AGS
Acta Geographica Silesiana, 12/1 (29)
WNoZ UŚ, Sosnowiec, 2018, s. 11–26
ISSN 1897–5100

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REGIONAL HYDROGEOLOGICAL CHARACTERISTICS OF THERMAL WATERS OF ALBANIA

Eftimi R., Frashëri A. **Regionalna charakterystyka hydrogeologiczna wód termalnych Albanii.** Albania jest krajem małym, ale jej regionalny obraz hydrogeologiczny jest bardzo heterogeniczny. Warunki geologiczno-strukturalne oraz geomorfologiczne Albanii wpływają na kształtowanie się różnych poziomów wodonośnych o odpowiednim typie hydraulicznym, zasobach, hydrodynamice i cechach hydrochemicznych. Wśród nich funkcjonują głębokie poziomy wodonośne, związane z różnymi utworami typu ewaporytów, skał węglanowych i molas, zawierającymi wody termalne. Najbardziej znaczące zasoby wód termalnych w Albanii stanowią węglanowe poziomy wodonośne. Uwzględniając warunki geologiczne, jak również cechy hydrochemiczne i termiczne, można wyróżnić cztery hydrochemiczne typy wód, związane z czterema prowincjami wód termalnych w Albanii. Wody typu H_2S, SO_4-Ca o temperaturze 43°C pochodzą z utworów ewaporytowych prowincji Korab. Wody typu Cl-Na-Ca lub Cl-SO_4-Na-Ca o zróżnicowanych temperaturach oraz różnej koncentracji H_2S, są związane z głęboko zalegającymi wapienno-dolomitowymi strukturami antyklinalnymi prowincji Kruja. Większość wód z depresji pre-adriatyckiej (PAD) pochodzących z głęboko zalegających neogeńskich, głównie tortońskich piaskowcowych poziomów wodonośnych należy do typu Cl-Na z H_2S i CH_4 , zazwyczaj z wysoką koncentracją Br i J. Nieliczne wody z prowincji jońskiej są typu Cl-Na i cechują się różnymi temperaturami. W niniejszej pracy przedstawiono cechy geologiczno-strukturalne, termiczne oraz hydrochemiczne każdej z wyróżnionych prowincji. Najbogatszą prowincją pod względem zasobów wód termalnych jest Kruja, w której granicach istnieje około 85% gorących i chłodnych termalnych źródeł H_2S.

Эфтими Р., Фрашери А. **Региональная гидрогеологическая характеристика термальных вод Албании.** Албания – небольшая страна, но ее региональная гидрогеологическая картина очень дифференцирована. Геолого-структурные и геоморфологические условия Албании влияют на формирование разных водоносных горизонтов, отличающихся подходящим гидравлическим типом, ресурсами, гидродинамике и гидрохимическими свойствами. Среди них функционируют глубокие водоносные горизонты, связанные с различными отложениями типа эвапоритов, карбонатных пород и моласс, содержащими термальные воды. Наиболее значимыми ресурсами термальных вод в Албании отличаются карбонатные водоносные горизонты. Учитывая как геологические условия, так и гидрохимические и термические свойства, выделяют четыре гидрохимических типа вод, связанных с четырмя провинциями термальных вод Албании. Воды типа H_2S, SO_4-Ca с температурой 43°C относятся к эвапоритным отложениям провинции Кораб. Воды типа Cl-Na-Ca lub Cl-SO_4-Na-Ca с дифференцированными температурами и разной концентрацией H_2S, связаны с глубокими известняково-доломитовыми антиклинальными структурами провинции Круя. Большинство вод преадриатической депрессии (PAD), относящихся к глубоко залегающим неогеновым, в основном тортонским песчаниковым водоносным горизонтам, принадлежат к типу Cl-Na z H_2S i CH_4, обычно с большой концетрацией Br и J. Воды Ионической провинции спорадически принадлежат к типу Cl-Na и отличаются разным температурами. В данной статье представлены геолого-структурные, термические и гидрохимические черты каждой из выделенных провинций. Самой богатой по ресурсам термальных вод является провинция Круя, в чертах которой сосредоточены около 85% горячих и прохладных термальных источников H_2S.

Key words: thermal and mineral water, geothermal energy, carbonate rocks, chemical type of water.
Słowa kluczowe: wody termalne i mineralne, energia geotermalna, skały węglanowe, typy chemiczne wód
Ключевые слова: термальные и минеральные воды, геотермальная энергия, карбонатные породы, химические типы пород

Abstract

Albania is a small country but its regional hydrogeological picture is very heterogeneous. The complex geological-structural and geomorphologic conditions of Albania have resulted in the formation of diverse aquifers with regard to their hydraulic type, resources, hydrodynamics and hydrochemical characteristics. Among them there are some deep aquifers associated with different rocks like evaporite, carbonate and molasses, hosting thermal waters. Carbonate aquifers constitute the most important thermal water resources of Albania. Based on geological conditions, as well as on hydrochemical and thermal characteristics, four hydrochemical water types related to four provinces of thermal waters are distinguished in Albania. H_2S, SO_4-Ca-type waters (temperature 43°C) originate from evaporite rocks of the Korab Province. Samples of the Cl-Na-Ca or Cl-SO_4-Na-Ca-type, of varying temperatures and H_2S concentrations, originate from deep-lying limestone-dolomite anticline structures of the Kruja Province. Most samples from the Pre-Adriatic Depression (PAD) related to deep laying Neogene, mainly Tortonian, sandstone aquifers are of the Cl-Na water type with H_2S and CH_4 gases and usually with high Br and J concentrations. A few water samples from the Ionian Province are of the Cl-Na water-type and measure varying temperatures. For each province the geological-structural, thermal and hydrochemical characteristics are described in the summary. The richest province in terms of thermal water resources is the Kruja Province, where about 85% of the warm and hot thermal H_2S springs are located.

INTRODUCTION

In Albania, the presence of high mountain chains and active fault systems favours the rise of deep waters that discharge at the surface as thermal springs, which in Albania are also mineral (fig. 1).

Fig. 1 Tectonic position of Albania
Rys. 1. Tektoniczna pozycja Albanii
Рис. Тектоническая позиция Албании

A number of important thermal springs rich in H_2S, rise from deep karst aquifers related to deep bury anticline carbonate structures. Important thermal water resources have also been explored by many deep oil and gas wells, both in deep carbonate aquifers but mostly in Neogene molasses aquifers which are shallower.

The first noteworthy investigation of thermal waters in Albania was undertaken by AVGUSTINSKI, ASTASHKINA, SHUKEVICH (1957). That study presented detailed chemical analyses of most thermal springs and some free flowing deep wells, and proposed a regionalization of thermal water types of Albania. Based on the data on deep wells of oil and gas fields of Pre-Adriatic depression, the hydrochemical characteristics of deep groundwater were summarized by SHTREPI (1971, 1972, 1980). The effect of evaporate tectonics on the development of regional faulting and the formation of thermal waters of the Kruja zone was described by VELAJ (1995, 1999, 2001). Studies on the geothermal field and an evaluation of geothermal energy in Albania were carried out during the preparation of the Atlas of Geothermal Resources in Albania. The temperature, average geothermal gradient, heat flow density and geothermal zone maps were produced from the data, at the depths of 100, 500, 1 000, 2 000 and 3 000 m below the surface (FRASHËRI et al., 2004).

The knowledge of the geological and tectonic settings of the hydrogeological structures of Albania and the character of the thermal water, mainly the hydrochemical characteristics, enables us to define the conditions of formation of thermal waters.

This paper represents a description in regional scale of thermal waters of Albania in close relation to the geological-tectonic construction of Albania, as part of the deep regional groundwater flow system, and the thermal springs as their discharge features (EFTIMI, FRASHERI, 2016).

GEOLOGICAL SETTING OF THE ALBANIDES

Albania is part of the Mediterranean Alpine Fold Belt and fits in the Dinaric-Hellenic range (fig. 1). The geological structure of the Albanides comprises two major units (fig. 2): Internal Albanides to the East and External Albanides to the West (AUBOUEN, NDOJA, 1964; PAPA, 1993; MEÇO, ALIAJ, 2000). Internal Albanides are characterized by the presence of an intensively tectonized ophiolitic belt.

Internal Albanides are further subdivided from East to West to *Korabi Zone* (Golia Zone in the Dinarides and the Pelagonian Zone in the Hellenides) mostly represented by Paleozoic terrigene metamorphic rocks, and *Mirdita Zone* (Serbian Zone in the Dinarides and as Subpelagonian Zone in the Hellenides) represented at the lower tectonic unit by an ophiolite belt (2–14 km thick). Two post orogenic sedimentary (intermountain) basins, the Burreli Basin and Korça Basin (Thessalyan basin in Greece), overlie transgressively the Mirdita zone. *Gashi Zone* continues as the Durmitori Zone of the Dinarides and consists of metamorphic and terrigene rocks, limestone and volcanic rocks (fig. 2).

