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DISSOLVED HELIUM AS INDICATOR FOR GEOTHERMAL WATER PROSPECTING

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ABSTRACT

The essence of this method is the study of helium in the accessible part of the lithosphere. The present paper is a summary of data obtained on helium dissolved in cold and geothermal groundwaters of Southern Bulgaria. More than 1000 samples from different water sources have been studied. Data were obtained on an analytical device "INGEM – 1". Helium distribution in the geothermal waters in two regions of Southern Bulgaria is viewed in more detail. The content of helium in groundwater varies widely for Bulgaria – from 0.5 Pa for the cold ground waters to more than 1 000 Pa for the geothermal waters. Also presented is the spatial distribution of helium and outlines the areas of maximal concentrations. This "picture" provides information about the existence and approximate location of tectonic faults and geothermal waters. Concentration of helium in waters commonly increases with increasing water temperature. A comparison between the helium and heat flow distribution in Southern Bulgaria is made. The results show that helium content in the waters can be a reliable and independent indicator for thermal water prospecting.

1. INTRODUCTION

Bulgaria covers an area of 111000 sq.km and it is a part of two regional tectonic structures - the Moesian plate (Northern Bulgaria) and the Alpine - Himalayan belt (Southern Bulgaria). All natural geothermal springs are found in Southern Bulgaria, which has a complex geological structure. The subject of this article is on helium dissolved in the geothermal water of the Southern Bulgarian reservoirs. The helium method is used because it is a reliable indicator for the presence of geothermal water at places where a higher than background helium concentration is found. It is a comparatively fast and cheap method and it can be used under field conditions. The results discussed in this article have been recently obtained after systematic analysis of helium content in the geothermal waters.The distribution of the helium in the geothermal waters in two regions of Southern Bulgaria is viewed in more detail in the Sofia and Chepino valleys. The largest hydrothermal reservoirs of the country are concentrated in these areas. They have different geological structure and tectonic conditions which make it possible to reveal the influence of these factors over the distribution of helium in the geothermal waters.

2. METHODOLOGY

The data on helium dissolved in the geothermal water were measured using INGEM-1 analytical device. The sensitive element has a tiny ionic pump with a hermetically sealed vacuumed chamber which is insulated to external impact. Only helium penetrates into the sensor through the membrane (Ianitzki, 1979). The device is applicable for both water and gas tests. The impact of temperature can be eliminated through corrections (by cooling of geothermal waters down to 25°C. Maximum precision is achieved by equalizing the temperature of the instrument and the substance. In most cases, in order to avoid any mistakes while testing, two or three samples are taken from the water sources and the most reliable results are used.

3. DISCUSSION AND RESULTS

It is known that there are three different migration forms of helium:

1) Dissolved ions of helium (He^+) or α - particles.
2) Neutral atoms located in the crystal lattice or in the closed pores of the materials and the rocks.
3) Neutral atoms of mobile gas.

Only the mobile form of helium is a subject of the present investigation. Of prime importance for the flow of helium towards deep aquifers are the following physical and chemical factors:

- the water medium fostering the diffusion of helium.
- the high temperature intensifying the mobility and the emanation from the crystals
- the duration of water-rock contact ensuring the necessary time and conditions for the process.

The dissolved helium content in the waters of Southern Bulgaria varies widely - from 0.5 Pa to more than 1000 Pa (for 38 of the tested water sources), Fig.1. Helium background has been established in surface waters - rivers, lakes and dams, as well as in the numerous sources which drain cold waters from the shallow aquifers. A higher helium content is found in waters with deep circulation and temperature above 20°C.

