THERMAL WATER RESOURCES IN JORDAN

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ABSTRACT

The known geothermal activity in Jordan is expressed exclusively in the form of thermal springs. Thermal water is also encountered in many boreholes drilled in the Jordan Valley, Azraq basin, and Jiza region. Other geothermal manifestations such as fumaroles, boiling mud and mud pools are not observed. Thus, there is no surface evidence that would indicate the existence of high temperatures at shallow depths.

The main structural element governing the morphology, hydrology and hydrogeology of Jordan is the Dead Sea Rift fault Zone. It trends nearly N-S and forms an active part of the African-Syrian Rift. As a result of this major structure many faults of different trends and ages affected Jordan. Sedimentary rocks cover almost the whole area of Jordan and have been subdivided into two major aquifer complexes: the upper and lower aquifers separated by more or less an impermeable sequence of marl and marly limestone of the Upper Cretaceous age.

Nearly all thermal springs and anomalously thermal wells are distributed along the eastern side of the Rift and discharge their water from the lower aquifer complex with temperatures ranging from 30 to 63°C. The Zara–Zarqa Ma'in thermal springs are considered as the major geothermal manifestation in Jordan due to their high temperatures and flow rates. Therefore, the Zara–Zarqa Ma'in thermal springs were subject to many geothermal investigations during the last four decades. The main result of these studies is that the thermal water originates as ground waters in the Paleozoic sandstone to the east of the Dead Sea Rift Escarpment and is heated by deep circulation (2-3 km) in a moderately elevated geothermal gradient. The water moves towards the rift, ascends via fractures and is cooled by ascending and mixing with local ground waters before issuing as thermal springs. To the east of the Rift, in the Jiza region, many wells have been drilled into the upper aquifer complex and discharge thermal water with temperatures up to 46°C. The dense faults net of the different trends in this region, strongly suggests that the two-aquifer systems are hydraulically connected. This allows the thermal water from the lower aquifer to flow up via faults (conduits) into the upper aquifer raising the groundwater temperature in the vicinity of these faults.

The known thermal water sources in Jordan belong to low-enthalpy geothermal sources, therefore, power generation is unlikely to be possible unless high water temperature is found by deep drilling. But the available sources are quite suitable for direct uses such as, spas, fish farming, space heating for selected constructions and other direct uses.

1. INTRODUCTION

Jordan has an area of about 90,000 km^2 and it is one of the Middle East countries located in the north-western part of the Arabian Peninsula (Figure 1). It consists of three elongated distinctive topographic provinces trending in a general north-south direction. The Rift Floor Province forms the western part of the country ranging in elevation from Sea level at the Red Sea coast to 240m above sea level (a.s.l.) in the Wadi Araba, and falls to a round 750 m below sea level (b.s.l.) at the bottom of the Dead Sea (Salameh and Bannayan, 1993). The highlands province located east of the Rift with a width ranging from 30 to 50 km and elevations up to more than 1,200 m a.s.l. in the south of Jordan. Highland elevations drop sharply to the Rift in the west, but gradually towards the Plateau in the east. The Plateau province developed at the eastern toes of the highlands with land surface ranging from 500 to 1,000 m. The Azraq Basin forms the deepest part of the plateau with an elevation of 500 m a.s.l.

