

Geology and hydrogeology of the Čemernica Mountain Massif, western Serbia

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Abstract. The mountain massif of Čemernica, western Serbia, is an orogenic feature of the Inner Dinarides. Hitherto, hydrogeological prospecting of the Massif was all on a regional scale, not detailed. Only scanty data, previously collected, were mappable on a scale larger than 1:100 000. The 2005 to 2008 research of the Čemernica Mountain Massif included geological and hydrogeological reconnaissance and mapping, the employment of remote sensing, a geophysical survey, the monitoring of quantitative and qualitative groundwater variation parameters, *etc.* The groundwaters of Čemernica are a large potential resource of water supply to multiple users. This paper is a contribution to the study of the geology and hydrogeology of the Čemernica Mountain Massif.

Key words: The mountain massif of Čemernica, western Serbia, Karst, Ćurčića Spring, Štitkovo Spring.

Апстракт. Планински масив Чемернице налази се у западном делу Србије. У геотектонском погледу, подручје истраживања припада рејону Унутрашњих Динарида. Досадашња хидрогеолошка истраживања на подручју планинског масива Чемернице нису имала карактер детаљних истраживања. Сва хидрогеолошка истраживања, подручја планинског масива Чемернице, имала су регионални карактер. Ретки су подаци који су прикупљени пре ових истраживања, а који се односе на ниво истраживања у размери крупнијој од 1:100 000. Истраживања планинског масива Чемернице која су изведена у периоду од 2005. до 2008. године, обухватила су геолошко-хидрогеолошко рекогносцирање терена и картирање терена, анализу терена методама даљинске детекције, геофизичка испитивања, осматрања квантитативних и квалитативних параметара режима подземних вода итд. Подземни водни ресурси планинског масива Чемернице представљају значајан потенцијал са аспекта вишенаменског коришћења. Овај рад има за циљ да дâ допринос познавању геолошких и хидрогеолошких карактеристика планинског масива Чемернице.

Кључне речи: Планински масив Чемернице, западна Србија, карст, Ћурчића врело, Штитково врело.

Introduction

The mountain massif of Čemernica extends over more than 50 km². Its geology and hydrogeology were explored in detail from 2005 to 2008 and mapped for the first time on a scale larger than 1:100000. The collected data were used to describe the geomorphology, hydrography, geology and hydrogeology of the massif. In addition to internal and external research, some laboratory analyses were made and are reported in the respective chapters of this paper. The identification of the lithostratigraphic units and their spatial relationships, the classification of groundwater bodies and their formation,

recharge and discharge mechanisms of the largest karst aquifer are all based on the acquired research data. The qualitative properties in addition to the quantitative aspect of groundwater for the karst aquifer were studied.

Geographical Location

The mountain massif of Čemernica in western Serbia is an area of 581 km² in the municipality of Nova Varoš, Zlatibor District. The size of the exploration area was greater than 50 km². The Čemernica Massif encompasses many heights within the elevation range from 1000 m

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to 1500 m, precisely from 1072 m (Štitkovo Spring) to the highest peak (Biješe Stene) 1494 m. The economy in the region is stagnant or declining. The tourist potential of the region, primarily the pearl of nature – the Uvac Lake, a meander cut-off of the Uvac River, habitat of the large griffon vulture, *etc.*, is undeveloped.

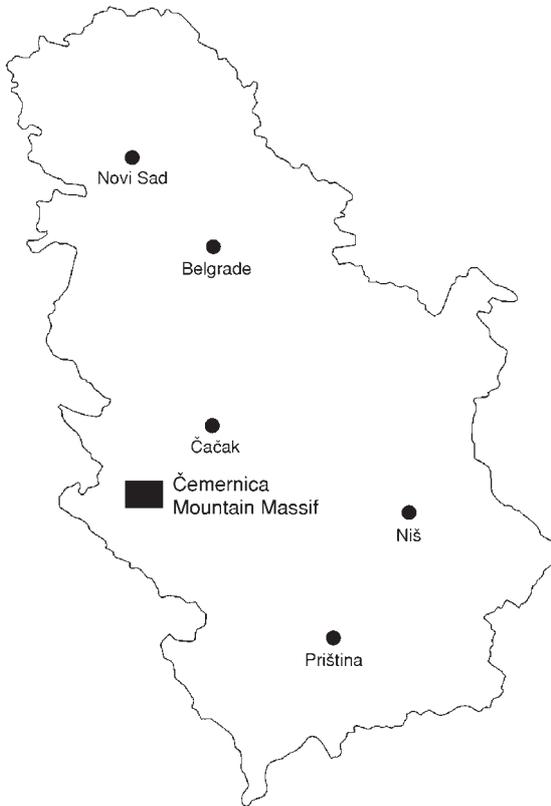


Fig. 1. Geographical location of Čemernica.

Research Concept and Methods

The steps of the geological and hydrogeological investigations in the Čemernica area were the following:

- Detailed analysis of the available research data, or identification of the morphologic features and the geological and hydrogeological character of the Čemernica Mountain Massif.
- Assessment of relevant climatic factors and hydrologic budget accounting.
- Spatial delineation of aquifers.
- Establishment of groundwater occurrence, movement and discharge.
- Interpretation of the physical and chemical properties, gaseous, radioactive and microbial compositions of the groundwater.
- Quantitative and qualitative assessment of the groundwater and its variation in time.
- Groundwater control conditions.

The Čurčića and Štitkovo Springs were monitored for one year to evaluate the usability of their waters with low concentrations of mineral matter.

The results obtained by multidisciplinary research of the water from the two springs were the basis for this work. The monitoring at the Čurčića and Štitkovo Springs was continuous over the year, while that at the Bursać and Kušića Springs was periodic.

Geology

Čemernica is one of the many carbonate rock areas in the region of Ivanjica and Golija. It belongs to the Drina–Ivanjica fault block (DIMITRIJEVIĆ & DIMITRIJEVIĆ 1974), or the former “inner Palaeozoic zone” (PETKOVIĆ 1961), or “Golija Zone” (AUBOUIN 1974). Previous study of geology of Čemernica has a short history and no published records.

General knowledge of its geology, acquired through mapping and from the base geological map, was used to identify the geologic formations in the field, to study their sedimentological and petrographic nature and structural character.

The mountain massif of Čemernica is composed of rocks formed through two sedimentation cycles. The older, prevailing cycle of the Ivanjica block is the Palaeozoic sedimentation cycle, not exposed everywhere on Čemernica, but lying under all newer formations. The other, Mesozoic cycle, is represented by more than one formation deposited from the Triassic through the Jurassic.

Palaeozoic

Late Palaeozoic rocks, represented by the Birać Formation, lie exposed in the deeply eroded Tisovica and Trudovačka valleys in the area of Štitkovo village (DJOKOVIĆ 1985).

The Birać Formation is composed of thin-bedded, laminated siltstones, metasandstones and some limestone lenses. Horizontal and wavy laminae in the siltstone bear ferruginous crusts. Successive on the siltstone is bedded metasandstone with a high proportion of angular quartz.

The stratification and attitude of the siltstone and sandstone in cross-sections indicate frequent turbidity currents, which produced turbidites.

