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HYDROGEOLOGICAL INVESTIGATIONS FOR MINERAL WATER AND CO_2 GAS IN THE VILLAGE OF BAC, BITOLA, THE REPUBLIC OF MACEDONIA

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Abstract tree exploration drill holes were dug in the Neogene Middle Pliocene sediments in the vicinity of the village of Bac for the investigation of the mineral water and CO_2 gas. The first drill hole (B 1) was dug 30 m in depth indicated a water bearing horizon in 0 to 26.4 m thick grey marly sandstone with a free level aquifer and ground water 2.2. m at depth and yield of 10 l/s.
The second and third drill holes (ED-1 and ED-2) were dug 301 m to depth and determined a free level aquifer, a sub artesian aquifer and four horizons with artesian aquifers. Mineral water and CO_2 gas were determined.
The yield of mineral water in both drill holes amounted to 40 l/s, and CO_2 gas to 2.16 t/h. Battery testing with self potential flow yielded 60 l/s mineral water and 3.238 t/h CO_2 gas for both wells.

Key words: Bac, mineral water, CO_2 gas, and artesian aquifer.

INTRODUCTION

Hydrogeological investigations carried out near the village of Bac situated some 20 km south east of Bitola (fig. 1) have determined that the south parts of the Republic of Macedonia are promising areas for mineral and CO_2 gas exploitation.

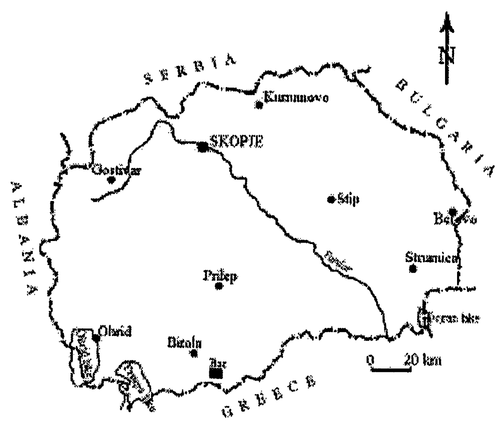

Fig. 1. Geographic position of Bac

GEOLOGICAL STRUCTURE OF THE AREA

The geographical structure of the wider vicinity of Bac (after Dumurdzanov and Hristov, 1976) consists of Precambrian and Cenozoic rocks.

The Precambrian rocks are the oldest formations in the area. They occupy the eastern part of the terrain. They are presents as (Gmb) augen amygdaloidal two mica gneisses, (Gmb) striped muscovite biotite gneisses, (Gmb) striped muscovite gneisses, (Sq) garnet staurolite micaschists, (Scu) garnet distene micaschists, (A) amphibolite schists and ($\delta\gamma$) massive medium to coarse-grained granodiorites.

The Cenozoic in the wider vicinity of the investigated area is present as Tertiary (Neogene) and Quaternary sediments.

The Neogene in the Pelagonian valley is widespread. It has developed within the Middle Pliocene sediments. The sediments transgressively overlie Precambrian rocks (gneisses and micaschists) and are present as gravel facies, sandstones, clays and loams which also represent the basal part of the Pliocene sedimentation.
The Quaternary in the wider vicinity is present as (Pr) proluvian, (d) deluvian and (al) alluvial sediments.

HYDROGEOLOGICAL FEATURES

Boundary and fracture types of aquifers were determined based on the geological composition of the terrain and structural porosity of the rocks, whereas free level and artesian aquifers were determined based on the hydrodynamic characteristics.
Boundary type of aquifers occurs in alluvial and proluvial layers and in Neogene Pliocene sediments made up of gravels and sandstones. Fracture type of aquifers have been found in the Precambrian rocks.
Based on the yield the boundary type of aquifers has been divided into those of low yield, medium yield and large yield. Artesian aquifers occur in several horizons in the Neogene Pliocene sediments, whereas free level aquifers are present in the top most horizon of the Neogene and in the alluvial and proluvial layers.

