NEW VIEW ON THE STRUCTURAL PATTERN OF METOHIYA BASIN AND ITS MARGIN

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Never before our imagination could be
measured with inventiveness of nature.
Richard Miller - "Nemesis", 1994

ABSTRACT. The region of Metohiyan depression and its complex geological margin is a morphotectonic entity formed over complicated structures of the basement. The first glance of the orographic-geological map or satellite image shows the hexagonal shape of the depression in clear contrast to the linear structure of the Vardar Zone. Sedimentation of Neogene deposits began in a trough whose "main shape was finished", and the depression itself had been formed and modified through a long period of time (Cvijić, 1924). This is indicated by slight deformations of Miocene deposits, somewhat stronger along the rim of the basin, and relatively great thickness of the Neogene in general, uniformity in lithological composition and other characters of deposits.

Гeological knowledge of Metohiyan depression and its margin, viewed through the reference data, is caracterised by the missing links of many facts and the fragmentation. Also, for some reason, a more comprehensive and reliable idea of the geological relationships or the evolution is difficult to conceive. Many contradictions in interpretations of the make-up and structure of the region are so great that inferences that may be drawn from the known facts are unreliable or relative.

This work will present the idea of Metohiya basin as a ring structure like one resulting from a meteorite impact. In view of its form (morphology) and some indirect indications, there are few conclusive evidences that it is an impact structure of about 50 km in diameter. Why? "Sometimes one should know what to look for to be able to see it," writes Richard Miller in The "Nemesis" (1994). From this standpoint, so far actual facts of a certainly strong impact neither have been viewed nor their evidence searched from any aspect (atomic-molecular, mineralogical, crystallographic, petrochemical, geoelectrical, structural, etc.). Structures in the marginal parts of Metohiya basin, which have different strike directions (NW-SE, NE-SW, ENE-WSW, E-W, N-S), may be well interpreted should we accept that they border an impact ring structure.

НОВ ПОГЛЕД ВЪРХУ СТРУКТУРНИЯ МОТИВ НА БАСЕЙНА МЕТОХИЯ И НЕГОВАТА ОКРАЙНИНА

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РЕЗЮМЕ. Региона на депресия Метохия със своите сложни в геоложко отношение окрайнини е морфотектонска единица, формирана върху структурно усложнен фундамент. От пръв поглед върху геолого-орографска карта или сателитно изображение на областта се долавя хексагоналната форма на депресията, силно контрастираща на линеарната морфоструктура на Вардарската зона. Отлагането на неогенски седименти започва в трогов басейн, чиято морфология е „вече завършена", а самата депресия се формира в продължителен период от геоложко време (Цвијић, 1924). Индикация за това се леките деформации на миоценските седименти, по-интензивни в бордовите части на басейна, относително голямата мощност на неогена като цяло, издържаността в литофациалния състав и др. особености на седиментите.

Геоложкото изучаване на Метошката депресия и анализа на литературните данни показват че са налице множество неизяснени въпроси, фрагментираност на данните и като цяло – липса на единен подход. Поради това е и трудно създаването на цялостна идея за нейната геоложка еволюция. Множество противоречия в досегашните интерпретации на състава и структурата на региона не позоляват да се направят надеждни и адекватни изводи.

В настоящата работа се представя идеята, че депресията в област Метохия е рингова/ пръстеновидна структура с импактен произход. Предвид нейната морфология и някои други непреки индикации, засега имаме малко убедителни доказателства за наличието на импактна структура с диаметър около 50 км. Защо? „ Понякога е важно да се знае какво се търси, за да може да се види" пише Ричард Милер в „Nemesis" (1994). Досега произходът на Метошката депресия не е бил разглеждан в такъв аспект и не са търсени доказателства на нито едно аналитично ниво (атомно-молекулно, минераложко, кристалографско, петрохимично, геоелектрично, структурно и т.н.) Структурите в окрайнините части на депресията, които имат различни посоки на простиране (NW-SE, NE-SW, ENE-WSW, E-W, N-S) биха могли да се интерпретират като бордове на една импактна рингова структура.

Introduction

The Methohiyan basin in the shape of a huge amphitheater of about 2000 km^2 in surface area is situated in the southern and southwestern parts of Serbia bordering on Albania. This depression, for its complex tectonic pattern especially on the margin, has been a subject of interest of many geologists and other natural scientists from the ancient times. Opinions about the origin of the depression, age of faults and Tertiary deposits and other aspects are controversial.

