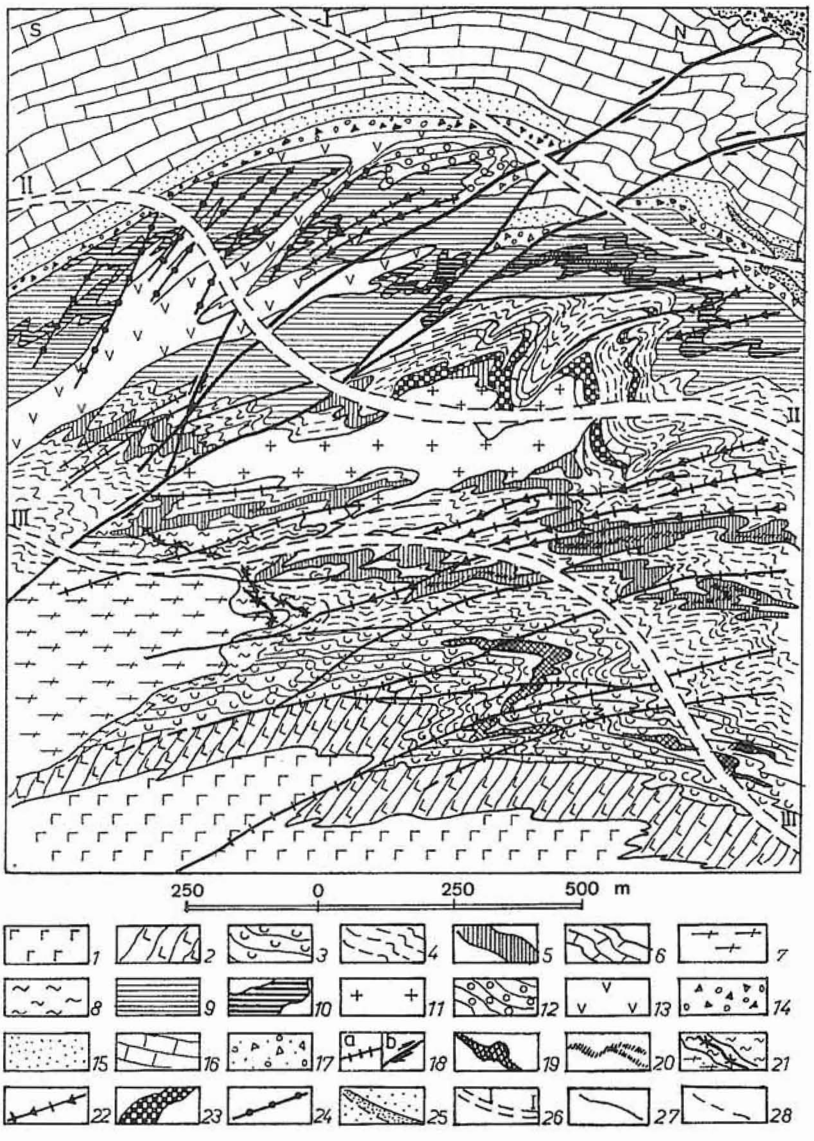

Fig. 2. Evolutionary geologic-genetic model for gold ore mineralization in the West Balkanides
Structural rock units and geological formations: Caledonian complex: 1–3 — Chernivrah unit: 1 — unit of banded cumulates, 2 — unit of sheeted dykes, 3 — pillow-lava unit; 4–8 — Berkovitsa unit: 4 — spilite-keratophyre formation, 5 — graphite-bearing lithostratigraphic horizons (graphite schist formation), 6 — marble-tuff schist formation, 7 — gneiss-granite formation, 8 — gneiss-amphibolite formation; 9–10 — Dalgidyal unit: 9 — conglomerate-sandstone-shale formation, 10 — carbon-rich lithostratigraphic horizons (graphite schist formation); Hercynian complex: 11 — granodiorite-graphite formation, 12 — conglomerate-shale-sandstone formation, 13 — basalt-andesite-dacite formation, 14 — sandstone-conglomerate formation; Mesozoic complex: 15 — sandstone formation, 16 — dolomite-limestone formation; 17 — Cenozoic

fields). Each of the six stages includes generation, concentration or re-distribution of gold from a free into a combined state or vice versa. This controlled the formation of several geologic-genetic types of gold deposits, characterized by particular prognostication criteria. In many cases the superposition of geological processes in time and space favoured the origin of complex polygenic-polychronous gold deposits which requires a more flexible approach to their prognostication and prospecting.

First (volcanogenic-sedimentary) stage. This stage is related to processes of formation of oceanic crust (Chernivrah unit), respectively to its topmost, pillow-lava subunit. The geodynamics setting favoured the origin of stratified gold-copper-pyrite deposits. Typical examples are those at Gorni Lom and the newly discovered mineralization at Yavorova glava. As a rule, the ore mineralizatons (pyrite, chalcopyrite, pyrrhotite, sphalerite, galena) occur in the form of stratified load-disseminated and banded massive ore bodies. Gold occurs in a fine dispersed state (emulsion inclusions) in pyrite and chalcopyrite.

