Structural pattern and neotectonic activity in the wider Majdanpek area (NE Serbia, Yugoslavia)

Miroslav Marković[1], Radmila Pavlović[1] Tomas Čupković[1], Periša Živković[2]

Abstract. The north-eastern Serbia is one of the most important ore bearing areas in Yugoslavia and Balkan. The Bor and Majdanpek are world-wide known copper ore deposits. Mineralization is connected with the Upper Cretaceous magmatism. The main ore controlling factor is fracture pattern.

The investigations of structural and morphological characteristics carried out in the wider Majdanpek area supplied new data on disjunctive structures and indicated an intensive neotectonic activity. A high degree of correspondence between the older fracture pattern and neotectonically active ruptures has been discovered. Tectonic activity that produced the Upper Cretaceous magmatism was prolonged through the Tertiary and Quaternary. The older ruptures were neotectonically reactivated, changing many times the sense and intensity of vertical movements.

The obtained results are a reliable base for selection of perspective ore bearing areas and rational planning of further detailed field structural and metallogenic investigations.

Key words: Yugoslavia, Majdanpek, copper ore, fracture pattern, circular structures, neotectonics

Introduction

The north-eastern Serbia is one of the most important ore bearing areas in Yugoslavia and Balkan. The Bor and Majdanpek copper ore deposits are world-wide known. Mineralization is connected with the Upper Cretaceous magmatism. The main ore controlling factor is fracture pattern. Tectonic activity that caused the Upper Cretaceous magmatism was prolonged through the Tertiary and Quaternary. During neotectonic period the older ruptures were reactivated, changing many times sense and intensity of the vertical movements.

A study of fracture pattern, circular structures as manifestation of magmatism, and neotectonic activity is essential for ore controlling structures determination and producing a reliable base for metallogenic characteristics definition. It enables selection of perspective ore bearing areas and a rational planning of further detailed structural and metallogenic field investigations.

In the wider Majdanpek area up to now necessary attention was not paid to the structural characteristics, magmatic activity and the youngest, i.e. neotectonic activity. Hence the investigations were focused on regional fracture pattern, identification of the circular structures and morphological characteristics of the area. The study comprehended analysis of available geological documentation and collecting of new data by remote sensing and quantitative geomorphological methods application.

Investigation were carried out in the area of 1.800 km^2, much broader than the one where known copper ore occurrences are registered. Widening of the area provides reliability of the satellite images and air photos examination, accuracy of mathematical and statistical procedures in quantitative geomorphological analysis and high credibility of obtained data interpretation. Position of the investigated area and its morphological features illustrates figure 1.

The investigation cornerstones

The geological environment of the wider Majdanpek area displays compiled general geological map (figure 2). Main lithological characteristic is the appearance of Upper Cretaceous magmatic complex. This is composed of volcanic-sedimentary rocks (tuff, tuffites, agglomerates and breccia), volcanic rocks

[1] University of Belgrade, Faculty of Minning and Geology, Djušina 7, 11000 Belgrade, Yugoslavia
[2] The Majdanpek Copper Mine, Svetog Save 2, 19250 Majdanpek, Yugoslavia
(Received 21.10.1996)

belonging to the three phases of extrusive activity, and, as the youngest ones, acid plutonic rocks of the Laramian age. The complex is generally oriented NNW-SSE. The same position have majority of the volcanic rocks extruded through tuff and tuffites, and acid plutonic rocks intruded in volcanic-sedimentary rocks. The well known Majdanpek copper ore deposit now in
exploitation by open pit mining, and very promising polymetallic deposit of Čoka Marin now in investigation, are connected with this magmatic complex.

The analysis of geologic composition indicates three essential characteristics of the magmatic complex, on which the principles of our investigations were based.

(1). The wide zone of magmatic rocks, generally oriented NNW-SSE narrows northward. Its width in the south is tens of kilometres. North from Majdanpek the zone is reduced into narrow linear structure a few hundreds meters wide. Thus the assumption that magmatic activity has followed a compound fault structure, fault zone or a system of faults, which narrowed and became deeper northward, is very logic one.

