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GEOLOGICAL CHARACTERISTICS OF THE REPUBLIC OF NORTH MACEDONIA

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A b s t r a c t: Detailed description of the geological characteristics of the Republic of North Macedonia is given. The characteristics of the six major tectonic units are described: the Vardar zone (VZ) in Central Region, the Pelagonian massif (PM), the West-Macedonian zone (WMZ) and a small part of the Cukali-Krasta zone (CKZ) in the west, and the Serbo-Macedonian massif (SMM) and the Kraishtide zone (KZ) in the east. The geological map with these units is also shown, including the most presented lithological units: Quaternary alluvial and deluvial/proluvial sediments, Neogene, Paleogene and Mesozoic clastic rocks, Mesozoic, Paleozoic and Proterozoic carbonate rocks, Paleozoic and Proterozoic metamorphic rocks from Pelagonian and Serbo-Macedonian massif and Neogene, Paleogene, Mesozoic and Paleozoic magmatic rocks. Additionally, special attention is given to the Neogene and the Quaternary in North Macedonia.

Key words: geology; tectonic units; lithological units; North Macedonia

INTRODUCTION

Although the exploitation and utilisation of precious and nonferrous metals, decorative stones and other mineral resources has a long tradition in the Republic of Macedonia, the first geological studies of any scientific weight within the territory were carried out in the first half of the 19th century, when geology was separated from natural science as the science of the Earth, its genesis and development. The first written geological studies on Macedonia were undertaken by the French geologist Ami Boué, who published a paper entitled "Geologie de la Macédoine" in 1840, a historical documentation of the early spread of geological scientific thought in Macedonia (Boué, 1840). After Boué's work in the second half of the 19th century, studies on the geology of Macedonia were carried out by several well-known German and Austrian geologists. At the end of the 19th century and especially in the first half of the 20th century, such work of foreign researchers intensified until in 1944, during the first government of the Republic of Macedonia, Geological Institute, the first national geological institution of Macedonia, was established by the department of National Economy.

With the establishment of this institution, the organized and systematic geological research of the Macedonian territory began including the preparation of targeted geological maps related to mineral resources, followed by a basic geological map at the scale of 1:100,000 (Federal Geological Survey of SFRY, 1963–1985) and basic metallogenic, hydrogeological and engineering-geological maps. In addition, numerous papers by various authors have been published, including monographs and articles studying the geological-tectonic and lithologic setting of certain parts or regions of the whole territory of North Macedonia, resulting in today's picture of the country's geological structure.

The major geological and tectonic characteristics of the Republic of North Macedonia are described by the following authors: Arsovski & Petkovski (1975), Pendžerkovski (1976), Pendžerkovski & Hadži-Mitrova (1977), Petkovski (1990), Serafimovski et al. (1995), Popov et al. (1996), Dumurdžanov et al. (2004, 2005, 2008), Stafilov & Šajn (2016, 2019), Stafilov et al. (2019).

Based on these earlier studies, it could be concluded that the Republic of North Macedonia has a complex geology and extensive configuration,

including many geological formations of different ages and different geologic and granular compositions, which have resulted in a large variety of soil types (Figure 1).

The oldest complexes are developed in the Serbo-Macedonian massif and the Pelagonian massif, and are represented by highly metamorphic Proterozoic rocks, as well as widely disseminated Riphean-Cambrian, Paleozoic, Mesozoic and Cenozoic rocks.

The thickness of the Earth's crust in Macedonia has been studied by several researchers, most recently in 2003–2004 by a team of French, Italian, Albanian, Macedonian and Bulgarian geologists, who defined the deep geological profile Transect III in terms of the following flow direction: Central Massif–Lyon Gulf–Provencal Basin–Sardinia–Tyrrhenian Sea–Apulia–Adriatic Sea–Albania–Macedonia–Bulgaria–Mezian Platform, in the framework of the project "Transmed Atlas: The Mediterranean Region from Crust to Mantle – Transect III" (Cavazza et al., 2004). The Macedonian part of Transect III and the interpretation of the Earth's crust was established based on geological data from the Basic Geological Map 1:100,000, the results of measurements carried out at two deep seismic profiles (Debar–Veles–Delčevo and Tetovo–Skopje–Kočani), as well as on 1:500,000 gravimetric and geomagnetic maps. According to these data (Dragašević et al., 1989), and the latest reinterpreted geophysical data from the Geological Survey of the Republic of North Macedonia, the lowest thickness of about 28 km occurs in the Vardar zone, which rises to 36–39 km in both the east and west (Stolić & Starčević, 2019a, 2019b).