The rocks of the Birać Formation were strongly folded and faulted through the Variscan and later Alpine orogenies. The stratigraphic position of the Formation is speculative. It was identified through evidence of the superposition of the subjacent Kovilje conglomerates and the superjacent Kladnica clastics.

Mesozoic depositional cycle

The Mesozoic cycle of deposition produced different formations, more during the Triassic than through the Jurassic. In the Čemernica area, the Kladnica, Bioturbate and Ravni Formations are Triassic, and the Diabase-Chert Formation is Jurassic.

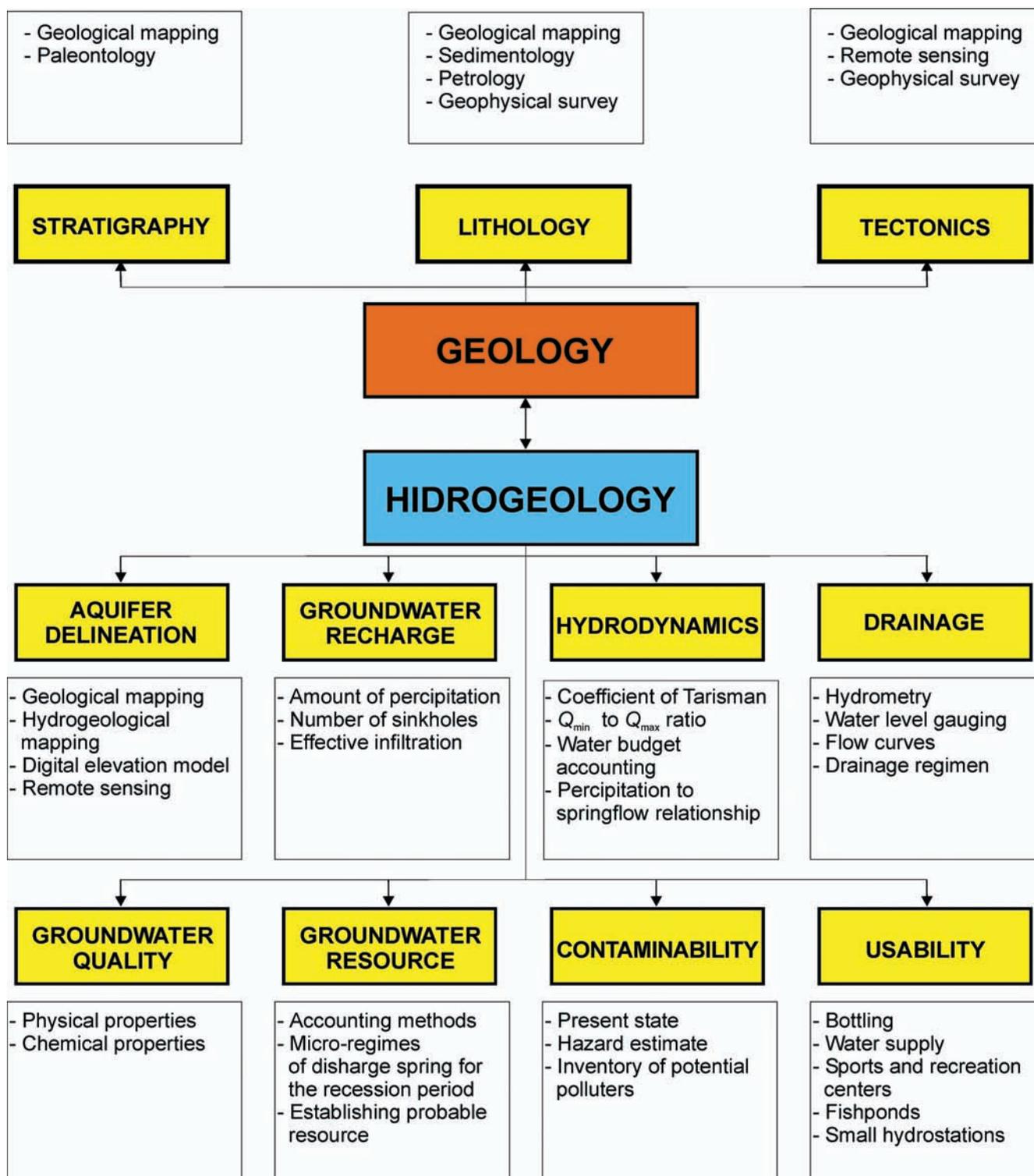


Fig. 2. Geological and hidrogeological research methods employed in the Čemernica Mountain Massif.

Triassic (T₁)

Sporadic exposures of continental clastics between the villages of Božetići and Šitkovo on the Čemernica SW ridges were identified as the Kladnica Clastics (NASTIĆ 1990, unpublished).

These clastics lie unconformably over Palaeozoic sedimentary and metamorphic rocks and under the Bioturbate Formation with the contact almost concealed but in tectonic contact with an ophiolitic mélangé.

An exposure of the Kladnica Clastics is located near the Šitkovo Spring in siliceous rocks of dominantly

quartz grains, quartzite and chert clastics in siliceous cement, reddish-coloured by Fe-minerals.

This time-stratigraphic unit was determined (beyond the limits of the Šitkovo village area) as Lower Triassic, based on its few conifer pollen grains.

Bioturbate Formation (T_1)

A succession of thin-bedded and shaley clay, identified as the Bioturbate Formation (DIMITRIJEVIĆ *et al.* 1980) on the Geologic Map Sheet Prijepolje, on the scale 1:50 000, can be recognized under massive limestone of the Ravni Formation in the Šitkovo and Trudovo village areas.

New cuttings of a village road near the spring exposed the internal lithologic structure of the Formation, which consists of thin micrite strata and silt and shale laminae. Micrite layers are torn in the sequence and strongly folded together with shale and silt (Fig. 3).

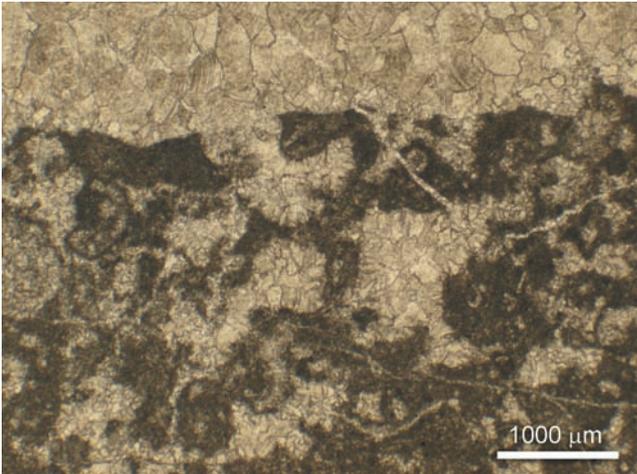


Fig. 3. Photographed thin-section from the Bioturbate Formation.

The Formation contains bioturbations of various sizes. Lower Triassic age was determined by its mega- and micro-faunal fossils (bivalves and foraminifers).

Ravni Formation (T_2)

Limestones of the Ravni Formation are most extensive in the Čemernica Mountain Massif, building up a varied surface topology from mountain peaks to karst poljes. The fault block of Čemernica varies in altitude from 110 m SW, where it is thin, to almost 1500 m in the north.