The higher helium waters (above 500 Pa) are in zones of the anomalous heat flow (up to 100 and more mW/m^2), (Bojadgieva et al,1991), Fig.1. There are structural conditions for intensive heat and mass transfer from the Earth's interior in these areas. The anomalously increased heat flow values are influenced by the presence of more intensive hydrothermal activity while the increased helium content is connected with the higher temperature of thermal waters with deep circulation. Out of all factors which influence the content and the regional helium distribution, the most essential ones for the region are the structural factors and the temperature. Based on this, the helium content in the underground waters can be used as an indicator for prospecting of deep geothermal reservoirs. In order to analyze in detail the geological factors which have influenced the helium content, two geothermal sites - Sofia valley and Chepino valley are considered. They are the biggest geothermal reservoirs in S.Bulgaria and the total capacity of their sources are more than 170 l/s and 130 l/s, respectively.

3.1. Sofia valley

Sofia valley (Fig.1) is a graben with a block structure, complicated inside by intensive faulting. The graben is filled with Neogene and Quaternary deposits while the surrounding mountains consist of varied Paleozoic and Mesozoic rocks, Fig. 2. The helium distribution map drawn for the valley (Fig.3) and the geological-heliometric cross sections (Fig.4) give a full picture about the spatial helium distribution and outline the zones with maximal helium concentration. These zones probably mark deep faulting. The first group of faults has an approximate direction N-S and follows a line from the village of Kurilo to Al.Voikov to Ilianzi to Sofia. The second group of faults has an approximate direction E-W along a line from the village of Ravno pole to the village of Birimirzi to Svoboda (in Sofia), Fig.3.

More than 300 samples from a total of 110 cold and geothermal water sources have been studied and hydro-chemical analysis are available for most. The interpretation of the data shows that the increase of helium concentration in the waters increases with the increase of the depth to bedrock, and with the depth of water circulation (Fig.2, 4), respectively. The depth of the bedrock in the valley is from 18-21 m below the surface (in W-1- Ivaniane and W-1-Kniajevo on the west) to more than 500 m (in W-4-Svoboda and W- 3 Ilianzi in the center) and even to 1200m at some places. The helium content in these sources differs as well: from 23-38 Pa (W-1 Kniajevo and W-2 Ivaniane) to 3504 -3720 Pa (W-4 Svoboda and W-3 Ilianzi).

The helium content is apparently also affected by the age of the lithological formations. It is lowest in waters accumulated in younger Senonian andesites (Gorna-bania, Kniajevo) and much higher in Triassic sediments (W-3 Ilianzi) and in the waters from Permian rocks (W-20 Kurilo), Fig.4.

High helium concentrations have been found in some of the sources draining the Neogene sediments (W-1 Birimirzi, W-320 Svetovrachene), but it is assumed that such waters have been secondarily accumulated in upper strata, while the bedrock from which they originate are probably of Triassic age. The helium content in the analyzed waters is correlated with their temperature and in most cases it increases with the water temperature increase.

There are a few exceptions though. For instance, in W-20 Kurilo (temperature 24^{o}C) and well W-1 Birimirzi (temperature 22^{o}C) helium is within the range of several thousand Pa. This is probably due to the mixing of thermal and fresh cold waters or to the longer residence time of the geothermal waters which they cooled without loosing their helium content.

There are some cases nevertheless, when at high water temperature (above 70^{o}C) the helium concentration is comparatively low - 90 Pa. This can be explained by the more intensive helium evolving from the water together with other spontaneous gases. Such anomalies are typical for other regions in Southern Bulgaria as well Sapareva banja (100^{o}C), Levunovo (86^{o}C) and Kozuh (75^{o}C), where the draining of waters is along fault zones.

3.2. Chepino valley

The geothermal reservoir, formed within Chepino valley (Fig.1) represents a non-stratified hydrothermal system of fissure circulation. From a geological point of view the area consist of Pre-Palaeozoic granites and metamorphites, intensively broken from tectonic activity which occurred before the Pleiocene, when the graben was formed. The geothermal waters are accumulated in granites and metamorphites (mainly marbles). The waters ascend through the zones of high tectonic disturbances and appear on the surface most frequently at the intersects of the faults.

