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A new view on the structural pattern of the Metohiya Basin and its margin: a preliminary note

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Never before could our imagination be
measured with the inventiveness of nature.
(Никада до сада наша машта није се
могла мерити са инвентивношћу природе)
Richard Miller, In "Nemesis", 1994

Abstract. The region of the Metohiyan depression and its complex geological margin is a morphotectonic entity formed over the 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, the "main shape of which was finished" and the depression itself had been formed and modified over a long period of time. This is indicated by the slight deformations of the Miocene deposits, somewhat stronger along the rim of the basin, and the relatively great thickness of the Neogene in general, uniformity in lithological composition and other characters of deposits.

This region in the south of Serbia was much explored during the last (20th) century, in the latter half in particular, when abundant and interesting information was collected on the geology, structural pattern and mineral resources. Some of the newly collected information has been published and threw new light on the geology of the Metohiyan depression and its margin. Other data, also important, have remained unpublished in numerous documentation funds.

Gaps in the geological knowledge of the Metohiyan depression and its margin, viewed through reference data, account for the missing links of many facts and fragmentation. Also, for some reason, a more comprehensive and reliable idea of the geological relationships or evolution is difficult to conceive.

This work will present the idea of the 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 indications 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". From this standpoint, so far actual facts of a certainly strong impact have neither been viewed nor their evidence searched for from any aspect (atomic-molecular, mineralogical, crystallographic, petrochemical, geoelectrical, structural, etc.). Structures in the marginal parts of the Metohiya Basin, which have different strike directions (NW–SE, NE–SW, ENE–WSW, E–W, N–S), may be well interpreted should it be accepted that they border an impact ring structure.

Key words: Metohiyan impact, impact structure, Metohiya, Serbia.

Апстракт. Метохијска котлина, у ширем смислу, са својим геолошки веома сложеним ободом, представља посебну морфотектонску целину формирану изнад врло компликованих структура "основног горја". Већ на први поглед на орографску – геолошку карту или сателитску слику, уочава се шестоугаона структура ове котлине, која јасно одудара од линеарне структуре Вардарске зоне. Седиментација неогених наслага започета је у рову чији је "основни облик био готов", а сама котлина настала је и бивала модификована постепено и кроз дуже геолошко време. На ово нас упућује мала поремећеност наслага миоцена, нешто већа уз обод басена, као и релативно велика дебљина наслага неогена уопште, уједначеност литофацијалног састава и других особина наслага.

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Ово подручје на југу Србије је у прошлом (20-ом) веку, а нарочито у другој половини, било интензивно истраживано. При тим радовима прикупљен је многобројан и интересантан материјал о геолошком саставу, структурном склопу и минералним сировинама овог подручја. Један део тих нових геолошких података објављен је у више публикација, многи од њих бацају нову светлост на геологију Метохијске котлине и њеног обода. Многи други, такође значајни подаци остали су, међутим, необјављени и налазе се у многобројним фондовским материјалима.

Због тих празнина геолошко познавање Метохијске котлине и њених ободних терена карактерише се, посматрано кроз податке из литературе, неповезаношћу многих чињеница и фрагментарношћу. Због тога се истовремено, тешко може добити прегледнија и поузданија слика о геолошким односима и геолошкој еволуцији тих терена.

У овом раду изнећемо идеју о Метохијском басену, као прстенастој структури која би одговарала метеоритском импакту. Ако изузмемо њен облик (морфологију) и неке посредне индиције, за сада, имамо мало материјалних доказа да је то импактна структура пречника око 50 km. Зашто? “Понекад је потребно знати шта тражите да би то и видели” каже РИЧАРД М. писац “Nemeze” (1994). До сада, са тог становишта, нису посматране реалне чињенице нити су тражени материјални докази на ниједном нивоу (атомско-молекуларном, минералошком, кристалографском, петрохемијском, геохемијском, структурном итд.) о једном свакако великом судару. Можда структуре у ободном делу Метохијског басена, које имају различите правце пружања (СЗ–ЈИ, СИ–ЈЗ, ИСИ–ЗЈЗ, И–З, С–Ј) moћи ће сасвим добро да се интерпретирају ако прихватимо, да је ово једна импактна прстенаста структура.

Кључне речи: Метохијски импакт, импактна структура, Метохија, Србија.

