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Preliminary Geothermal Investigation Northwest of Lake Kerkini, Strymon Basin (Macedonia, Northern Greece)

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The investigated area is located in the Strymon basin (Macedonia, Northern Greece), which constitutes a typical post-orogenic graben of primary geothermal interest due to its favorable geological and tectonic conditions and the identified low enthalpy fields at the basin margins. Taking into account the existence of the Lithotopos-Iraklia low enthalpy (temperature) geothermal field east of Lake Kerkini (Strymon basin), a preliminary geothermal exploration was conducted by I.G.M.E. (nowadays Hellenic Survey of Geology and Mineral Exploration) northwest of Lake Kerkini. The exploration process included collection and evaluation of geological, tectonic and geophysical data, wellhead and downhole temperature measurements, water sampling and analyses from selected wells and geochemical assessment of groundwater (Kougoulis *et al.*, 2005).

The basement of the explored area is mainly composed of various types of gneisses, amphibolites, amphibolite gneisses, schists, gneiss-schists, and pegmatite-aplite veins (small outcrops of meta-ultrabasic rocks and marbles) and belongs to the Serbo-Macedonian Massif (Vertiskos Unit). Granitoids have intruded the Vertiskos Unit. The Upper Permian/Lower Triassic Kerkini Granitic Complex (granites and granodiorite) intrudes this Unit northwest of the investigated area. The crystalline basement is covered by Neogene (Pliocene)-Quaternary terrestrial, fluvio-terrestrial, fluvio-torrential and fluvial marsh sediments consisting of pebbles, gravels, sandstones, clays and sands. Quaternary complex alluvial fans are developed along the southern margins of the Kerkini Mountains (north of the investigated area). Scree and talus cones occur at the base of the Kroussia Mountains, northwest of Lake Kerkini (Staikopoulos *et al.*, under publication; Ioannides *et al.*, under publication).

The main fault systems are oriented in NW-SE, NE-SW and E-W directions. The large high-angle NW-SE normal fault located along the longitudinal axis of Lake Kerkini is an important tectonic structure between basement and basin sediments which delineates the western margin of the Strymon basin and affects the geothermal conditions of the area. Another major tectonic structure is the E-W fault zone, which is located along the base of the Kerkini Mountains, related to the active N-S extensional stress field and bounds the northern margin of the Strymon basin. A number of faults in the above-mentioned directions are covered by the basin sediments.

The hydrogeological behavior of the geological units depends on their lithology and tectonic features. The basement is composed of impermeable metamorphic and granitic rocks but the intense fracturing and faulting create a secondary permeability and favor water circulation. The Neogene-Quaternary sediments are characterized as permeable - semipermable formations. Alluvial fans, scree and talus cones have high permeability and host good water-yielding aquifers due to their coarse-grained character and significant groundwater recharge with surface water. Several cold springs occur at the Kerkini Mountains yielding small to moderate quantities of water.

Geoeletrical survey involving a series of Vertical Electric Soundings (VES) with the Schlumberger array was carried out by I.G.M.E. north of Lake Kerkini in 1985 (Nikolaidis and Theodoridis, 1986). Geoeletrical sections oriented in N-S direction constructed from VES points. The interpretation and evaluation of these geoelectrical measurements have resulted in the following conclusions: (a) The resistivity values of the Neogene sediments overlying the basement range between 9 and 390 Ω.m due to the presence of clays, fine-grained and coarse-grained deposits. (b) Higher resistivity values of the Neogene sediments occur in the area south of the Kerkini Mountains. North of Lake Kerkini their values are lower than those northward (foothills of the Kerkini Mountains). (d) The alluvial fans, scree and talus cones show higher resistivity values (90-1,300 Ω.m) related to the grain-size distribution of deposits and the presence of water-bearing strata. (d) The total thickness of the Neogene and Quaternary sediments reaches 700m north of Lake Kerkini. (e) Significant basement subsidence associated with E-W normal faults has been identified in the foothills of the Kerkini Mountains. (f) North of the village of Kerkini, the basement has subsided steeply by about 300m (from 150 to 450m depth) due to normal fault activity. This normal fault can be considered to be a possible northwestward extension of the large high-angle NW-SE normal fault which is located along the longitudinal axis of Lake Kerkini and delineates the western margin of the Strymon basin. In general, the area is intensely tectonized and small-scale horst and graben structures have been formed.

Water temperature measurements were performed at the wellhead of 26 existing irrigation and water-supply wells, 30-162m deep, during their pumping. These wells are fed by water-bearing strata consisting of sands, gravels and pebbles intercalated with clay layers. The wellhead temperature values range between 14.6 and 22.0ºC. The maximum temperature of 22ºC was measured at the wellhead in well A-52, 81m deep (Figure 1), located in the village of Kerkini. Except for the wellhead temperature measurements, downhole temperature measurements were conducted in wells A-128, A-130 and A-131 (Figure 1). In well A-130, the temperature of 21.2ºC was recorded at depth of 121m (Kougoulis *et al.*, 2005). Taking into account that the mean annual air temperature of the area is 15.2ºC, the average geothermal gradient for the total depth is calculated to be 4.96ºC/100m. This value is higher than the normal geothermal gradient of 3ºC/100m.