The increase of helium concentration in geothermal water is typical for the granites and silicate metamorphites in the region of Southern Bulgaria. The rocks, in most cases, generate radiogenic helium according to the structural characteristics and tectonic activity of the regions. Within the borders of the valley the following geothermal reservoirs have been formed: Chepino, Ladgene, Kamenitsa, Draginovo and Rakitovo.

About 200 samples from 36 geothermal sources from the prospected area have been studied and 35 have been analyzed. It has been established that the helium content increases gradually from southwest to northeast. In Chepino it varies from 29 Pa (W-1) to 83 Pa (W-2), in Ladgene-1 and Ladgene-2 the helium content ranges from 39 Pa (spring 18) to 414 Pa (W-7 Topilata), while in Kamenitsa it is from 296 Pa (W-3) to 503 Pa (spring 7). The helium content in Draginovo is about 400 Pa. When comparing the results of hydro-chemical studies with the results of the helium data it becomes evident that there is a certain dependence between the helium content in the waters and the quantity of sodium, potassium, chloride, sulphates, fluoride and silicate acid in them. With the increase of the helium content the amount of the above listed components and the TDS of the waters also increase (Fig.5). The geothermal water temperature increases in the same direction - from 48^{o}C (Chepino reservoir) to 94^{o}C (Draginovo reservoir). A well expressed helium, temperature and hydro-chemical zonality is observed in this region, that is due to the lack of mixing of geothermal waters with cold waters from the shallow horizons

It has been established for Southern Bulgaria that helium can be traced only in geothermal waters while in shallow cold waters and in surface waters it is absent. In all cases where helium in cold waters (under 20^{o}C) was found, the hydro-chemical analysis proved that these were cooled mineral waters or mixed cold and thermal waters.

Based on this we consider that helium can be used as a reliable and independent indicator for geothermal water prospecting in Southern Bulgaria. A comparison between helium quantities dissolved in the waters and the helium evolved with spontaneous gases has been made by Pentcheva & Hristov (1989). It shows that helium in the South Bulgarian geothermal waters is in equilibrium between the two phases.

4. CONCLUSIONS

1. The maximal helium concentration coincide with deep faulted zones of water circulation. This explains the high helium values (above 500 Pa) which occur in zones of increased heat flow.

2. Helium content in the waters can be a reliable and independent indicator for thermal water prospecting. Based on the large number of analysis for the region of Southern Bulgaria it is established that only thermal waters and their derivatives contain helium.

3. It was found that dissolved helium is correlated with the temperature, the TDS of the waters, the lithological type and the geological age of the rocks, as well as by other factors. These relations are confirmed for the studied geothermal sites.