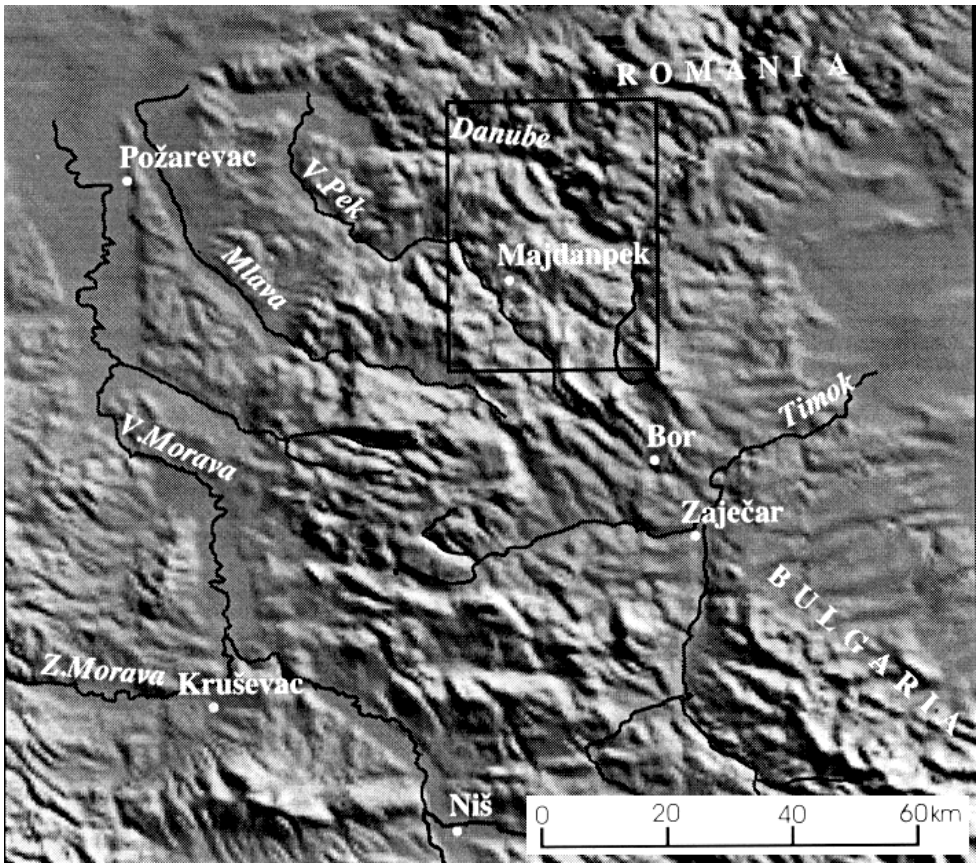


Fig. 1. The computer produced block-diagram based on topographic map, showing the position and morphology of the investigated area.

(2). Tectonic activity prolonged with shorter or longer breaks and intensity changes from Mesozoic to the Tertiary and Quaternary. The older ruptures were manifoldly reactivated. The youngest, neotectonic structures have important influence on the ore deposits displacement and may represent a significant criterion for investigation.

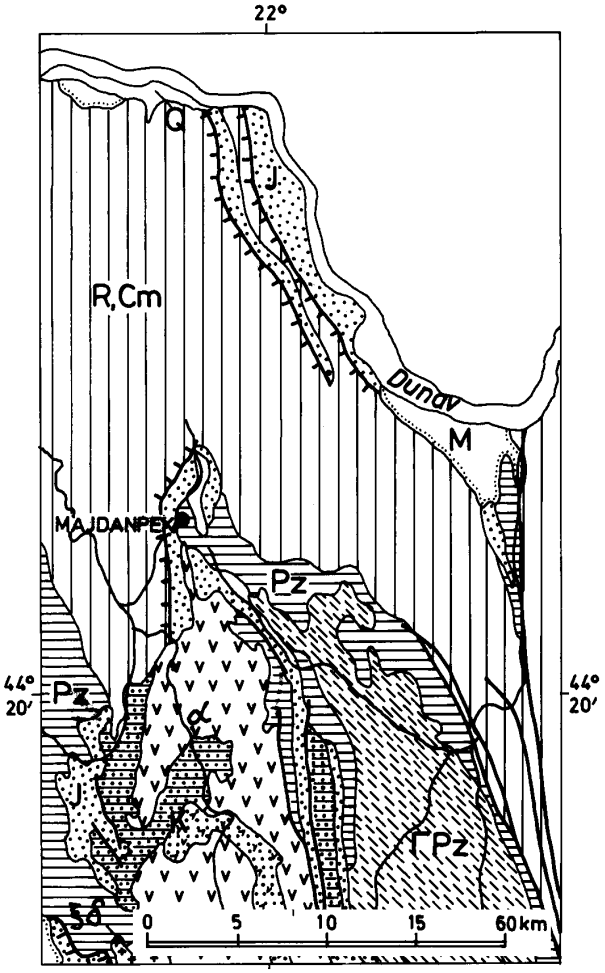
(3). The magmatic activity of the investigated area is of Upper Cretaceous, precisely of Senonian age. The youngest, acid plutonic rocks occurrences were caused by the Laramian tectonic movements, taking place at the end of Upper Cretaceous and the beginning of Palaeogene. The Senonian age of volcanic rocks offers no possibilities for preserving volcanic forms in the present topography. Strong Laramian folding, especially very intensive tectonic activity at the Palaeogene and Neogene boundary during the Savian and Styrian phases, have completely destroyed volcanic relief. Reliable reconstruction of volcanic centres is impossible. Only circular structures, as manifestation of magmatic activity, may indicate general locations of these centres.