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 its margin, has been the subject of interest of many geologists and other natural scientists from 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) maintained that Metohiyan depression was formed and modified (the phase of faulting of the Dinarides) over a relatively long geologic time and is a typical example of an intermontane depression – tectonic valley filled with terrestrial deposits with coal. The same author explained the formation of the depression by subsidence resulting from a large-scale orographic convergence of the 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, the “main shape of which was finished”. If the “ground was fractured” and “the main shape was finished” does this not suggest certain doubts of CVIJIĆ in the formation of the depression by “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 pre-existing 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) wrote: “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 the 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 the 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 (1967) refers to the Metohiya depression as “a large molasse basin particular in its position”. He takes it to be a typical example of “an inherited depression that was formed at the point of convergence of Dinaric and Bosnia–Raška Zone of the Inner Dinarides”. It is classified into the “central molasse depressions”.

A contribution in the collective authorship of a 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 “grabenform” 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 a crucial effect on the deviation of folds from the 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, the membership in the Dinarides of which has never been disputed".

PETKOVIĆ & 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 from which molassic sediments deposited."

BOKČIĆ (1983) does not consider the Metohiyan Basin 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 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, the entire southeastern Europe and southwestern Asia began to move through the section from the style platform to the south Budva–Ionian–Tauride margin". As the movements to the west and northwest were soon retarded by resistance met by the northern part of the 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 which disturbed the earlier paleomagnetic balance, or the pre-existing distribution of plates, occurred between the Eocene and the Middle Miocene.

All these large-scale displacements (which have continued to the present day) had a 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 & ĐOKOVIĆ 1993; MAROVIĆ *et al*. 1998; PETKOVSKI 1990). 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 the rising of the Dinaric orogen was a result of contraction caused by the interaction of African (Adriatic) and European (Mesian) plates and of the relative thickening of the 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 the 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 & ĐOKOVIĆ 1993; PETKOVSKI 1990).

A new neotectonic (geodynamic) process that evolved through two phases: from the Middle Miocene to the 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 the 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, the most conspicuous of which is the Metohiyan trough. Spreading in the transverse zone must have reflected, to a lesser extent, on the west, deep into the Mediterranean. The eastward extension bent to Sofia and passed the southern Sredna Gora 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 the 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 to the formed boundary (Skutari–Peć). The earthquake epicentral depths were about 10 km (KRSTIĆ *et al*. 1997). The seismic activity indicates movements of 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) formed the circular crater which was modified by other tectonic movements. The very beginning of the formation of the depression is difficult to determine from 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 the Shar Mountain and southeastern, eastern, northeastern and northwestern parts of the Metohiya depression. The 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 various 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 constitute large parts of the 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 prevail.

Upper Cretaceous is dominantly in the calcareous facies in the Paštrik area and largely in flysch facies in the eastern margin of the Metohiya Basin.

The 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 rock**s** have a small distribution as compared to Pliocene, around Peć and in the northeastern part of the depression (Rudnik, Banja, Crkolez, Rakoš), known in the 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 a 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 margin of the basin. Distinct lower and upper tuff boundaries indicate rapid deposition of ash. In the 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 the northern basin as Miocene (ATANACKOVIĆ, 1959).

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

(a) Lower Pliocene deposits. The principal characteristic of the Lower Pliocene, which has a fairly large coverage in the northern Metohiyan depression, is its large coal deposit. The unit is divided the underlying strata and 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 the Peć area of the depression. The coal measures, about 35 m thick, and the overlying barren rock material, clay-marl deposits with some red burned are Upper Pontian. 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 the 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.

The 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 geotectonic entity that extends from Serbia into