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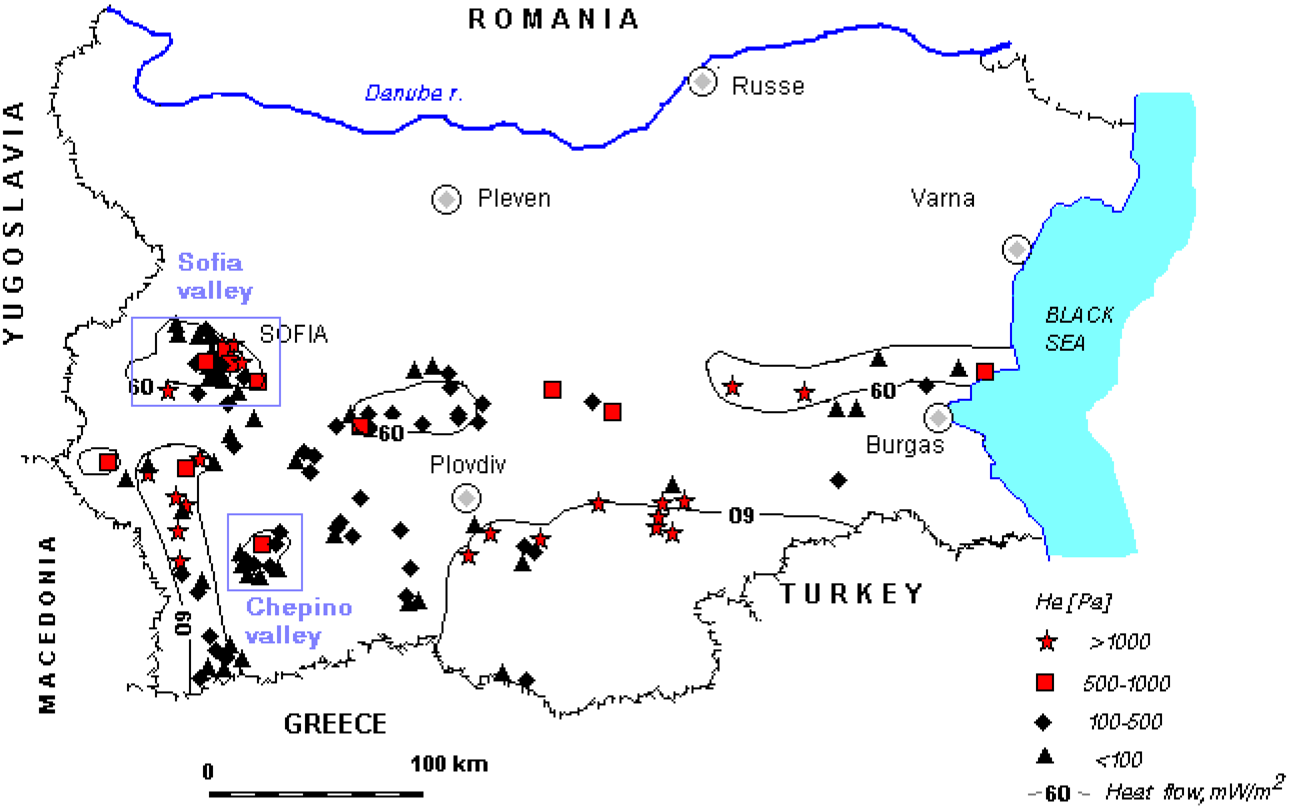