Fracture pattern and circular structures

Fracture pattern represented by linear structures, and circular ones as expression of magmatic activity, was defined by comparative examination of satellite images and stereoscopic analysis of air photos. For analysis the images of Landsat-2 and 3 missions, green, red and infrared bands, scale 1:250.000, and black and white air photos, scale 1:32.000 were used. Obtained results displays map (figure 3). The traces of disjunctive structures are categorized as observed or inferred. Observation certainty of a fracture trace depends on its reflex in
topography. Clear rupture expression in relief reveals its very young, the Neogene and/or Quaternary activity. Thus
classification based on certainty criterion has also the chronological connotation.

The significance of a fracture was the other criterion applied for structural analysis. It is based on a fracture trace length. Regional directions, predestinated by disjunctive structures, are long tens of kilometres. They, as a rule, comprehend many compound structures as fault zones, systems of close mutually parallel faults, etc. Rarely big individual ruptures occur. These structures are prolonging one after another with the same strike. Shorter and longer interruptions between them are quite common. Their geometry and kinematics differ significantly from one part to another.

Fractures of the local importance can be followed by kilometres, rarely up to ten kilometres. They are not continuing one after another. The local fractures also can be compound structures as minor fault zones or systems of parallel faults, or they are individual ruptures varying in geometry and kinematics.



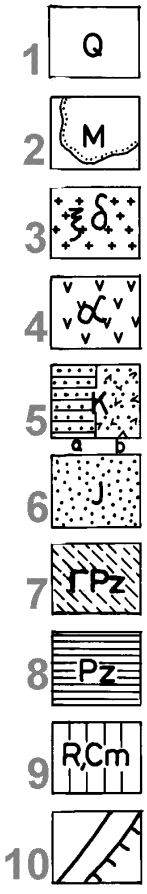


Fig. 2. General geological map of the investigated area based on the data of Antonijević et al. (1974), Bogdanović et al. (1978) and Institute for geological and geophysical investigations (1968).

Legend: 1. Quaternary deposits; 2. Transgressive undifferentiated Miocene sediments; 3. Cretaceous to Palaeogene monzonite; 4. Upper Cretaceous andesite; 5. Turonian-Senonian rocks: a. limestones, limestones with hornfels, marls, dolomites; b. pyroclastites with andesite effusions; 6. Jurassic sediments: limestones, dolomites, marls, clastites; 7. Palaeozoic granites 8. Palaeozoic gneiss and schists; 9. Rifeo-Cambrium: metamorphic rocks of the Vlasina complex. 10. Regional faults and overthrusts.

In the Majdanpek broader area two systems of big regional directions predestined by ruptures occur. The most prominent are structures oriented NW-SE. One of them controls the Danube river course in the

north and can be followed downstream from Dobra to the Donji Milanovac town. The other one is located along the Šaška river valley. It strikes across Majdanpek towards northwest. The third structure controls position of the V. Pek valley. It can be followed towards SE across localities Čoka Marin and Vlaole. The last one of this system is located in the extreme SW part of the investigated area.

The other system of big structures has NNE-SSW orientation. Two of them are notable. In the extreme eastern part located is well-known fault of the Porečka river, located also on the general geological map (figure 2). It passes in the north to Rumania, and in the south goes out of the investigated area. The other structure of same orientation strikes over Majdanpek and can be followed to the Danube river. The Majdanpek Mine is situated at the intersection of this structure with the rupture striking along the Šaška river valley.

In the southern end of the investigated area the big rupture of general west-east strike is delineated. The most of it is inferred. The structure is cut in many places by ruptures of NW-SE orientation.