External Albanides are part of the South Adriatic sedimentary basin, even though characterized by the lack of magmatism and by more regular structural models compared to the Internal Albanides, and are highly affected by the late Miocene tectonic stages. The Albanides are interrupted by a system of longitudinal faults of NW-SE direction and

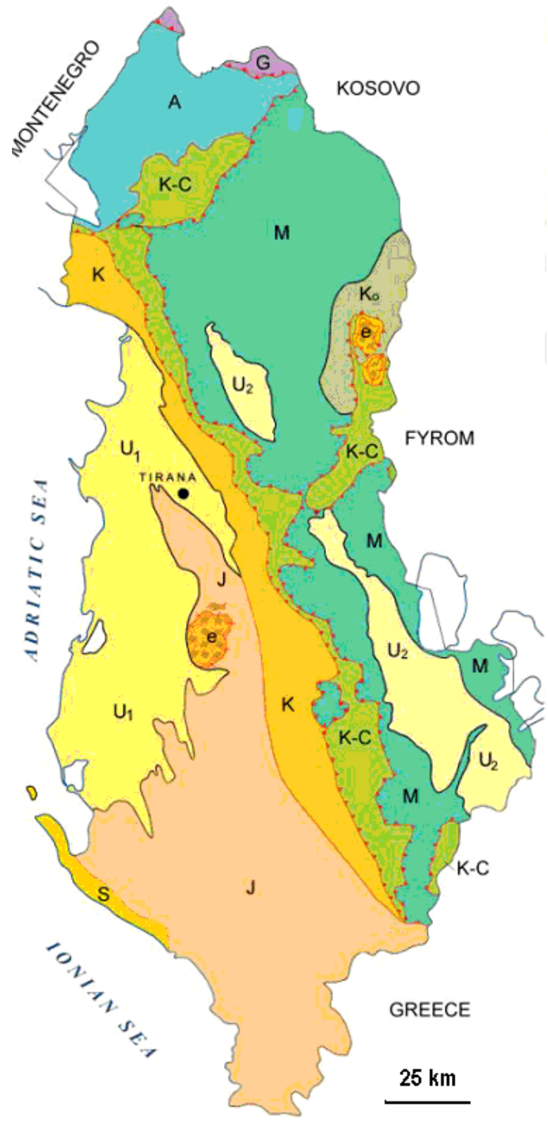

Fig. 2. Tectonic setting of Albania:
Inner Albanides: Ko – Korabi Zone; M – Mirdita Zone; G – Gashi Zone and U2 Burrel and Korça Basins. External Albanides: A – Alps Zone; K-C – Krasta-Cukali Zone; K – Kruja Zone; I – Ionian Zone; S – Sazan Zone. U1 – Peri-Adriatic Depression and U2 – Burrel and Korça Depressions (acc. to XHOMO et al., 2002)

Rys. 2. Budowa tektoniczna Albanii:
Albanidy Wewnętrzne: Ko – strefa Korabi; M – strefa Mirdita; G – strefa Gasi; U2 – obniżenia Burrel i Korça. Albanidy Zewnętrzne: A – strefa Alp; K-C – strefa Krasta-Cukali; K – strefa Kruja; I – strefa jońska; S – strefa Sazan. U1 – depresja Peryadriatycka , U2 – depresje Burrel i Korça (wg: XHOMO et al., 2002)

Рис. 2. Тектоническое строение Албании:
Внутренние Албаниды: Ко – зона Кораби; М – зона Мирдита; G – зона Гаси, U2 – бассейны Буррель и Корча. Внешние Албаниды: А – зона Альп; К-С – зона Краста-Чукали; К – зона Круя; I – зона Ионическая; S – зона Сазан. U1 – депрессия Пери-Адриатическая, U2 – депрессии Буррель и Корча (по: XHOMO et al., 2002)

some transversal faults that even touch the mantle (Aliaj, 1989; Frashëri, Bushati, Bare, 2003). The tectonic zones of the *External Albanides* extend in the western part of Albania comprise the *Alps Zone* (analogous to the High Karst in the Dinarides and to Parnas Zone in the Hellenides) where the oldest outcropping rocks are Permian sandstones and conglomerates, but most of the zone consist mainly of Mesozoic limestone forming some monoclines, combined with smaller anticlines.

The *Krasta-Cukali Zone* (analogous to the Budva Zone of the Dinarides and the Pindos Zone in the Hellenides) and represents an intermediate zone between the Internal and External Albanides. Is mostly filled with Cretaceous and Paleogene flysch formations and some limestone, but Triassic-Cretaceous limestone prevails in the Cukali Mountain.

The *Kruja Zone* (analogous to the Dalmate Zone of the Dinarides and to the Gavrova Zone of the Hellenides) consists of some elongated anticline structures of Cretaceous–Eocene carbonate limestone, dolomite limestone and dolomites covered by Oligocene flysch deposits. In the northern part of the zone, Tirana syncline is developed, where Tortonian molasses transgressively overlies flysch formations. The carbonate section plunges down to 10 km, and is underlain by Triassic-Permian evaporate rocks (Velaj, 1999, 2001; Frashëri, 2007).

The *Ionian Zone* is developed in western and southern part of Albania. Over Permian-Triassic evaporate rocks, the oldest rocks of this zone; lay a thick sequence of Mesozoic-Eocene carbonate rocks, consisting of limestone and less of dolomite and charts. On carbonate rocks lay Oligocene and Neogene flysch deposits. This zone is characterized by the presence of some elongated anticline and syncline belts of NW-SE direction belts dissected by longitudinal tectonic faults along their western flanks.

The *Sazan zone*, integral part of the Apulia platform, consists of thick Cretaceous-Eocene limestone and dolomite section transgressively covered by marl Burdigalian deposits.

The *Peri-Adriatic Depression (PAD)* covers the Ionian, Sazan and Kruja tectonic zones and is a fore-deep depression filled with Middle Miocene to Pliocene-Quaternary molasses, with the maximal whose thickness of about 5 000 m in the Adriatic Sea shore area, transgressively lying over older carbonate and flysch formation.

GEOTHERMAL REGIME

Geothermal field studies and geothermal energy evaluations in Albania are based on temperature logs of 84 oil and gas wells and 59 shallow boreholes (Frashëri at al., 2004; Frashëri, Kodheli, 2010; Frashëri, 2013), as well as natural thermal water springs and geological structures with a high water temperature have also been investigated.

Temperature maps along with geothermal gradient, heat flow density and geothermal resources maps have been compiled for depths of down to 3,000 m. The geothermal field is characterized by a relatively low temperature gradient. The temperature at the depth of 500 meters is between 21 and 24°C. The highest temperatures, up to 36°C at 1 000 meters and 105.8°C at 3 785 meters depths are measured in PAD wells (fig. 3).

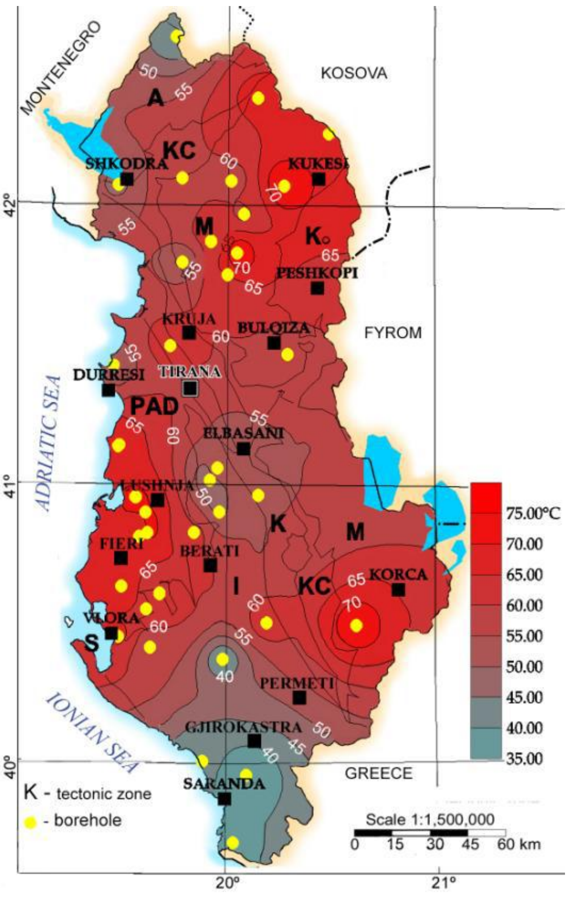

Fig. 3. The temperature at the depth 3 000 m
Rys. 3. Temperatura na głębokości 3 000 m
Рис. 3. Температура на глубине 3 000 м
(after – wg – по: Frasheri et al., 2004)

The temperatures in the ophiolitic belt (Mirdita Zone) are higher than in the sedimentary basin at the same depth. The lowest temperatures were measured in the mountainous regions of the Mirdita Zone, as well as in the Albanian Alps, where there is intensive circulation of cold karstic descending water whose temperature is less than 8°C. The same occurs around huge karst massifs in South Albania, where zero gradients are measured in some deep wells, like Kalcat well, which is about 2 000 m deep (FRASHËRI et al., 2004). Geothermal gradients here increase to 36 mK/m in the north-eastern and south-eastern parts of Albania (fig. 3; FRASHËRI, 2013). The configuration of isotherms fits well to the structures of Albanides.