Although formed during different geological periods, the Macedonian geotectonic units are generally elongated in the NNW–SSE to N–S direction, with their mutual contacts marked by regional faults of deeper character formed or reactivated by the Laramide compression (Laramide orogene phase). Units are generally overthrust from east to west, with the highest occurring in parts of the Western-Macedonian zone in the form of the Cukali-Krasta zone, as seen in the depth profile. Local contacts are covered with Tertiary and especially Neogene sediments.

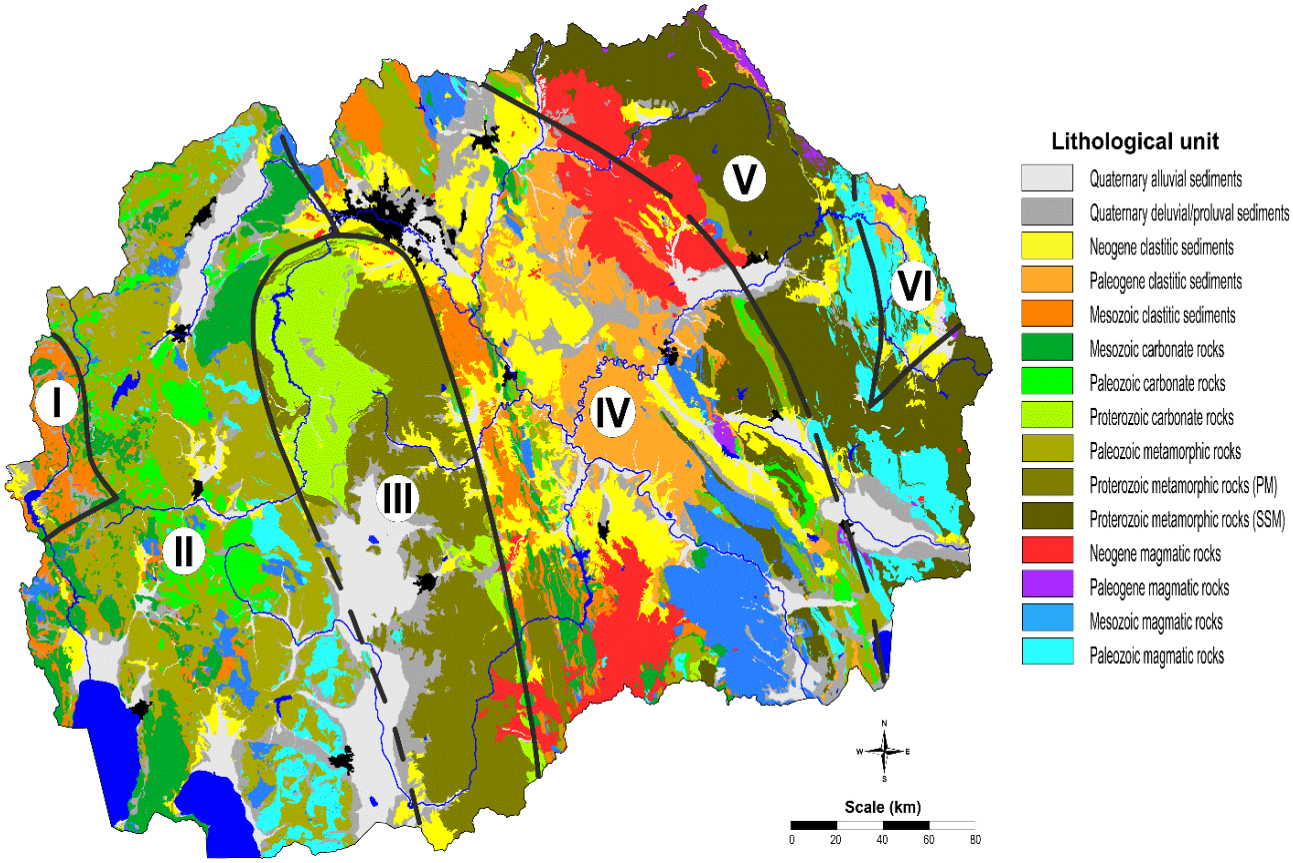

Fig. 1. Simplified geological map of the Republic of Macedonia Tectonic units (according to Arsovski, 1997):
I – Cukali-Krasta zone (CKZ), II – West-Macedonian zone (WMZ), III – Pelagonian massif (PM). IV – Vardar zone (VZ), V – Serbo-Macedonian massif (SMM), VI – Kraishtide zone (KZ).