Ruptures of local significance follow big, regional directions predestinated by disjunctive structures. Several systems of local structures can be defined. They strike in NW-SE, NNE-SSW, W-E, WNW-ESE and NE-SW directions. The last orientation was not registered among regional ruptures.

The two of regional disjunctive structures are of high importance for occurrence and position of magmatic complex. One in the west has NNE-SSW orientation. It strikes across Majdanpek and can be followed up to the Danube river. The Majdanpek ore body, now in exploitation, is connected with this structure. The eastern structure strikes NW-SE and passes along the V. Pek valley, across the Čoka Marin and Vlaole localities, than towards SE to the Krivelj and Bor mines, out of investigated area boundaries. The Čoka Marin ore bode follows it (figure 3). Between this two structures the Senonian volcanic and plutonic activities have taken place.

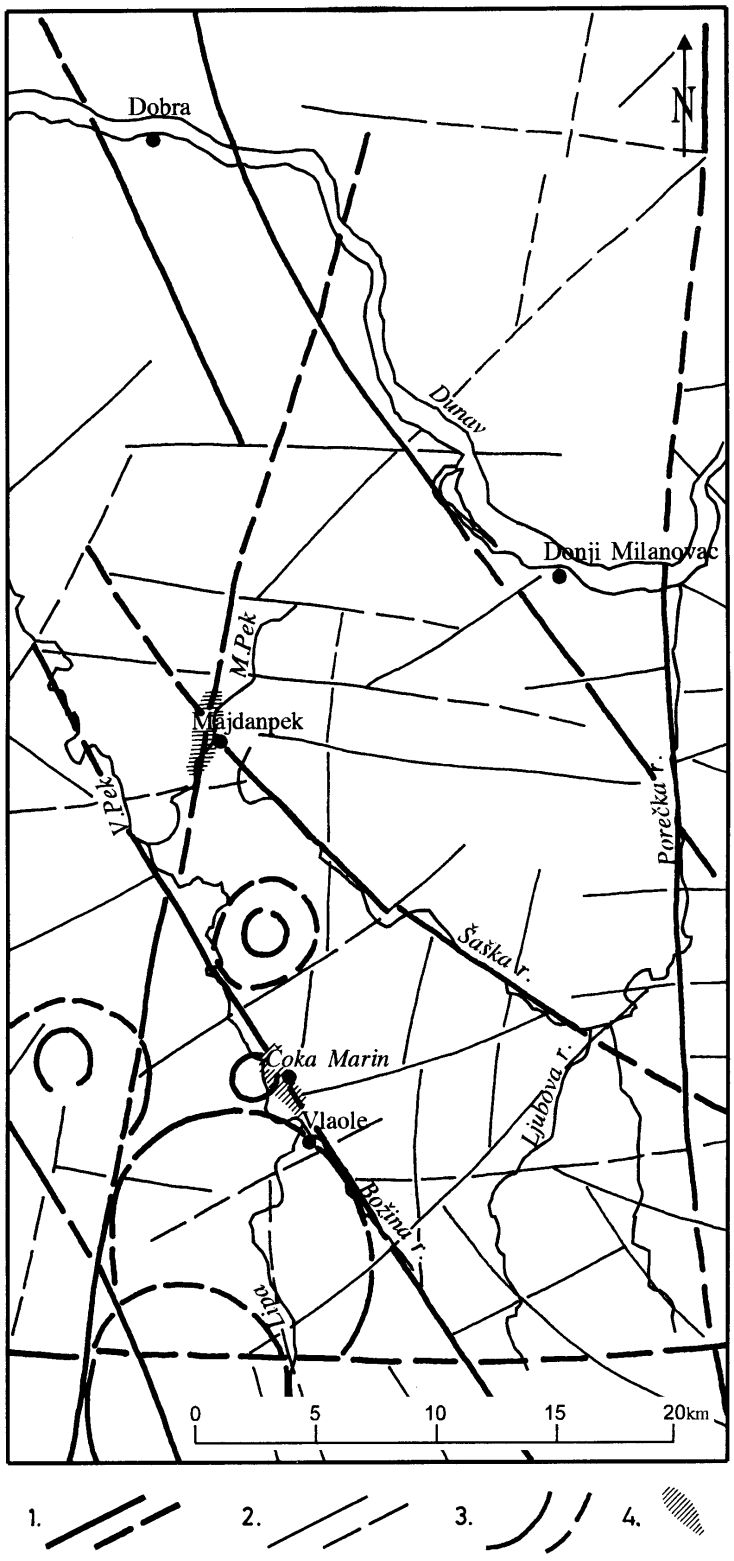


Fig. 3. Map of the fracture pattern and circular structures.