Second (sedimentary-diagenetic) stage. This stage is related to sedimentary diagenetic processes in areas of palaeocontinental margins of island-arc basins where most of the organic substance was concentrated. In this environment several carbon-rich horizons in the Berkovitsa and Dalgidyal units formed. The most typical deposits of this type are located in the area of the Prodancha and Stara Rivers and at Naidenitsa, Chereshovitsa, Rupski dol, Sredogriv, Srebarna, Momina mogila (Fig. 1). During the formation of the three carbon-rich horizons, the conditions were extremely favourable for deposition of pyrite, arsenopyrite and other mineral aggregates which

complex (pebble-sandstone formation); 18: a — clastic metamorphosed zones within dominantly blastic rocks, b — mylonite thrust and nappe zones; geologic-genetic types of gold mineralizations: 19 — volcanogenic-sedimentary gold-copper-pyrite type, 20 — sedimentary-diagenetic gold-pyrite type in black slates, 21 — postmetamorphic-hydrothermal (amphibolite facies) quartz-gold-silver type, 22 — postmetamorphic-hydrothermal (greenschist facies) gold-polymetallic type, 23 — gold-skarn type, 24 — postmagmatic-hydrothermal gold-polymetallic type, 25 — gold placers; 26 — possible erosion levels: I–I — weak, II–II — middle, III–III — deep; 27 — definite geological boundary; 28 — uncertain geological boundary

Ewolucyjny geologiczno-genetyczny model mineralizacji złotonośnej zachodnich Bałkanidów

Jednostki strukturalne i formacje geologiczne: kompleks kaledoński: 1–3 — jednostka Chernivrah: 1 — jednostka kumulatów wstęgowych, 2 — jednostka dajek pokładowych, 3 — jednostka law poduszkowych; 4–8 — jednostka Berkovitsa: 4 — formacja spilitowo-keratofirowa, 5 — poziomy litostratygraficzne grafitonośne (formacja łupków grafitowych), 6 — formacja łupków marmurowo-tufitowych, 7 — formacja gnejsowo-granitowa, 8 — formacja gnejsowo-amfibolitowa; 9–10 — jednostka Dalgidyal: 9 — formacja zlepieńcowo-piaskowcowo-łupkowa, 10 — poziomy litostratygraficzne wzbogacene w węgiel (formacja łupków grafitowych); kompleks hercyński: 11 — formacja granodiorytowo-granitowa, 12 — formacja zlepieńcowo-łupkowo-piaskowcowa, 13 — formacja bazaltowo-andezytowo-dacytowa, 14 — formacja piaskowcowo-zlepieńcowa; kompleks mezozoiczny: 15 — formacja piaskowcowa, 16 — formacja dolomitowo-wapienna; 17 — kompleks kenozoiczny (formacja żwirowo-piaskowcowa); 18: a — zmetamorfizowane strefy klastyczne wśród dominujących skał klastycznych, b — zmylonityzowane strefy nasunięć i płaszczowin; typy geologiczno-genetyczne mineralizacji złotem: 19 — wulkaniczno-sedymentacyjny typu złoto-miedź-piryt, 20 — sedymantacyjno-diagenetyczny typu złoto-piryt w czarnych łupkach, 21 — postmetamorficzno-hydrotermalny (w facji amfibolitowej) typu złoto-srebro, 22 — postmetamorficzno-hydrotermalny (w facji zieleńcowej) typu złoto-polimetale, 23 — skarny złotonośne, 24 — pomagmowo-hydrotermalny typu złoto-polimetale, 25 — złoto okruchowe; 26 — prawdopodobne zasięgi erozji: I–I — słaby, II–II — umiarkowany, III–III — głęboki; 27 — określone granice geologiczne; 28 — niepewne granice geologiczne absorbed gold from sea water. This is indicated by the high clarke content of gold in the carbon-rich horizons also contain sedimentary-diagenetic sulphides.

The direct chemical links between organic matter and gold, as shown by N. Ermolaev, N. Sozinov (1986), are of minor importance for the increase of background gold content in the organic deposits and are expressed in the deposition of gold-containing metallo-organic complexes.

Third (metamorphic-hydrotermal) stage. This stage is related to the specific and local metamorphic processes under conditions of greenschist and amphibolite facies.

The results of B. Buryak (1986), B. Blyuman (1988) and other investigators have shown that the amount of uncombined (migrating) gold increases in greenschist facies metamorphism. In particular, during the process of graphitization, considerable amounts of gold and other elements are released due to desorption of gold-containing bitumen from the dispersed organic matter and to recrystallization of sedimentary-diagenetic sulphides. The higher migration ability of gold in these sulphides creates favourable conditions for active involvement of this element in migrating postmetamorphic solutions, i.e., deposition of industrial gold-bearing ore concentrations may occur.