From a tectonic point of view, Macedonia comprises six major tectonic units (Arsovski, 1997), including the Vardar zone (VZ) in the central region, the Pelagonian massif (PM), West- Macedonian zone (WMZ) and a small part of the Cukali-Krasta zone (CKZ) in the west, and the Serbo-Macedonian massif (SMM) and Kraishtide zone (KZ) in the east of the country (Figure 1).

In the geological map (Figure 1) the most presented lithological units are included: Quaternary alluvial and deluvial/proluvial sediments, Neogene, Paleogene and Mesozoic clastic rocks, Mesozoic, Paleozoic and Proterozoic carbonate rocks, Paleozoic and Proterozoic metamorphic rocks from Pelagonian and Serbo-Macedonian massif and Neogene, Paleogene, Mesozoic and Paleozoic magmatic rocks..

CUKALI-KRASTA ZONE (CKZ)

The Cukali-Krasta zone is mainly prevalent in Albania, with the small part found in Macedonia occurring in the vicinity of Debar (the Debar zone). This zone is composed of Upper Cretaceous, i.e. Turonian, conglomerates – sandstones, claystones and limestones with olistostromes – on a thickness of up to 1000 m, on which Senonian rudist limestones with a thickness of 300–400 m are developed. In this zone evaporites and minor Paleogene sediments are present.

The boundary with the West-Macedonian zone is marked by the Stogovo nappe, after which the Paleozoic, Triassic and Jurassic complex occurs as a bundled mass, with an allochthonous length of 7–10 km (probably more) through the Upper Cretaceous sediments and evaporites of the Cukali-Krasta zone. This zone in the Debar area essentially represents a tectonic half-window.

Very important in the Cukali-Krasta zone is the diapiric structure of Dešat Mt., composed of anhydrite and gypsum, characterized by partial but noticeable diapiric, internal folding and brecciation, with the development of tectonic breccias – milonites at the contacts with the adjacent rock masses.

The age of the evaporites is problematic. According to Albanian geologists (Aubouine & Ndojaj, 1964), the diapirs are of Triassic evaporites, but there are also contrasting opinions that they are in fact Lower Cretaceous evaporites (in Ulcinj, Montenegro) (Aubouine & Ndojaj, 1964; Robertson & Shallo, 2000).

WEST-MACEDONIAN ZONE (WMZ)

According to its lithostratigraphic and tectonic structure, magmatism and degree of metamorphism, the West-Macedonian zone can be characterized as a single block unit within the Internal Dinarides, nested among the Pelagonian massif to the east and ophiolite Merdita and Cukali-Krasta zones to the west (in Albania).

The internal tectonic structure of the zone is constructed mainly during the Hercynian and Laramide compressions, with softer fold structures (synclinal structures of the Bistra and Galičica Mts. and many others) appearing in its inner parts. In the border areas with the Merdita and Cukali-Krasta zones and the Pelagonian massif, the folds exhibit a western vergence (including the Pesjak–Dobra Voda inverted syncline at the boundary with the Pelagonian).

Segmentation of the mass with regional reversed faults, shells and snappes, with a dominant NW–SE orientation and western vergence, is caused mainly by Laramide compression (Stogovo and Galičica nappes, etc.). The Pyrénées–Sava movements are less affected and are expressed primarily in the western border areas, manifested by new faulting, incurring and local folding.

The West-Macedonian zone is lithologically built of lowgrade metamorphic rocks and anchimetamorphic Paleozoic rocks and magmatites, Triassic and Jurassic sediments and magmatites, as well as Tertiary sediments.

The **Paleozoic** predominates in the composition of the Western-Macedonian zone, as it is represented both in the lower level, i.e. in the Cambrian-Ordovician complex, and in the upper level, i.e. in the Silurian-Devonian complex. Between these two complexes there is a metamorphic discordance; the contact is very often characterized by faults, while the stratigraphic transition is still unclear (probably

transgressive). The two centres are characterized by the intrusion of Hercian magmatism.

The Cambrian-Ordovician complex is detected in natural cross-sections at depths of up to 5–7 km and represents one volcanogenic sedimentary lithozone metamorphosed to green schists facies. In the vertical profile of the lithozone, quartz-sericite, quartz-sericite-chlorite, graphitic and green schists, metaconglomerates, quartzite, as well as minor marble bands are changed at all levels with intrastratificated masses of metagabbro, metadiabases, metarhyolites and metakeratophyres. Cambrian microfauna has been identified in the carbonate layers on Karaorman Mt., while the upper levels are characterized by the presence of Ordovician trilobites and other fauna and flora.