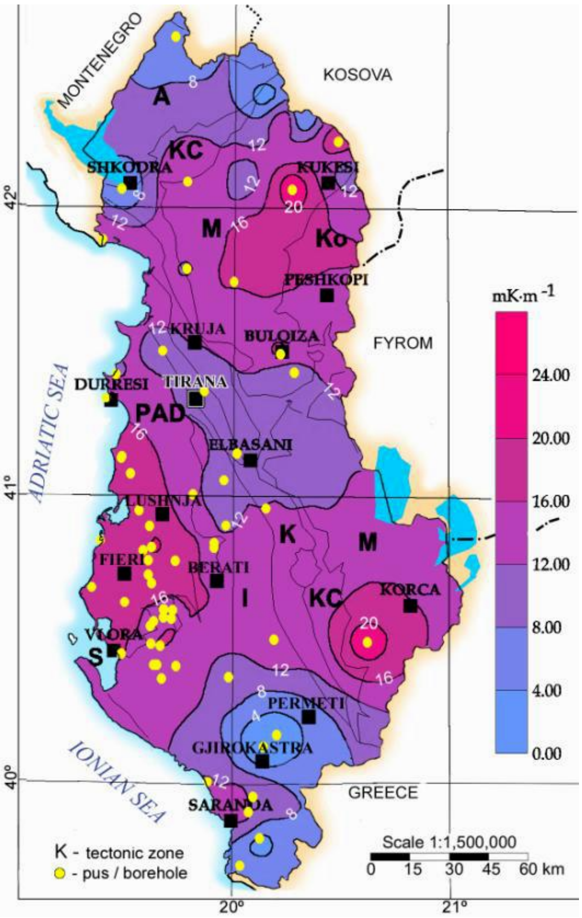

Fig. 4. Average geothermal gradient map
Rys. 4. Przeciętny gradient geotermalny
Рис. 4. Средний геотермальный градиент
(after – wg – по: FRASHERI et al., 2004)

The External Albanides, like the Dinarides, are characterized by a low geothermal gradient and the geothermal field features a relatively low temperature gradient (fig. 4; FRASHËRI, 2013), comparing with neighboring countries (LAMBRAKIS, KALLERGIS, 2005; BOROVIĆ et al., 2015; PAPIC, 2015). The largest gradients are detected in the molasses anticline structures of PAD. The highest values of about 21.3 mK/m are observed in the Pliocene clay section (FRASHERI et al., 2004; FRASHERI, 2007; FRASHERI, KODHELI, 2010; FRASHËRI, 2013).

The gradient decreases by about 29% are observed in the carbonate anticline structures in the Ionian Zone, where the gradient is mostly about 15 mK/m. The lowest geothermal gradients, of 5 mK/m, are registered in the southern part of the Ionian Zone and in the Albanian Alps where are located the largest carbonate structures of Albania.

Values of 7–11 mK/m are observed in a deep syncline belt of the Ionian and Kruja zones. Modelling indicates that the gradient decreases at a depth of more than 20 km, which coincides with a crystalline basement top (FRASHËRI et al., 2004; FRASHERI, 2013).

The maximal heat flow density of 42 mW/m^2 is observed in the centre of PAD. The 30 mW/m^2 value isotherm is opened towards the Adriatic Sea shelf. In the ophiolitic belt in eastern Albania, heat flow density values are up to 60 mW/m^2.

Increasing heat flow over the ophiolitic belt is linked with heat flow from granites of the crystal basement. Heat Floe Density contours offers a clear configuration of the ophiolitic belt.

Geothermometers are used to provide an indication of temperatures in geothermal reservoirs. The mean estimated temperatures of all thermal springs as calculated by Na, K and Ca geothermometers, are similar and vary between 197 and 230°C. Based on geothermal modelling, one can suppose that thermal waters rise from depths of about 8–10 km, with temperatures as high as 220°C (FRASHËRI et al., 2004; EFTIMI, FRASHERI, 2016).

THERMAL WATER PROVINCES

Albania's complex geological, structural and geomorphological conditions results in the formation of the heterogeneous aquifers regarding to their hydraulic type, resources, hydrodynamics and hydro-chemical characteristics (EFTIMI at al., 1985; EFTIMI, 2010). The presence of major aquifers of thermal waters affected by slip-strike faulting and related extension processes created conditions for the formation of the thermal and mineral waters in the hydrogeological structures. These faults play a very significant role in allowing the thermal fluids to rise from their storage zones (reservoirs) to regional aquifers (LAMBRAKIS, KALLERGIS, 2005). Among them there are some deep aquifers related to diffe-