Legend: 1. Regional directions predestinated by ruptures: observed and inferred. 2. Local ruptures: observed and inferred. 3. Traces of circular structures: observed and inferred. 4. Ore body.

Analysis of satellite images and air photos was focused on circular structures. Due to the intensive post-magmatic tectonic activity the Senonian volcanic topography was completely destroyed. However the deeper magmatic activity is reflected on the surface by circular structures. Uplifting over shallow intrusions and centres of former volcanic activity could be predestination for the formation of circular structures. These are manifested by bow shaped ridges, radial and ring drainage network.

Several circular structures, kilometres in diameter, are discovered in the south of Majdanpek. The best

preserved is the one located between Majdanpek and Čoka Marin. It consists of two concentric drainage rings. Westward from the Čoka Marin locality identified is, also on the drainage basis, a part of circular structure with diameter of two kilometres. Its eastern part was cut off by regional rupture Vlaole - Čoka Marin - V. Pek. That fact indicates reactivation of the old ruptures, formed during Upper Cretaceous, or earlier. Movements along these ruptures occurred through the Tertiary, and possible were active also during Quaternary.

In the western part of map (figure 3), westward from the Čoka Marin circular structure, another structure with two concentric drainage rings is located. However, its northern part is hypothetic. The Vlaole locality lays at the NNE rim of the big structure, eleven kilometres in diameter. Its southern half can not be even supposed.

In the SW part of map a circular structure with eight and half kilometres diameter is delineated. It is also manifested by bow shaped, ring arranged ridges. The structure is disordered by faulting, well expressed especially at its western rim. In the structure centre the Laramian acid plutonic rocks are outcropping. It is obvious that the structure genesis was connected with the shallow Laramian intrusion.

The data on detailed field structural investigations in the areas showing the remnants of circular structures are still missing. However, some of elements of dip measurements (Antonijević et al., 1974.; Bogdanović et al., 1978 and Institute for geological and geophysical investigations, 1968) indicate existence of such forms.

Neotectonic activity

As neotectonics here are understood the tectonic movements during the Neogene and Quaternary. The Neogene beginning (Oligo-miocene) correspond to the appeasement of the Savian and Styrian phases of Alpine orogenesis. This is time when the main features of present relief were formed. The younger tectonic, or neotectonic movements directly reflex on relief characteristics. Hence, as the most appropriate investigation method, the procedures of quantitative geomorphological analysis are applied.

The investigation methodology

In the wider Majdanpek area two essentially different procedures are applied. The first one is the energy of relief analysis. The second procedure is analysis of differences between the present relief and theoretical model of its development. The application of two mutually independent procedures was aimed to check their accuracy and to increase the credibility of the obtained results.

Energy of relief represents the potential energy defined as result of multiplication of rock mass with its elevation and the gravity acceleration. An analysis of the energy of relief understands measurements by unit fields of equal areas. For such fields mass and gravity acceleration can be treated as constant values. Thus the energy of relief is expressed by differences between the highest and lowest points inside of every unit field.

The height differences in general are consequence of neotectonic activity which controls relief development. These are result of the vertical movements, the uplifting and subsiding of different blocks. However, the energy of relief is influenced by local conditions too. It varies with changes of lithological composition and structural pattern, initial topography, development of geomorphological, exogenic processes, etc. To emphasize regional control by neotectonic movements local influences have to be eliminated.

The systematical energy of relief measurement by a network of unit fields offers the base for construction of map with contour lines. Smoothing of this map by means of known moving averages method eliminates local anomalies of the relief energy. In such way the general trend of contour lines is pointed out, and delineated are big structures formed under control of neotectonic movements.

The interpretation of map with energy of relief contour lines is reasonably simple. The positive anomalies, i.e. fields with increased energy of relief values, indicate the uplifting blocks. The negative anomalies correspond to the blocks of subsiding. The contour lines orientation and gradient define neotectonical structures, predominantly ruptures, as the boundaries between blocks with different signs and intensities of vertical movements.

The other procedure understands the theoretical model of relief construction. It represents the features that present topography would gain if formed in total absence of any tectonic movement. Comparison of the theoretical model with the real relief discovers neotectonic movements that took place from the relief formation up to the present days. Procedure was introduced by Marković (1983). Its reliability was many times checked and confirmed.