The Silurian-Devonian complex has undergone the anchiometamorphic alteration and has a thickness of 2.5 to 3 km. The lower part is composed of metasandstones, argiloschists and siderite-chamosite shale, together with less abundant metarhyolites and metadiabases, with an assumed Silurian age. The upper part consists of calcareous shale and limestone marbleisred limestones with a thickness of up to 600 m in which Lower and Middle Devonian fossils of brachiopods, clams, corals, tentaculites, cephalopods, crinoids and conodonts are found.

Hercynian granitoids with larger masses occur in the areas of the Pelister, Plakenska and Kruševo Mts., with smaller bodies occur elsewhere in the zone. While the plutonic mass of the Pelister and Plakenska mountains is dominated by granites, granodiorites, syenites, syeno-granites and syeno-diorites, that of the Kruševo Mts. is composed of granites and granodiorites. Hercynian granitoids participated in low-grade metamorphic changes during the Paleozoic, while larger intrusive contacts are characterized by contact metamorphic changes in the adjacent shale.

Triassic material is widely distributed throughout the Galičica, Petrina, Bistra, Jablanica and Šar Planina mountains. These begin with transgressive Olenekian-Anisian conglomerates, sandstones and clay with thicknesses up to 150 m, followed by minor limestone subordinately dolomite with cherts of old Middle-Upper Triassic in age. The total Triassic mass is 600–700 m thick, with paleontological evidence quite well documented in the form of ammonites, brachiopods, gastropods, shellfish, conodonts, algae and others.

The **Jurassic** is represented by Pelagonian volcanogenic–sedimentary accumulates in the areas of the Korab–Dešat mountains,. Radika Valley and Mt. Jablanica. The sedimentary mass is up to 1500 m thick, beginning with Lower Jurassic sandstone conglomerates, clay with cherts and limestone with flysch character, penetrated by diabases, gabbros, keratophyres and rhyolite, further with limestones and ending with breccia conglomerates with olistostromes of Upper Jurassic age. In the boundary sections with the Merdita zone in Albania, tectonic ultrabasites (Ljubaništa, Jablanica, etc.) occur. Smaller intrusive bodies of Jurassic granites are present at several localities.

PELAGONIAN MASSIF (PM)

The Pelagonian massif is a relict of a Proterozoic crystalline mass, with typically developed domes, brachy and open folds, which generally give the massif its anticlinorium shape. Along the periphery the Proterozoic mass is largely surrounded by a Riphean-Cambrian metamorphic complex.

The boundary with the West-Macedonian zone is represented by a deep regional reversed fault that penetrates the mass to the west, and with the Vardar zone by a system of parallel deep faults along which are imprinted tectonic ultrabasites. During younger orogenic phases, the Pelagon mainly suffered segmentation into smaller blocks.

The **Proterozoic** complex is a relict of the Grenville continental crust with a typical internal structural construction of domes, brachy and open folds. Lithologically it is built by high-grade metamorphic rocks and granitoids.

In central parts of the complex it is present down to a depth of 10–11 km, with pronounced vertical lithostratigraphic and metamorphic zoning. The lithostratigraphy of the metamorphic complex is as follows:

– Lower formation (series). The lower 7–8 km represents a lower metamorphic complex that underwent metamorphism in the epidote-amphibolite and amphibolitic fascies, composed of a zone of the lower gneiss (two-mica-almandine gneisses and rare amphibolites) over which an area of the upper gneiss (mixed zone) is developed built of two-micas, muscovite, porphyric and phengite gneisses and

migmatites, and disthene staurolite micaschists, amphibolites and quartzites.

– Mixed formation (series). It lies above the lower formation. This formation ranges in depth from 200 to 700 m and contains alternating cipolines, gneisses and micaschists.

– Marble formation (series). It reaches a thickness of up to 3 km and represents the upper part of the Proterozoic metamorphic complex. This forma tion consists of several horizons of calcite-dolomite, calcite and dolomite marbles.

Granitoids. The metamorphic complex polyphase is intruded by granitoids with an absolute age of 800–1000 million years, represented by granodiorites, quartz-diorites and granites as well as pegmatites, quartz and aplite dykes. These intrusions caused both the intense destruction of the existing folds and a progressive metamorphism, phenomena that were particularly expressed in the central parts of the massif.

Riphean-Cambrian. As a partially interrupted aureole, the Riphean-Cambrian complex surrounds the crystal mass of the Pelagonian massif with a transgressive and discordant contact. The mass has a thickness of 1500–2000 m, metamorphosed in the conditions of epidote-amphibole facies, and is built of garnet, graphitic and micaschists, marbles and metabasites. The age of the complex was determined by pollen analysis and correlation. Blue schists with crossite, glaucophane and phengite are locally developed at the contact with the Vardar zone.