DIGGING OF EXPLORATION DRILL HOLES

Three exploration-exploitation drill holes were dug in the Neogene Middle Pliocene sediments in the vicinity of Bac.
The first drill hole (B1) aimed at discovering ground water for technological use. It was dug 30 meters to depth; the diameter being 310 mm. Exploitation structure of 160 mm diameter was placed inside. The drill hole determined only one 0 to 26.4 m horizon with a free level aquifer and ground water 2.2. m at depth.
The second and third drill holes (ED-1 and ED-2) were dug 301 m to depth with beginning diameter of 660 mm and final of 295 mm. Exploitation structures the diameter of 508 – 160 mm were built. The part between the drill holes and the built in construction of 0 to 80 m in depth was insulted with cement and the part from 80 to 301 m was filled with 4 to 8 mm granulate.
The distance between the second and the third drill hole amounts to 30 m. After digging the second drill hole, large amount of self-potential mineral water and gas of 8.8. bar pressures were obtained and there was a need to relax the large pressure in the collector environment. The same lithological and hydrogeological composition was determined in both drill holes due to the closeness of the holes. The thickness and description of the lithologic members is given in Table 1.
Hydrogeological cross section obtained based on the data of the drill holes (ED-1 an ED-2) is shown in fig. 2.

Table 1. Thickness and description of the lithologic members of the drill holes ED-1 and ED-2.

Depth	Lithologic description of material during drilling
0.00-3.00	Fine dusty sand
3.00-6.00	Silty sand
6.00-26.40	Grey cracked marls (free level aquifer)
26.40-63.00	Compact grey marls
63.00-67.00	Coal
67.00-69.00	Coal clayey dust
69.00-84.00	Grey sands, gravels with interlaeyrs of clay (subartesian horizon)
84.00-109.00	Coal
109.00-144.00	Grey fine-grained sands (artesian horizon)
144.00-146.00	Brown clays
146.00-176.00	Grey fine-grained sands (artesian horizon)
176.00-194.00	Grey fine-grained sandstones
194.00-200.00	Grey fine-grained clayey sands
200.00-224.00	Grey sandstones
224.00-229.00	Grey sandstones and conglomerates
229.00-236.00	Grey medium-grained sands with fragments of gravel, water and (CO_2) gas (artesian horizon.
236.00-240.00	Grey sandstones
240.00-276.00	Grey clays
276.00-283.00	Grey fine-grained sands (artesian horizon)
283.00-301.00	Grey clays and clayey sands

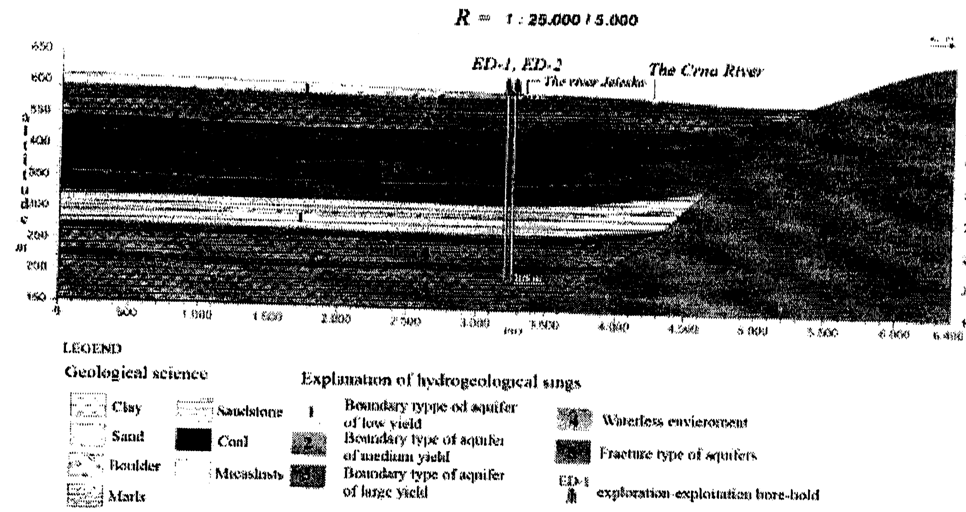

Fig. 2. Hydrogeological cross-section

The cross-section shows that the first free level aquifer occurs from 0 to 26.4 m in depth with grey fissured marls, whereas 69 to 84 m at depth a sub artesian aquifer occurs in grey sands and gravel in clay interbeds. A water-bearing complex consisting of four artesian horizons was determined in grey fine-grained sands 109 to 283 m in depth. The first 35-m thick horizon occurs 109 to 144 m in depth. The second, 30 thick horizon, occurs 146 to 176 m at depth and the third, 7 m thick horizon in which CO_2 was determined, 229 to 236 m in depth. The fourth, 7-m thick horizon was found 276 to 283 m in depth.

