

Recent hydrogeologic study of the Vis island

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Abstract

The Vis Island belongs to the group of the Middle Dalmatian islands. It comprises an area of about 90.2 km². Morphologically, three belts of highlands and two depressions with karst poljes are significant. The highest point on the island is Hum with 587 m a.s.l. the island's water supply is organized from the water-supply station "Korita", situated in the central part of island, in tectonically formed depression. There are two additional captured objects: the well K-1 above the Komiža town and the spring "Pizdica". The most important hydrogeological role on the island have two hydrogeological barriers, one in the Komiža Bay, completely made of impermeable igneous and clastic rocks, and another one, the recently recognized relative barrier in the area of Dračevo, Plisko and Velo polje. Since the island karst aquifer is in permanent dynamic relation with seawater, classical geologic, structural and hydrogeologic investigations have been performed with application of hydrogeochemical methods taking into account the natural chemical tracer content of groundwater and its variations in different hydrologic and vegetation conditions. Precipitation regime is very unfavorable with regard to the recharging of island's aquifer, because dry periods are usually very long. During the summer tourist season, when the number of inhabitants and fresh water consumption considerably increase, amounts of island's groundwater suitable for water supply and irrigation rapidly decrease. Sometimes, insufficient quantity of fresh water on the Vis Island causes restrictions. Concerning the development of tourist potential and the present agricultural activities, summer lack of water is a serious restrictive factor. Some results of the performed hydrogeological study, important as a basis for island's fresh water potential assessment, will be presented.

General data

The Island of Vis, belongs to the group of the middle Dalmatian islands. Its area is 90.2 km², which places it on the ninth place among the Adriatic islands. It is situated at 55 km from the land, so at the same time it is one of the farthest inhabited Adriatic islands. Morphologically, three hill chains and two valleys containing several smaller karst fields are well distinguished. The mentioned morphological entreties strike east – west. The highest peak is Hum (587 m), located about 2.5 km southeast of Komiža, and there

are Orlovica, Mali Hum and Široko brdo as well. The territory of Vis island has a distinguished Mediterranean climate. The characteristics are long and hot summers with very high medium air temperatures in August (26.0 °C) and droughts during several months, so the years without rain for 3–4 months are not rare. The winters are soft (medium air temperature in January is 10.1 °C). Mediterranean evergreen vegetation of low bush type is dominant. Other agricultural plants are olives, lemons, mandarins and several indigenous sorts of grape vine. Similar to other Adriatic islands, there are

no surface waterflows. Periodical torrent flows can emerge after heavy rainfalls, mainly in the area of Komiža.

The basis for water supply of the Vis island is the pumping site "Korita" which feeds the water supply system. The pumping site is located in the middle part of island and it consists of six deep drilled wells, where four of them are used for water supply. Besides the mentioned, there is the pumping site "Pizdica" in Komiža bay, which is used periodically. The problems of groundwater shortage emerge in dry periods when the natural inflows from rainfalls are decreased to minimum, or they are completely absent, whereas the consumption is increased, what is emphasized during the tourist season when the number of inhabitants is multiplied several times. During the last several years, hydrogeological investigations were performed on the island. On that basis, several variants of water supply system improvements have been proposed.

Geology and structure

On the Vis island occur rock from Jurassic (Triassic) up to Quaternary age. The oldest deposits are clastic sediments with gypsum interbeds of upper Malm age ($J_3^{3?}$). With them, occur spilites and diabases ($\beta\beta$), as well as pyroclastics (ω), in the Komiža bay. The age of these rocks is not yet determined, so in older papers in literature (Crnolatic, 1953) the mentioned clastics are said to be of lower or upper Triassic age. In newer papers (Borović et al., 1977) they were described as clastics of upper Malm age.