Thus, Cvijić (1901, 1913, 1924) maintains that Metohiyan depression was formed and modified (the phase of Dinarides faulting) over a relatively long geologic time and is a typical example of the intermontane depression - tectonic valley filled with terrestrial deposits with coal. The same author explains formation of the depression by subsidence resulting from a large-scale orographic convergence of Prokletije and Shar Mountains, or the convergence of the Dinaric and Shar-Pind systems, and the numerous marginal faults on the northern, western and southern sides as "formed by abrupt bending of folds from the Dinaric into Metohiyan (system) giving the impression that the ground was fractured. Sedimentation of Neogene deposits began in the graben whose “main shape was finished”. If the “ground was fractured” and “the main shape was finished” does not it suggest certain Cvijić's doubt in the depression formation by “the convergence”? The hypothesis of convergence of two systems is still prevailing with minor variations.

Important information on the presence and historical evolution of the depression is contained in Kober (1952) that reads: “Peć depression, almost 100 km wide, divides the Dinarides and the Hellenides and is a tectonic line of the first order. It strikes transversally to the Dinarides direction short of Prishtina in the east. At the present time it is covered by younger and Upper Cretaceous formations.” It may be deduced that Kober assumed faulting of the preexisting structures even before the Upper Cretaceous.

Old alpine orogenies led to large structural deformations and subsidence along longitudinal and transversal dislocations in the convergence zone of magmatic and sedimentary rocks. Možina et al. (1961) write: “folding and faulting were the strongest in the Laramian, less strong in Pyrenean and Savian orogenies”. Each phase, according to the same authors, was characterized by disjunctive movement that led to subsidence of masses “along intermittent and newly formed dislocations and to formation of basins in which Tertiary sediments were deposited”. However, the movements could have been older.

Vidović (1965) refers to the Peć faulting feature as “a deep fault through Earth's crust” associated in time with “the earliest differentiation of the Dinaric geosyncline - the Caledonian phase”. Vidović, like Cvijić, describes that geotectonic zones and directrices converge to the Peć fault, which is the boundary “of the Dinaric and Shar-Pind systems”.

Ćirić (1962/63, 1967) refers to the Metohiya depression as “a large molasse basin particular in its position”. He takes it to be a typical example of “inherited depression that was formed at the point of convergence of Dinaric and Bosnia-Raška zone of the Inner Dinarides”. It is classified into “central molasse depressions”.

A contribution in collective authorship of Zagreb Industroprojekt (1969) hypothesizes that during the Mesozoic the Metohiyan basin was part of a relatively narrow "eugeosyncline" extending from Albania to this area. They describe the depression as a "graben-form" most likely in the "continental phase - without sediment filling" in the time interval K_2-Ol_1.

A note of interest (Bogdanović, 1976) is that “intrusion of the huge Mirdita peridotite massif in the late Triassic and early Jurassic led to the bending of Triassic and Paleozoic strata that surrounded the Mirdita pluton”. He states that the Mirdita peridotite massif “had the crucial effect on folds' deviation from NW-SE to NE-SW or even E-W direction”. This fold deviation, and the depression formation, occurred, according to Bogdanović, “before the Upper Cretaceous, but after the Triassic”, and the diagonal Peć and Prizren faults were certainly older than the “Lower Miocene volcanogenic series near Trepča and on Kopaonik, but younger than the Lower Cretaceous”.

According to Maksimović (1978), the study area of the Peć part of Metohiya belongs to “central ophiolite, which is the most distinctive zone whose membership in the Dinarides has never been disputed”.

Petković and Sikošek (1976) argue that the period of Neogene tectonics is characterized by the following: “Savian-phase orogeny activated old and formed new vertical structures, along which land was dissected, depressions formed and filled with Tertiary waters in which deposited molassic sediments.”

Bokčić (1983) does not take Metohiyan basin for a “static basin” predisposed for filling. It was a highly dynamic depression where tectonic movements though frequent, were not abrupt or variable. Tectonic events influenced the formation of relatively thick deposits of different types: Lower Pliocene coal to about 60 m or a “group” of deposits of uniform grain size. This is particularly true of lake deposits of the Middle Miocene and Lower Pliocene.