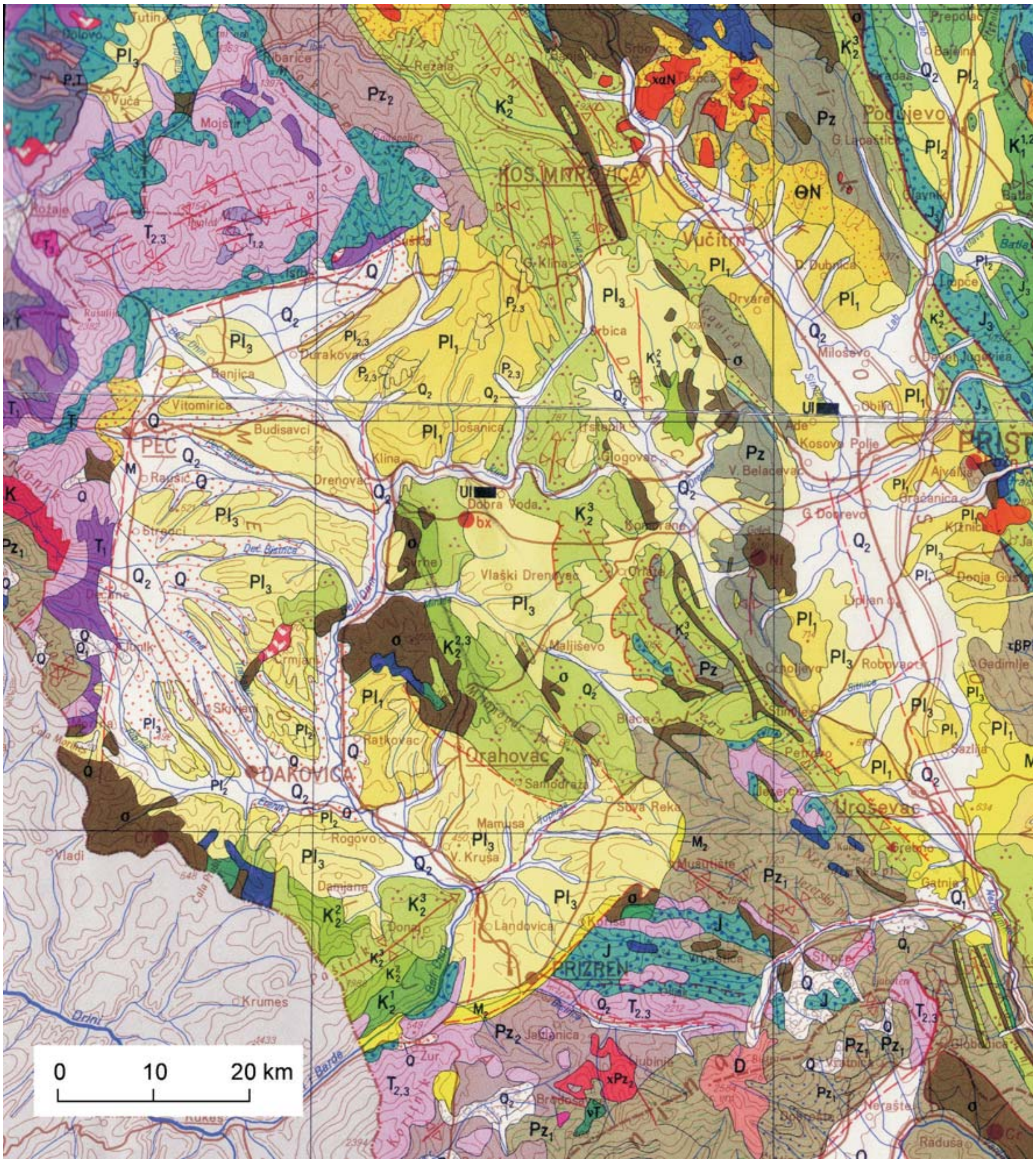

Fig. 1. Geological map of the Metohiyan Basin and its margin (Geological map of Yugoslavia 1:500 000, Federal Geological Survey, Belgrade, 1970). GSm, Gneiss and mica-schist; Pz, Paleozoic metamorphite; xPz, Paleozoic igneous rocks; PT, Permo–Triassic; T, Triassic; vT, Triassic igneous rocks; J, Jurassic; $\beta\beta$J, Jurassic diabase; Se, Serpentinite; K, Cretaceous; E,Ol, Eocene–Oligocene; θN, Neogene pyroclastics; M, Miocene; Pl, Pliocene; $\alpha\alpha$qN, Neogene dacite andesite; xαN, Neogene quartz latite; $\theta\tau\beta$Pl,Q, Pliocene and Quaternary pyroclastics and feldspar leucite basite; $\tau\beta$Pl,Q, Pliocene and Quaternary feldspar leucite basite; Q, Quaternary; Ul, coal.

Bosnia in the NW and Macedonia and Albania in the 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 the direction north–south on the eastern margin of the depression. Major tectonic units in this area, which control the tectonic depression, are: a marginal system of faults, the river Klina fault system and the Ćićavica thrust-sheet (PETKOVIĆ & SIKOŠEK 1976) (Fig. 2).

