BGS 6TH CONGRESS,
Budapest, 2-6 October 2011

ORIGIN AND TEMPERATURE PROFILES OF THERMAL WATERS FROM THE DEPTHS OF THE ALBANIDES

Alfred FRASHËRI
Anesti QIRINXHI
Faculty of Geology and Mining, Polytechnic University of Tirana

ABSTRACT

In this paper, geological data on the depth of origin and temperature profiles of thermo-mineral waters are presented. Albania is rich in geothermal resources of low enthalpy with geothermal energy located in different areas of the country and thermo-mineral waters of sulphate, sulphide, methane and iodinate-bromide types located in three geothermal zones. The location of geothermal springs, their reservoirs and physic-chemical properties of the waters, geothermal regime of the geological structures of the Albanides based on temperature at different depths, geothermal gradient and heat flow density are here analysed in detail. This study is an integrated part of interpretation of geological settings in Albania, contributing in two main fields: i) regional geological field of the Albanides, depth ruptures, etc., and ii) regional and local studies focused on potential of thermal and mineral water resources and the geothermal market in Albania. Both of these aspects are here presented and analysed.

Keywords: thermo-mineral water, heat flow density, geothermal gradient, geothermal zone

1. INTRODUCTION

Albania is rich in low-enthalpy geothermal resources and mineral waters. The amount of geothermal energy produced from low-enthalpy resources and the large number of mineral water sources provide not only a basis for successful application of modern energy technologies in the country, but also an opportunity for effective economic and successful integrated and cascade use of geothermal energy. Thermo-mineral waters, their geothermal properties, heat flow density, geothermal gradient and temperature are important signals that can be taken from the geological depths of the Albanides, geological structures located in Albanian territory.

Much research has been carried out on geothermal, hydro-geological, hydro-chemical, biological and medical effects of thermal and mineral water resources, the results of which are depicted in maps and geothermal sections. Temperature maps along with geothermal gradient, heat flow density and geothermal resources maps have been compiled for depths of down to 3,000m. Natural thermal water springs and geological structures with a high water temperature have also been investigated.

One of the aims of the present study was to identify the relationship between the high temperature of these spring waters and their origin. Geological data gathered from the depths of the Albanides are analysed based upon a complex set of geothermal signals.

2. METHODS

Studies into geothermal fields and evaluation of geothermal energy in Albania (illustrated in Frashëri et al., 2004; Frashëri and Kodhelaj, 2009) were carried out on the basis of temperature logs at 84 deep oil and gas wells and 59 shallow boreholes. The results of the geothermal studies are illustrated in maps and geothermal sections, including temperature maps for depths down to 3000m, geothermal gradient maps, heat flow density and geothermal resources. The natural springs of thermal waters and their reservoirs have already been investigated. A platform of integrated and cascade use of geothermal energy resources in Albania was performed in 2009, within the framework of the National Water and Energy Research and Developing Programme 2007–2009 (Frashëri and Kodhelaj, 2009).

3. RESULTS AND DISCUSSION

Thermo-mineral waters of low enthalpy

Figure 1 depicts many of the thermal springs and wells of low enthalpy in Albania, located mainly in areas of regional tectonic seism active fractures. Thermal sources are located in three geothermal zones:

1) Kruja geothermal zone extends from the Adriatic Sea in the North down to South-Eastern Albania, at the border with Greece. Geothermal aquifers are represented by a karstified neritic carbonate formation of numerous fissures and micro fissures.

At the northern part of the region some springs and deep wells of discharged thermo-mineral waters meet. The hot waters are of type Mg–Cl and have salinity varying from 4.6 to 19.3g/l, Ca, Na, Cl, K, SO_4, SO_4, HCO_3, and H_2S, pH value between 6.7 and 8, and density from 1.001 to 1.006g/cm^3. The thermal waters of Nosi Spring contains less than 1.2 TU tritium (^3H) and –7.66‰ Standard Mean Ocean Water (SMOW) $\delta^{18}O$. The low level of tritium indicates that these thermal waters were created centuries ago. Wellhead temperatures in the Tirana–Elbasan northern sub-zone vary from 60 to 65.5°C. In hole Kozani 8, the temperature at the top of aquifer reaches 80°C. According to the temperature logs for Ishmi 1/b and Galigati 2, temperatures deep in the carbonate section are, respectively, 42.2°C and 52.8°C, while the aquifer temperatures, according to Fournier, Truesdell and Na+K+Ca geothermometers are respectively 254°C, 235°C and 143°C.