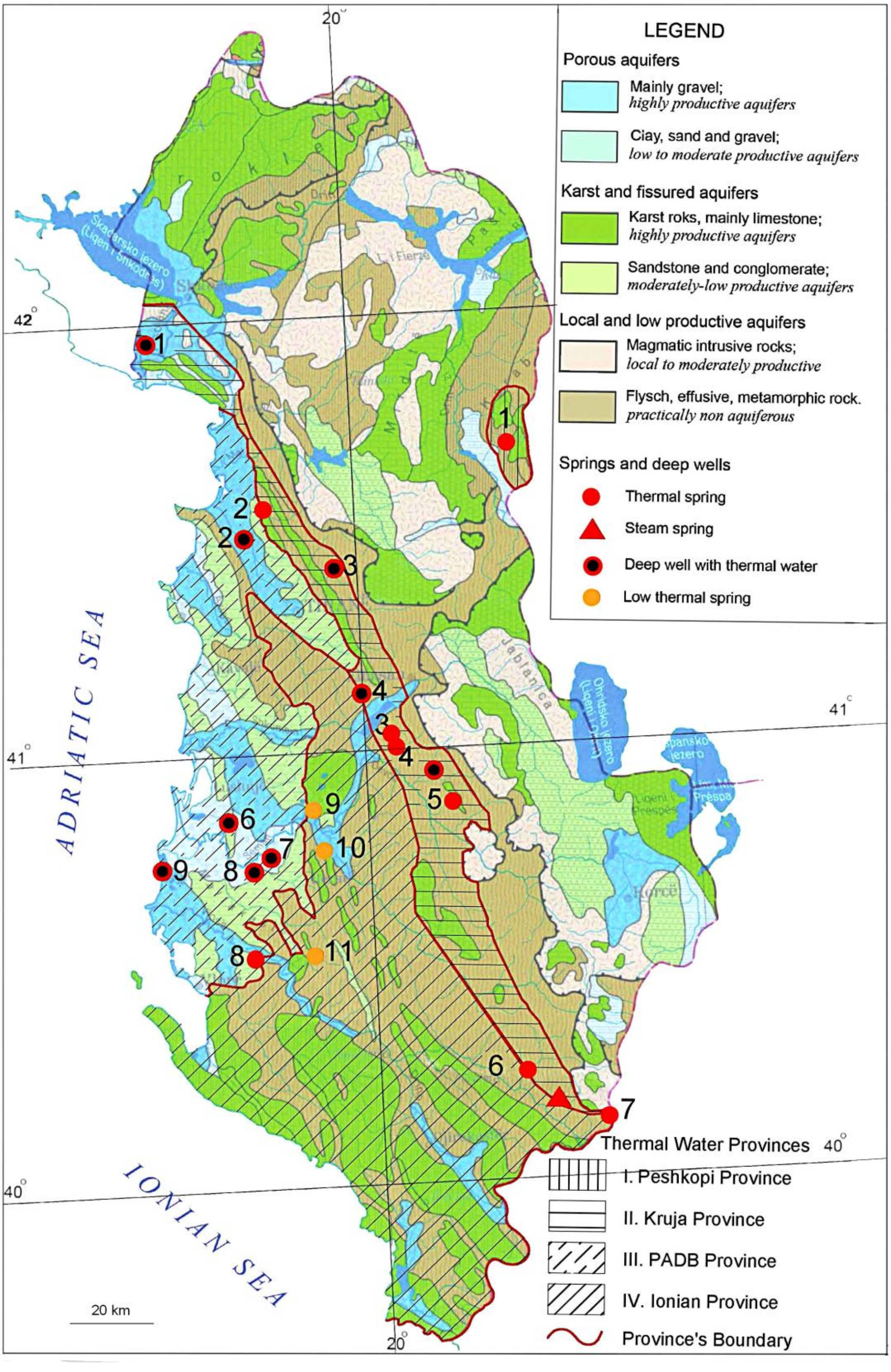

Fig. 5. Map of thermal water provinces of Albania and main thermal water springs and deep boreholes: Thermal water provinces: I – Peshkopia Province; II – Kruja Province; III – PAD Basin province; IV – South Ionian Province. Thermal springs: 1 – Peshkopi, 2 – Mamurras, 3 – Elbasan (Llixha), 4 – Hidraj, 5 – Holta, 6 – Përmet, 7 – Leskovik, 8 – Selenicë; Deep wells: 1 – Dajç-2, 2 – Ishmi-1b, 3 – Shupal, 4 – Kozan-8, 5 – Galigat-2, 6 – Ardenica-3, 7 – Marinza-547, 8 – Verbas-2, 9 – Seman-3; Low thermal springs: 1 – Karbunara, 2 – Ura Vajgurore, 3 – Kapaj (based on IHM of Europe, Albania; sc. 1:1.5., EFTIMI, 2010)

rent rocks like evaporite, carbonate and molasses, which host thermal waters. Thermal waters of Albania are localized in four thermal water provinces: Peshkopia, Kruja, PAD Basin and South Ionian (fig. 5).

Peshkopia Province represents the central part of the Korab Zone, which is characterized by the presence of two tectonic windows (total surface about 90 km²), where gypsum and anhydride dome structures outcrop (MELO, 1986; MELO et al., 1991); the salts are almost absent (VELAJ, 2001). In the contact of the gypsum with surrounding Paleogene flysch formations two important sulphur thermomineral springs known as Peshkopia Spa, issue (fig. 6). Shallow circulating groundwater recharges some cold springs, temperature 11.2–13°C.

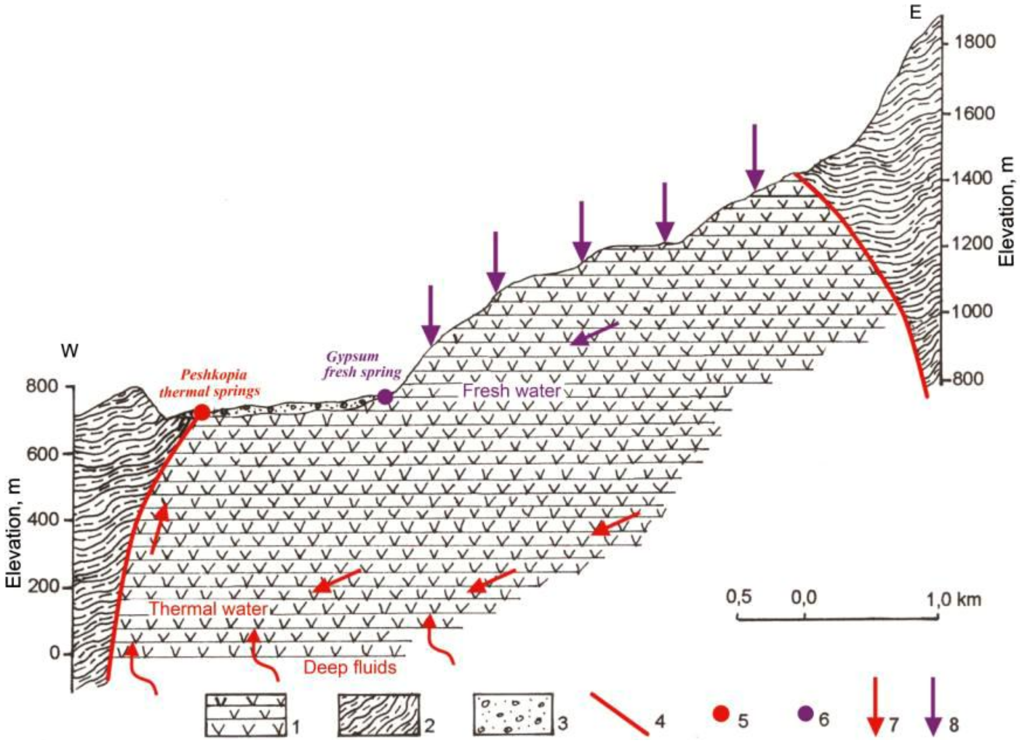

Fig. 6. Section through Peshkopia thermal spring (after: EFTIMI, FRASHERI, 2016):
1 – gypsum, 2 – flysch, 3 – alluvium, 4 – tectonic fault, 5 – Peshkopi thermal spring, 6 – fresh water spring, 7 – thermal water flow, 8 – fresh water flow

Rys. 6. Przekrój przez termalne źródło Peszkopia (wg: EFTIMI, FRASHERI, 2016):
1 – gips, 2 – flisz, 3 – aluwia, 4 – uskok tektoniczny, 5 – źródło termalne Peszkopia, 6 – źródło wody słodkiej, 7 – kierunek przepływu wody termalnej, 8 – kierunek przepływu wody słodkiej

Рис. 6. Разрез через термальный источник Пешкопия (по: EFTIMI, FRASHERI, 2016):
1 – гипс, 2 – флиш, 3 – аллювий, 4 – тектонический сброс, 5 – термальный источник Пешкопия, 6 – источник пресной воды, 7 – направление течения термальной воды, 8 – направление течения пресной воды

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Rys. 5. Prowincje wód termalnych Albanii, główne źródła wód termalnych i głębokie odwierty (studnie): Prowincje wód termalnych: I – Peszkopia; II – Kruja; III – PAD Basin; IV – Południowojońska; Źródła termalne: 1 – Peszkopi, 2 – Mamurras, 3 – Elbasan (Llixha), 4 – Hidraj, 5 – Holta, 6 – Përmet, 7 – Leskovik, 8 – Selenicë; Głębokie studnie: 1 – Dajç-2, 2 – Ishmi-1b, 3 – Shupal, 4 – Kozan-8, 5 – Galigat-2, 6 – Ardenica-3, 7 – Marinza-547, 8 – Verbas-2, 9 – Seman-3; Chłodne źródła termalne: 1 – Karbunara, 2 – Ura Vajgurore, 3 – Kapaj (na podstawie: IHM of Europe, Albania; sc. 1:1.5., EFTIMI, 2010)

Рис. 5. Карта регионов термальных вод Албании, основных термальных источников и глубоких скважин: Регионы термальных вод: I – Пешкопия; II – Круя; III – Бассейна ПАД; IV – Южно-Ионический; Термальные источники: 1 – Пешкопи, 2 – Мамуррас, 3 – Эльбасан (Лидьжа), 4 – Гидрай, 5 – Гольта, 6 – Пермет, 7 – Лесковикк, 8 – Селенице; Глубокие скважины: 1 – Дайч-2, 2 – Ишми-1b, 3 – Шупал, 4 – Козан-8, 5 – Галигат-2, 6 – Арденица-3, 7 – Маринза-547, 8 – Вербас-2, 9 – Семан-3; Прохладные термальные источники: 1 – Карбунара, 2 – Ура Вайгуроре, 3 – Капай (на основании: IHM of Europe, Albania; sc. 1:1.5., EFTIMI, 2010)

The formation of the springs is related to a deep fault developed along the Black Drin River (MELO, 1986; MELO et al., 1991; XHOMO et al. 2002). The water is of SO_4-Ca-type, with elevated concentrations of Cl and HCO_3 and temperatures from about 35°C to 43.5°C. These waters feature low total dissolved solids (TDS), about 4 g/l, and H_2S of about 50 g/l; the upward flow rate of the springs is about 23 l/s (table 1). Similar to Peshkopia's thermal springs there are some also in Dibra, Macedonia (JÓŹWIAK, ANDREJCZUK, RÓŻKOWSKI, 2012).

Shallow groundwater circulating in the gypsum deposits recharges a number of big cold sulphate springs (fig. 6).