The theoretical model making requests reconstruction of topography from the earliest phase of its evolution. The reconstruction is performed by topographic extermination of the effects of younger geomorphological processes. This is done by formal generalization of contour lines. Obtained map of reconstructed topography is smoothed by computer, using again moving averages. The effect of smoothing is decreasing of the highest and increasing of the lowest elevations. The very same would be the effect of geomorphological processes developed under theoretical conditions of the absolute tectonic repose. Hence the smoothed map of reconstructed topography represents the theoretical model of relief development in the investigated area.

Correlation between the maps of actual, present day relief and theoretical model of its development during the time enables quantification of the neotectonic activity. The correlation was performed by computer, using the same network of points placed on both maps. Differences between the two maps are presented by contour lines. These discover positions and mutual relationships of blocks with differential vertical movements, the rupture structures appearing as their boundaries, the signs and intensities of neotectonic movements.

Neotectonic interpretation of the map showing differences between actual relief and its theoretical model is based on the principles applied at the energy of relief analysis. The positive anomalies display uplifted blocks, the negative correspond to the subsided blocks. The contour lines values indicate signs and intensity of vertical movements, their orientations and densities discover position of neotectonically active structures.

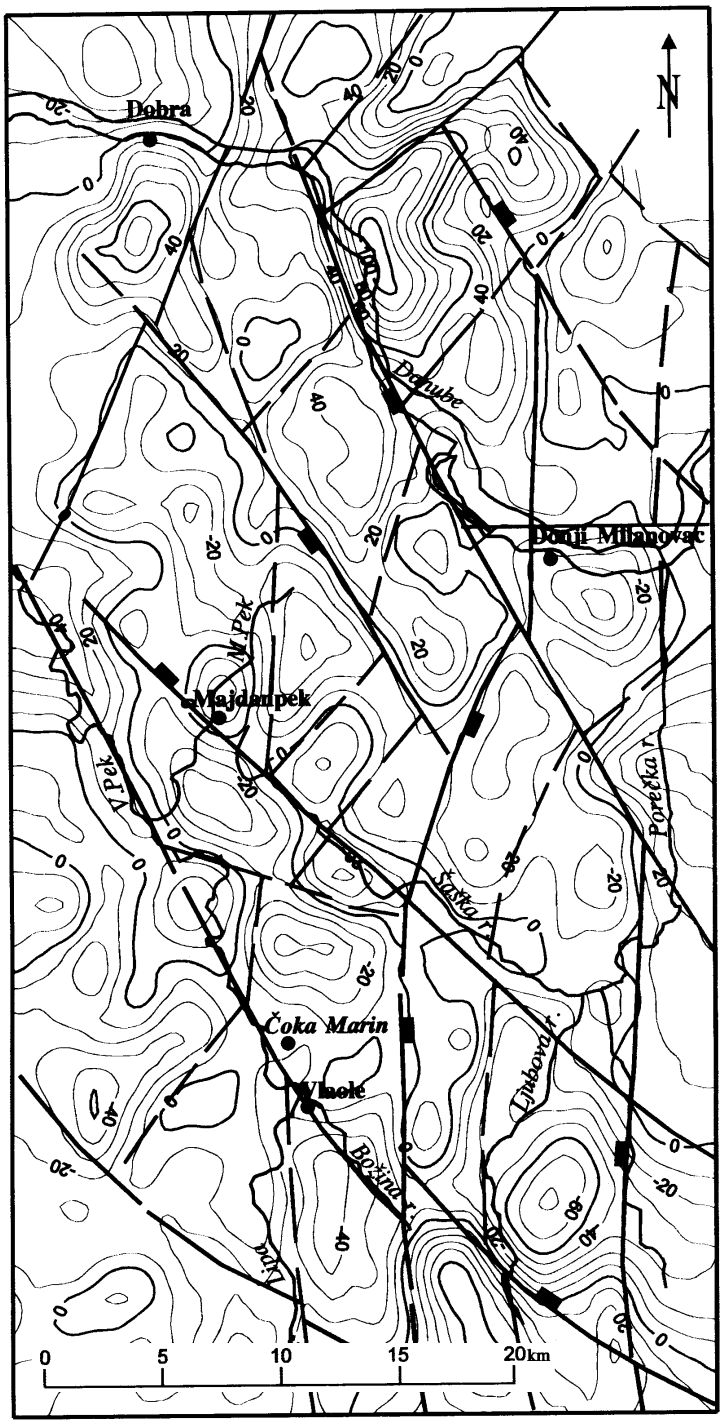


Fig. 4. Map of the neotectonic activity. Heavy lines show neotectonically active structures. The downthrown blocks are marked. The contour lines represent values of morphometric parameter in meters.