Hadži et al. (1974) associate tectonic events in the region with the plate rotation, in detail the collision of plates and the growing pressure of the Arabian-African plate on Eurasia. To quote: “under the growing pressure of the Arabian platform from SE to NW in the late Eocene, entire southeastern Europe and southwestern Asia began to move through the section from the style platform to south Budva-Ionian-Tauride margin”. Because the movements to the west and northwest were soon retarded by resistance met by the northern part of Karnic-Apulian massif, individual plates deviated in the Oligocene to SW, or to the oceanic region of the present-day central Mediterranean. From variations in the paleodeclination and paleoinclination it may be inferred that the events that upset the earlier paleomagnetic balance, or the preexisting distribution of plates, occurred between the Eocene and the Middle Miocene.

All these large-scale displacements (that have continued to the present day) had great influence on the youngest structural relationships established through the Neogene and the Quaternary. In modern views, the neoalpine structural relationships are marked by continental subduction of the Adriatic plate under the Dinaric orogen during the Neogene and the Quaternary (Marović et al., 1993, 1998; Petkovski, 1990). The structures such as basins, troughs, and even true basins (Aegean Sea) formed in the post-collision phases and/or under some particular circumstances within the perimeter of the Dinaric orogen. Movements manifested in the border belt of the Adriatic plate and the Dinaride-Hellenide orogen had a direct effect on the neostructural plan of the study area. The littoral belt is a zone of marked level difference. Subsidence was a consequence of the Adriatic lithosphere deflexion during its subduction under the Dinaric orogen, and rising of Dinaric orogen a result of contraction caused by the African (Adriatic) and European (Mesian) plates interaction and of relative thickening of Earth's crust.

Younger Neogene basins in the region may be genetically associated with extension processes, or explained as the result of tectonic activities during most of the Neogene and through the Quaternary, formerly differentiated (rising and sinking) and later epeirogenic rising. However, the formation of initial depression structures is directly related to the closing movements of the second formational phase (during the Paleogene to the earliest Neogene), when contraction was marked by reverse slipping, imbrication, thrusting over and transcurrent shearing along intermittent dislocations of N-S, NW-SE and NE-SW directions (Marović et al., 1993; Petkovski, 1990).

A new neotectonic (geodynamic) process that evolved through two phases: from Middle Miocene to Quaternary and reached the paroxysm in the Pliocene, represented by the clockwise rotation of the Hellenides and the Dinarides pushed by the Asia Minor plate, could have influenced the evolution of neoalpine (neotectonic) structural relationships in South Serbia, Macedonia and a larger area (Krstić et al., 1977). The rotation resulted from the formation of the western and northwestern parts of the Aegean island arc; its effect reached the Skutari-Peć transverse, known as Mirdita Zone (Bilibajkić et al, 1979; Marović, Đoković, 1995). It was along the Skutari-Peć transverse that the Dinaric-Hellenide orogen arcuated and formed, on its convex side, trough structures, most conspicuous of which is Metohiyan trough. Spreading in the transverse zone must have reflected, in a lesser measure, on the west, deep into the Mediterranean. The eastward extension bent to Sofia and passed the southern Sredna Гора trough boundary to southern Bulgaria. Within this transverse fracture, differential displacements influenced the formation of many faults of NE-SW strike direction and relatively narrow Tertiary basins normal to the Dinaric ones (NE-SW). Similar events also occurred along transversal fractures Elbasan-Kyustendil, Joannina-Plovdiv and on the Aegean geofracture (Petkovski, 1997).

A zone of more frequent earthquake events extends south of and parallel with the formed boundary (Skutari-Peć). The earthquake epicentral depths were about 10 km (Krstić et al., 1997). The seismic activity indicates movements of the more recent history. Active seismotectonic levels are associated mainly with young systems, faults of neotectonic manifestation.

As described above, views on the origin and age of the Metohiyan basin and its structures are controversial. The depression could not have been formed in a lineament structure, eventually initiated by rotation, though it is hard to imagine a homogeneous geological body to be moved by conjugate forces. It seems more likely that an impact body (impactite, asteroid) had formed the circular crater that was modified by other tectonic movements. The very beginning of the depression formation is difficult to determine in the present stage of our knowledge and on the available information.