Calcium sulphate is formed by the dissolution of gypsum, according to the following reaction:

$$CaSO_4{\cdot}2H_2O \rightarrow Ca^{2+} + SO_4^{2-} + 2H_2O.$$

If oxygen is absent and reducing conditions prevail, sulphate may be reduced by organic matter to produce hydrogen sulphide (FENG'E et al., 2005; REIMANN, BIRKE, 2010):

$$CaSO_4^{2-} + 2CH_2O \rightarrow CaCO_3 + H_2S + 2HCO_3.$$

H_2S result to be an indicator for the bacterial activities which are more active at higher temperature (ANDREJCHUK, KLIMCHOUK, 2001; FENG'E et al., 2005).

In Peshkopia is one of most popular and modern spas of Albania, but in the same time the primitive modes of balneology, using natural pools with thermal waters, are still popular (photo 1).

Photo 1. Near Peshkopia thermal spring the local people use a natural pool for curative baths (phot. by R. Eftimi

Fot. **7.** Basen termalnego źródła koło Peszkopia miejscowa ludność wykorzystuje do kąpieli leczniczych (fot. R. Eftimi)

Фото. **7.** Источник термальных вод рядом с Пешкопия используется местным населением для лечебных целей (фот.: Р. Эфтими)

The main data on Albania's thermal waters, summarized in Tables 1 and 2 and a Piper diagram (fig. 7) is used for the classification of Albania's thermal springs.

Table 1. Thermal springs of Albania (g – gypsum, l – limestone, d – dolomite; s – sandstone) (after: AVGUSTINSKI, ASTASHKINA, SHUKEVICH, 1957; EFTIMI, FRASHERI, 2016)

Tabela 1. Źródła wód termalnych w Albanii (g – gips, l – wapienie, d – dolomity, s – piaskowce) (wg: AVGUSTINSKI, ASTASHKINA, SHUKEVICH, 1957; EFTIMI, FRASHERI, 2016)

Таблица 1. Источники термальных вод Албании (g – гипс, l – известняки, d – доломиты, s – песчаники) (по: AVGUSTINSKI, ASTASHKINA, SHUKEVICH, 1957; EFTIMI, FRASHERI, 2016)

Spring	Province	Q	T	TDS		Parameters, mg/l									Chemical type
	lithology	l/s	°C	mg/l	H_2S	Ca	Mg	Na	K	Cl	SO_4	HCO_3	Br	J	
1-Peshkopi 1	Korab, g	14	43.5	4050	50	826	100	279	54	488	1686	839	2.1	0.6	SO_4-Ca
1-Peshkopi 2	Korab, g	8	35	3530	32.8	754	83	266*	-	411	1569	712			SO_4-Ca
2-Uji Bardhë 1	Kruja, l, d	20	18.5	1254	70	150	51	242*		433	132	414			Cl-HCO_3-Na
2-Uji Bardhe 5	Kruja, l,	20	22.5	5332	350	389	168	1264*		2382	616	532			Cl-Na-Ca
2-Uji Bardhe 6	Kruja, l,	7	21.5	5190	326	389	166	1301*		2340	599	526			Cl-Na-Ca
3-Llixha	Kruja,	3.1	56	6827	406	802	197	1301*		2352	1799	425			Cl-SO_4-Na-Ca
3-Llixha	Kruja, l, d	16-28	55	6804	403	794	199	1194*		2359	1778	1000	5.5	1.1	Cl-SO_4-Na-Ca
4-Hidraj 1	Kruja, l,	18	55	6746	378	802	200	1257*		2311	1731	455.7			Cl-SO_4-Na-Ca
4-Hidraj 3	Kruja, l,	13-28	58	6746	408	794	203	1150*		2302	1753	447			Cl-SO_4-Na-Ca
5-Holta	Kruja, l,	50-70	24.1	2224	?	217	222	181*		245	1261	232			SO_4-Mg-Ca
6-Permet 1	Kruja, l,	2.0-	26.8	1186	2.6	100	29	310	0.4	496	97	285			Cl-Na
6-Permet 5	Kruja, l,	5-50	30	1532	5.8	125	39	411*		684	155	210			Cl-Na

6-Permet 8	Kruja, l	70-	30	1567	5.8	127	35	398*		702	157	212			Cl-Na-Ca
7-Leskovik	Kruja, l	15	26.7	1002	7	103	30	205*		321	160	226			Cl-Na-Ca
8-Selenica 1	PBP, l		23	9104	289	376	117	2975*		4910	239	683			Cl-Na
9-Karbunare	PBP, l	07-	18.5	3850	0.01	125	63	1258	5.5	1932	59.3	625			Cl-Na
10-Urra	PBP, l, d	400	17	546	14	107	13	72	1	141	20.7	316			HCO_3-Cl-Ca-
11-Banjo Kapaj	Ionian, l, d	20	17.7	370		108	13	12.8	3.1	25	26	361			HCO_3-Ca

*The value is the sum of Na and K.

Table 2. Deep wells with thermal water of Albania (g – gypsum, l – limestone, d – dolomite; s – sandstone) (after: AVGUSTINSKI, ASTASHKINA, SHUKEVICH, 1957; EFTIMI, FRASHERI, 2016)

Tabela 2. Głębokie odwierty z wodą termalną w Albanii (g – gips, l – wapienie, d – dolomity, s – piaskowce) (wg: AVGUSTINSKI, ASTASHKINA, SHUKEVICH, 1957; EFTIMI, FRASHERI, 2016)

Таблица 2. Глубокие скважины с термальной водой в Албании (g – гипс, l – известняки, d – доломиты, s – песчаники) (по: (after: AVGUSTINSKI, ASTASHKINA, SHUKEVICH, 1957; EFTIMI, FRASHERI, 2016)

Well	Province	Depth m	Q l/s	T ° C	TDS g/l	Parameters, g/l								Chemical type
						Ca	Mg	Na+K	Cl	SO_4	HCO_3	Br	J	
Dajç 2	Kruja - l, d	612	-	29.0	37.0	1.16	0.59	12.0	19.3	3.72	0.34			Cl-Na
Ishmi 1b[1)]	Kruja - l, d	2220	3.5	57.0	12.6	1.24	0.35	3.87	6.75	2.31	1.28			Cl-SO_4-Na-Ca
Shupal 1	Kruja - l,d	1794		29.5	2.37	0.27	0.13	0.32	0.36	1.28	0.6			SO_4-Cl-Ca-Mg
Kozan 8	Kruja - l, d	1837	10.3	65.5	4.1	0.64	0.14	0.73	1.43	1.51	0.24			Cl-SO_4-Ca-Na
Galigat 2	Kruja - l, d	2914	0.9	45.0	5.67	0,7	0.12	1.21	2.20	0.94	1.00			Cl-SO_4-Na-Ca
Ardenica 12	PBP - s	3000	18.0	32.0	53.6	1.21	0.84	18.4	32.3	0.75	0.11	110	21.2	Cl-Na
Marinza 547	PBP - s	?	?	31.0	56.6	0.99	0.35	0.89	31.9	2.89	0.16			Cl-Na
Verbas 2	PBP - s	1035	1.3	29.3	8.2	0.32	0.28	31.2	4.60	0.03	0.56			Cl-Na
Seman 7	PBP - s	1980	30.0	67.0	20.7							25.0	30.0	Cl-Na
Grekan 4	Ionian - g	1214	0.7	35	326	1.40	2.90	120	191	7.2	1.9	768	0.84	Cl-Na
Delvina 4	Ionian - l	3780	?	21	69.0	4.60	1.20	20.8	38.3	1.92	3.78	114	35	Cl-Na

[1)]The H_2S concentration is 1200 mg/l

Kruja Province overlaps the homonymous tectonic zone and is the most interesting province in terms of quantity and quality of thermal waters. Tirana syncline, located in the northern part of the province, consist an artesian basin that features two important aquifers hosting thermal waters. The deep aquifer, that of Mesozoic-Paleogene carbonates construct several outcropping and some deep buried anticline structures tectonically overthrown to the west. The shallower aquifer is represented by low permeable Neogene molasses rocks (EFTIMI, 2003), mostly consisting of intercalation of low thick sandstone layers with siltstone and claystone which transgressively lies on Mesozoic-Paleogene rocks (fig. 8). The deep carbonate aquifer is developed also in the central and in the southern part of Kruja zone where hosts important thermal water resources.