The analyses of mentioned two essentially different parameters were carried out independently. The source of data on relief was photogrammetric topographic map, scale 1:25.000. For mathematical and statistical data elaboration the self developed software package is used. Graphic data manipulation, like interpolation, construction of contour lines and block-diagrams, etc., is performed also by computer, applying appropriate commercial software packages.

Anomalies of two parameters, presented by contour lines, show very high degree of analogy. The final interpretation of neotectonic activity is based on averages of pondered sums of both, also presented by

contour lines. Their values are given in meters. They are proportional, but not equivalent to the amounts of vertical neotectonical movements. Values of morphometric anomalies and amounts of vertical movements should not be mutually equalized.

Interpretation of neotectonic activity

The map of neotectonic activity (figure 4) fully corresponds to the map of regional structure pattern (figure 3). Neotectonic structures, defined as boundaries between the blocks of differential vertical movements, are in agreement with the regional directions predestinated by disjunctive structures. All delineated neotectonic structures are grouped according to their orientation into two systems. The first one comprehends structures generally striking NW-SE. The other system made structures varying in orientation from N-S to NNE-SSW. These structures, defined by orientation, values and densities of contour lines of morphometric parameters, divide investigated area into blocks of differential vertical movements. The space positions of blocks illustrates block-diagram (figure 5).

Big regional structures can be recognized also on the map of neotectonic activity as neotectonically active. Such are structure which controls the Danube river course downstream from Dobra to Donji Milanovac, structure of the Porečka river, structure of the Šaška river striking across Majdanpek, structure V. Pek - Čoka Marin - Vlaole, and so on. Expression of older regional structures on the neotectonic map confirms assumption on their manifoldly renewed activity. The quantitative geomorphological analysis proves the Neogene, probably Quaternary

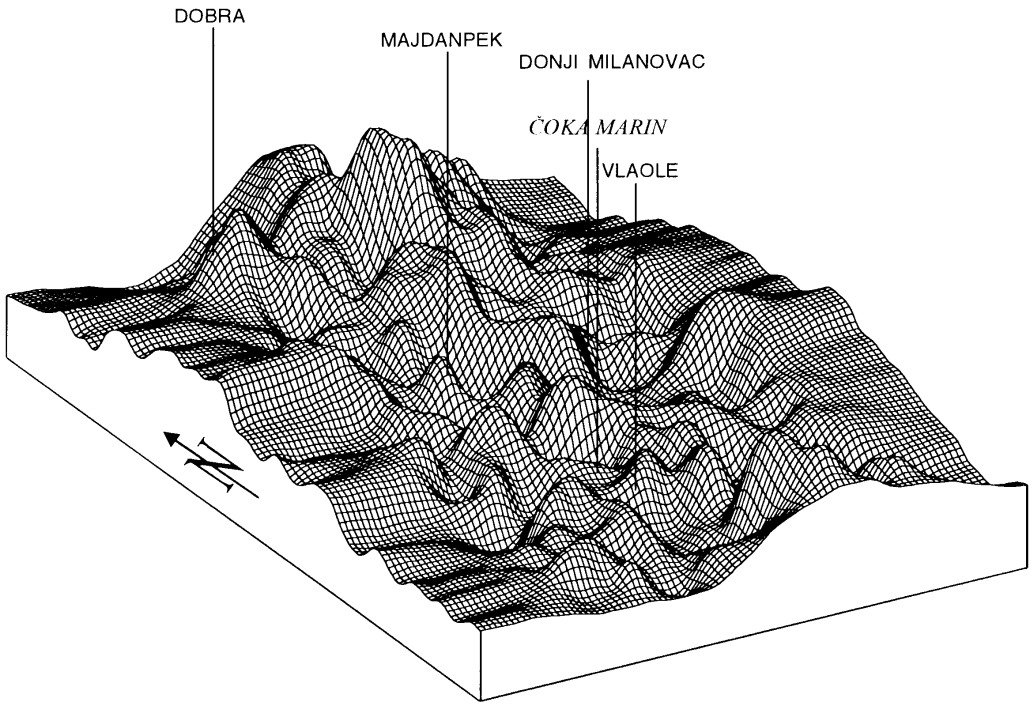


Fig. 5. Block-diagram showing positions of blocks with differential neotectonic vertical movements.

activity of these ruptures. Their direct influence on the mineralization distribution and position is very possible.