Figure 1. Helium and Heat Flow distribution in Southern Bulgaria

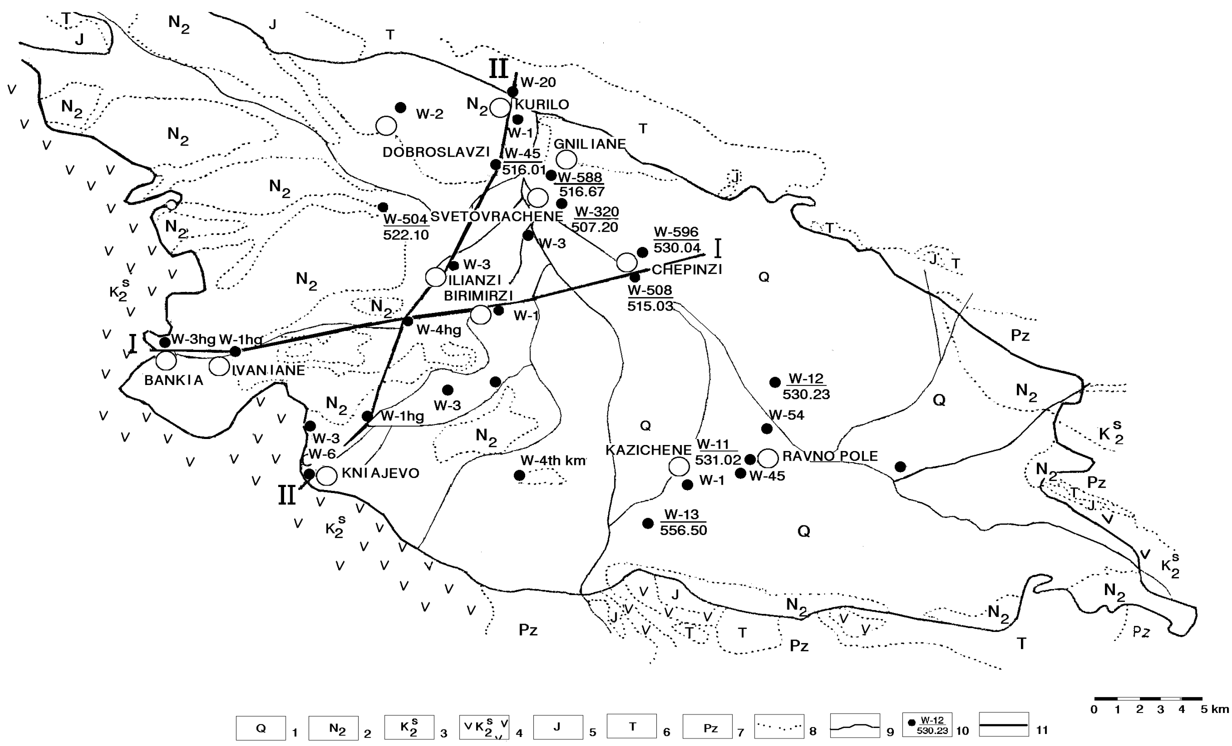

Figure 2. Geological map of Sofia valley

1-Quaternary sediments; 2-Pliocene clays and sands; 3-Senonian sediments; 4-Senonian andesites and andesite tuffs; 5-Jurassic sediments; 6-Triassic sandstones and limestones; 7-Paleozoic schists and quartz rock; 8-boundaries between the formations; 9-boundaries of the valley; 10-well/ altitude; 11-profile lines