Geology and Structural Pattern

The Metohiyan basin and its margin are made up of Paleozoic, Mesozoic and Cenozoic sedimentary and various types of igneous rocks (Fig. 1).

Paleozoic sedimentary rocks build up the basal parts of Shar Mountain and southeaster, eastern, northeastern and northwestern parts of Metohiya depression. Lower Paleozoic is represented by Silurian and Devonian, and the Upper Paleozoic by Carboniferous and Permian. The Silurian-Devonian complex consists of two series: lower, dominantly greenschist of high crystallinity and upper rocks of lower metamorphic grade. The complex equivalent to the Upper Paleozoic consists in the lower part of lustrous foliated phyllite, greenschist, slate and slate clay, and of varied sandstones, marbleized limestones and conglomerates in the upper part.

Mesozoic sedimentary rocks are widespread in the eastern, northern and western areas of the Metohiyan depression. Triassic sedimentary rocks build up large parts of northwestern and northern Metohiyan depression, and much of the marginal Prizren Polje and Shar Mountain in the form of east-west lands. These rocks are light-grey, whitish or white limestones, occasionally dolomite.

Jurassic is characteristic for typical diabase-chert formation and serpentinite where Triassic and partly Upper Cretaceous rocks are prevailing. Upper Cretaceous is dominantly in the calcareous facies in Paštrik area and largely in flysch facies in the eastern margin of Metohiya basin.

Tertiary is represented by Neogene formations - freshwater Miocene and Pliocene deposits of large thickness and relatively complex lithology. There is no paleontological evidence of Lower Neogene deposits in the deepest part of the basin.

Miocene sedimentary rocks have a small distribution as compared to Pliocene, around Peć and in northeastern part of the depression (Rudnik, Banja, Crkolez, Rakoš), known in literature as the Peć Series. It is made up of sands with gravel lenses, whitish ostracod marls, a few tuff layers, coarse green sands and small-grained conglomerates, and few coal seams. The series is deformed and inclined to the west, northwest and north at different angles (from 10º to 45º). Coal seams are thin (between 0.1 m and 1.2 m). Also thin beds and coaly clay interbeds occur in the upper part of the series. The age of the Peć Series is most likely Middle Miocene and Upper Miocene (Sarmatian). Its thickness is about 450 m. All this is indicative of a long lake phase with shallowing episodes (Milošević, 1966; Antonijević et al., 1969; Bokčić, 1983).

Interstratal tuff emplacements suggest volcanic activity, during the deposition, along dislocations on the basin's margin. Distinct lower and upper tuff boundaries indicate rapid deposition of ash. In views of many investigators, volcanic activity occurred in the Middle Miocene. Identical or very similar volcanic evidence is identified in the underlying Kosovo Series. Most references describe Kosovo tuff interbedded in white marls of northern basin as Miocene (Atanacković, 1959).

Pliocene rocks have a large distribution in Metohiyan depression and form two horizons: (a) Lower Pliocene deposits and (b) Middle and Upper Pliocene deposits.

(a) Lower Pliocene deposits. Principal characteristic of the Lower Pliocene, which has a fairly large coverage in northern Metohiyan depression, is its large coal deposit. The unit is divided into the underlying strata and the coal measures and overburden.

The underlying strata are widely exposed and transgressive over the Peć Series. They consist of conglomerate and sandy green clay with $CaCO_3$ concretions and knots. Fossils have not been found. These strata are identical with those underlying the coal measures in Kosovo. The estimated thickness of the underlying strata is between 200 m and 300 m.

The coal measures and the overburden are exposed in Peć area of the depression. Upper Pontian is the coal measures, about 35 m thick, and the overlying barren rock material, clay-marl deposits with some red burned. The entire overlying sequence is highly fossiliferous and resembles Kosovo deposits, which indicates a wide communication of Kosovo and Metohiya lakes (Milošević, 1976; Atanacković, 1959).

(b) Middle and Upper Pliocene. Younger Pliocene deposits of sand and sandy marl conformably overlie the coal measures. Their distribution is relatively small in northern Metohiya, but is more widespread in Đakovica-Prizren part of the depression where they are the only Neogene deposits. These deposits, abounding in molluskan fossils, primarily unionids and viviparids, have a total thickness of about 300 m.