The limestones are slightly recrystallized and dolomitic (Fig. 4). Massive limestones prevail over thick sets of beds in Čemernica, while stratified limestones are recognized only low in the column above springs.

The SW border of Čemernica is steep, produced by an overthrust, and the entire mass of limestone is karstified. The limestone block is thin in the centre, its surface mildly trough-like, like the Rujište and Veliko Polje, which allow percolation of surface water and groundwater recharge.

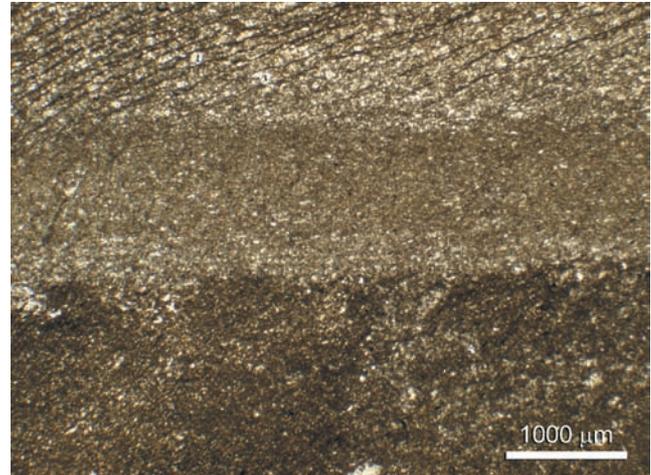


Fig. 4. Photographed thin-section from the Ravni Formation.

Triassic rocks in the ophiolite belt and its border were taken formerly for exposures of the basal diabase-chert, and Triassic rocks on the SW margin of the Ivanjica Palaeozoic for transgressive, deposited where they still are. It was proved that many Triassic plates, in the form of oligoplasas, lie over the diabase-chert formation, which implies that kilometric limestone plates slid by gravity from the Palaeozoic base into a mélangé trough.

Jurassic (J)

A Jurassic ophiolite mélangé was recognized in Trudovo area. Its constituents are greywacke, shale, sandstone, limestone, chert and radiolarite. Other rocks of the formation are diabase, spilite, keratophyre, *etc.* Direct contact of Jurassic rocks and limestones of Čemernica is normally tectonic, extending NW of Čurčići. Rocks of the ophiolite mélangé will not be described in detail as they are irrelevant to the mentioned springs.

Photogeology

The task of photogeology was defined as: photographic recording and study of the wider structural pattern of Čemernica: faulting and folding features, lithologic variation, and intensity of karstification within the carbonate rocks extent (unpublished, PAVLOVIĆ & ČOLIĆ *et al.* 2006).

The photogeological interpretation was initially confined to the carbonate extent of Čemernica and its

direct contact with the non-carbonated basement, but it was later extended to Carboniferous, Permian and Lower Triassic clastics. The photogeological study eventually included all features of some hydrogeologic relevance. The interpreted aerial photographs covered an area of 54 km².

The sedimentary rocks that build up Čemernica Mountain and its ranges are Lower or Middle Triassic in age. Triassic rocks lie over Permian–Triassic coarse clastics (quartz conglomerate and sandstone) in the northern, southern and south-eastern ranges and over Carboniferous metasandstones in the north-eastern ranges. In the west, the Triassic carbonates of Čemernica are in tectonic contact with Jurassic carbonate and chert of the diabase-chert formation.

Fractures, distinctive morphologic features in the surface configuration, were identified on satellite images of the pattern of fractures (Fig. 5). These are kilometric to decakilometric fractures. Given the size of the study area and the photo and map scales, the identified faults were not classified by importance, even if some of them extend beyond the area limits. These features were classified only in relation to the reliability of identification: observed and inferred. With respect to their expressive morphology, these features may be said to be the features of neotectonic activity, which may be important in addressing hydrogeological problems. The faults in the Čemernica area are classified into two systems.

The NNE–SSW to E–W systems are particularly well arranged, sub parallel, cutting through Čemernica and extending eastward into Permian–Triassic or Carboniferous rocks.

The other system of kilometric to some decakilometric, the faults have the strike direction NNE–SSW. The morphologic features of these faults suggest that the former system may be more significant for groundwater flow.

A regional fault on the Čemernica western border runs across the entire study area from NNW to SSE, mostly being the contact between Triassic limestones and the older clastics. Several strong springs occur at the cross points of this and the faults in NE–SW strike direction. The regional fault is a complex morphologic feature, of a fault zone type in places. It crosses numerous minor faults where its disruption and displacement are manifested.

The detailed structural pattern and the lithologic units obtained by stereoscopy are given on a photogeological map. The fractures are classified only on the reliability of identification. The carbonate-built Čemernica is densely faulted by hkm- and km-long fractures of two fracture systems: the dominant one with a NE–SW strike direction and the other with a NW–SE strike direction. The systems are conspicuous in the surface configuration, marked by series of elongated sinkholes, short dry valleys or abrupt changes in the slope angle.

Fractures in noncarbonated rocks in the south-eastern and eastern parts of the area control the flow direc-

tion or divert it at a right angle. East to west oriented fractures in the SE control largely the surface morphology and possibly also the groundwater flow.

The fault pattern in the easternmost part of the area differs greatly from the carbonate-built Čemernica. Kilometric and decakilometric faults strike dominantly in the N–S direction. Faults in other directions are fewer and shorter.

Morphologic features of hydrogeological interest in Čemernica may be the well-exposed large faults in the strike directions NE–SW to E–W; a complex system on the western border of Čemernica with the occurrences of strong springs and a gravity fault in Zečko Polje.

Geophysical Information

Geophysical prospecting was the basic additional exploration for the study of the geology or the type and extent of the lithologic units. The measurements were performed in Rujište Polje (Fig. 6).

The purpose of the geoelectrical survey was to establish the thickness of the uppermost rock complex, the spatial distribution and depth of each lithologic unit, then to measure the depths to aquifers and to identify faults and fault zones. The method used in the exploration was geoelectrical resistivity sounding in order to estimate the extent and depth of each lithologic unit. Geoelectrical soundings were taken along sections 1 and 2 (Figs. 7 and 8), with measurements in eleven sounding points with an AB/2 current electrode separation of up to 300 meters, at the azimuth direction 110°/280°. A symmetrical, Schlumberger array of current and potential electrodes, A-MN-B, was applied. The resistivity measurement results were interpreted both qualitatively and quantitatively. The former covered interpretation of the resistivity plots that show horizontal changes in the electrical resistivity, and the latter, interpretation of the resistivities and thicknesses of the logged formations. The specific electrical resistivity (ρ) and thickness (h) were computerized for each logged lithologic variety. The obtained parameteric values were plotted on sections 1-IPI and 2-IPI, and deep geoelectric sections.

The specific electrical resistivities were measured by geoelectric sounding from ES-1 to ES-11, on which four different lithologies were identified;

- Broken Triassic limestone,
- Broken Triassic limestone and water?,
- Massive or thick Triassic limestone, and
- Quartz conglomerate and sandstone.