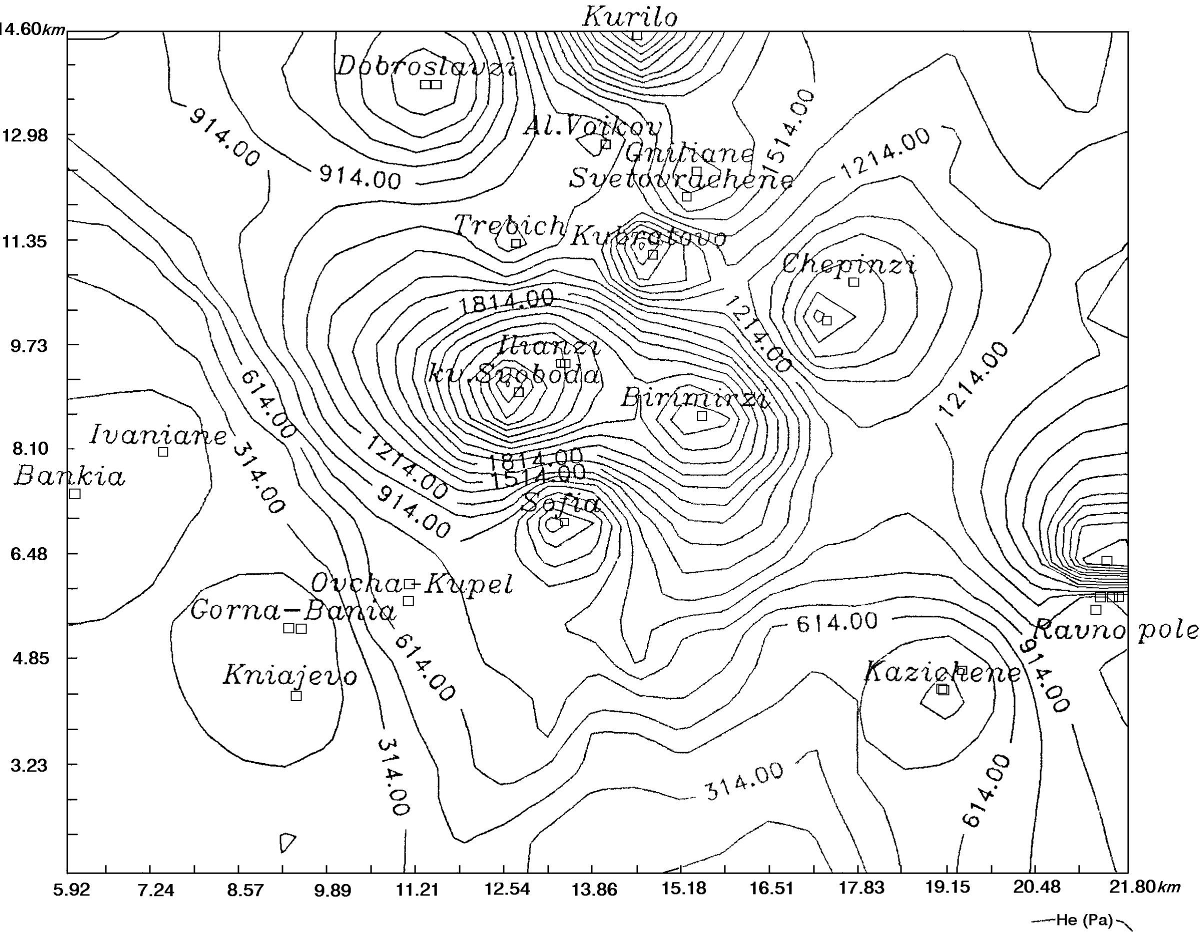

Figure 3. Helium distribution in Sofia valley

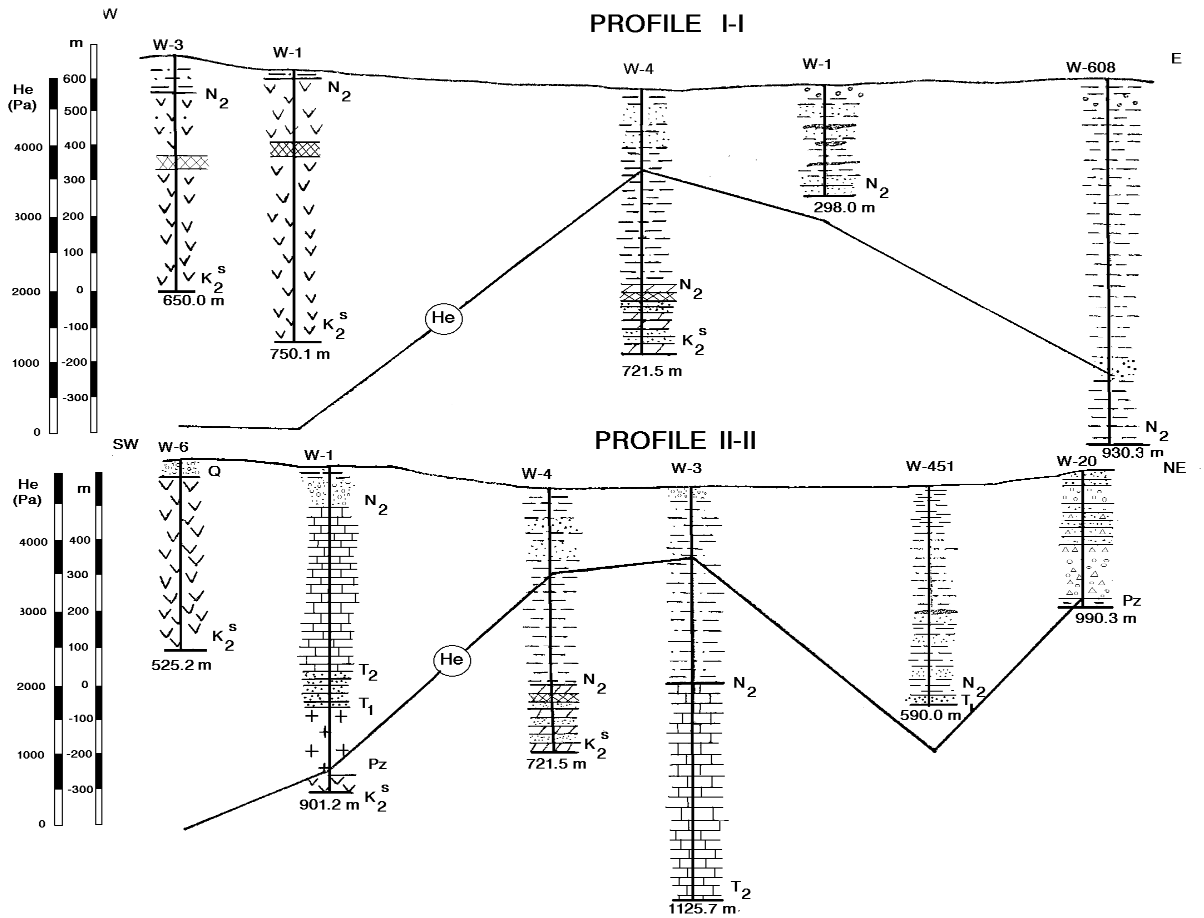

Figure 4. Geological-helium