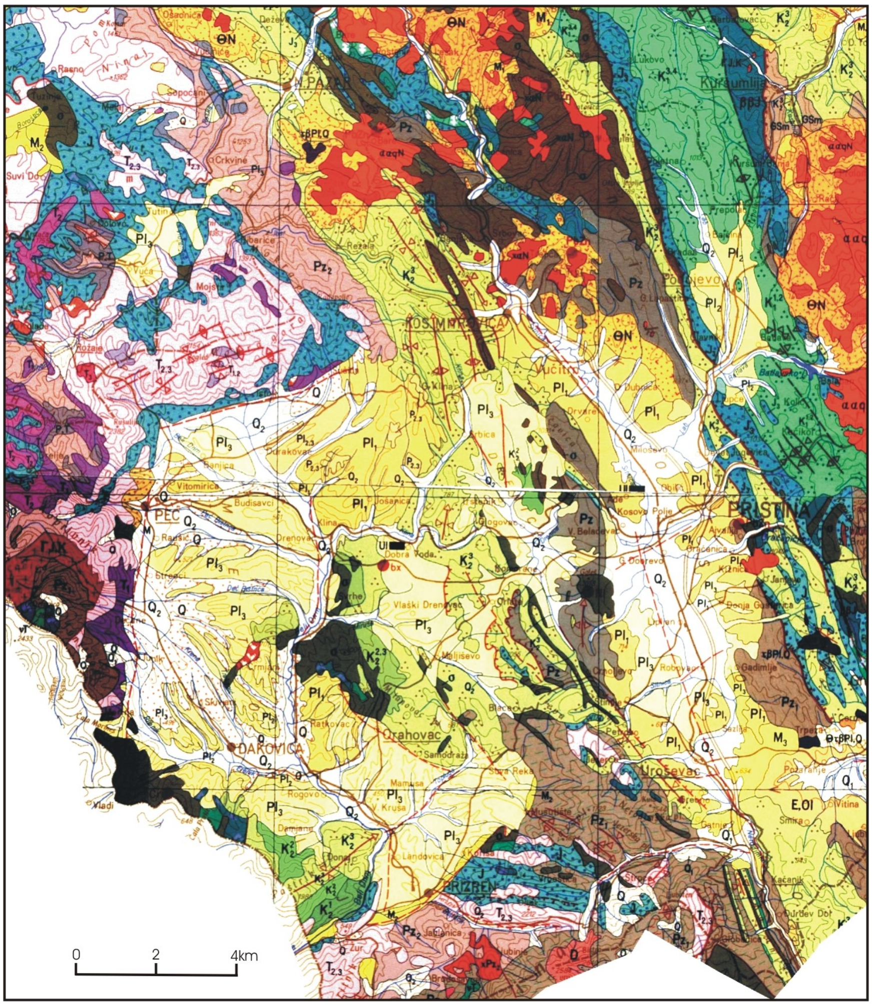

Fig. 1. Geological map of Metohiyan basin and its margin: GSm – Gneiss and mica-schist; Pz – Paleozoic metamorphite; xPz – Paleozoic igneous rocks; PT – Permo-Triassic; T – Triassic; vT – Triassic igneous rocks; J – Jurassic; ββJ – Jurassic diabase; Se – Serpentinite; K – Cretaceous; E,Ol – Eocene-Oligocene; θN – Neogene pyroclastics; M – Miocene; Pl – Pliocene; ααqN – Neogene dacite andesite; xαN – Neogene quartz latite; θτβPl,Q – Pliocene and Quaternary pyroclastics and feldspar leucite basite; τβPl,Q – Pliocene and Quaternary feldspar leucite basite; Q – Quaternary; Ul – coal

Quaternary is represented, among others, by rocks that indicate glaciation, which must have preceded the formation of the large pre-Mindel fluvio-glacial terrace of Orno Brdo.

The territory of Metohiya is a part of the Inner Dinarides geoectonic entity that extends from Serbia into Bosnia in NW and Macedonia and Albania in SE. The tectonic depression of Metohiya is radial in form and has a complex tectonic pattern on its periphery. Rock strata are tightly folded, faulted and imbricated. Fold axes have different trends, Dinaric or Metohiyan, and strike direction north-south on the eastern margin of the depression. Major tectonic units in this area, which control the tectonic depression, are: marginal system of faults, the river Klina fault system and the Ćićavica thrust-sheet (Petković, Sikošek, 1976).