VARDAR ZONE (VZ)

The Vardar zone separates the Dinarides, i.e. the Pelagonian massif and the West-Macedonian zone, to the west, from the Serbo-Macedonian massif to the east. It is an old structure, that probably dates back to the Lower Paleozoic. In this area a continuous thinning of the continental crust occurred, which during the Lower Jurassic completely transited into the rift zone (narrow ocean, like the Red Sea). It stretched north from the Pannonian Basin through Belgrade–Southern Serbia–Central Macedonia to the Aegean Sea, where it turned out to the east and continued as the Izmir-Ankara ophiolitic zone in Turkey.

The spreading of the oceanic crust in the Vardar zone continued until Upper Jurassic–Lower Cretaceous, when the regime changed and the process of unilateral eastern subduction under the Serbo-Macedonian mass began.

Further developments in the zone included alternation of extension and compression. For example, during the extension phase at the end of the Lower Cretaceous and in Upper Cretaceous, the troughs were filled with flysch and flyschoid sediments were created as in the Eocene–Oligocene.

During the Lower Cretaceous, between the Turonian and Senonian as well as the Paleocene and Oligocene, a compressive regime characterized by intense folding and thrusting, with a Young-Cimmerian, sub-Hercynian, Laramide, Pyrénées–Sava orogene phase of which traces in Vardar zone complexes are preserved.

With regard to its internal tectonic structure, the Vardar zone can be considered as a tectonic mélange, with a zone of thrust and incurring to the W and SW and with the presence of deep faults. This area is characterized by the presence of crystal blocks of Kozjak and Small Rupa (separated from the Pelagonian massif), the Serta–Gradeški Mountains and the Bučim block (separated from Serbo-Macedonian massif), as well as Paleozoic low-metamorphic rocks, Triassic continental sediments, Jurassic ophiolites and ultrabasites and Cretaceous sediments, all segmented in many shells penetrated to the SW and W in Eocene-Oligocene sediments and vulcanites.

The **Paleozoic** is represented in the lower level by volcanogenic sedimentary formations of various shales, metadiabasites and metarhyolites of the assumed Cambric-Ordovician age, and in the upper level of low-grade schists and marbles of Silurian-Devonian age. Paleontologically they are relatively sterile in fossil material and their ages mainly were determined by pollen analysis and correlation. The whole complex has been extensively folded, stripped and overthrust to the W and SW as a result of the Hercynian orogeny and especially the young Cimmerian and Laramide compression, traces of which have been clearly decoded.

The **Triassic** is preserved in several stripped masses in the western part of the zone. The sediments, paleontologically documented with the Lower, Middle and Upper Triassic ages, are represented by basalt conglomerates, sandstones, and clay which dominant up to 150 m and through which limestones with a thickness of 450–500 m develop.

The **Jurassic** period is the most important phase in the development of the Vardar zone as a rift zone. Sometimes significantly widespread oceanic crust, later occupied by subduction and multiple compressions (collision processes), the zone was split into many elongated stripped masses and smaller bodies, the most important segment of which is the Demir Kapija-Gevgelija complex where the lithostratigraphy of the oceanic crust is completely preserved.

In this ophiolitic massif, the oceanic crust is exposed in a cross-section in which the following 8 superposed formations occur:

- olivine, pyroxene and amphibolite gabbros and associated verlites, dunites and troctolites,
- sheeted (dyked) complex,
- massive basalts,
- spilitised pillow basalts,
- spilite keratophyre level,
- terrigenous-basalt-chert formation,
- flysch formation,
- carbonate formation (Tithonian).

Jurassic magmatism is also characterized by the appearance of collision granitoids with an absolute age of 152–162 million years, as represented by quartz-monzonites, granites and granodiorites which occur in very long masses in the section of the Gradeški Mountains – Serta, Gurničet, Bučim block, Lojane and other places. Here they are subject to strong contact changes, mostly with the Paleozoic shales and ophiolite masses of the Demir Kapija – Gevgelija massif and Lojane.

Along the deep faults and major overthrusts and shells of the Vardar zone there are intruded masses of tectonic ultrabasites, of which the largest are the Ljuboten ultrabasic massif, the Lojane and Rabrovo massifs and Bogoslovec.