These rocks are overlain by Cretaceous carbonate rocks whose age is well documented paleontologically (Borović et al., 1977). Occur brown-grey limestones of Berriasian age (K_1^{1+2}) and on them grey dolomites of Neocomian age (K_1^{1+2}) lie. The upper stages of lower Cretaceous age (Barremian, Aptian, Albian) are represented with grey-brown limestones (K_1^{3-5}). Upper Cretaceous (Cenomanian, Turonian) is represented by dolomites that contain interbeds and lenses of limestone (K_2^{1-2}). The final unit of Cretaceous is represented with limestones of Senonian age (K_2^3). Total thickness of Cretaceous carbonate beds is over 2000 m, and they are the most represented on the surface.

The youngest Quaternary (Pleistocene) sediments are found in joint systems, local depressions and karst fields. There are silty clays (terra rossa – ts) and talus breccias – (sbr). Characteristic sediments on the island are bedded sands – p that are, most likely, of eolian origin (Marković-Marjanović, 1978). The hypothesis of eolian origin of these sediments presumes their sedimentation from northeast direction, from the surfaces that are today under the sea. These sands there are finds of gastropods (*Pupa muscorum* L.) characteristic for Riss and early Würm.

The island of Vis belongs to tectonical unit called "Middle Dalmatian islands" (Borović et al., 1977) which is divided in three smaller units: Brač island, Hvar island and Vis island. These units are part of the Adriatic carbonate micro plate that was formed during several tectonic phases, from Laramian at the turn of Cretaceous to Tertiary as the oldest phase, to Pyrenean that dates in upper Eocene and that left the most distinguished marks. The Pyrenean phase caused significant tectonic deformations of terrain with evolution of scaly structures due to the northeast stress. Regional stress orientation change during neotectonic phase of evolution lead to dominantly horizontal movements along the existing joint systems, as well as to creation of new joint systems generally parallel to basic axis of anticline structure with strike east – west, which subsides towards the east with average angle of 10 degrees. The anticline core is built of clastic rocks with gypsum and eruptives probably of upper Jurassic age, while the limbs are built of Cretaceous carbonates: limestones and dolomites. Anhydrites are located in deeper layers (probably below lower Cretaceous) in much wider area than the area of Vis Island (Šušnjarić, 1967). Regional compression caused diapiric gypsum and anhydrite movements, which along with other factors, created tectonic framework for development of karstification processes. The described structure was cut with several longitudinal faults (with strike subparallel to fold axis). In the anticline apex, which is presumed to be practically in the middle of the island and can be traced along the whole islands length, significant extension stresses and horizontal block movements existed, traces of which can be seen on the numerous

outcrops, which lead to significant fracturing of rock mass. Within the recent investigations, structural elements were measured on totally 62 outcrops, which enabled determination of the field of local stress. In the zones of extension and fracturing of carbonate rocks, it came to intense karstification in rocks liable to such processes, which enabled creation of significant joint pore space in the ground. Generally, in the karst terrains, anticlines are the suitable environment for accumulation or directing of groundwater flows.

Hydrogeology

The island of Vis is a separate hydrogeological entirety, whose properties depend on local lithological and structural relations, proper input (effective precipitations) and output of water from the system. The output consists of evapotranspiration, pumping quantities on wells and outflows on springs. Significant springs are the ones in Komiza bay, but smaller appearances in Vis bay and along the east and west coast have been registered that are supposed to be connected almost exclusively to surface and shallow ground waters that outflows after the heavier rains. Karstification is the natural process that significantly changes hydrogeological medium in which it is developed. When this process advances, which is the case in Dinaric and Adriatic belt respectively, the porosity of rocks is not only of joint type, but also of joint-solution type. Since the space arrangement of carbonate rocks and basic structural-tectonical characteristics of the area were pointed out above, it is necessary to emphasize also the fresh water influence on karstification processes. Today's level of karstification reaches the same depth as the fresh water. That surely is not today's sea level because it must be presumed that the fresh water lens stretches below sea level also. Through the geological history the karstification process has developed more or less continuously so for the describing the karstification phases through geological history we use the term paleokarst. For hydrogeological considerations, the paleokarst generally is not interesting because its structures and forms are mostly lost during the later geological processes. Therefore, the