The values of ρ indicated a vertical discontinuity or fault of SW–SE strike direction.

The conclusions based on the geophysical exploration in Rujište Polje, Čemernica, are the following:

- The lithologic units determined based on specific resistivities are: fragmented Triassic limestone over a water table, water-bearing fragmented Triassic lime-

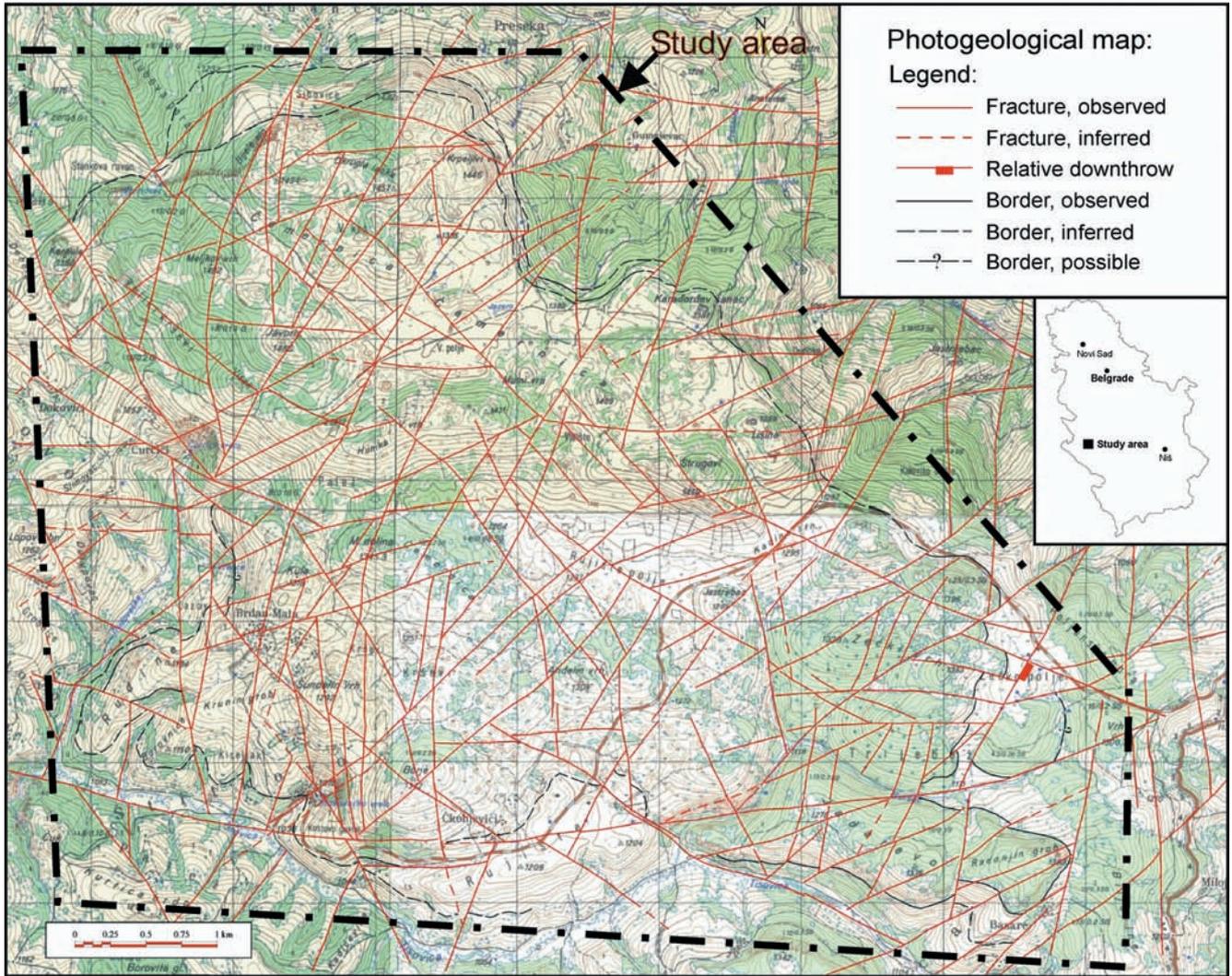


Fig. 5. Regional fault pattern (PAVLOVIĆ & ČOLIĆ 2006, unpublished).

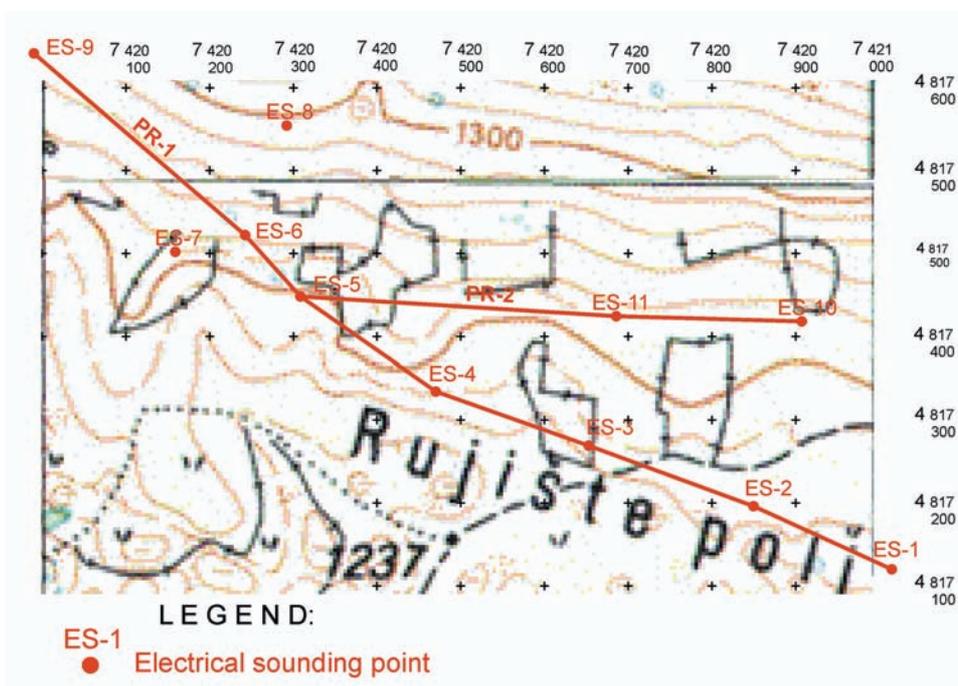


Fig. 6. Configuration of the geophysical sections in Rujište Polje.