Albania's most important thermal springs are situated in Kruja Province, and are related to the deep carbonate aquifer; including the group of springs Uji Bardhe near Mamuras, Llixha and Hidraj near Elbasan, and Holta, Permet and Leskoviku in south-eastern Albania (fig. 4). Some thermal springs emerge on the periphery of carbonate structures recharging them like this of Uji Bardhe Springs, but Llixha and Hidraj springs rise along a supposed tectonic fault developed in Oligocene flysch formations. The thermal water is formed in the Llixha anticline and moves upward along the tectonic fault developed in Paleogene flysch formation over which an permeable olistolith horizon, about 20 m thick, facilitates ascending thermal water flow (fig. 9).

The thermal springs of Holta, Permet and Leskovik, in south-eastern Albania, are related to some carbonate structures covered by Paleogene flysch formation, and emerge on the stream beds of some beautiful narrow limestone canyons. Each group of springs have more than three issues with total discharges of about 20 to more than 100 l/s; in fig. 9 are shown two issues of Permet springs (photo 2).

In Kruja zone there are also five deep wells, depth about 2 000–3 000 m tapping thermal water of carbonate aquifer (table 2). Three of deep wells, namely Ishmi-1b (fig. 8), Kozan-8 (photo 3) and Galigat-2 are the most important concerning the water quality, the water temperature and for their water curative values (table 2).

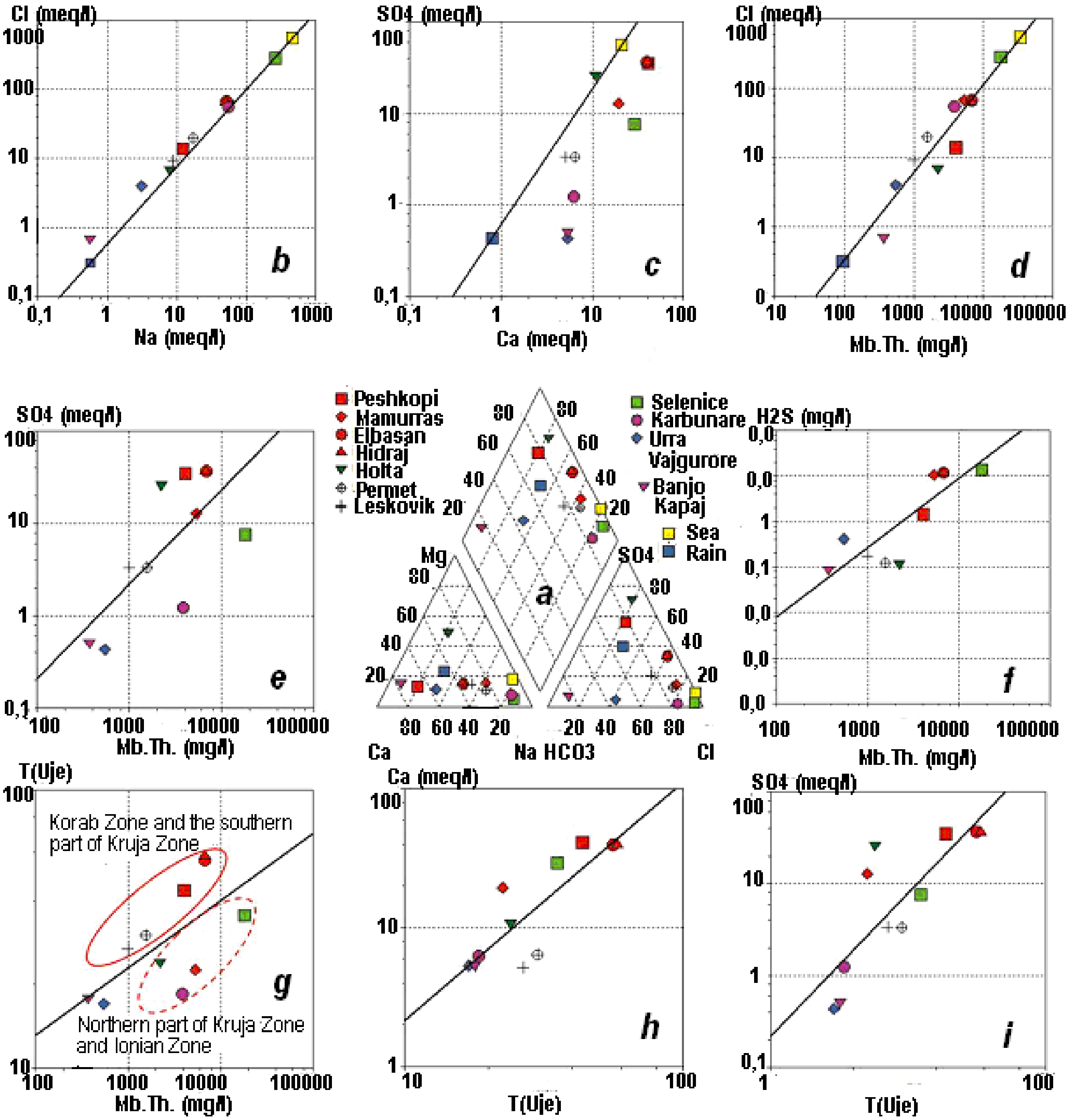

Fig. 7. Thermal springs (after: EFTIMI, FRASHERI, 2016):
a – Piper diagram, b – Cl vs. Na, c – SO_4 vs. Ca, d – Cl vs. TDS, e – SO_4 vs. TDS, f – H_2S vs. TDS,
g – Temperature (T) vs. TDS, h – Ca vs. T, i – SO_4 vs. T

Rys. 7. Źródła termalne (wg: EFTIMI, FRASHERI, 2016):
a – diagram Pipera, b – Cl vs. Na, c – SO_4 vs. Ca, d – Cl vs. TDS, e – SO_4 vs. TDS, f – H_2S vs. TDS,
g – Temperatura (T) vs. TDS, h – Ca vs. T, i – SO_4 vs. T

Рис. 7. Термальные источники (по: EFTIMI, FRASHERI, 2016):
a – диаграмма Пайпера, b – Cl vs. Na, c – SO_4 vs. Ca, d – Cl vs. TDS, e – SO_4 vs. TDS, f – H_2S vs. TDS,
g – Температура (T) vs. TDS, h – Ca vs. T, i – SO_4 vs. T

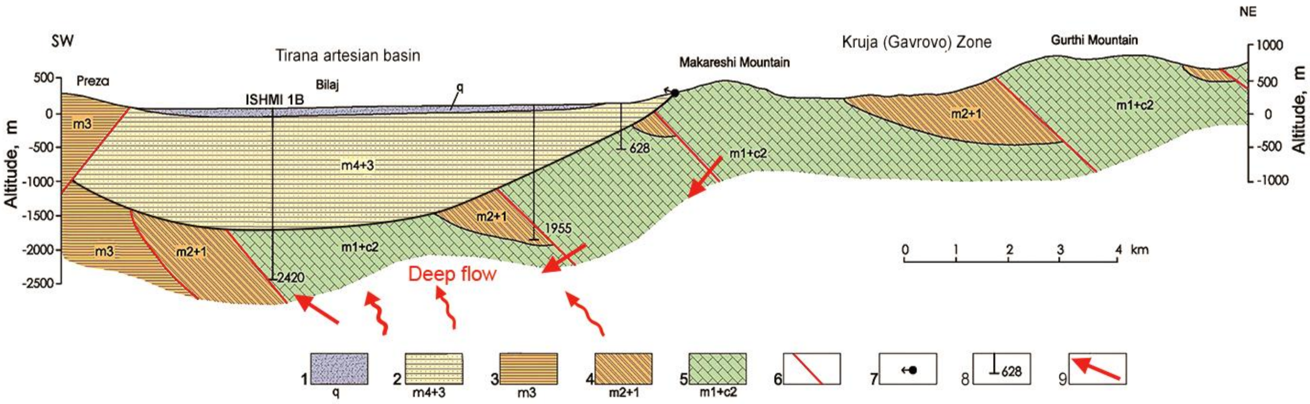

Fig. 8. Hydrogeological cross-section of the central part of the Tirana Basin (after: EFTIMI, 2010):
1 – sands, gravels and silt, 2 – sandstones, siltstone and clays, 3 – clays, sandstones and siltstones, 4 – clays, siltstones and sandstones (flysch), 5 – limestone, dolomite limestone and dolomites, 6 – major fault, 7 – karst spring, 8 – deep well with thermal water and the depth in meters, 9 – thermal water flow

Rys. 8. Przekrój hydrogeologiczny przez środkową część Basenu Tirany (wg: EFTIMI, 2010):
1 – piaski, żwiry, mułki, 2 – piaskowce, mułowce i iły, 3 – iły, piaskowce i mułowce, 4 – iły, mułowce i piaskowce (flisz), 5 – wapienie, wapienie dolomitowe i dolomity, 6 – główne uskoki, 7 – źródło krasowe, 8 – głębokie odwierty z wodą termalną i podaną głębokością (m), 9 – kierunek przepływu wody termalnej