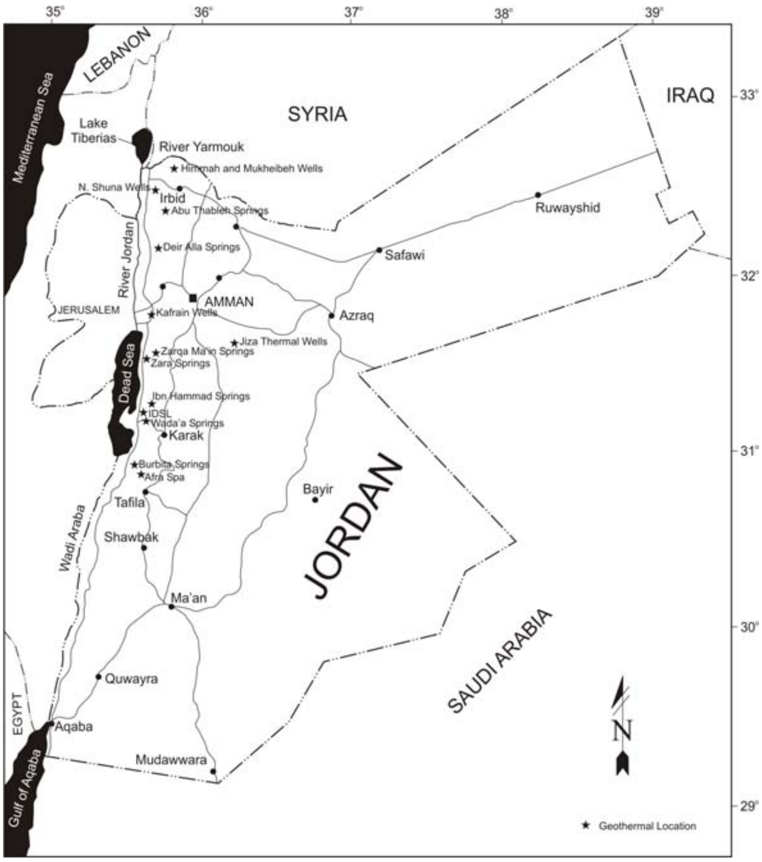

FIGURE 1: Jordan and thermal water resources locations

This sharp variation in topography within a small country leads to great differences in its climate. Therefore, the highlands have a semi-arid Mediterranean climate, characterized by a cold, wet winter and a moderate dry summer. The plateau (desert) has an arid Mediterranean climate, with a dry cold winter and a hot summer. While the climate in the Jordan Valley and the Dead Sea can be classified as an arid climate with a hot summer and a warm winter.

The main structural element governing the morphology, hydrology and hydrogeology of Jordan is the Dead Sea Rift fault zone. It trends nearly N-S and forms an active part (1100 km) of the African-Syrian Rift, which extends about 6,000 km, from East Africa through the Red Sea, Wadi Araba, Dead Sea, Jordan Valley to south Turkey. The Dead Sea Rift consists of two faults: The southern fault, called the Wadi Araba fault and the northern fault, called the Jordan Valley fault. The Wadi Araba fault starts from The Gulf of Aqaba to the Dead Sea basin along its eastern shore and ends at its north-eastern corner. The Jordan Valley fault starts in the south-western part of the Dead Sea and continues to the north along its western shore to the east of Lake Tiberius.

Two theories were used to explain the formation of the Dead Sea Rift: vertical movement (graben tectonics) and horizontal movement (plate tectonics). Detailed investigations have proved the horizontal movement theory, the Arabian plate having moved continuously to the north (Quennell, 1956; Freund et al., 1970; Abed, 1982; Girdler and Styles, 1983 and others). The left-lateral strike slip displacement along this transform boundary was estimated in Jordan to be about 107 km by Quennell (1956). Research results from the Midyan peninsula (Bayer et al., 1988; Purser and Hoetzl, 1988) and from the ocean spreading in the Gulf of Aden (Gass, 1979) document a more or less continuous movement since about 12 million years ago.

As a result of the major structures and the continuous northward movement of the Arabian plate, faults of different trends and ages have developed in Jordan due to different stress fields resulting from the different tectonic movements in different ages. The main fault trends are N-S sinistral strike-slip faults, E-W dextral strike-slip faults, NW-SE tensional faults and NE-SW compressional faults. The crossing of the fault systems acted locally as conduits for the Neogene-Pleistocene basaltic intrusions and flows. Several of the E-W faults are traceable for tens or hundreds of kilometres from the Rift to the east (Figure 2).