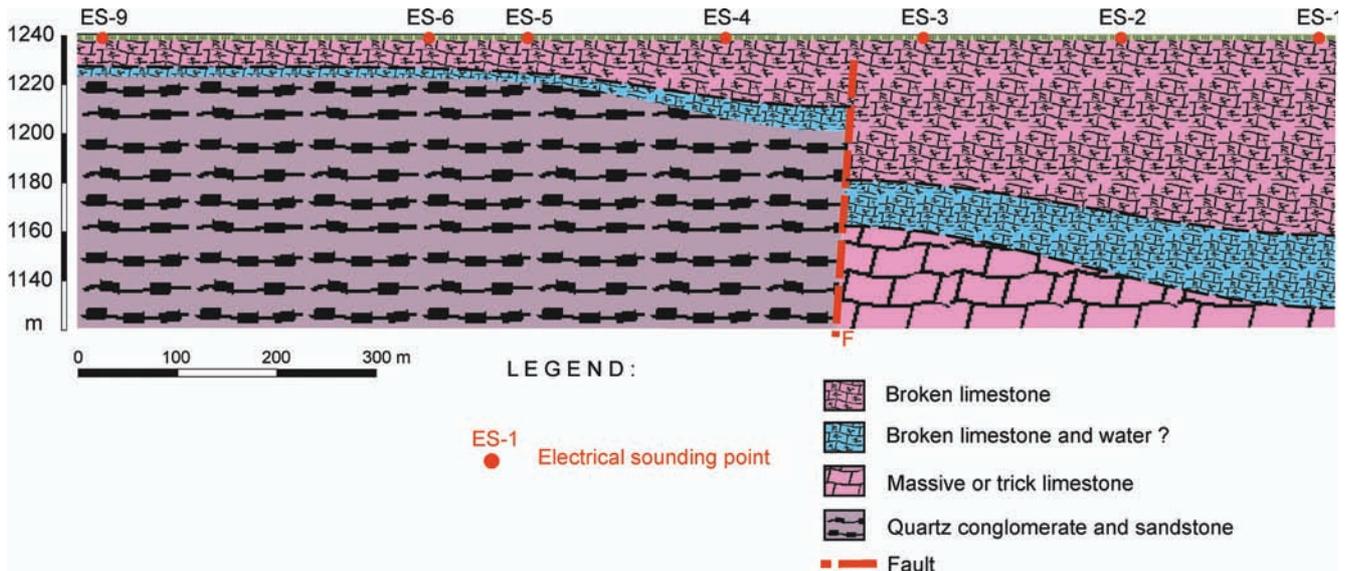


Fig. 7. Deep geoelectric section 1 across Rujšite Polje.

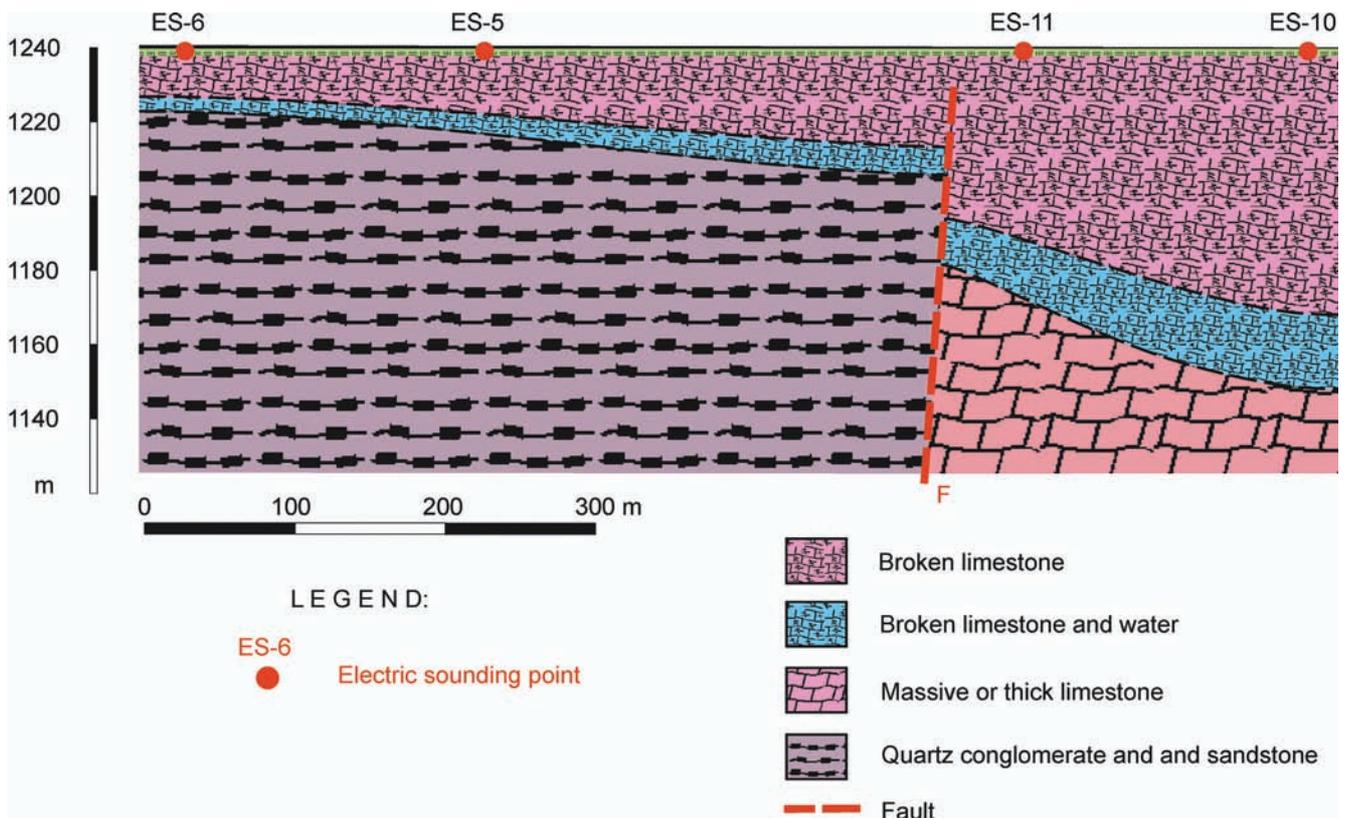


Fig. 8. Deep geoelectric section 2 across Rujšite Polje.

stone, massive or thick Triassic limestone, quartz conglomerate and sandstone.

– A vertical break or fault in the SW–NE strike direction was registered in both electric profiles based on the values of the parameter r .

Hydrogeology

The water-bearing rocks of the Čemernica Mountain Massif are classified by porosity into the following types (Fig. 9):

- Intergranular aquifer in alluvial deposits of the Tisovica.
- Karst aquifer in Middle Triassic limestone (Ravni Formation).
- Fractured aquifer of low potential in Lower Triassic rocks (Bioturbate Formation).

There is a fourth type – provisionally “waterless” rocks.

The **Intergranular aquifer** in alluvial deposits of the Tisovica is linear, narrow, directly controlled by a fault that predisposed the Tisovica course. The alluvial deposits of the Tisovica vary in thickness between 6 m and 8 m to 10 m at the most. An aquifer of this type is of minor economic importance for groundwater utilization because its extent is restricted and the water storage is small and variable.

The **Karst aquifer** of Middle Triassic limestone is centrally located in the Massif area. As limestones occupy almost half the Čemernica area, this type of aquifer is the largest in area and depth.

In terms of groundwater resources, the karst aquifer is the most important in the region. Carbonate rocks formed in the Triassic are also extensive in the Inner Dinarides of western Serbia and traceable over a long stretch in this region.