Vertical neotectonic movements offer rather simple model of differentially moved blocks. Uplifting and subsiding of blocks occur along the structures striking NW-SE. The most upthrown block is located northeast from the Danube river, in the Rumanian territory. From this block steps-like subsiding is taking place towards NE and SW. The central neotectonically subsided block is located in the Majdanpek Mine area. Its north-western boundary makes neotectonically active rupture Majdanpek-Šaška river. Further to the south-west the blocks show steps-like uplifting. The whole investigated area thus displays neotectonic pattern of a compound tectonic graben structure. The Majdanpek Mine and the promising Čoka Marin area are located on the south-western boundary of it.

The another compound tectonic graben structure, generally oriented north-south, is situated in the eastern part of the map (figure 3). Its eastern boundary makes known the Porečka river fault. The western border fault of this graben intersects and removes regional structure V. Pek - Čoka Marin - Vlaole. This structure is prolonging towards south-east and crosses the Bor ore deposit. It can be defined as the main ore controlling structure. The biggest subsiding amounts in this second graben occur in the extreme south-eastern part of the investigated area.

The values of contour lines vary in a limited range. Except in the north-eastern part of the map, in Rumania, the differences between extreme negative and positive anomalies hardly exceed a hundred meters. These values are proportional to the vertical movements amounts. Hence it could be concluded that neotectonic activity was not of high intensity. The vertical movements amplitudes during the Neogene and Quaternary the most probably have values of hundreds of meters.

Conclusion

The formation of ore bodies in the Majdanpek broader area is connected to the Upper Cretaceous magmatism. Magmatic complex, generally oriented NNW-SSE, is controlled by regional disjunctive structures. The western boundary rupture strikes NNE-SSW, the eastern one NW-SE. Ore controlling regional ruptures have the same orientation. The forms of previous volcanic relief can not be reconstructed. Position of the Senonian magmatism centres is indicated by circular structures. These occur along regional ruptures, or at their intersections with minor, local disjunctive structures.

The tectonic activity continued through Tertiary and Quaternary. Activity of the older ruptures was manifoldly renewed during neotectonic period. Along these structures differential movements of blocks took place, followed by changes of signs and intensities of vertical movements. The neotectonic structures have taken control of the mineralization position. Hence these could be an important criterion for investigation. The main ore bearing areas of Majdanpek and Čoka Marin are located in compound neotectonic graben structures.

Besides the exploited Majdanpek ore body, controlled by NNE-SSW striking fault, the most significant mineralization zone is connected to the neotectonically reactivated structure striking NW-SE. It can be followed between localities Čoka Marin and Vlaole. This zone up to now was not completely defined, nor investigated. Based on results of fracture pattern, neotectonic activity and circular structures occurrences study a program for further detailed structural and metallogenic investigations is prepared (Jankovic et al., 1996).

References

Antonijević,I., Kalenić,M., Dordević,M., Lončarević,Č., Čičulić,M. & Škuletić,T.: The base geological map SFR Yugoslavia, sheet Bor, 1:100.000. *Federal Geological Institute, Belgrade (in Serbian) 1974.*

Bogdanović,P., Marković,V., Dolić,D., Dragić,D., Rakić,M., Babović,M., Rajčević,D., Popović,V. & Milošević,Lj.: The base geological map SFR Yugoslavia, sheet Donji Milanovac, 1:100.000. *Federal Geological Institute, Belgrade (in Serbian) 1978.*

Institute for geological and geophysical investigations: The base geological map SFR Yugoslavia, sheet Žagubica, 100.000. *Federal Geological Institute, Belgrade (in Serbian) 1968.*

Janković,S., Marković,M., Pavlović,R., Jelenković,R. & Čupković,T.: Metallogenic-structural and morphological characteristics of the Čoka Marin - Majdanpek area, as the base for mineral potentiality forecasting. *Study. Documentation of the Majdanpek Copper Mine. Majdanpek (in Serbian) 1996.*

Kalenić,M. & Hadži-Vuković,M.: The base geological map SFR Yugoslavia, sheet Kučevo 100.000. *Federal Geological Institute, Belgrade (in Serbian) 1978.*

Marković,M.: The principles of applied geomorphology. *Geoinstitute, special issues, book 8. Belgrade (in Serbian) 1983.*