attention should be given to present karstification processes and to the processes in immediate geological history – Quaternary, especially Holocene. Probably the most crucial data for such research is the data on sea level variations during the same period. For example, it is presumed that the sea level at the end of the last glaciation, Würm, was, on the average, about 31 m below today's sea level (Šegota, 1968). The tectonic factors of rising and lowering the rock masses also influence the sea level in a particular area. The data exist that the sea level in Vis surrounding was lowered for almost 100 m (Marković-Marjanović, 1978) during Würm, so the karstification base was about 100 m lower than today's. Therefore, the karstified and permeable rocks could be expected to lie significantly below today's karstification base. This fact is very important from the water supply aspect, i.e. the existence and in-depth strike of fresh water lense on Vis, and from the aspect of determination of the nature of fresh – salt water contact. The importance also lies in the possibility for deep intrusion of salt water or even the possibility for existence of old (trapped) sea water below the fresh water lens. However, taking all the facts into consideration, it is possible to conclude that tectonics had the biggest influence on the depth of Quaternary karstification, rather than the eustatic changes. From the hydrogeological aspect it is also very important to emphasize the fact that the karst forms and cavities of larger dimension on the Vis island are mostly filled with fine grained material. This means that after the phase of intense karstification a different phase followed, during which the water circulation lead to filling the caverns and joints with silty-clayey and sandy material. These circumstances lead to evolution of the Vis aquifer, because the groundwater outflow significantly slowed down owing to secondary filling of caverns, cavities and discontinuities, and also the sea intrusion slowed down. In this way the dynamic equilibrium of these two most significant water bodies was established. Hydrogeologically, the following units can be distinguished on the island: the carbonate, predominantly calcareous water bearing rocks of Cretaceous age, which function as the permeable area; impermeable igneous, pyroclastic, and clastic rocks, which function

as the hydrogeological barrier, and dolomitic limestones in the base of sequence of karst poljes on the south and north brim of island. The latter function as a relative hydrogeological barrier that prevents the outflow from the aquifer towards the north and south coast, and at the same time prevents the sea water intrusions into the aquifer (fig. 1). The area of karst poljes that stretches along the south side of the island (Plisko polje, Velo polje, Dračevo polje) should be especially emphasized. In the karstified carbonate rocks under the poljes, the filling in is significantly increased, which lead to the decreased hydraulic conductivity of rock masses which today it function as a relative hydrogeological barrier (Terzić et al., 2002).

Hydrogeochemistry

The usage of hydrogeochemical methods and of natural tracers for the investigations of coastal and island aquifers is becoming an irreplaceable approach that enables determination of connections of island aquifer with sea, of salinity origin, of conditions for renewal the groundwater and of hydrodynamic conditions in the island aquifers. As the most common natural tracers the groundwater temperature, electrolytic conductivity, total dissolved solids and chloride content are used. In the recent time the ionic ratio, stable isotopes and inert gasses composition are also used. However, the groundwater salinity in the coastal area and on the islands of the Adriatic Sea can be of various origins. The most common case is mixing with today's sea water, then mixing with old or so called aged sea water and rarely, the regionally limited cases are a consequences of evaporites (gypsum, anhydrite) in the lithology of karst aquifers. The procedures, such as groundwater overexploitation in coastal and island aquifers for various needs, agricultural activities accompanied by fertilizing and often irrigation procedures can cause the increase of groundwater salinity (Richter, B. C. & Kreitler, C. W. 1992; Fidelibus, M. D. & Tulipano, L. 1986, 1990; Gimenez, E. & Morell, I. 1997; Kapelj, S. 1997; Kapelj, J. et al., 1997, 2000). Therefore, on the Vis island, it is exceptionally important to find the origin and the age of salinization. This is important for

the management optimization of the existing fresh water reserves on the island and to find the most perspective areas for new fresh water catchments. The results of such investigations are mostly based on determined variations in chemical and isotope composition of groundwater, on ionic ratios and on calculations obtained by geochemical modelling. This paper shows the results gathered during the initial phase of hydrogeological investigations of water potential on the Vis island.