The Lëngarica River thermal springs, Postenani steam springs and Sarandaporo springs are located in the southern sub-zone of the Kruja geothermal area. Thermal water discharges as a result of contact between Eocene fissured, karstified limestone and the flysch section. The steam flows upwards from the tectonic fault. Waters do not contain H_2S and CO_2. They have a mineralization factor from 7 to 9 times less than that in the northern sub-zone. The water temperature is 29°C, while the discharge varies between 30 and 40 l/s. In the Kruja geothermal area most of Albania's geothermal resources are located. For the Tirana–Elbasan northern sub-zone the specific reserves vary from 38.5 to 39.6 GJ/m^2. The southern sub-zone has a lower concentration of resources of 20.63GJ/m^2.

2) Located in the coastal area of Albania, Ardenica geothermal zone comprises the molasses Neogene brachyanticlines and the northern pericline of Patos–Verbas carbonate structure, with the overlying Neogene molasses and it is intercepted by the Vlora–Elbasan–Dibra transverse fault. The Ardenica geothermal reservoir comprises sandstone sections of Serravallian, Tortonian and Pliocene age. Hot water discharges from some deep wells. Water flowing into these boreholes discharges from a depth interval varying from 1,200 to 3,758 m. The thermal waters are of type Ca–Cl type and contain between 21.2 and 33 mg/l iodine, 110mg/l bromide and 71mg/l boric acid. Aquifer temperatures are higher in the sandstone layer than in any other layer. At the wellhead, temperatures vary from 32 to 67°C, while the resources density range from 0.25 to 0.39 GJ/m^2.

3) Peshkopia geothermal zone is located in North-East Albania. Water at 43.5°C discharges from a group of thermal springs with a yield up to 14 l/s. The occurrence of these springs is associated with a deep fault at the periphery of a gypsum diapir of Triassic age penetrating the Eocene flysch. A deep fault represents a seismoactive tectonic belt. The thermal waters are of SO_4–Ca type, with mineralization of up to 4.4g/l and containing 50mg/l H_2S.

Geothermal regime of the Albanides

The tectonics of the region, lithology of its geological section and the local thermal properties of the rocks and geological location impact the Geothermal Regime of the Albanides.

At a depth of 500m, the geothermal field is characterized by relatively low temperatures, from 20°C to 21°C. In the Peri-Adriatic Depression, wells at a depth of 1,000m have a higher temperature, of up to 36°C. At a depth of 6,000m, in the central part of the Peri-Adriatic Depression, the temperature is 105.8°C. The isotherm runs parallel with the Albanides strike. The temperatures in the ophiolitic belt are higher than in the sedimentary basin at the same depth.

In the Pliocene clay section, at the centre of the Peri-Adriatic Depression, the geothermal gradient displays the highest value, about $21.3mK.m^{-1}$. The largest gradients are detected in anticline molasses structures. The gradient decreases from 10 to 29 per cent where the limestone core of anticlines in the Ionic tectonic zone is located, showing that in a depth of 20km a decrease in the gradient could be observed. This change in gradient coincides with the top of the crystal basement. In the ophiolitic belt of the Mirdita tectonic zone, in north-eastern and south-eastern Albania, the geothermal gradient values increase up to $36mK.m^{-1}$. Following geothermal modelling, the gradient decrease could be observed also in an area deeper than 12,000m at the ophiolitic belt, at the top of the Triassic salt deposits.

In Albanides, the thermal field scattering (Figure 2) of heat flow density regional pattern is characterized by the highest value of heat flow, $42mW/m^2$ in the centre of the Peri-Adriatic Depression. The $30mW/m^2$ value isotherm is open towards the Adriatic Sea shelf. Heat flow density values are lower than $25–30mWm^{-2}$ in the Albanian Alps area. This phenomenon has occurred because of the great thickness of sedimentary crust, mainly carbonate, in this zone. In the ophiolitic belt in eastern Albania (Qirinxhi, 2006), heat flow density values go up to $60mW/m^2$ (Frashëri et al., 2004). Heat Flow Density contours offer a clear configuration of the ophiolitic belt.