The irregular metamorphism, i.e., the alternation of blastic and cataclastic layers, is an important condition for concentration of post-metamorphic mineralization in the West Balkanides. From lower to higher hypsometric levels of the Lower Palaeozoic sections there is a gradual transition (in regional plan) from blastic to cataclastic phenomena. The most important cataclastic zones, accompanied by macroflaser textures, occur at the boundaries of lithostratigraphic horizons of contrasting physico-mechanical behaviour. Such zones, characterized by considerably higher permeability, host several postmetamorphic banded-veinlet-disseminated gold-polymetallic mineralizations (Fig. 2).

The amphibolite facies metamorphic processes at the periphery of the granodiorite bodies themselves create conditions for transition of gold in the substratum from a free to a combined state as observed in many other regions (B. Blyuman, 1988). Gold in such cases occurs mainly in the form of admixtures in sulphides and different iron oxides. Typical examples are the numerous load-disseminated gold-silver ore mineralizations associated with the Stakevtsi granite.

Fourth (skarn) stage. This stage is related in space and time to the Hercynian granitoids of Sveti Nikola and Klisura type and to the supposedly comagmatic granite porphyry and diorite porphyrite dykes. The ore bodies are localized in the apical parts of the plutons and may be referred to the gold-skarn type of deposits. The skarn bodies are predominantly lenses (diffusion skarns) and veins (infiltration skarns). Recrystallized skarns with superimposed quartz-gold-sulphide mineralization are of industrial interest. The content of gold in the skarn ore bodies is higher in proximity to carbon-rich lithostratigraphic units which demonstrates their genetic links.

Fifth (postmagmatic-hydrothermal) stage. This stage in the evolution of gold mineralizations is related spatially and paragenetically to the Permian magmotectonic activity of the region. The numerous quartz-gold-sulphide veins are controlled by oriferous NE, NW and WNW trending faults (P. Vassilev, 1965; N. Obretenov, I. Peev, 1969). The thickness of the ore bodies varies from several centimetres to 2.5 m and their length from 50–60 to 350–500 m. Main ore minerals are galena, sphalerite, pyrite, arsenopyrite, chalcopyrite, sheelite, native gold, electrum, and native silver. Some of the richest ore columns are localized in cataclastic fault zones along the contacts of Permian dacite-andesite dykes. Typical examples of these mineralizations are most of the ore veins in the Govezda deposit, the best surveyed gold deposit in the West Balkan metallogenic zone.

Six (exogenic) stage. This stage includes the formation of lateral and alluvial gold placers of different size. Favourable conditions for the origin of lateral gold-bearing placers existed during the Carboniferous (gold-bearing conglomerates), the Permian and the Triassic (gold-bearing breccia-conglomerates). There are also Quaternary alluvial deposits. Some of them, known since ancient times, are located along Ogosta river.

CONCLUSIONS

The proposed evolutionary (polygenous-polychronous) geologic-genetic model for gold mineralizations in the West Balkan zone predicts six types of gold deposits for prospecting works, each described by a specific complex of prognostication criteria.

The spatial superposition of mobilization, regeneration and generation processes which differ in age lead, in some regions, to formation of more complex gold-polymetallic deposits which show the features of several genetic types of ore mineralizations.

As a whole, the importance of the different industrial types of gold mineralizations depends mainly on the pre-metamorphic productivity of the host rocks, on the character and intensity of mobilization and regeneration processes and on the factors which control the concentration of ore mineralizations.

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Received: 1.09.1994

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EWOLUCJA METALOGENICZNA METAMORFIKU ORGANOGENICZNEGO W NW BUŁGARII — GEOLOGICZNO-GENETYCZNE TYPY MINERALIZACJI ZŁOTA I ZŁOTA Z POLIMETALAMI

Streszczenie

W rozwoju metalogenicznym dolnopaleozoicznych, organogenicznych skał północnego obszaru Bałkanidów wyróżniono 6 stadiów generujących różne typy złóż rud złota: 1 — złoża złoto-miedziowo-pirytowe pochodzenia osadowo-wulkanicznego, 2 — złoża złoto-pirytowe występujące w utworach węglistych pochodzenia osadowo-diagenetycznego, 3 — postmetamorficzno-hydrotermalne złoża kwarcowo-złoto-srebrowe, 4 — skarnowe złoża złota, 5 — hydrotermalne złoża złota polimetalicznego, 6 — piaski złotonośne. Nakładanie się w niektórych obszarach procesów mobilizacji, generacji i regeneracji w czasie i przestrzeni prowadzi do tworzenia bardziej skomplikowanych genetycznie i czasowo złóż złota. Zaproponowany model rozwoju może być wykorzystany dla prognozowania sześciu wymienionych genetycznych typów złóż złota.