profiles in Sofia valley

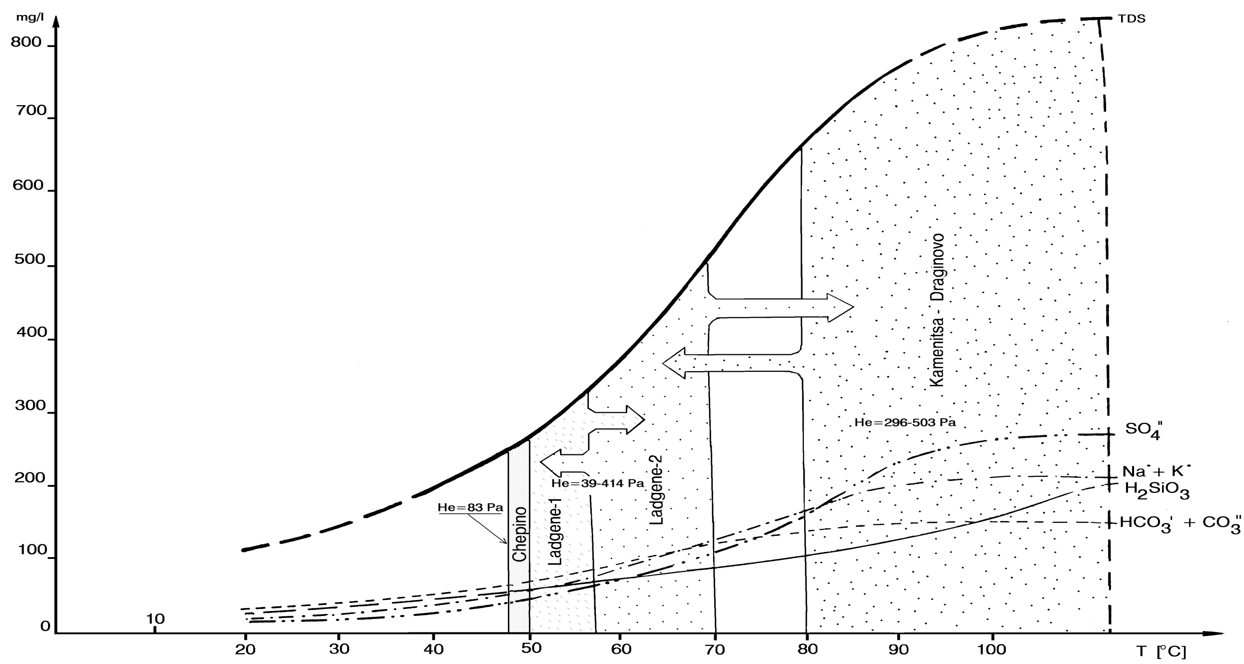

Figure 5. Chemical composition versus measured water temperature in Chepino valley.