The view so far prevailing is that the Metohiyan depression was formed by the 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 the Metohiyan tectonic depression on the 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). The 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 strike directions Dinaric orogen structures, 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 the 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 the NE, the direction presently referred to as Metohiyan, because it is best marked around the Metohiyan depression".

Similar curvings are noted on the other side of the Metohiyan depression in the Shar Mountain system (Shar, Koritnik and Paštrik), where the meridian direction changes into the Metohiyan direction (NE). CVIJIĆ (1901, 1924) tried to explain the phenomenon by tectonic control. His hypothesis was that the curving of the folds and directrices in Prokletije and further westward caused the orographic bending.

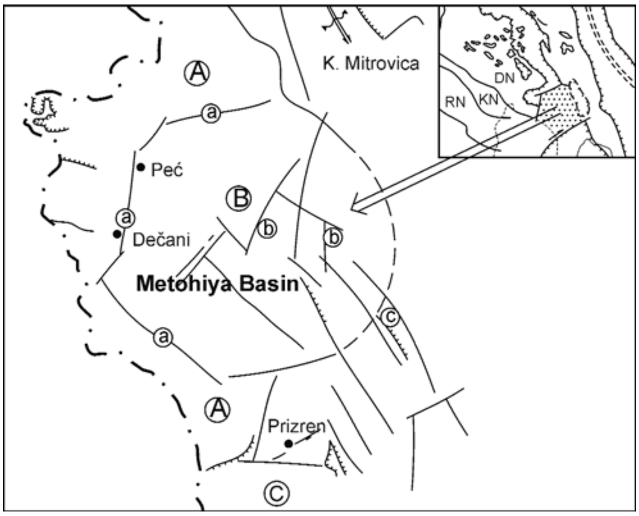

Fig 2. Tectonic map of Metohiya and its margin (modified after PETKOVIĆ & SIKOŠEK 1976). DN, Durmitor nappe; KN, Kuči (Žijovo) nappe; RN, Rumija nappe. Geotectonic units: A, Central Paleozoic and ophiolite belt; B, Tectonic depression of Metohiya (a, Metohiya depression marginal fault system, b, the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

General Impact Effect and Product (Impactite)

It is interesting to note that not one of geologists or other researchers who studied this region ever thought of the impact of 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 family planets of the Earth (Mars, Mercury, and Venus) and their satellites the Moon, etc.) 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 the ring structures were impact craters and that no more than 20% of all the 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 had decreased 200 to 300 times (it was calculated that in the early stages of the Earth's evolution, 10^3–10^4 bodies between 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 as 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 is 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 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 have been 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 the 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 the formation of its upper mantle. This is equally interesting for tectonists and petrologists, geochemists and sedimentologists, or, in other words, for many disciplines of geological science.

Principal bombardment effects are the following: (1) essential contribution to the planet is energy on the account of rapidity of the strikes, transformation of kinetic into thermal energy, (2) initiation of volcanism, the products of which mostly fill craters and (3) meteorite bombardment on the Earth's surface, which led to essential redistribution and mixing of material, and to changes of its chemical composition.

Nevertheless, it is interesting to learn and explain the character of basalt volcanism on different planets, because basalt is one of the essential constituents in the crusts of planetss. It is well known 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's family? The question is still obscure because the 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 an elevated central area of shock-metamorphosed rocks, which form a central peak and/or inner ring (ANTONOVIĆ & SIMIĆ 2006).

A brief review of the geology and geophysics of many Earth's craters can be found in the works by DENCE *et al*. (1977) and MASAITIS *et al*. (1980). In some examples of extraordinary geological circumstances, the formation of large impact structures influenced the precipitation and emergence on the ground of surface ore deposits (e.g. Ni-sulphides in the Sudbury structure; MORRISON 1982). In some impact structures, appreciable reserves of hydrocarbon were also formed, as in the Boltish depression (YURK *et al*. 1975) and Viewfield (SAWATZKY 1977). An impact exerts deep effects on the local geology, disturbing 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's 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 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, which caused volcanic events over a large area (GRIEV & PARMENTE, 1984).