The view so far prevailing is that Metohiyan depression was formed by stepwise subsidence (about 1000 m) along the system of bounding faults as they strike today. The system of faults of ENE-WSW strike, probably Pontian in age (Cvijić, 1913), bound Metohiyan tectonic depression on north and south. On its western rim there are two faults: one almost N-S from Peć to Dečani, and the other NW-SE from Dobroš to Damnjan forming its southwestern boundary (Fig. 2). Thus shaped depression was filled with Miocene terrestrial sediments, with the central occurrence of tectonically controlled Cretaceous deposits and serpentinite. The tectonic depression of Metohiya is located in the “migration” area of the Dinaric orogen structures strike directions, where during the neotectonic events, the pressure release was the greatest.

The term “Metohiyan direction” was introduced by Cvijić (1924). He noted in the extreme south that Dinaric mountain ranges curved from NW-SE to E-W or NE-SW, locally N-S, while the outer folds nearer to the Adriatic Sea retained the Dinaric direction (NW-SE), sank to the level of the Drim and Bojana rivers backland and converged “at an obtuse angle with Albanian folds of the Mediterranean direction”. However, “internal directrices bent right behind Skutari, in Tarabaš and Rumija to NE, the direction presently referred to as Metohiyan, because it is best marked around Metohiyan depression”. Similar curvings are noted on the other side of Metohiyan depression in the Shar Mountain system (Shar, Koritnik and Paštrik), where meridian direction changes into Metohiyan direction (NE). Cvijić (1901, 1924) tried to explain the phenomenon by the tectonic control. His hypothesis was that curving of folds and directrices in Prokletije and further westward caused the orographic bending.

Impact Effect and Product (Impactite)

It is interesting to note that nobody of geologists or other researchers who studied this region ever thought of the impact by an extraterrestrial body, though images of such bodies from artificial satellites have become available (Antonović & Simić, 2006). As a result of cosmic explorations in the late 20th and beginning of the new century, an abundance of information has been obtained on the composition and structure of planets in the solar system, what led to new knowledge and a new scientific discipline, Comparative Planetology.

Studies of the surface geology of the Earth family planets (Mars, Mercury, and Venus) and their satellites Moon and so on) have shown that many characteristic features of their surface configuration and deeper structures are controlled by ring (circular) structures of various dimensions. It has been noted that most of ring structures were impact craters and that no more than 20% of the all ring structures were volcanic craters (Markov, 1984; Antonović, Simić, 2006). Estimates have shown that intensive meteorite showers were dominant in the early phases of their evolution, from 4 to 3.8 milliard years, and before two milliard years decreased 200 to 300 times (it was calculated that in the early stages of Earth's evolution, 10^3-10^4 bodies from 10 km to 100 km in radius should have fallen on its surface at a velocity rate between 10 km/s and 20 km/s; in: Markov, 1984). Intensive bombardment of planets in the early stage of their evolution should be considered a universal process of substance transformation for any solid body of the solar system. The geochemical effect of this impact transformation has been inadequately evaluated and studied, or little has been known about the proportions of the events, their effects and influences on the evolution and transformation of the continental crust.

If the Earth's nearest neighbours were exposed to meteorite showers in different stages of their history, there should be hardly any doubt that meteorites fell on the Earth surface as well. As mentioned earlier, many specialists in Earth geology have given little consideration to or ignored impact occurrences as a geological process on the Earth, even if they were obvious and should have been taken into consideration both in the early geologic history and the latest biological evolution of the plant Earth. It is understandable, because endogenic processes have done much in erasing the traces of impacts. Moreover, at the present time, about a hundred impact structures, some of 140 km or more in diameter are identified on the Earth (Barsukov, Bazilevskiy, 1984; Markov, 1984; Griev, Parmente, 1984; Gluhovskiy, Pavlovskiy, 1984; Masaitis et al., 1984; Engelgardt, 1984; Feldman, 1984; Antonović, Simić, 2006).

The study of tectonics and magmatism in the early stage of Earth's evolution is very important in itself, because it affords insight into the origin of the geological history of our planet, and a view on the sources of its upper mantle formation. This is equally interesting for tectonists and petrologists, geochemists and sedimentologists, or in other words, for many disciplines of the geological science.