Hydrogeochemical facies

The measured groundwater temperatures in December 1999 are in accordance with average annual air temperatures on the Vis island. In June 2000 the higher temperatures were determined on all springs and the largest deviations were determined on the springs Batuda, Draga Voda, Velo Žalo and Gusarica, as the results of higher portion of warm water contribution, hence the drainage of shallow parts of island aquifers. The total dissolved solids (TDS) in the samples collected on the Vis island vary from 380 mg/l to over 1300 mg/l (fig. 2).

In the groundwaters distant from the coast, the values are lower and the deviations from two measurings are smaller. In the coastal springs the highest concentrations of total dissolved solids, accompanied by wider deviation regarding the time and hydrological conditions during sampling, were recorded. Thus, in the samples collected in June, after the dry period of several months, the groundwater mineralization was higher on all the locations except on Batuda and the well Velo Žalo in Komiža.

The basic chemical composition of the Vis island groundwaters mostly originated from dissolution of rocks that build the aquifer. The vicinity of the sea caused that the hydrogeochemical water types on the Vis island belong to the so-called mixed type – from CaNaMg-HCO₃Cl to NaMgCa-ClHCO₃. The presence of gypsum and anhydrite in the area of Komiža causes the increase of sulphate percentage in waters that outflow in the coastal springs Gusarica and Kamenica II, so the waters adopt a partial sulphate character, and the they are of the CaNaMg-SO₄HCO₃Cl type.