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

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 a crater;

c) transformation of the 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 a collision, may be considered at several levels:

1. On the atomic/molecular level, the shock wave causes atom compaction, or destruction of atomic or molecular bonds. The high temperature rise 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. On 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 the 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. The 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

The 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, the 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 the Metohiyan depression is manifested in sharp changes of the strike directions, from E–W to NW–SE to NE–SW to N–S (Figs. 1 and 2). An impact or a vestige of its edge may explain the 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, strikes in the NW–SE direction from Dobroš to Damnjan. The eastern border of the Metohya Basin is similarly curved. The morphology of the bent structures and abrupt change in their strike directions on the edge of the Metohiyan depression can be satisfactorily explained neither by the convergence of the Dinaric and Shar-Pindus systems nor by plate rotation or gravitational sliding. The best explanation is that it was produced by an impact.

2. Another feature suggesting its impact structure is the 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 some rock as those building up the sides of the depression. Also, subsidence is manifested (DRAGAŠEVIĆ 1974), in the then thinner Earth's crust in the structures, by a lower common thermal gradient.

3. More evidence of the likely impact character of the 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 the formation of Orahovac peridotite? The answers to this and many other questions may be searched for in the 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, and geophysical studies.

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Резиме

Нови погледи на структурни склоп Метохијског басена и његовог обода

Метохијска котлина представља једну од крупних и у структурном погледу сложених геотектонских јединица у јужној Србији. Значајне тектонске јединице, које се у том простору јављају, односно које условљавају појављивање те саме депресије су ободни систем раседа и систем раседа реке Клине и краљушт Ћићавице. И летимичним погледом на геолошко-структурну карту овог подручја Србије неке особености избијају у први план:

1. Оно што је одмах уочљиво је необично савијање дубинских структура у јужном, западном, северозападном и северном делу Метохијске котлине, што се манифестује наглим променама правца пружања од И–З, СЗ–ЈИ, СИ–ЈЗ, С–Ј и др, (сл. 1, 2). Ове ненадне и нагле промене правца пружања структура, њихов скоро кружан (прстенаст) облик може бити објашњен импактом, односно може бити наслеђен од обода импакта. На западном ободу постоје два раседа, који се пружају: један од Пећи до Дечана, скоро у правцу С–Ј, а други, који чини југозападну границу басена, протеже се у правцу СЗ–ЈИ, од Доброжа до Дамњана. Нешто слично имамо и у источном ободном делу Метохијског басена. Оваква морфологија структура са великим повијањем и наглим променама правца у ободном делу Метохијске депресије, не може се задовољавајуће објаснити, тектонским сутоком Динарске и Шарско–пиндске системе, као ни евентуалном ротацијом пложа или гравитацијским колапсом, већ импактном структуром.

2. Следећа особеност која указује на импактну структуру је седиментолошки препознатљива готово 1000 метара дубока кружна депресија испуњана неогеним седиментима са великим наслагама угља, ограничена разломљеним и деформисаним творевинама "централног палеозојског и офиолитског појаса" (сл. 2). Заправо основу седимената (кластита) који испуњавају котлину чине стене које изграђују ободни део депресије. Исто тако је евидентно тоњење (види ДРАГАШЕВИЋ 1974), мања дебљина Земљине коре у овим структурама, као и нижи температурни ток (градијент) од уобичајених.

3. Следећи доказ у односу на могуће импактне карактере структура нуде неке геофизичке чињенице. У првом реду је сагласност позитивних геомагнетских аномалија са овом кружном прстенастом структуром (ВУКАШИНОВИЋ 2005).

4. Идеју о прстенастој структури поткрепљује дистрибуција олигомиоценских интермедијарних вулканита, који су жесто носиоци великих и местимижно богатих Pb–Zn лежишта (североисточо од Метохијске котлине – Трепча и др.).

Формирање метохијске депресије, тешко је временски тачно одредити. Највероватније да се то десило пре горње креде, а после тријаса (могуће и у палеогену). Неки аутори (БОГДАНОВИЋ 1976) скретање набора везује за Мирдитски перидотитски масив. Није ли скретање бора и настанак ораховачког перидотита временски повезано и узроковано метеоритским ударом, односно импактом. Одговор на ово питање и, многа друга, крије се како у седиментима Метохије, тако и творевина његовог обода и захтева студиозно проучавање. Та проучавања морају да буду мултидисциплинарна и свеобухватна од геолошко-структуролошких, атомско-молекуларних, кристалографских, минералошких, петролошких, геохемијских, геофизичких и других испитивања.