The mountains of the Dinarides, with few exceptions, extend NE to SW (Čemernica, Zlatar, Zlatibor, Tara, Jadovnik, *etc.*) and are structured largely of Triassic limestones. It follows from all the above-stated that the groundwaters in the aquifers formed by the dissolution action – carbonate rocks – are the most abundant in the region.

The principal source of groundwater recharge in the characteristic open hydrogeologic structure of Čemernica is the atmospheric precipitation that falls on limestone outcrops. The high capacity and velocity to respectively receive and transmit atmospheric water are attributed to the geological set-up, structural pattern and degree of karstification.

Groundwater flow, predisposed by the structural pattern, has the general direction from east to west, as indicated by spring flows draining this type of aquifer. The volumes of water discharged by the Šitkovo and Čurčiča Springs in the west are much higher than spring flows elsewhere in the area. The groundwater flow directions depend, as mentioned before, on faults, fractures and karst caverns formed through either tectonic events and/or karstification.

Groundwater in the extensive karst aquifer naturally drains through a number of karst springs. The major springs are Šitkovo, Čurčiča, Bursać and Kušića. Their minimum flows vary from 4 l/s to 17.6 l/s (Šitkovo and Čurčiča) and from 5 l/s to 10 l/s (Bursać and Kušića). All springs that drain the Čemernica Karst Massif are contact springs between the permeable Triassic limestone and impervious rocks. Each of the four springs is natural and undeveloped.

Fractured aquifer has a smaller water-yielding capacity and extent than the karst aquifer. It is the most

widespread in the NE and W of the considered area. Two major springs (Šitkovo and Čurčiča) discharge at the contact of the two formations and the Middle Triassic limestones of Čemernica. A smaller area of Lower Triassic, fractured but of lower potential, rocks is located SW of the Bursać Spring. This aquifer has two sources of recharge. The groundwater in the aquifer of the fractured carbonate and Lower Triassic rocks is replenished by infiltrated atmospheric water and ground water from the adjacent, karst aquifer. The primary flow directions and qualitative properties of groundwater in this type of aquifer have neither been determined, nor can a satisfactory estimate of the water budget be given.

Provisionally “waterless” rock areas are those built up of Jurassic (Malm, Dogger) ophiolitic mélangé and Permian–Triassic sedimentary rocks. The rocks identified on the basis of field data as provisionally “waterless” lie in contact with karstified or fractured rocks of low-potential capacity.

Quantitative Groundwater Regime

The total quantity of groundwater involved in the drainage of the Čemernica Massif was monitored at the Čurčiča and Šitkovo Springs and intermittently measured at the Bursać and Kušića Springs. Gauging stations were set up for precipitation and hydrologic parameters at the Čurčiča and Šitkovo Springs in order to obtain representative information for a quantitative estimate of spring flows. The measurements in the Čurčiča and Šitkovo Springs were taken once in two months, or a total of six measurements in both springs. The measured flows were used to construct flow curves, which were used as the basis for the estimation of other parameters of the flow of the Čurčiča and Šitkovo Springs (Tab. 1).

Tab. 1. Quantitative parameters for the different springs.

Occurrence	Q_{\min} (l/s)	Q_{\max} (l/s)	Mode of discharge
Čurčiča Spring	43.6	495	Gravity flow
Šitkovo Spring	17.5	313	Gravity flow
Bursać Spring	4	10	Gravity flow
Kušića Spring	10	25	Gravity flow

The flow data for the Čurčiča and Šitkovo Springs were used for an interpretation of the retention properties of the Triassic limestone aquifer of Čemernica.

Different drainage micro regimes, or drainage coefficients, have respective physical implications. Drainage coefficients of the order $\alpha \sim 10^{-2}$ are generally related to large karst caverns or fractures, while lower slopes of the straight lines ($\alpha \sim 10^{-3}$) indicate slow discharge via smaller fractures, fissures or clastic-filled karst cavities (KREŠIĆ 1991).

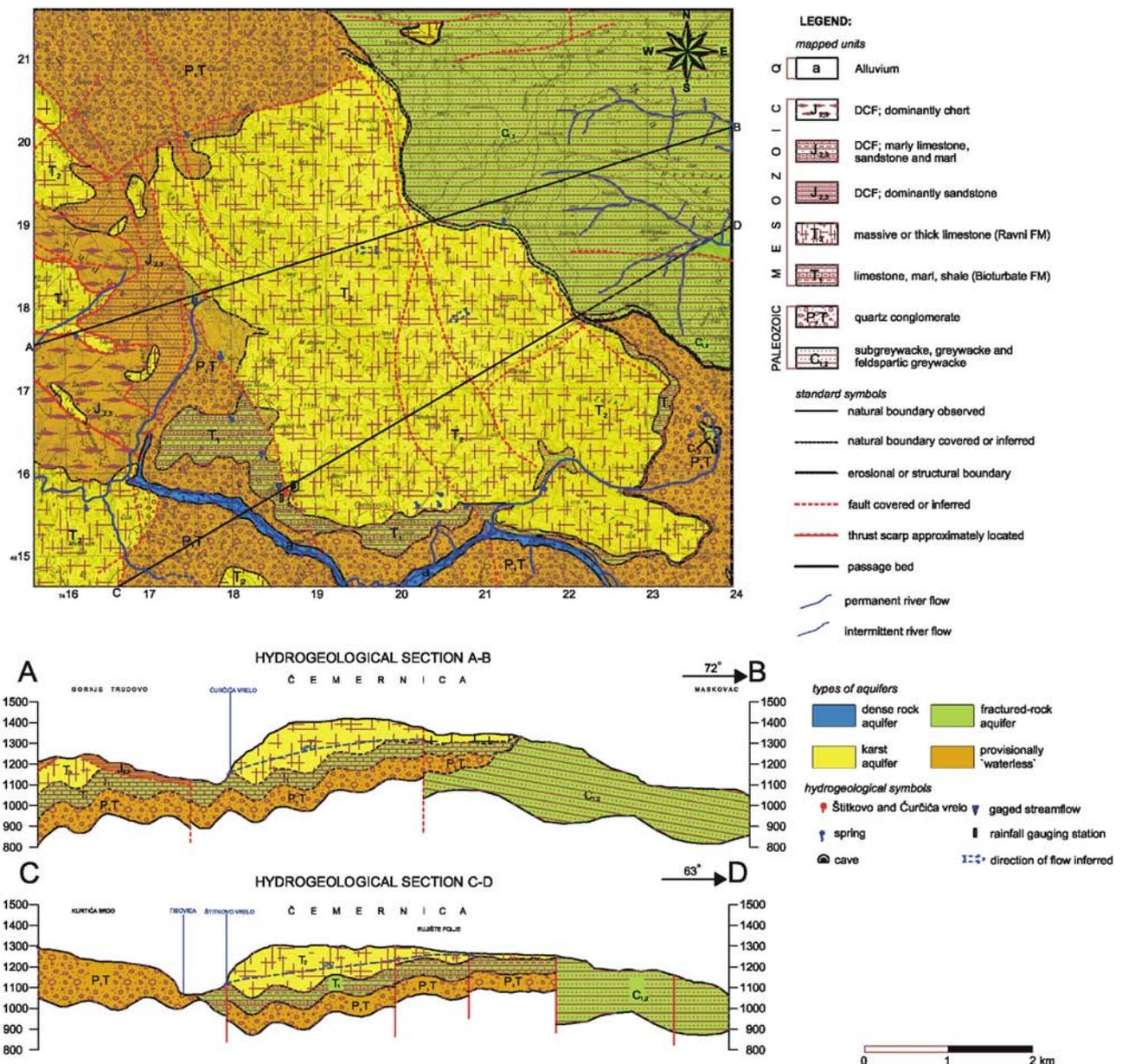


Fig. 9. Schematic hydrogeological map of the Čemernica Mountain Massif.