Principal bombardment effects are the following: (1) essential contribution in the planet energy on the account of very rapid strikes, transformation of kinetic into thermal energy, (2) initiation of volcanism, products of which are mostly filling craters and (3) meteorite bombardment on Earth surface that led to essential redistribution and mixing of material, and to the change of its chemical composition.

Nonetheless is interesting to learn and explain the character of basalt volcanism on different planets, because basalt is one of essential constituents in planet crusts. We know well that in the Phanerozoic history of the Earth, the primary mass of basalt formed in contemporary oceans and their paleoanalogues. May this pattern of an early stage of the geological history of Earth be applied to other planets of the Earth family? The question is still obscure because moon “seas” and “continents” are not analogues, in the strict sense of the word of similar structures on the Earth.

Craters more than 2 km across in sedimentary and more than 4 km in crystalline rocks have a characteristic depth-to-diameter ratio of less than 1/10 and elevated central area of shock-metamorphosed rocks that form central peak and/or inner ring (Antonović, Simić, 2006).

A brief review of the geology and geophysics of many Earth craters can be found in the works by Dence et al. (1977) and Masaitis et al. (1980). In some examples of extraordinary geological circumstances, formation of large impact structures influenced the precipitation and emergence on ground surface ore deposits (e.g. Ni-sulphides in Sudbury structure (Morrison, 1982) or uranium in Caswell structure (Johns, 1970). In some impact structures also were formed appreciable reserves of hydrocarbon, as in Boltish depression (Yurk et al., 1975), Viewfield (Sawatzky, 1977) and Red Wing Creek structure (Brennan, 1975). An impact exerts deep effect on local geology, upsetting the physical and chemical balance in rocks, which in particular cases leads to the formation of a structure of much larger horizontal scale than the largest volcanic product.

The effects that indicate a large-scale impact on the early Earth crust may include the following: landform of a few km in amplitude, thermal gradient rise in the lithosphere and the atmosphere directly beneath the shock site, controlled ascension to the surface of deep material, some potential energy for the next eruption of basalt on the account of adiabatic expansion, endogenic mineralizations (Pb-Zn and the like), geomagnetism and other relevant indications (Antonović, Vukašinović, 1989/1990).

In case of the relatively thin lithosphere of the Earth, which probably was even thinner in the early history of the planet, large-scale impacts could have supplied asthenosphere material to the ground surface, what caused volcanic events over a large area (Griev, Parmente, 1984).

An impact is followed by transformation of the large impact basin. The transformation processes include contraction and expansion after the heat loss, subsidence and rise after the shock, degradation of landforms on the account of erosion and rapid relaxation, filling basin.

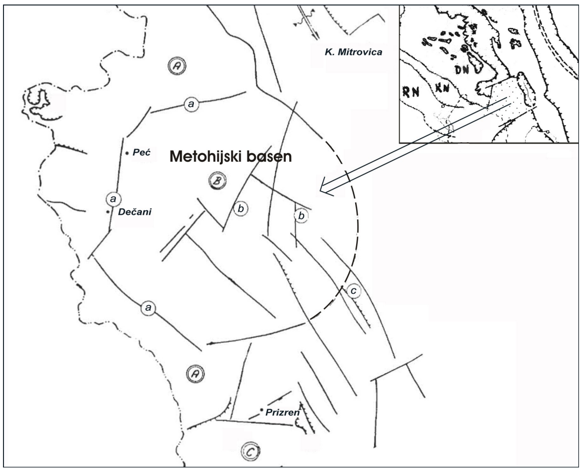

Fig. 2. Tectonic map of Metohiya and its margin (modified after Petković and Sikošek, 1976): DN – Durmitor nappe, KN – Kuči (Žijovo) nappe, RN – Rumija nappe, Geotectonic units: A. Central Paleozoic and ophiolite belt, B. Tectonic depression of Metohiya (a. Metohiya depression marginal fault system, b. the Klina system of faults, c. Ćićevica thrust sheet), C. Korab nappe

During the hypervelocity impact of a relatively solid body onto the hard planetary surface, there follows a rapid succession of phases:

a) penetration of the impacting body and consequent compression, compaction of material,

b) excavation – caving and formation of crater,

c) transformation of transient crater and its filling both underneath (rapid replacement of dislodged and crushed socle) and above (numerous settlings and emplacement of ejected, broken and molten material of target rocks).

