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# Link between active tectonics/faulting and mineral and thermal water occurrence in Republic of North Macedonia

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# Връзката между разломната тектоника и наличието на минерални и термоминерални води на територията на Република Северна Македония

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**Abstract.** According to the tectonic architecture of the Balkan Peninsula, the territory of Macedonia belongs to the Dinarides, Rhodope and Carpatho-Balkanides. In a relatively small area, Macedonia has a very complex geological and tectonic structure, which was shaped by intense and long-term processes, followed by magmatism of a wide spectrum, from the ultrabasic to the acidic. From a stratigraphic point of view, geological formations consist of the oldest Precambrian high-grade metamorphic rocks to the youngest Quaternary deposits, and such a complex geological structure conditions the creation of different hydrogeological structures (open, semi-open and closed) in which different hydrogeological processes take place. As a result of complex tectonic activity on the territory of Macedonia, numerous mineral and thermal waters are present. The aim of this paper is to show the link between the occurrence of thermal and mineral waters and the active tectonics along which they are represented.

*Keywords*: active tectonics, mineral, thermomineral and thermal waters, Republic of North Macedonia.

## Introduction

The Republic of North Macedonia, as part of the Balkan region, tectonically belongs to the Mediterranean orogenic area of the Alpine-Himalayan belt. Territorially, it is located in the southern and central part of the Balkan Peninsula and occupies part of the mountain systems: Hellinides, Dinarides and Balkanides. It borders Bulgaria to the east, Albania to the west, Greece to the south, and Serbia to the north. The total area of Macedonia is 25,713 km$^2$ and with an average height above sea level of 850 m, dominated by mountainous and hilly terrain segmented by deeply cut river valleys and a river network of mostly dendritic type. The valley of the Vardar River, dominated by the hypsometrically lowest parts, divides the Republic of North Macedonia into two parts, so that three orographic units are generally distinguished on the territory of Macedonia: Western part of Macedonia, Povardarje or Central part and Eastern part.



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The eastern part of Macedonia is dominated by mountain massifs that are part of the Rhodope Mountains and are represented by isolated mountains separated by incised valleys of the left tributaries of the Vardar. Among the mountain massifs, the Osogovo Mountains (highest peak Rouen 2251 m), Plachkovica (Lisec 1754 m), Ograzden (1744 m) stand out. The solitary elevations are built mainly of granite, crystalline schist and magmatite. Between them stretch basins filled with tertiary lake sediments: Strumica basin, Kumanovo basin and Ovche pole.

The western part is somewhat hypsometrically higher than the eastern part of the country, and it is built of newly folded mountains built of Paleozoic slates and Mesozoic limestones, of which the following mountains should be mentioned: Baba (2601 m), Shar-planina (2748 m), Korab (Veliki Korab 2764 m, at the same time the highest peak of Macedonia), Jakupica (Solunska glava 2540 m), Nidze (2521 m), Kozuf (2176 m) and others. Between the mountains there are deep valleys of the Black Drim and several mountain basins: the Poloska Basin, the Debar basin, the Ohrid basin, the Prespa basin and the Bitola-Prilep basin.

The central part, or Povardarje, is a tectonically active area filled with lakes and rivers. It consists of a series of basins interconnected by gorges, going from north to south: Skopje Basin, Veles Basin, Tikvesh, and Gevgelija Basin. This region is also the most densely populated, with notable cities including Skopje, Veles, Kavadarci, Negotino, and Demir Kapija.

## Regional tectonics of the Republic of North Macedonia

On the territory of Macedonia, there are 4 separate geotectonic units (from west to east): Western - Macedonian, Pelagonian horst – anticlinorium, Vardar zone and Serbo-Macedonian massif, which differ from each other in terms of their composition and evolution (Arsovski, 1997).