Based on the distribution of the wellhead water temperature measurements, the corresponding isothermal curves were constructed (Figure 1). A geothermal anomaly is identified in the area of the village of Kerkini. The isothermal curves

trend SE-NW following the direction of the NW-SE western marginal fault of the basin. These curves remain open toward Lake Kerkini indicating the southeastward continuation of the geothermal anomaly. Considering that the isothermal curves in the neighboring Lithotopos-Iraklia low enthalpy geothermal field have characteristic NW-SE elongated shapes coinciding with the direction of the marginal fault (Karydakis *et al.*, 2005), it can be assumed that the observed small geothermal anomaly northwest of Lake Kerkini is a continuation of the above-mentioned field.

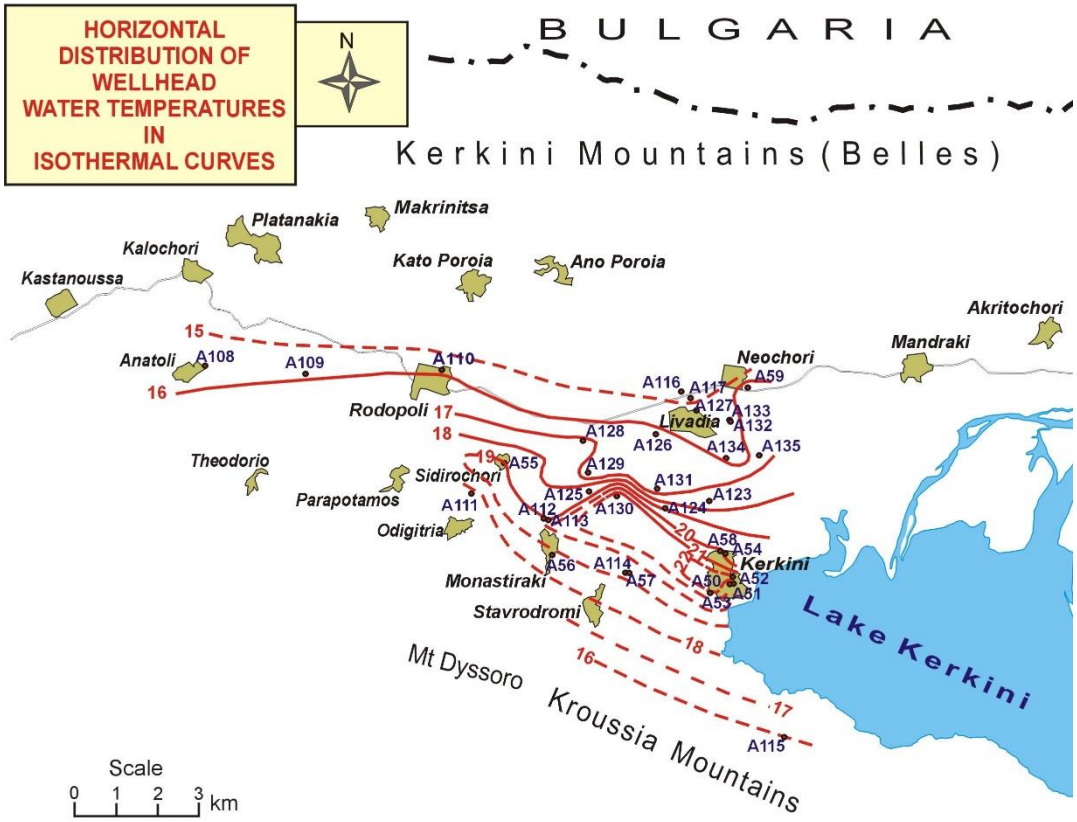

Figure 1. Distribution of isothermal curves based on the wellhead temperature measurements northwest of Lake Kerkini.

Water sampling and analyses from 10 selected wells were carried out (Kougoulis *et al.*, 2005). These water samples are classified as Na,Mg-HCO_3, Na,Mg-HCO_3SO_4, Na,Ca-HCO_3SO_4, Mg,Ca-HCO_3 and Mg-HCO_3 types. The coldest water sample (T=14.6ºC) from well A-116, 100m deep, has very low TDS (0.29 g/l), shows an almost neutral character (pH: 7.27) and belongs to Mg,Ca-HCO_3 type. The water sample from well A-53, 100m deep, having a temperature of 21.5ºC, TDS content of 0.54 g/l and showing an alkaline character (pH: 8.20) is classified as Na,Mg-HCO_3 type. Wells A-123, A-111, A-112, A-124, A-113, A-130, A-58 and A-52, 58-162 m deep, yield waters of 17.5-21.0ºC which belong to the following hydrochemical types: Mg,Ca-HCO_3, Na,Ca-HCO_3SO_4, Mg-HCO_3 and Na,Mg-HCO_3SO_4. These waters are characterized by low EC (440-680 μS/cm) and TDS (0.27-0.49 g/l) values and have a neutral to slightly alkaline pH (7.05-8.0). The plot of Na+K vs. Ca+Mg shows two main water groups: Group I (samples A-52, A-58, A-116, A-123, A-124, A-130) consists of waters of 14.6-21.0ºC with elevated concentrations of Ca+Mg (63.2-100.8 mg/l) and low concentrations of Na+K (13-23.8 mg/l). Group II (samples A-53, A-111, A-112, A-113) consists of waters of 17.9-21.5ºC with moderate concentrations of Ca+Mg (57.1-69.8 mg/l) and Na+K (59-133 mg/l).

The preliminary geothermal investigation northwest of Lake Kerkini has shown that a small positive geothermal anomaly controlled by the western marginal NW-SE fault occur in this area. The vicinity of the area with the Lithotopos-Iraklia low enthalpy geothermal field and the shape of the isothermal curves indicate the need for further systematic geothermal exploration.

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