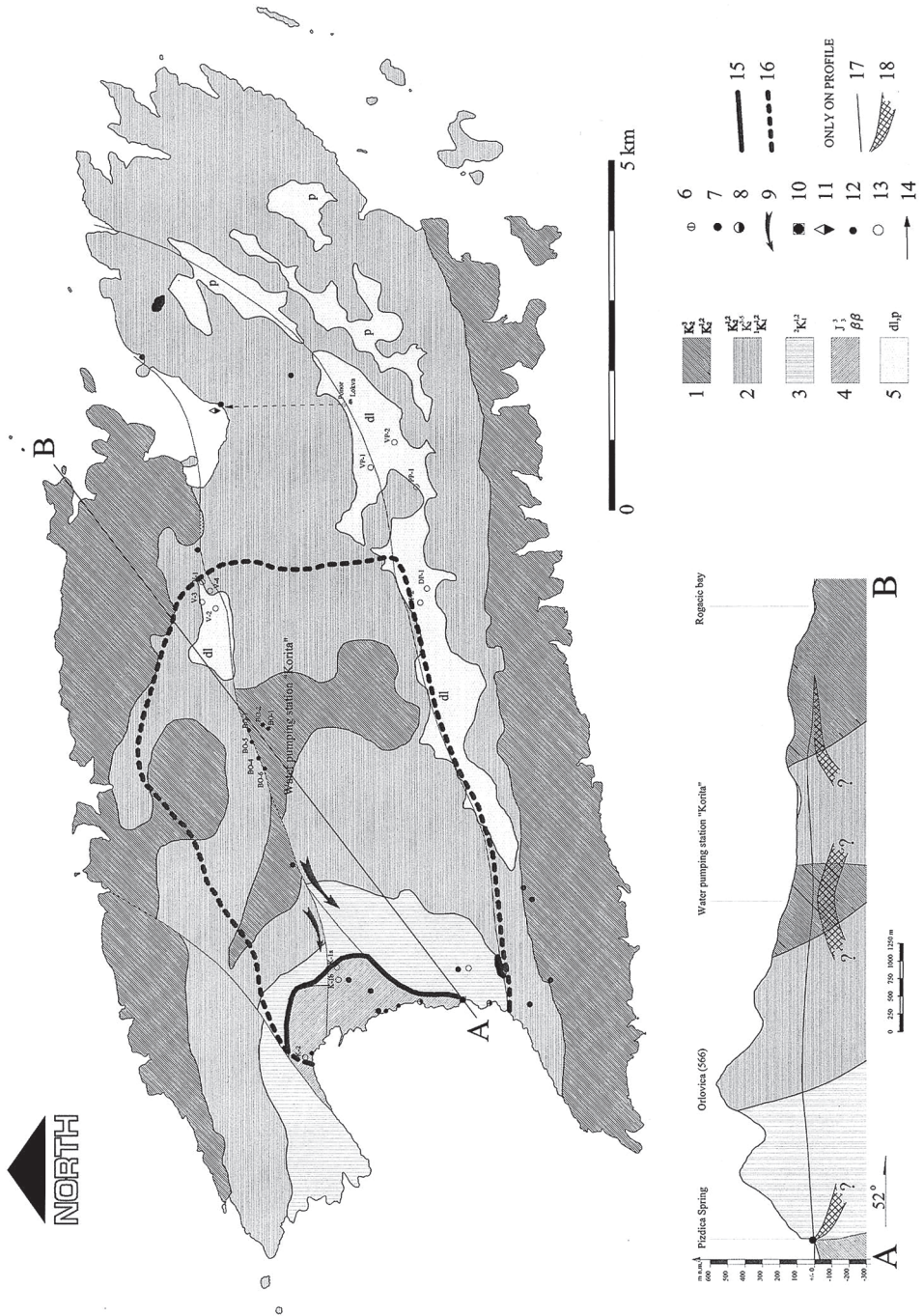


Figure 1. Schematic hydrogeological map of the Vis island. 1 – fractured, karstified, well permeable limestones; 2 – fractured dolomitic limestones, less karstified; 3 – dolomites of very low permeability; 4 – clastic and igneous rocks, barrier; 5 – Quaternary deposits, karst poljes, barrier; 6 – swallow hole; 7 – spring Q < 1 l/s; 8 – intermittent spring; 9 – main drainage direction; 10 – capped spring; 11 – spring; 12 – water supply well; 13 – borehole; 14 – estimated underground connection; 15 – water divide; 16 – underground water divide; 17 – estimated groundwater level; 18 – estimated transition zone.