*The Western Macedonian Zone* is characterized by a complex geological structure, so there is a noticeable difference in the geological composition between the eastern and western parts. In the eastern part, there are larger granite massifs such as Pelister, Krushevski, etc. In the western part of this zone, in addition to the Paleozoic, there are also Mesozoic deposits, mainly carbonate, and Tertiary sediments, that are also widespread, which mostly fill the basins. *The Pelagonian horst-anticlinorium* is built of high-grade metamorphic rocks, subdivided into two complexes: the lower and the upper metamorphic complex. The upper metamorphic complex consists of two series: mixed and marble series, while the lower metamorphic complex is represented various geisses. *The Vardar zone* is located east of the Pelagonian horst, whose geological-stratigraphic structure is significantly different from other geotectonic units in Macedonia. It consists of morphogenetic blocks from the Serbo-Macedonian massif and the Pelagonian horst. The Precambrian is represented by high-grade metamorphic rocks (gneisses and micaschists), which were once part of the Serbo-Macedonian massif and the Pelagonian horst, and today represent separate morphogenetic blocks. The Paleozoic is quite widespread in the Vardar zone, and lithologically it is represented by a series of crystalline schists of lower crystallinity. The Mesozoic in this zone is fully developed, with the Senonian deposits having the greatest distribution in the Vardar zone (among other chalk deposits), and they extend along the valley of the Lepenec River, Skopska Crna Gora in the southeast towards the Macedonian-Greek border. *The Serbo-Macedonian massif* is built of different rocks of different ages. There are different structural forms, young horsts, anticlines and synclines of different dimensions and directions, interspersed with dislocations and faults (seismically active), along which individual blocks descend and create Neogene tectonic depressions filled with lacustrine Pliocene and Quaternary sediments (extending in Serbia, Macedonia, Bulgaria and Greece).

## Occurrences of thermal, thermomineral and mineral waters on the territory of the Republic of North Macedonia

There is a certain number of published works that concern certain phenomena of thermal, thermomineral and mineral waters of Macedonia (hereinafter referred to as T, TM and M waters of Macedonia), which mainly concern their chemical composition (Baić, 1929). The first regional survey of these waters (a total of 170 occurrences) with the aim of determining their basic chemical composition was carried out by Gjorgi Kotevski, and he published the results in his doctoral dissertation (Kotevski, 1979) as well as later results in Kotevski 1987. During 2023 and 2024, a repeat visit and sampling of waters and sediments of significant occurrences of T, TM and M waters on the territory of Macedonia (total of 66 occurrences) was carried out with the aim of define the chemical composition of waters (macro and micro components) and sediments. The location of these phenomena is given in Figure 1.

The largest number of occurrences of T, TM and M waters is found mainly in the area of the tectonically very unstable Vardar zone. Then in