Рис. 8. Гидрогеологический разрез через среднюю часть Бассейна Тираны (по: EFTIMI, 2010):
1 – пески, гравий, алевриты, 2 – песчаники, алевролиты, глины, 3 – глины, песчаники, алевролиты, 4 – глины, алевролиты, песчаники (флиш), 5 – известняки, доломитовые известняки, доломиты, 6 – важнейшие сбросы, 7 – карстовый источник, 8 – глубокие скважины с термальной водой с указанной глубиной (м), 9 – направление течения термальной воды

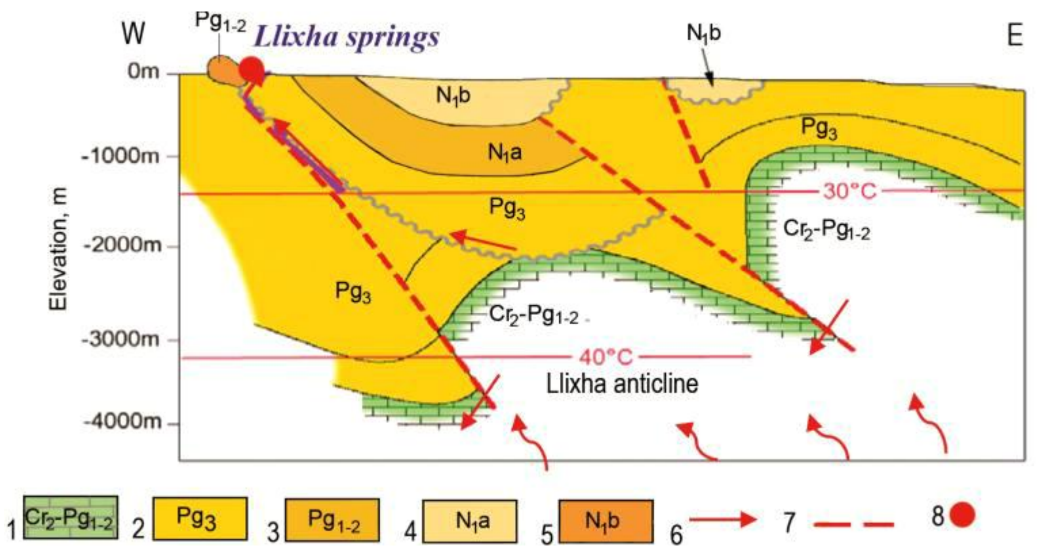

Fig. 9. Cross-section of the Llixha anticline (after: FRASHERI, KODHELI, 2010):
1 – Upper Cretaceous-Paleocene, limestone, 2 – Oligocene, flysch, 3 – Paleocene-Eocene, limestone olistolite, 4 – Low Neogene, Aquitanian clay flysch, 5 – Low Neogene, Burdigalian, clay, 6 – thermal water flow, 7 – tectonic fault (supposed), 8 – thermal water spring

Rys. 9. Przekrój przez antyklinę Llixha (wg: FRASHERI, KODHELI, 2010):
1 – górna kreda-paleocen, wapienie, 2 – oligocen, flisz, 3 – paleocen-eocen, wapienie olistolity, 4 – dolny neogen, Akwitanian, flisz ilasty, 5 – dolny neogen, Burdigalian, iły, 6 – kierunek płynięcia wód termalnych, 7 – uskok tektoniczny (prawdopodobny), 8 – źródło wody termalnej

Рис. 9. Разрез через антиклину Лидьжа (по: FRASHERI, KODHELI, 2010):
1 – верхний мел-палеоцен, известняки, 2 – олигоцен, флиш, 3 – палеоцен-эоцен, известняки олистолиты, 4 – нижний неоген, аквитаниян, глинистый флиш, 5 – нижний неоген, бурдигалиан, глины, 6 – направление течения термальных вод, 7 – тектонический сброс (вероятный), 8 – источник термальной воды

a

b

Photo 2. Two issues of Permet thermal springs:
a – spring nr 8 discharge 30–70 l/s, b – Prof. Andrejchuk of University of Silesia, Poland, visiting spring nr 5, discharge 5–50 l/s (phot. by R. Eftimi)

Fot. 2. Dwa przykłady termalnych źródeł Permet:
a – źródło nr 8 o wydajności 30–70 l/s, b – Prof. Andrejczuk z Uniwersytetu Śląskiego, Polska, przy źródle nr 5 o wydajności 5–50 l/s (fot. R. Eftimi)

Фот. 2. Два примера термальных источников Пермет:
а – источник № 8 расходом 30–70 л/с, b – проф. Андрейчук из Силезского университета, Польша, у источника № 5, расходом 5–50 л/с (фот.: Р. Эфтими)

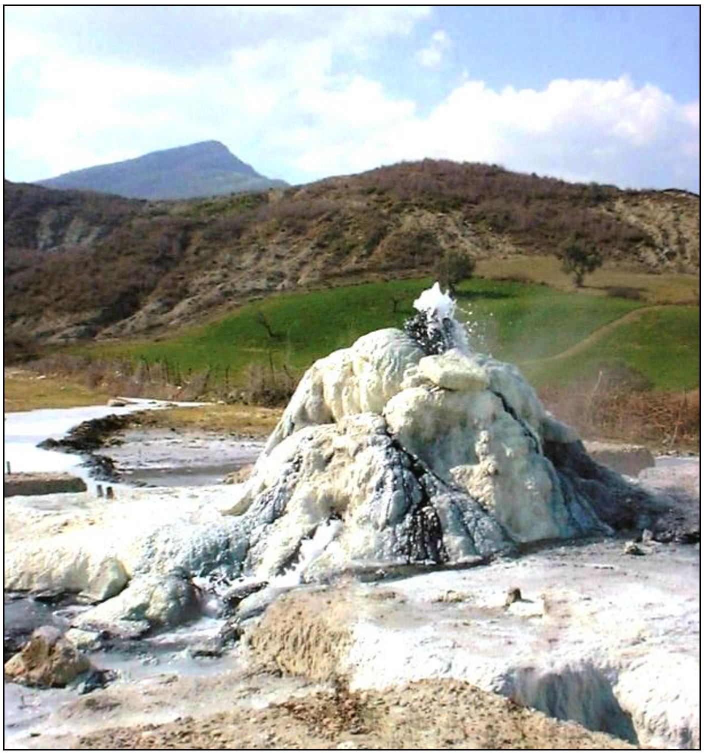

Photo 3. Overflowing deep thermal water well Kozani-8, in Kruja Province (phot. by A. Frasheri)

Fot. 3. Wypływ wody termalnej z głębokiego odwiertu Kozan-8 w regionie Kruja (phot. by A. Frasheri)

Фот. 3. Отток термальной воды из глубокой свкажины Козан-8 в провинции Круя (фот.: А. Фрашери)

As shown in table 1 and 2, thermal waters of Kruja Province are quite different regarding to their physical and chemical characteristics, but two hydrochemical types prevail: Cl-SO_4-Na-Ca and Cl-Na-Ca. The maximal water temperature is for the springs 56°C and for the wells 65°C; the maximal sulphide gas concentration for the springs is about 400 mg/l and for the deep wells 1200 g/l, measured in the deep well Ishmi-1b (fig. 8). As the waters of this type are related to deep anticline structures, long groundwater circulation is assumed, which favours increases in Cl and Na concentrations. With regard to the enrichment of the waters with Ca and SO_4, it appears to be attributable to two processes; a) ascending SO_4–Ca waters circulating in deep-seated evaporite deposits, and b) pyrite oxidation according to the reaction (APPELO, POSTMA, 1999; REIMANN, BIRKE, 2010):

$$2FeS + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

The local pyrite oxidation and the reduction of sulphates are responsible also for the presence of H_2S.

Both processes are possible. The presence of evaporite rocks under the Mesozoic carbonate structure mainly in the central part of the Kruja Province, backed by geological studies (VELAJ, 1995, 2001; SILO V, NISHANI, SILO E., 2010), facilitates sulphate hypogenic speleogenesis (ANDREJCHUK, KLIMCHOUK, 2001), allowing the intensive transfer of hot water to springs along the strike and deep traverse to the structures faults. The second process is facilitated by the presence of pyrite crystals in the carbonate structures of Kruja Province (EFTIMI, 1998).

Thermal springs in the southernmost part of Kruja Province, specifically Permet and Leskovik, are of the Cl-Na-Ca-type (with elevated HCO_3 concentrations). They are characterized by low H_2S concentrations, varying from about 4 to 6 g/l.