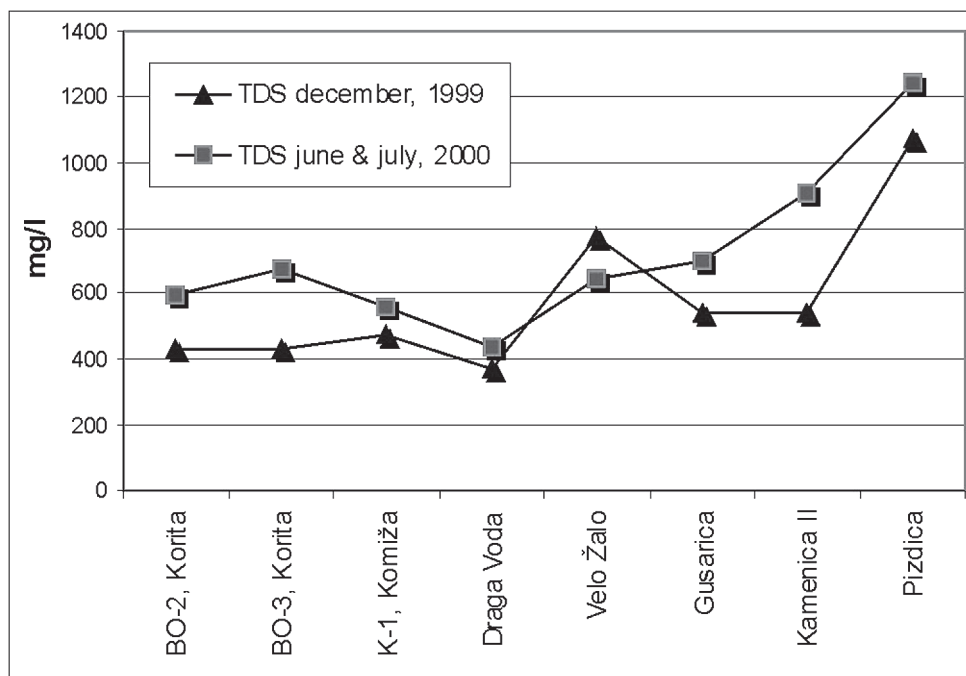


Figure 2. The content of totally dissolved solids in the groundwater samples of Vis Island

The springs Pizdica and Velo Žalo in the coastal area of Komiza have the biggest percentage of chlorides. The interesting, and, due to insufficient investigations and monitoring, up to now unexplainable fact is a greater percentage of chlorides during the hydrologically higher waters in December 1999. To which extent the mentioned phenomenon is connected with sea influence will have to be determined, because the origin of chlorides can be connected with washing of salt from the surface, where the salt developed there by sedimentation of the so called salt-spray water (the sea water parts of aerosol dimension), and/or it is the reflection of washing out the pollution from the ground and epi-karst zone by precipitation (fertilizers, septic tanks etc.). However, the percentage of sulphates is higher during the hydrologically lower waters. Then, the increased sulphate percentage in the groundwaters is the result of drainage of deeper parts of aquifer, where the evaporite sediments are in the contact with carbonate parts of the aquifer.

Conclusions and propositions

Synthesis of the existing understanding of the Vis island hydrogeology makes obvious the fact that the areas of various groundwater qualities can be separated. The middle part of the island, the most distant from the sea, represents the most appropriate area for the groundwater exploitation, because there the ground water has the lowest salinity and the smallest deviations of dissolved salts in the two hydrologically different parts of the year. The springs in the Komiza bay are all salted; the salinity of the springs Gusarica and Kamenica II mostly belongs to the increased percentage of sulphates, and in the springs Pizdica and Velo Žalo, located on the edge of southern part of the bay, it belongs to the increased percentage of chlorides. According to the acquired knowledge, the problem of shortage of installed pumping capacity in the water supply system of the Vis island does not exist. The problem lies partially in the losses in water supply system and partially in the fact that the