Origin of thermo-mineral waters and temperature depth signals

The entire water chemical composition and the geological setting of geothermal systems in the Albanides have been investigated to evaluate the origin of the dissolved constituents and mechanisms of water–rock interaction. The temperature of 80–100°C of thermal waters at the top of the limestone and sandstone reservoirs at a depth of 1,000–3,500m, higher than those (40–60°C) of the surrounding geological section at the same depths, indicates that the brackish thermal fluid moves upwards to the surface from deeper horizons. The faults are seismological active belts, providing a preferentially upward path for the warm waters, allowing them to travel at depths without losing heat (Figure 3). The temperatures of 150–250°C at the aquifers, where brackish thermo-waters are formed, according to the geothermometers data, indicate clearly that the depth of the aquifers ranges from about from 15 to 20 km, based on geothermal modelling (Figure 4).

Faults were generated as a result of the compression stress leading to rock deformation. Correlation among tectonics, seismological activity and geochemical features of the circulating fluids indicate that these fluids comprise water extracted from the rocks as a result of compression stress.

Composed mainly of massive gypsum, the outcrops of salt bodies are encountered in different zones of the Albanides. In Peshkopia, in central-eastern Albania, gypsum bodies can be massively found, representing a tectonic window, surrounded by Palaeogenic and Palaeozoic rocks of the Korabi tectonic zone. Some gypsum bodies locally found are composed of different halogen salts such as rock salt (NaCl) and sylvine (KCl), outcrops among Jurassic, Cretaceous, Palaeogene carbonate rocks and Palaeogene flysch. These are related to thrusts and developed in the Ionian tectonic zone (Qirinxhi et al., 1991). The outcrops in the Dumrea region, of a large gypsum body, surrounded by Neogene rocks, are also related to the thrust. This is the so-called Dumrea gypsum stock, a very large tectonic wedge, for long time incorrectly regarded as a diapiric body. Once the tectonic stresses, related to the Alpine Post-Oligocene and Post-Tortonian Tectogenesis (Qirinxhi et al., 1991) appeared, all the aforementioned gypsum and gypsum-halogen salt bodies moved upwards.

The geological and geophysical data show the gypsum and halogen-salt horizon lying under carbonate Triassic rocks, though previous studies mark gypsum and halogen-salt rocks belonging to the Triassic age. This incorrect stratigraphic analysis was a consequence of the interpretation of contact between the calcareous rocks of Upper Triassic age, gypsum and halogen-salt rocks in the Ionian tectonic zone. This issue is also depicted in the most recent geologic map of Albania (Institute of Geologic Research, 2002; scale 1:200,000). However, gypsum and halogen-salt rocks in Albania are of Permian age, representing pre-Alpine platform formations, from a geological point of view analogous to their homologues, well known in different regions of European countries (in e.g. Russia and Germany), and in Asia (e.g. Uzbekistan, Dagestan; Betechtin, 1956). Gypsum and halogen salts were formed in the Permian, in a shallow of a very large sea basin(s) under arid climate conditions, widely spread in the area of Laurasia, or in all the submerged continents of the World.

Geothermal fluid moves upwards through the Paleozoic gypsum–halogen-salt bed at the bottom of the sedimentary crust, and bodies outcropped up to surface. Moving towards the surface, thermal waters may become abundant with various chemical elements and at a shallow depth polluted by underground water, creating their chemical composition.

At a depth of more than 150m, the gypsum is formed mainly from anhydrous $CaSO_4$ as a result of the reaction $CaSO_4 + 2H_2O = CaSO_4 - 2H_2O$. Thermal waters coming from the depth penetrate the gypsum horizon, following faults or between-layer surfaces, dissolving them, becoming first enriched with sulphuric acid. They are mostly enriched through dissolution of disseminated pyrite crystals from diabase and amphibolite, mostly present in a deep area near the gypsum horizon. Their outcrops near the gypsum layer, in the Ionian tectonic zone (Qirinxhi, 1970) are a clear confirmation of this analysis. Enriched in SO_4^{--} and in Ca^{++}, thermal waters have more dissolvent capacity as they dissolve gypsum and bring also from each molecule the water released from the dissolved gypsum. The same process takes place with the halogen salts. After dissolution, cations and anions pass into the thermal waters transformed in thermal-mineral waters, still containing the cations and anions.

The occurrence of thermal-spa waters, related to the presence of a major fault system and deep origin of the geothermal fluids, is the basis on which these faults represent the regional deep fractures.