Temperatures vary from 26 to 31°C. The groundwater is fresh; TDS is about 1.0 to 1.6 g/L. At some big springs of Kruja Province, like Uji Bardhe near Mamurras and those of Permet, ascending thermal flows mix with shallow cold groundwater, resulting in significantly differing physical and chemical properties from one spring issuer to another.

The upper (shallow) molasses aquifer of Tirana lies above the carbonate and flysch deposits and consists of an intercalation of sandstone, siltstone, and claystone deposits of Aquitanian to Serravallian age. As the active porosity of Neogene sandstone aquiferous rocks is generally low, the capacity of the wells is very small, usually less than 1.0 l/s (EFTIMI, 2003), and the temperature is generally lower than 25°C down to a depth about 1 000 m. A particular geothermal phenomenon of this province is the Postenan steam spring, issuing from a tectonic fault crossing the Postenan limestone anticline structure (fig. 4), but its characteristics have not yet been investigated.

Identified geothermal resources of Kruja Province, in carbonate reservoirs, are 5.9·108–5.1·109 GJ (FRASHËRI et al., 2004 2007). Exploitable thermal water resources of Kruja Province could be increased, by drilling boreholes to tap thermal water of buried structures at a suitable depth which mostly vary from about 600 m to 1 200 m.

Peri-Adriatic Basin Province (PABP) is a huge artesian basin, deepening to the NW under the Adriatic Sea. Three important aquifers have been identified in this basin: the deepest aquifer is that of carbonate rocks; the intermediate aquifer consists of sandstone Neogene molasses, and the upper aquifer is comprised of Pliocene sandstone-conglomerate formations.

The deeper, carbonate rock aquifer is tapped by deep oil and gas wells located only on the southern periphery of the basin, mainly in the Patos-Verbas area. The highest water temperature of 50°C is measured in well Bubullima-5, free flowing from the tapped depth interval of 2 355–2 425 m. Generally, the groundwater of this aquifer is of Cl-Na type, highly mineralized and with a clear tendency of TDS increase with depth, from about 1 to 3 g/l at depths around 1 000 near the outcrop of large carbonate structures to about 40–90 g/l at depths around 2 000–2 500 m far from such structures. With regard to gases, the presence of CH_4 and H_2S is evidenced but their concentrations at most of the deep wells have not been measured.

The Neogene molasses aquifer is tapped by deep wells located mostly in oil and gas fields reach in organic mutter. The total thickness of the Neogene molasses increases to the NW and along the Adriatic Sea coast it is about 5 000 m. Thermal waters are localized mainly in Tortonian sediments, such as sandstone and conglomerates. Particularly significant are the free-flowing wells of Ardenica and Seman structures located in the central part of PABP (table 2). The groundwater temperature of Ardenica wells varies from 32 to 38°C and TDS according to the aquifer depth vary from 38 to 56 g/l. In well Seman-3 (at the Adriatic Sea water line), the free-flowing groundwater temperature is 67°C and as resulted from the calculations the temperature in the aquifer at the depth of 3 758 m is around 100°C (FRASHERI et al., 2004; FRASHERI, 2013). The chemical water type is Cl-Na and TDS is around 20 g/l. The thermal waters tapped by the deep wells in PABP are rich in CH_4 gas, but the presence of H_2S has also been confirmed. Usually the water has a high content of Br and J, whose concentrations vary from 20 to 85 g/l for Br and from 20 to more than 120 g/l for J. The formation of the Cl-Na-type thermal waters is related to groundwater metamorphism, due to long water–rock interaction mechanisms, and to the release of marine sedimentary water from the pores of the rocks at high pressure conditions.

The third aquifer of PABP is related to the upper part of Pliocene deposits (Rrogozhina formation), which maximal thickness is about 750 m and consisting mostly of sandstone and conglomerate layers. The groundwater of the Rrogozhina formation is usually fresh to low mineralized, hard, with increased Fe concentrations and mainly of the HCO_3-Mg-type. Down to the maximal investigated depth of around 500 m, the water temperature is about 18°C.

South Ionian Province is the largest thermal water province in Albania, but not the richest. This province consists of a number of Mesozoic carbonate anticline and syncline chains, filled mainly with Paleogene flysch formations, dipping to the NW, under the PAB Basin. The presence of thermal springs has not been identified in this province; there are only big fresh and low thermal springs like Banjo Kapaj, which temperature is 17.5°C. Some deep oil and gas wells located in the northernmost part of the province discharge free-flowing, high temperature and highly mineralized groundwater. Among them the most important is well Grekan-4, situated in the eastern periphery of the Dumre gypsum dome. This well spurts groundwater from a depth of about 1 200 m; the groundwater temperature is 35°C, TDS resulted 325 g/l and bromine concentration about 768 g/l. Some deep wells drilled in the Delvina syncline, in South Albania, also discharge highly mineralized groundwater of the Cl-Na-type.

CONCLUSIONS

The geothermal regime of the Albanides is governed by regional tectonics, lithological compositions, local thermal properties of the rocks, and the Earth's crust settings. In Albania thermal water consist of natural springs and of deep wells drilled for the oil and gas exploration.

Albania in general is characterized by low geothermal gradients. The geothermal field is characterized by a relatively low temperature gradient. The highest measured thermal water temperature in Albania is 83°C, but the aquifer temperature of the basins calculated by means of geothermometers is greater than 200°C.

The thermal waters in Albania are characterized by quite various chemical water types with a wide range of TDS, temperature and yield depending on the nature of the aquifers of thermal water, the tectonic situation, storage conditions, depth and the mixing of thermal and fresh waters near the ground surface.

Four thermal water provinces, with well-defined chemical characteristics, are distinguished.

Peshkopia Province is characterized by the presence of H_2S thermal springs of the SO_4-Ca type, whose temperature is 43°C. The thermal water circulates in the gypsum-anhydride deposits of central part of Korab Mountain. Some sources with shallow circulation though of SO_4-Ca type, as the deep ones, are low temperature and H_2S is missing.

Kruja Province is the richest in thermal waters. In this province is recognized the largest representation of springs and deep wells with thermal water (about 85%). The most important aquifer from the genetic viewpoint of thermal waters, in this province and in Albania in general, is Mesozoic-Paleogene carbonate aquifer. Many deep carbonate structures, some outcropping and some situated usually at depths 1 500–3 000 m, are water-saturated and regarding the quality mainly two chemical water types are identified. Thermal waters of the central part of Kruja Povince, due to the presence of gypsum deposits at depths, are of Cl-SO_4-Na-Ca chemical type, TDS about 4–12 gr/l, water temperature vary from 22 to 65°C and H_2S concentrations usually is more than 250 mg/l. In southern part of the province thermal waters are of Cl-Na-Ca type; TDS is 1 to 2.2 gr/l and H_2S concentrations vary from 2 to 7 mg/l.

In *PADP Province* two aquifers reach in organic mutter, that of Mesozoic-Paleogene carbonate aquifer and that Neogene molasses aquifer host thermal water. Both aquifers are investigated mainly by deep wells of oil and gas well fields; their depth usually varies about 1 000 to 3 000 m. Most of thermal waters are highly mineralized, of the Na-Cl type, TDS about 3 to more than 100 gr/l, with CH_4 and H_2S gases, and usually with high Br and J which concentration vary from 20 to about 80 mg/l. The highest measured temperature in carbonate aquifer is 50°C (in Bubullima deep well) and in Neogene molasses aquifer the measured temperature is 67°C (at well head of Seman deep well).

South Ionian Province is the poorest in thermal waters, but near the Dumre gypsum dome (central Albania) high temperature Cl-Na thermal water with a bromine content of about 768 g/l is tapped at a depth 1 200 m.

Albania's thermal water resources are used by some health spas; like the well-known spas of thermal springs Peshkopa, Llixha and Hidraj in Elbasan, as well as three two other spas use the thermal water of the deep wells Ishmi 1b (known as Bilaj spa), and Kozani 8.

The long term balneology experience of H_2S thermal waters of Albania confirm their successful use for curing a long list of illnesses like chronic rheumatic illnesses, digestive apparatus illness as colitis and gastritis; urinal apparatus illnesses as cystitis, chronic infections; gynaecological illnesses such as sterility; respiratory apparatus illnesses as asthma, chronic bronchi; paralyses, traumatic damages and illnesses of the skin. In the most popular spas are used modern methods of treatment of the clients, but in the same time the primitive modes of balneology using natural pools filled with thermal water are still popular.

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Received: 14 November 2017
Wpłynął do redakcji: 14 listopada 2017
Поступила в редакцию: 14 ноября 2017