The **Cretaceous** is present in the form of Aptian-Albian-Cenomanian-Turonian flyschoid terrigenous and minor calcareous sediments. These have a thickness of up to about 1800 m and lie transgressively over the Jurassic ophiolites, which are particularly widespread in the central parts of the Vardar zone. In the western parts of the Vardar zone, Senonian flysch carbonate sediments with a thickness of about 2200 m are developed. All are paleontologically documented.

Eocene-Oligocene flyschoid and flysch sediments have been formed in the Tikveš and Ovče Pole basins, with the thickness reaching 3.5–4 km and often occurs in several smaller relicts distributed over the Vardar zone. The layers are slightly folded and are also locally stripped and overthrust to the SW due to the Pyrénées–Sava compression. Lithologically, Eocene basal, lower and upper flysch lithozones and an Oligocene terrigenous-carbonate lithozone are presented. Based on a rich fossil fauna assemblage including gastropods, shells, corals, nummulites, microforaminifers, nanofossils and pollen, a mainly Upper Eocene and Oligocene sediment age was determined, with lower masses probably originating from Middle Eocene.

Tertiary volcanites. Eastern parts of the Vardar zone, particularly the boundary areas to the Serbo-Macedonian massif, are characterized by the widespread distribution of volcanic masses, including the Kratovo–Zletovo and Bučim–Damjan–Borov Dol volcanic areas as well as in SW parts of the zone area of Kožuf Mt.. This volcanism is mainly of intermediate character and is represented by andesites, andesite-latites, latites and quartz latites, with rare rhyodacites, trachytes and basalts. In the Kratovo–Zletovo and Bučim–Damjan–Borov Dol areas, volcanism started in Upper Oligocene, with maximal intensity occurring in the Lower and Middle Miocene at 25–14 Ma. Mt. Kožuf volcanism is younger and was active from the Upper Miocene and Pliocene until the beginning of the Quaternary – with an absolute age of 6 to 1.8 Ma.

Active volcanism in the Vardar zone during the Upper Miocene–-Pliocene resulted in the products of alkaline basalts from which larger effusive magma masses and necks occur in the areas of Staro Nagoričane near Kumanovo, Gjuriški Monastery, Ežovo Hill and elsewhere.

SERBO-MACEDONIAN MASSIF (SMM)

It is assumed that the Serbo-Macedonian massif is an accretionary wedge on the eastern margin of the Eurasian plate, located in front of the Carpatho–Balkanides and pulled down over the Vardar zone. The main mass is built of Lower or overthrust Proterozoic and Upper Riphean-Cambrian complex, together. There are also relicts of Lower Paleozoic schists and intrusives of Hercynian granitoids. In the northeast there are numerous cliffs of Triassic sediments, as well as small masses of Eocene-Oligocene sediments and Oligo-Miocene volcanics.

Proterozoic material is present in deep cross-sections in the form of various highly metamorphous types of gneiss, mica, amphibolites and rare metagranites and eclogites. The complex has been exposed to many orogenic phases (Baikal, Caledonian, Hercynian, Alpian) and has experienced major structural and petrological changes. The mass is multiple wedged, with an appearance of retrograde metamorphism, diaphtoresis and others.

The **Riphean-Cambrian** is represented by a volcanogeno-sedimentary mass, with characteristic ophiolites in Bulgaria known as the Froloshka formation and in Serbia as the Vlasina complex. It is separated from the Proterozoic mass by stratigraphic and metamorphic discordance, and is built by green-schistoid fascia metamorphites, i.e. metaconglomerates, metasandstones, diverse green schist, and metagabbro and metadiabases. These are signifcantly altered by the impact of Hercynian granitoids.

The **Old Paleozoic** is represented by some small relict masses, which appear as enclaves in masses of Hercynian granitoids. These are mainly low metamorphic argiloschists and quartz-sericite and graphitic shales of Silurian-Devonian age.

Hercynian granitoids are relatively widespread in the massif, with many varieties concentrated mainly in two batholiths: Delčevo and Ograždeni. Both batholiths are associated with metasomatic intensive contact change to the Proterozoic and Riphean-Cambrian complexes, but they themselves have also suffered significant tectonic destruction due to the compressions of the Alpine orogeny. The Delčevo batholith consists of two formations: Delčevo and Golak. The Delčevo formation consists of coarse-grained porphyroids, monzonitic fine-grained, pink medium-grained and leucogranites, granophyric granites, granite porphyry, granodiorites and quartz-diorites. The Golak formation is composed of aplite granites, aplites and granophyric granites.