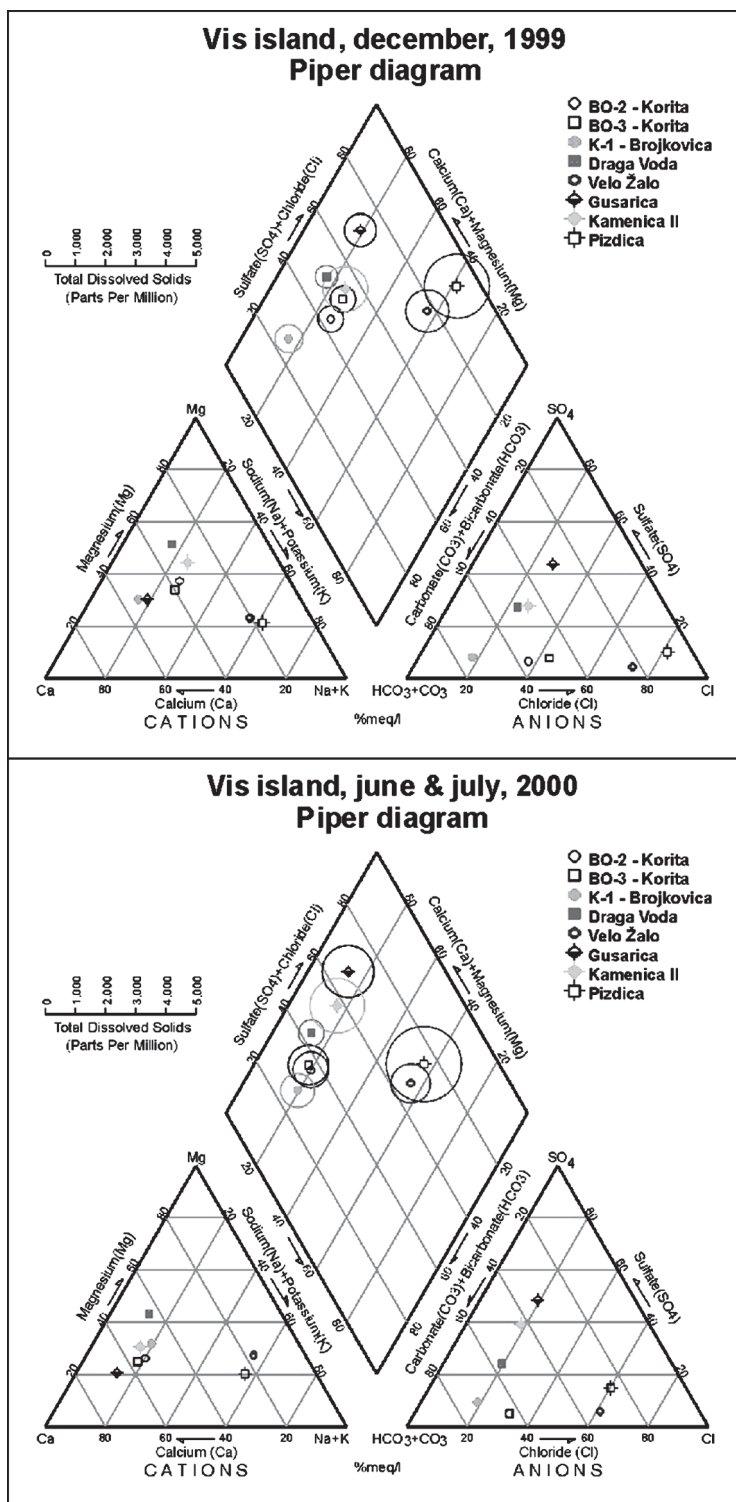


Figure 3. Piper's diagram of major ionic composition

groundwaters from the central part of island (Korita) and karst aquifer are naturally drained generally towards the west (Komiža bay). There, in contact with the hydrogeological barrier (that consists of diabase, spilite and clastic deposits), they flow out on the spring "Pizdica", and after that into the sea. On the south (as well as on the north) part of the island there are no permanent or significant periodical springs, suggests the existence of an underground relative barrier for groundwater flow in the part from Podhumlje to Plisko polje. The waters from the Quaternary deposits in this part of terrain probably flow out in the subsurface sea spring "Kut" in Komiža bay. The nature of north and south natural barrier is not yet sufficiently known. Between the karst springs "Pizdica" and "Gusarica" there are several smaller springs in the Komiža bay, the so-called "flysch" springs judging from the hydrogeochemical properties and from the outflow regime. Their inflow area is the local catchment area of Quaternary slope talus deposits in the immediate hinterland. This point at, the fact that in the Komiža bay the igneous and clastic rocks function as a complete underground and surface hydrogeological barrier, because the karst aquifer is drained on the boundary parts of surface manifestation of the mentioned barrier (Pizdica and Gusarica). The main goal of future activities should be the learning about the hydrogeological properties of aquifer on the island that include: the groundwater renewal dynamic, hydrodynamic conditions, average retention time for aquifer groundwater and the evaluation of contribution of waters of various origin with special attention to the salinity problem. Under the term groundwater dynamics the knowledge of the level of new groundwater contributions influencing the total water volume in the ground and the seasons they are mostly related to, has been considered. How much the new contributions are homogenized with the existing water in the ground determines the hydrodynamic conditions in the aquifer, and the average retention time in the aquifer refers to the average time that the water

particle spends in the ground. Also, the space arrangement of fresh and salt water mixing zones should be investigated, which can be established with geochemical investigations in deep boreholes that should be drilled for that purpose.

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