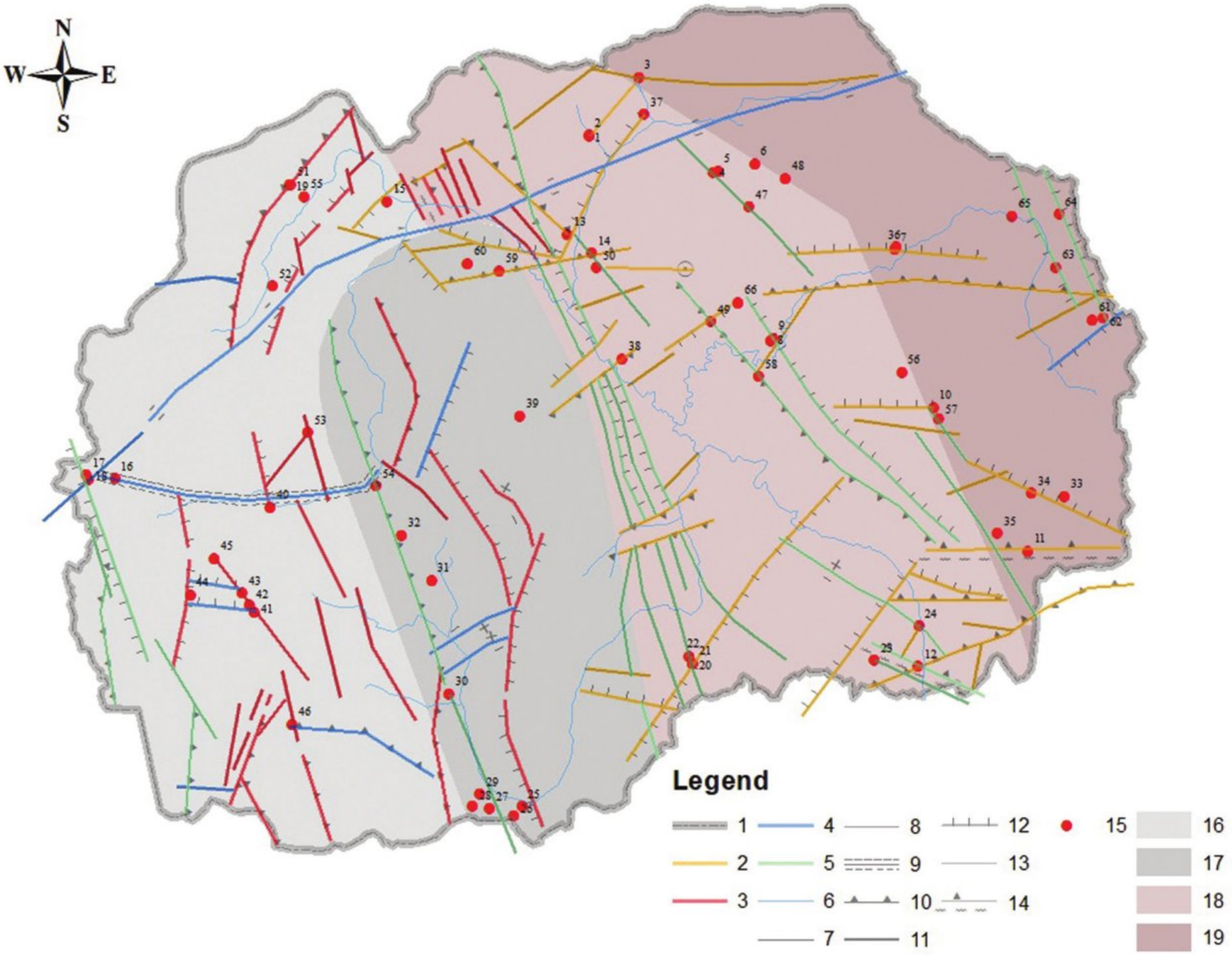


**Fig. 1.** Map of neotectonically active fault structures, Legend: *1*, Boundary; *2*, neo-tectonic transverse and diagonal faults; *3*, neo-tectonic longitudinal faults; *4*, reactive transverse and diagonal faults *5*, reactive pre-neo-tectonic faults – longitudinal; *6*, river; *7*, vertical displacement; *8*, horizontal displacement; *9*, milonitized fault zone; *10*, faults – contrasts expressed in the relief; *11*, faults – moderately expressed in the relief; *12*, faults – weakly expressed in the relief and assumed; *13*, fault as a conduit for volcanic activity; *14*, fault as a conduit for thermal-mineral springs *15*, Occurrence of thermal and mineral water springs; *16*, Western- Macedonian zone; *17*, Pelagonian horst – anticlinorium; *18*, Vardar zone; *19*, Serbo-Macedonian massif

the Serbo-Macedonian mass and the Western-Macedonian zone, as well as in the areas that are directly related to them. In contrast to these, the mineral waters in Pelagonia are linked to Neogene sediments of the Miocene–Pliocene and Quaternary, i.e. unbound or weakly bound clastic sediments, and are characterized by an increased concentration of carbon dioxide.

## Discussion with conclusion

The appearance of thermal and thermomineral waters on the territory of Macedonia is, among other things, the result of a very complex tectonic structure. Almost all occurrences of thermal waters are related to deep fault structures and are located in the peripheral parts of the basins, the formation of which is mainly Oligocene and Pliocene in age, when the shape of the relief changed fundamentally during the Alpine orogenic phase, as well as later when the collapse of the old Aegean land occurred (Egeides) in the Mediterranean Sea. The faults that caused the appearance of thermal waters in Macedonia, in a regional sense, can be said to be deep-seated failures of the earth's crust, which were reactivated in the recent geological past. The maximum water temperature was registered in the village of Podlog (Popovski et al., 2005), more precisely, it is a well 600 m deep, which self-flows to a temperature of 79 °C. This well is located within the Kochani basin and is part of the geothermal system in the volcanic Kratovo-Zletovo region. The main characteristics of the geothermal system of the Kochani Valley

are: the presence of two geothermal fields, Podlog and Istibanja, without a hydraulic connection, since the primary heating body is built of Precambrian gneiss and Paleozoic schists. This is the highest recorded water temperature on the territory of Macedonia obtained by drilling, and the maximum temperature of the reservoir is considered to be around 100 °C.

The appearance of cold mineral springs is also related with fault structures, but their appearance can also be a consequence of local conditions (Ǵuzelkovski, 1997). First of all, it refers to the formation of sediment deposits in lake basins. A characteristic example of the aforementioned are the cold mineral waters in Pelagonia (occurrence numbers 26, 27, 28 and 29), as well as in the localities of Arilevo, Plasnica and Krusheani (occurrence numbers 31, 32 and 54).

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