DRILL HOLE TESTING

Drill hole testing was done by measuring water pressure and observing the manometer gas pressure.
Drill hole B1, at stabilized flow yielded poorly mineralized water of 10 l/s and minimal pressure of CO_2 gas.
Measurements of water pressure and gas in drill holes ED-1 and ED-2 indicated stabilized pressure of mineral water the capacity of 40 l/s for each drill hole, and gas flow from each was 2.16 t/h. Battery testing with self-potential water of both aquifers gave total yield of 60 l/s mineral water and 3.238 t/h CO_2 gas. The difference in yield and gas of individual and battery testing is due to the radius of influence of drill holes and their distance.

CALCULATION OF HYDROGEOLOGICAL PARAMETERS

Investigations carried out on exploration dill holes determined the following parameters:

COEFFICIENT OF FILTRATION IN AQUIFERS (ED-1 AND ED-2)

The coefficient of filtration in both aquifers was calculated based on data of examination test using Forhajmer's equation $K = \dfrac{0.16Q}{rS}$ for m > 105 and condition R/m < 10.

For Q = 40.01 l/s yield of aquifer,
R = 0.1475 m semi diameter of aquifer,
S = 88.0 m total depression,
Ksr = 4.93 x 10^{-4} m/s.

COEFFICIENT OF TRANSMISSIBILITY

The transmissibility coefficient was calculated by the formula:
$T = Ksr \times m$ (m^2/s)
T = 4.63 x 10^{-2} (m^2/s)

RADIUS OF INFLUENCE

The radius of influence of aquifer was calculated for unlimited spread in conditions of feed using the Kozeni's formula:

$$R = \sqrt{\frac{12T}{\mu}}\sqrt{\frac{Qh}{\pi}}$$

T = 72 hours (duration of testing)
h= 88 m (lowering of total depression level)
Q = 50 l/s (yield)
μ = 0.2 (specific yield)

R = 524 m

MINERAL WATER RESERVES

Calculation was performed only for exploitable reserves of mineral water and CO_2 gas.
Estimated water reserves are 10 l/s and minimum (insignificant) CO2 gas flow were discovered in drill hole B-1.
Total reserves after investigations in drill hole B-2 and B-1 determined 60 l/s at manometer pressure P = 0.0 bar and gas flow of 3.238 t/h.

QUALITY OF MINERAL WATER AND CO_2 GAS

Examination on the quality of mineral water and gas were carried out in the Republican Institute for Health Protection in Skopje. Results indicate that the mineral water belongs to the Ca-Mg-Sr-F-K bicarbonate waters. According to physico-chemical features it does not meet the requirements due to the elevated amount of colour, turbidity, Fe and Mn contents. The water should be purified before use. Studies carried out on CO_2 indicated that it is of high quality amounting to 99.975 %.
Bacteriological and radiological analyses indicated that the mineral water is good.

GENESIS OF MINERAL WATER AND CO_2 GAS

The occurrence of mineral water and gas is related to deep faults and Pliocene sediments. The basal parts of the Pliocene are composed of water permeable coarse-grained clastic material - sands and gravels. The series is overlain, both horizontally and vertically, by alternating water permeable and non-permeable sediments. These are located lower than the feeder zone that is favorable for the formation of artesian aquifers. Neogene layers are of slight dip towards the central part of the Bitola valley that allows movement of ground waters to the central parts of the valley.
Recharge of artesian aquifers is done mainly by surface water flows, atmospheric falls that infiltrate into the marginal mountainous terrains round the valley, by ground water flow from surrounding fracture porosity aquifers located at higher hypsometric level and water flow from deeper water bearing environments.
The connection between artesian pressures in the drill holes and intensity of rainfalls was noticed. In spring, when rainfalls are intense, artesian pressure in aquifers increases indicating that at that time there is an increased recharge of ground water reserves.
There are two theories in connection with the genesis of the gas in the Bitola valley. After Guezelkovski (1999), free CO_2 gas in the mineral waters in the basin is of endogene origin. The gas coming from great depth through the major dislocation passing through the valley and other block faults and fissures flows out and acidises the artesian water bearing horizons.