The Ograždeni batholith consists of many structural and textural granite varieties. This batholith is a bearer of intensive sodium metasomathosis and around its perimetric boundary it has developed an aureole of contact metamorphism. The Triassic material of the massif is mainly developed in the northeastern parts, most frequently with rock overthrust over Riphean-Cambrian rocks, Hercynian granitoid masses and Paleogene material, but also with smaller masses lying transgressively over granitoids. It is represented by terrigenous basalt and calcareous sediments.

The **Paleogene** is represented by several relict masses of Eocene-Oligocene age, which are very similar to the Ovče Pole basin in terms of lithostratigraphy and fossil content.

Tertiary volcanics occur in numerous elongated subvolcanic or volcanic bodies and pyroclastic masses, mainly andesite, latite-quartzites and dacites occur in Toranica–Delčevo–Buković–Dvorište–Ilovica area. Their absolute age is Upper Oligocene-Lower Miocene.

KRAISHTIDE ZONE (KZ)

This area is assigned by Arsovski (1997) and, according to Karagjuleva et al. (1974), represents the southernmost segment of Carpatho-Balkanides, which is interwoven into the Serbo-Macedonian. The largest part of the zone is located in Bulgaria and is characterized by a special type of alpine development compared to the adjacent areas. In Macedonia it covers an area of about 800 km^2 and is widely spread in the border area with Bulgaria on the upper reaches of the Bregalnica river. It includes areas of the Tertiary, Pijanec (Delčevo-Pehčevo) graben and the surrounding massifs: Golak in the west and Mt. Vlaina in the east.

Within the Kraishtide area, a special type of green shale formation has formed, represented by the increased occurrence of metagabbros, metadiabases and green metasandstones floating in Hercynian aplitoid granitoids. During the Middle Alpine period, the Pijanec graben was formed on which Eocene flysch sediments are imposed, together with Plioquaternary molasse deposits. During the last Alpine stage, starting from the Oligocene, an intensive acidic volcanism was manifested.

THE NEOGENE IN NORTH MACEDONIA

The above description of the individual geological units does not include information on the Neogene because of the geological and tectonic processes, i.e. neotectonic movements, that developed during this period were perpetuated throughout the Republic of North Macedonia and beyond, without regard to individual tectonic units (Dumurdžanov et al., 2008). Namely, after the Sava compression in

the Upper Oligocene–Lower Miocene of this area and the central Balkans, a regime of relative tectonic stability and peneplanation of the terrain prevailed, from which period are preserved various relicts of the then established plains.

At the end of the Lower Miocene–beginning of Middle Miocene, Macedonia and the wider region were encompassed by an extension that caused the vertical tectonic segmentation of the terrains into blocks of elevation (horsts) and blocks of sinking (grabens). This extension was imposed on all tectonic units present within Macedonia, with the boundaries of the Neogene grabens and horsts located inside and not following the boundaries of these units.

Gravitational fault structures conditioned the relocation of terrains and the graben formations, which mostly converted to freshwater lake basins, with this taking place over several stages and with varying intensity. Starting with the end of the Lower Miocene–beginning of the Middle Miocene, the tectonic mobility of the terrains was characterized by periods of intense and reduced mobility and the formation of Neogene-Quaternary basins in 5 distinct cycles:

- Cycle I (Baden – beginning of Upper Sarmatian): onset of the formation of the Skopje, Kumanovo, Probištip, Kočani and most probably the Slavište basins.
- Cycle II (Upper Sarmatian – Meot): Pelagonia, Strumica, Polog, Veles, Tikveš, Mariovo, Kičevo, Piskupština, Delčevo-Pehčevo and Berovo basins.
- Cycle III (Upper Meot – Pont): Prespa, Ohrid, Debarca, Debar and Dojran basins.
- Cycle IV (Pliocene): Lakavica, Gevgelia, Poreče and Mavrovo basins.
- Cycle V (Pleistocene): Demir Hisar, Valandovo, Gevgelia and Raec basins.

In the oldest basins the stratigraphic column of the Neogene is completely developed, from Middle Miocene (Baden) to Quaternary sediments, while in the youngest only Pliocene-Quaternary and Quaternary sediments are present. The age of the sediments in most of these basins is documented based on fossil evidence in the form of gastropods, shellfish, macroflora (leaves) and diatoms.

As a result of these neotectonic movements, some of which continue today, a total of 27 grabens have formed in Macedonia, together with the associated preserved lake sediments. In the Neogene active volcanism was also present, as mentioned above in connection with the Vardar zone and the Serbo-Macedonian massif.