For a valid analysis of the retention capacity of an aquifer, a new period was necessary of no less than ninety days effective rainfall, resulting in continuous runoff without replenishment (groundwater recession).

An interval of constant runoff or groundwater recession was registered at the Šitkovo Spring within the observation period from 30 August 2006 to 9 January 2007. The recession continued for 131 days, an interval of constant runoff without replenishment sufficiently long for analysis.

The considered recession limb of the hydrograph is shown in Fig. 10. Note that there were some ineffective rainfalls in the observation period.

As the maximum to minimum spring flow ratio ($Q_{\max} : Q_{\min}$) was 1 : 3.63 during the groundwater re-

cession, the obtained analytical results should be taken with due caution (a reliable ratio by this method should be $Q_{\max} : Q_{\min} = 1 : 10$). The recession limb of the hydrograph indicates two different runoff micro regimens.

The obtained runoff coefficients ($\alpha_1 = 0.071779$ and $\alpha_2 = 0.0142$) are of the same order of magnitude ($\alpha \sim 10^{-2}$), but are different between themselves. The value of the coefficient α_1 indicate higher retentive properties in one micro regimen and the value of α_2 suggests lower retentive properties of karst in the other micro regimen.

The Šitkovo Spring flow data from one hydrogeologic cycle were used to calculate the degree of karstification and to determine the dominant groundwater flow directions. The maximum to minimum Šitkovo Spring

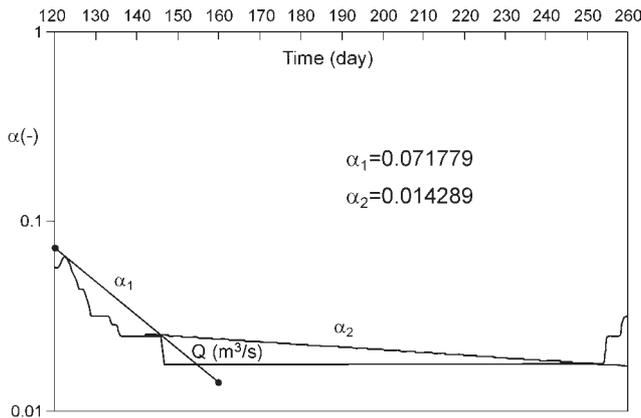


Fig. 10. Analysed recession limb of the Štitkovo Spring hydrograph for the runoff period from 30 August 2006 to 9 January 2007.

flow ratio (for the whole period) of about eighteen indicated one dominant flow direction, almost certainly controlled by the structural features of the karst aquifer and many minor water paths.

An interval of continuous groundwater runoff, or recession, was registered at the Ćurčića Spring during observation of the flow regime from 1 July to 16 October 2008. The recession of the groundwater lasted 108 days and could be used in the analysis. The recession curve is shown in Fig. 11. The value of the coefficient α_1 indicates a higher, and α_2 lower retentive properties in the former and latter micro regimes, respectively. Intermittent rainfalls were ineffective in affecting the groundwater runoff regimes.

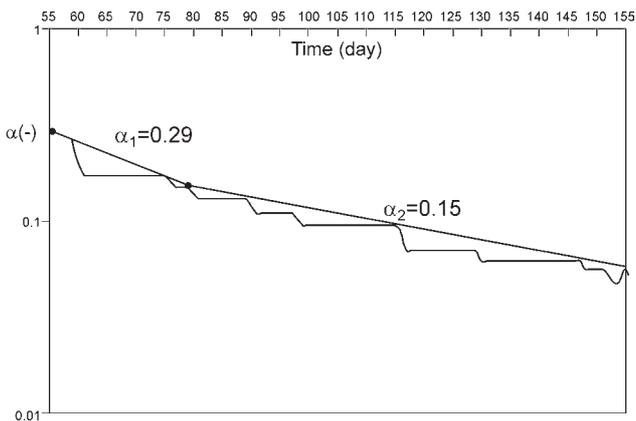


Fig. 11. Analyse of the recession limb of the Ćurčića Spring hydrograph for the runoff period from 1 July to 16 October 2008.

As with the Štitkovo Spring, the maximum to minimum flow ratio ($Q_{\max} : Q_{\min}$) was less than 1 : 10, specifically 1 : 5.31. The analytical results obtained by the Tarisman method should, therefore, be taken with due caution.

Qualitative Groundwater Regimes

Groundwater from the karst aquifer only was tested for its qualitative properties, because the karst aquifer is much more abundant in water than the others in the region. The tested samples were mainly of the calciumhydrocarbonate (Ca-HCO_3) class of water, directly related to the source of origin. Another essential characteristic of the water was comparatively uniform mineral matter in water, not higher than 300 mg/l.

The **temperature** range of the water is from 6.5° C in the Kušića Spring to 9.3° C in the Štitkovo Spring. All spring waters in the area may be assigned to the group of cold waters. Only the water from the Kušića Spring was below the temperature range 7° C to 12° C, considered suitable for human consumption (DRAGIŠIĆ 1997).

The **acidity** of the water is uniform within the pH range from 7.5 to 8. In this respect, all the waters, except for springs, were neutral to mildly basic.

The **specific conductance** of the tested groundwater samples was uniform, being within the range from 349 $\mu\text{S/cm}$ (Kušića Spring) to 430 $\mu\text{S/cm}$ (Štitkovo Spring).

The **mineral matter** in the groundwater varied within the range from 225.56 mg/l (Kušića Spring) to 290 mg/l (Štitkovo Spring). According to this parameter, the tested samples were low-mineralized groundwater.

The **total hardness** range was from 11.20° dH (Kušića Spring) to 12.18° dH (Bursać Spring). In the classification after Klut, the water of the two springs is moderately hard. In addition to total hardness, the water was tested on permanent and temporary hardness. The difference between total and temporary hardness was very small, indicating a high proportion of carbonate salts, primarily calcium salt, and low proportion of Cl^- and SO_4^{2-} ions.

Sodium and Potassium ($\text{Na}^+ + \text{K}^+$). The sum of the sodium and potassium ion concentrations varies from 0.76 mg/l (Ćurčića Spring) to 9.96 mg/l (Kušića Spring), the highest being in the latter spring.

Calcium (Ca^{2+}). The dominant cation in the spring waters was the calcium ion, Ca^{2+} . All spring waters in the given area therefore belong to the calcium (Ca^{2+} -water group) in the O.A. Alekin classification. The calcium ions are derived from the extensive limestones in the area. The calcium concentration varies from 69.3 mg/l (Ćurčića Spring) to 86.4 mg/l (Štitkovo Spring).