The shock wave spreads from the shock zone in concentric rings and is manifested in: (a) evaporation, (b) complete melting, (c) partial melting and plastic deformation, (d) crushing and fissuring. In crater structures only relics have remained, formed in the zone of partial melting and plastic deformation, and complete in the zone of crushing and fissuring. According to current estimates, the area of complete destruction in an impact crater (zones a, b and partly c) is characterized by high pressure (about 25 GPa).

Rock and structure transformation, during the collision, may be considered at several levels:

1. At the atomic/molecular level, the shock wave causes atom compaction, or destruction of atomic or molecular bonds. High temperature raise leads to dehydration of water-bearing minerals, carbonate decomposition and moisture evaporation,

2. On the crystal lattice plane, fine mosaic cracking of crystal structure and lattice rearrangement or complete destruction at a higher or lower level,

3. At the mineral level, transformation evolves through several successive stages: (a) propagation of the shock wave (progressive shock metamorphism), (b) heat effect from the impact melt source (pyrometamorphism) and its cooling (crystallization, glass formation, neocrystallization, recrystallization, polymorphic transitions, etc.), and (c) during the action of aqueous solutions that flow through the cooled rock mass.

The processes, due to high temperature and pressure generated within the short time of collision, lead to different structural transformations and formation modes of the group of crystal and glass phase: crystals under high pressure, monomineral and polymineral impact glass, grassy condensate, glassy products of pyrometamorphic melt and glassy products of thermal decomposition. Glassy formations or tektites are small, rounded, spherical or uniform-surface bodies found in groups. Tektites have high silica (70%-80%), aluminium oxide (11%-15%) and alkalis (Na_2O+K_2O from 3.34% to 4.04%), and very low water contents (Rika, Malyshevskaya, 1989).

Impact structure

Metohiyan depression in South Serbia is a large geotectonic unit of complex structure. Major tectonic units in the region, which control the depression, form a system of marginal faults, a fault system of the River Klina and Ćićavica overthrust nappe.

The geological-structural map of this Serbian region clearly shows its principal features:

1. Distinct bending of deep-seated structures in the southern, western, northwestern and northern parts of Metohiyan depression is manifested in sharp change of strike directions from E-W to NW-SE to NE-SW to N-S (Figs. 1 and 2). Impact or a vestige of its edge may explain abrupt changes in the strike direction, or almost circular pattern of the structures. The western margin is formed by two faults: one, extending from Peć to Dečani, almost N-S, and the other, bounding the basin on southwest, which strikes in NW-SE direction from Dobroš to Damnjan. The eastern border of the Metohya basin is similarly curved. Morphology of the bent structures and abrupt change in their strike directions on the edge of Metohiyan depression may not be satisfactorily explained neither by convergence of the Dinaric and Shar-Pindus systems nor by plate rotation or gravitational sliding. The only explanation is that it was produced by impact.

2. Another feature suggesting impact structure is a recognizable circular depression, almost a thousand metres deep, filled with Neogene sediments including thick coal deposits, bounded by fractured and deformed rocks of "the central Paleozoic and ophiolite belt" (Fig. 2). The base under

the depression fill (clastics) is the rock as those building up the sides of the depression. Also, subsidence is manifested (Dragašević, 1974), and then thinner Earth's crust in the structures, and a lower the common thermal gradient.

3. More evidence of the likely impact character of structures is provided by some geophysical data, foremostly the agreement of positive geomagnetic anomalies with the circular structure (Vukašinović, 2005).

4. A supportive evidence of the circular structure is the distribution of Oligocene/Miocene intermediate igneous rocks, which frequently bear large and locally Pb-Zn rich deposits (NE of Metohiya depression, Trepča, etc.).

The time when Metohiyan depression was formed is difficult to determine. It probably occurred before the Upper Cretaceous, after the Triassic (possibly also in the Paleogene). Some references (Bogdanović, 1976) associate the fold deflections with the Mirdita peridotite massif. Could not a meteorite impact cause synchronous deviations of folds and formation of Orahovac peridotite? Answers to this and many other questions may be searched in sediments of the Metohiyan depression and rocks building up its edges. The search must be multidisciplinary and comprehensive to include geological-structural, atomic-molecular, crystallographic, mineralogical, petrological, geochemical, geophysical studies.

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