The heat value is less than the continental average. In the Albanian sedimentary basin, at the centre of the Peri-Adriatic Depression of the External Albanides, this low heat value has occurred due to the great thickness of a mainly carbonate sedimentary crust in the zone. Radiogenic heat generated in the ophiolites is very low. under such conditions, increase in heat flow in the ophiolitic belt is related to heat flow transmitted from depth. The highest value of the heat flow density in this belt is the consequence of smaller thickness of the geological section at the top of the crystalline basement, and the MOHO discontinuity. The granites of the crystalline basement along with the radiogenic heat generation comprise the heat source. In the ophiolitic belt there are some hearths observed of higher heat flow density. Heat flow anomalies are based on intensive heat transmitted from deep and transversal fractures.

4. CONCLUSIONS

This paper highlights three main issues. Firstly, at a depth of 15–20 km, thermo-mineral spring waters in Albania are of tectonic stress origin. Secondly, thermal waters generally rise from depth from a Triassic–Paleozoic salt bed at the bottom of the sedimentary crust. The permeable fault zones, seismologically active, provide the upward path of the thermal fluids. Near the surface, these waters mix with cold fresh underground water from limestone or sandstone structures. Finally, the granites of the crystalline basement, combined with the radiogenic heat generation, provide the heat source in the ophiolitic belt of the Albanides, with the small thickness of the geological section at the top of the crystalline basement.

REFERENCES

Betechtin AG, 1956. Kurs mineralogii. *Gosgeoltehizdat Literaturi po Geologii i Ochrane Nedr. Moskva*.

Frashëri A, Çermak V, Doracaj M, Liço R, Safanda J, Bakalli F, Kresl M, Kapedani N, Stulc P, Halimi H, Malasi E, Vokopola E, Kuçerova L, Çanga B, Jareci E, 2004. *Atlas of Geothermal Resources in Albania. (Albanian, abstract in English),* Faculty of Geology and Mining, Tirana.

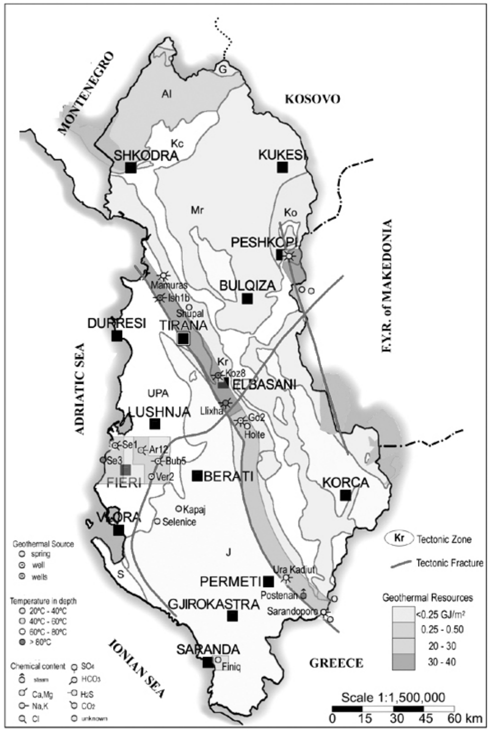
Frashëri A, Kodhelaj N, 2009. *Geothermal Resources in Albania and platform for their use. Monograph.* (Eds. Çela B, Londo A, Shtjefni A, Pano N, Alushaj R, Bushati S, Thodhorjani S.) Faculty of Geology and Mining and Faculty of Mechanical Engineering, Polytechnic University of Tirana. (Albanian, abstract in English).

Institute of Geologic Research, 2002. *Geologic Map of Albania & cross sections. Scale 1:200000*, Fier Oil and Gas Institute and Geologic and Mining Faculty of Tirana University. (In Albanian).

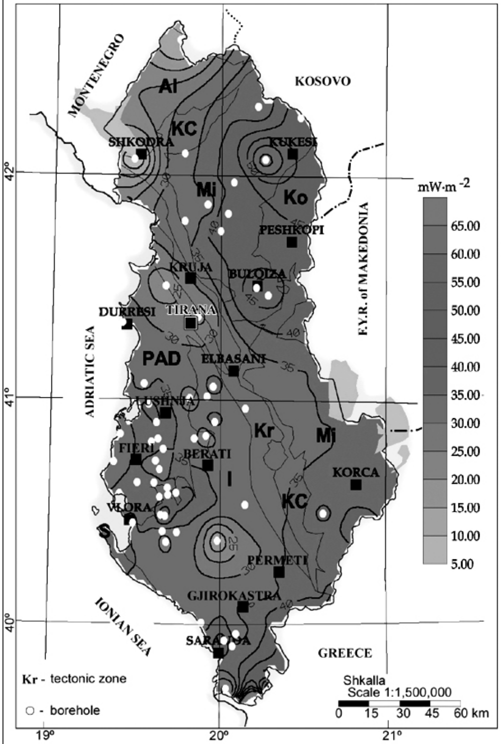
Oxford University Press, 1990. *Concise Dictionary of Chemistry*. New Edition. Oxford & New York.