Magnesium (Mg^{2+}). The magnesium ion concentrations, much lower than those of calcium, in the spring water varied from 1.22 mg/l (Kušića Spring) to 4.26 mg/l (Bursać Spring).

Hydrocarbonates (HCO_3^-). All the tested water samples were in the Alekin Hydrocarbonate Class. Concentrations of dominant hydrocarbonate HCO_3^- ion were within the range from 97 mg/l (Ćurčića and Štitkovo Springs) to 251.94 mg/l (Kušića Spring).

Sulphates (SO_4^{2-}). The sulphate concentrations were very low, from 2 mg/l (Ćurčića Spring) to 7 mg/l (Bursać Spring).

Chlorides (Cl^-). Like the sulphates, the chloride concentrations in the spring water samples were very low, varying from 1 mg/l (Ćurčića Spring) to 12.76 mg/l (Bursać Spring).

Nitrates (NO_3^-). The nitrate concentrations were very low, far below the maximum allowed concentration. A nitrate ion (NO_3^-) concentration of 5.2 mg/l was detected in the Štitkovo Spring water.

Generally, the samples from all springs in the area were of the calcium hydrocarbonate Class, Ca-HCO_3 , with a mineral matter content below 300 mg/l.

The spring waters were cold, neutral to mildly basic and moderately hard. The concentration of the individual elements in the water was below the maximum allowed concentration. The waters tested in the field were clear, without colour, taste and odour. Figure 12 illustrates A graphical presentation of the chemical composition of the tested groundwater (Piper Plot) is illustrated in Figure 12.

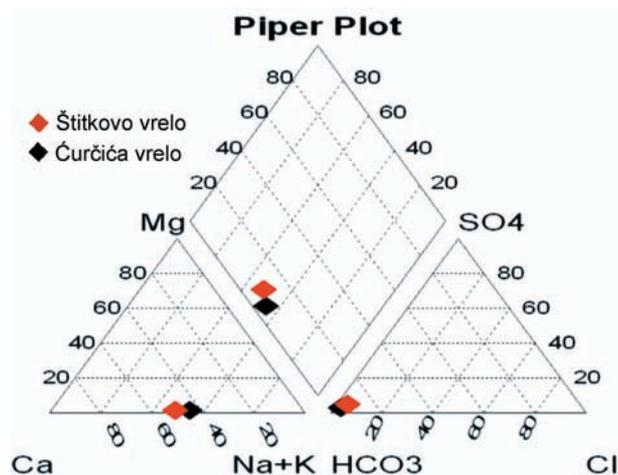


Fig. 12. Trilinear diagram of chemical composition of groundwater draining the karst aquifer of Čemernica.

Conclusions

Geological and hydrogeological explorations in the Čemernica Mountain Massif were carried out from 2005 to 2008, through field and laboratory research including stages of hydrogeological reconnaissance and mapping.

The groundwater regimes were monitored at the discharge points of the Ćurčića and Štitkovo Springs over one year, from 1 May 2006 to 1 May 2007. The qualitative and quantitative properties of groundwater were intermittently tested in the Bursać and Kušića Springs.

Other relevant parameters – daily precipitation height, springflow rates and water temperatures – were also monitored over the same period, while the physical and chemical properties of spring water (four full sets of

analyses,) were determined quarterly. The inferences are the following:

The Mountain Massif of Čemernica is a structural part of the western-Serbia Inner Dinarides, structured of Palaeozoic and Mesozoic rocks.

The tectonic pattern of the Massif, based on remote sensing information, indicates two dominant strike directions, NNE–SSW to E–W. The whole Čemernica is intersected by faults, which extend eastwards into Permian–Triassic or Carboniferous rocks. The surface features of the faults suggest their being preferential conductors of groundwater.

Middle Triassic limestones form a karst aquifer, the largest in the Massif.

The karst aquifer is an uncovered hydrogeologic structure of known recharge and discharge zones.

The springs that drain the karst aquifer are characterized by high flow rates (Q_{\min} 4 to 43.6 l/s; Q_{\max} 10 to 495 l/s).

The mean monthly water temperature varies from 8.5° C to 9.9° C.

The Ćurčića Spring belongs the calcium hydrocarbonate water group with the content of dissolved solids ranging from 0.2 to 0.3 g/l with a temperature range from 8.6° C to 9.7° C.

The information acquired by geological and hydrogeological research indicates potentially available resources of groundwater for various purposes (water supply, fish ponds, bottling, small power stations).

The results of this research provide for the first time a thorough insight into the water resources in the Čemernica Mountain Massif.

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Резиме

Геологија и хидрогеологија и планинског масива Чемернице, западна Србија

Геолошко-хидрогеолошка истраживања планинског масива Чемернице су трајала од 2005. године до 2008. године. Истраживања су методолошки била подељена у неколико фаза са применом пуног обима теренских, лабораторијских и кабинетских метода, укључујући фазе хидрогеолошког рекогносцирања и картирања терена.

Режим подземних вода које се дренају на Ђурчића врелу и Штитковом Врелу, праћен је континуално у периоду од годину дана, тачније од 01. 05. 2006. до 01. 05. 2007. године. На врелу Бурсаћ и Кушића врелу вршена су периодична осматрања квантитативних и квалитативних својстава подземних вода.

Током тог периода праћени су режимски параметри попут дневних сума падавина, издашности и температуре подземних вода које се дренају на

овим врелима, као и квартално одређивање параметара физичко-хемијског састава ових вода (4 комплетне анализе "В" обима). На основу овако постављеног концепта закључује се следеће:

– Планински масив Чемернице у геотектонском смислу припада Унутрашњим Динаридима западне Србије и изграђен је од стена палеозојске и мезозојске старости.

– Анализа тектонског склопа, вршена методама даљинске детекције указала је на постојање два доминантна правца руптура ССИ–ЈЗЗ до И–З. Ове руптуре секу целу Чемерницу, а према истоку пружање им се наставља и у пермотријаским или карбонским седиментима. Према њиховом морфолошком изразу на површини терена, може се претпоставити да је први систем значајнији за циркулацију подземних вода.

– Карстни тип издани формиран у оквиру средњотријаских кречњака је доминантан на подручју истраживања.

– Карстни тип издани формиран је у оквиру отворене хидрогеолошке структуре, где су познате зона прихрањивања и зона истицања.

– Извори који дренају карстни тип издани карактеришу се значајном издашношћу ($Q_{\min} = 4\text{--}43.6$ l/s, $Q_{\max} = 10\text{--}495$ l/s).

– Средња месечна температура воде кретала се од 8.5°C до 9.9°C .

– Изворске воде "Ђурчића врела" су маломинерализоване воде са минерализацијом од 0.2 до 0.3 g/l, хидрокарбонатне класе-калцијумске групе са температуром у опсегу $8.6\text{--}9.7^{\circ}\text{C}$.

– Резултати добијени геолошко-хидрогеолошким истраживањима указали су на значајан потенцијал подземних вода које се могу користити за различите потребе (водоснабдевање, рибњаци, флаширање, мини хидроелектране).

Резултати добијени овим истраживањима представљају прва детаљнија истраживања овог типа на планинском масиву Чемернице.