On the basis of seismic surveys from 2000 (GPS measurements comprising 24 measuring points, evenly distributed within the territory of Macedonia) and the interpretation of a team of American, Macedonian, Bulgarian and Albanian geologists, it is assumed that the terrains of Macedonia are moving south at a speed of 2–4 mm per year (Burchfiel et al., 2006).

THE QUATERNARY IN NORTH MACEDONIA

Quaternary sediments are mostly developed in the valleys where they cover the Neogene sediments, or on the mountain slopes. The duration of the Quaternary is about 2 Ma is divided according to geological age: Lower Quaternary – Q1: Pleistocene (glacial time), and Upper Quaternary – Q2: Holocene (postglacial era).

Pleistocene sediments are widely distributed on the territory of the Republic of North Macedonia. These sediments are mixed and various genetic types occurred in them. Higher mountains in the Republic of North Macedonia were affected by the process of glaciation (freezing) and were covered with glaciers. The general trend of elevation of terrains in conjunction with climate change condition to form glacial (moraine) and glaciofluvial sediments. Various preserved morphological forms of high mountains (waves, cirques, moraines, glacial lakes and others) clearly indicate that at all of our mountains above 1200–1500 m height was developed glaciation (Solunska Glava – Mokra Gora, Stogovo – Karaorman, Korab – Šar Planina, Pelister, Bistra, Jablanica, Karadžica, Jakupica, Nidže – Kožuf, Ruen, etc.). The development of Pleistocene glaciation was confirmed by paleontological studies by which on the many locations (Makarovec, Javorec, Orešani, Brodsko, etc.) certain fossils were found, mammal association of Riss-Würm integration and Würm glaciation.

Lake-swamp sediments are represented by gravels, sands, silt, dusty clay, rarely peat and limestone. They have a wide distribution in the areas of Ohrid, Prespa and Dojran lakes, which reaches a thickness of 50–60 m, and also in most

valleys such as Pelagonia, Skopje, Polog, Kičevo, Strumica, Tikveš and others. Terrigenous material is well treated, not sorted, poorly layered or non-layered.

Volcanogenic sediments are widespread especially in the Kratovo-Zletovo volcanic area and the most significant are tuffs, ignimbrites, andesites, trachyandesites, dacites, kyanites, basalts etc.

Young Holocene products have a large distribution at the territory of the Republic of North Macedonia. These deposits are represented by:

- River terraces which are developed in the lower flows of the major rivers such as Vardar, Treska, Lepenec, Crna Reka, Babuna, Pčinja, Kriva Reka, Bregalnica, Crn Drim and others. Terrace material is represented by various granulated gravels, sands and layered subclays.
- Proluvial deposits are found in the peripheral parts of the Pelagonia, Kičevo, Gevgelija, Debar and other valleys, on the slopes of the mountains of Plačkovica, Skopska Crna Gora, Stogovo. The deposits occur in large areas in the form of cones, represented by coarse-grained non-classified rounded or sharp-edged material.
- Deluvial deposits consist of sharp-edged pieces of adjacent rocks, mixed with sand and clay materials. The thickness of the deluvial deposits is 5–10 m. They occupy larger areas on the slopes of the mountain massifs.
- Alluvial deposits are developed in the river beds of all major rivers: Vardar, Treska, Crna Reka, Drim, Pčinja, Bregalnica, Babuna and others. The deposits are represent by rounded pebbles and gravely-sandy-clay material.

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Р е з и м е

ГЕОЛОШКИ КАРАКТЕРИСТИКИ НА РЕПУБЛИКА СЕВЕРНА МАКЕДОНИЈА

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Клучни зборови: геологија; тектонски единици; литолошки единици; Северна Македонија

Во трудот е даден детален опис на геолошките карактеристики на Република Северна Македонија. Опишани се карактеристиките на шесте главни тектонски единици: Вардарската зона (VZ) во централниот дел на земјата, Пелагонискиот масив (PM), Западно-македонската зона (WMZ) и помал дел од зоната Цукали-Краста (CKZ) во западниот дел, Српско-македонскиот масив (SMM) и Краиштидната зона (KZ) во источниот дел. Прикажана е и геолошка карта со овие единици, како и најзастапените литолошки единици: квартерни седименти на алувиум и делувиум/пролувиум неогени, палеогени и мезозојски кластични карпи, мезозојски, палеозојски и протерозојски карбонатни карпи, палеозојски и протерозојски метаморфни карпи од Пелагонсискиот и Српско-макеоднскиот масив и неогени, палеогени, мезозојски и палеозојски магматски карпи. Дополнително, посебно внимание е посветено на неоген и квартер во Северна Македонија.