Qirinxhi AS, 1970. On problems of the space location of ultrabasic rocks of Dinarido- Taurid folded Alpine Belt in Albanides example. *(In Albanian, abstract in English). Përmbledhje Studimesh*, **2**, 79–98.

Qirinxhi A, Nasi V., Hyseni A., Kokobobo A., Leci V., 1991. Review on relations of Albanide tectonic zones and the main features of their inner structure. (Albanian; abstract in English). *Buletin i Shkencave Gjeologjike*, **1**, 129–137.

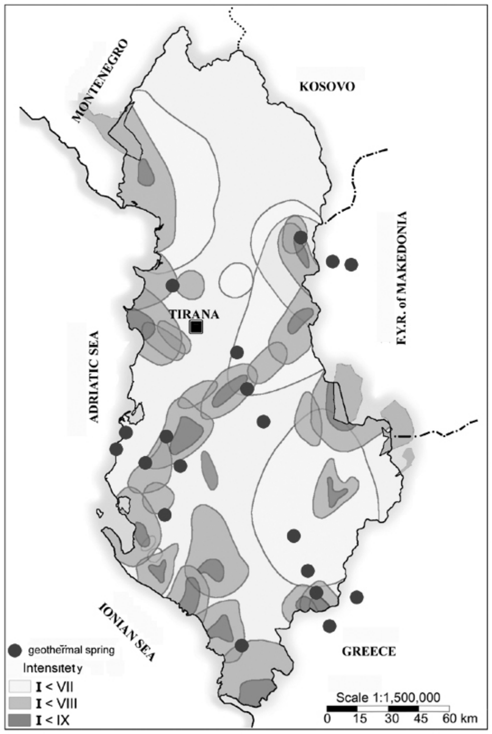


GEOTHERMAL ZONES MAP IN ALBANIA Fig. 1



HEAT FLOW DENSITY MAP OF ALBANIA

Fig.1



GEOTHERMAL SPRINGS AND EARTHQUAKES ISOSEISTES
MAP OF ALBANIA

Fig. 3

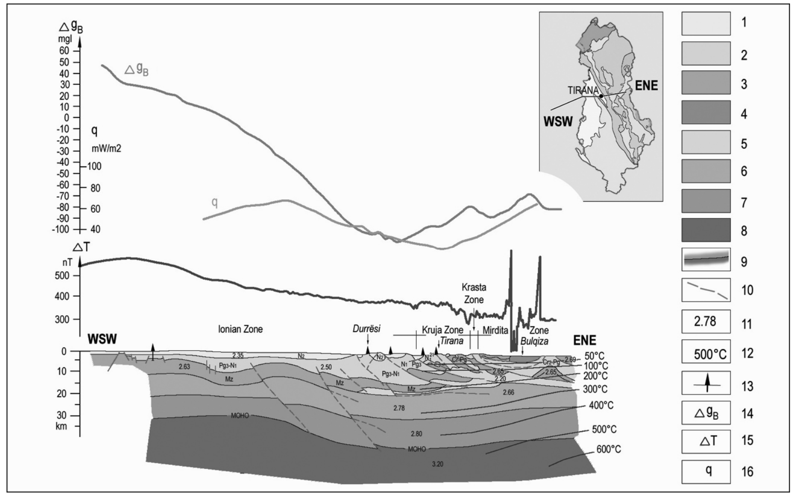


Fig. 4. Geophysical regional profile Albanid 1:
Falco Adriatic Sea–Durrës–Tirana–Peshkopi
(gravity data for Adriatic Sea after Richetti, 1980).
1, Pliocene (N_2); 2, Lower Miocene (N_1)–Paleogenic flysch (Pg_3); 3, Mesozoic limestone (Mz); 4, Ultrabasic rocks; 5, Salt; 6, Crystal Basement; 7, Basalt Crust; 8, MOHO Discontinuity; 9, Depth up–disjunctive tectonic; Density, g/cm^3; Temperature, °C; 13, Deep well; ΔG_B, Bouguer Anomaly; T, Total Magnetic Field Anomaly; q, Heat Flow Density.