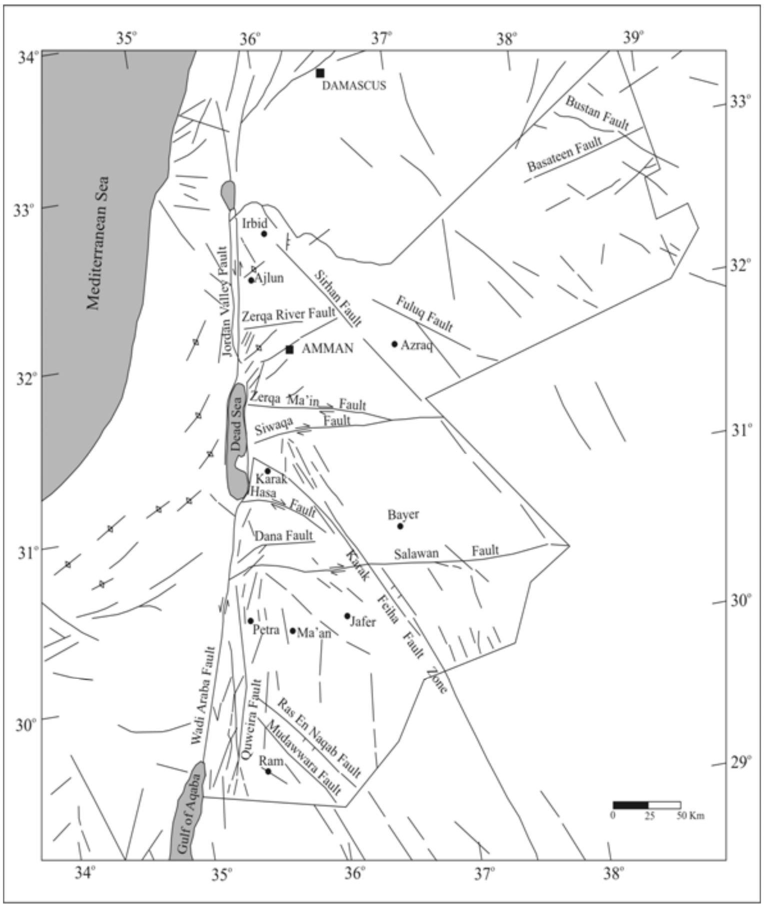

FIGURE 2: The structural map of Jordan (Sawarieh, 2005)

Almost the whole area of Jordan is covered by sedimentary rocks with a thickness of up to 5,000 m as it was taped in deep wells in the Azraq Basin. The Precambrian basement rocks are only exposed in the south-west of the country (Aqaba region). The sedimentary sequence in Central Jordan has been subdivided into two major aquifer complexes: the upper and lower (Salameh and Udluft, 1985; Sawarieh, 2005). The upper aquifer complex consists of limestone, chert, and marly limestone of the Upper Cretaceous age. This aquifer complex is known as a B_2/A_7 aquifer and is considered as a major source for fresh water for domestic use in Jordan. The lower aquifer complex consists mainly of sandstone of Lower Cretaceous and older ages. The two aquifer systems are separated by more or less an impermeable sequence forming an aquitard known as A_{1-6} and consists of about 400 m of marl and marly limestone of the Upper Cretaceous. Most of the recharge enters the upper aquifer in the structurally high outcrop areas along the highlands, where rainfall is relatively high. Generally, groundwater flows to the east within this aquifer. The main recharge source to the lower aquifer is the downward leakage from the upper aquifer system in the eastern parts of Jordan. The groundwater flows in the lower aquifer from the east towards the Dead Sea in the west, which is the ultimate point for all flows in Jordan (Figure 3).

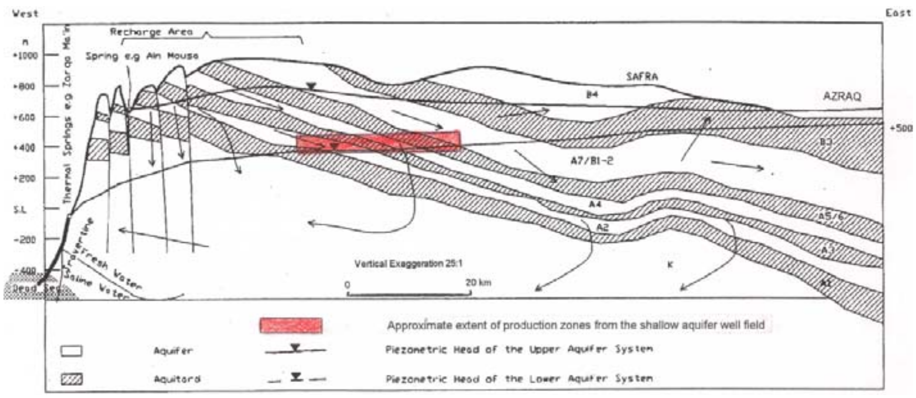

FIGURE 3: Geological cross section and groundwater flow model (Salameh and Udluft, 1985)

2. THERMAL WATER RESOURCES

The geothermal activity in Jordan is expressed entirely in the form of thermal springs. Other geothermal phenomena such as fumarolic activity and boiling mud pools or altered ground are not found. Thus there is no physical evidence from surface manifestations of the existence of high temperatures at shallow depths.

The location of nearly all thermal springs and anomalously hot thermal deep wells (Mukheibeh, North Shuneh, Jica wells and TDS-1) is dictated by their proximity to the Dead Sea Rift. Generally, they are distributed along a distance of about 200 km on the eastern side of the Rift and discharge their water mainly from the lower aquifer complex with temperatures ranging from 30 to 63°C (Figure 1). The Zara-Zarqa Ma'in thermal springs complex at the Dead Sea Shore form the main geothermal manifestation in Jordan with temperatures up to 63°C.

In the Jiza region (Central Jordan) about 30km east of the Zara–Zarqa Ma'in thermal springs, many wells were drilled into the upper aquifer complex (<400 m depth) in the last three decades, mainly by the private sector for agricultural purposes. Most of these wells discharge thermal water with temperatures up to 46°C.

3. HEAT SOURCES:

In the last four decades, many investigations of the geothermal water resources have taken place. Many of these studies were done for, or directed by the Natural Resources Authority. The thermal waters of Zara-Zarqa Ma'in have been subjected to several studies regarding their chemistry, heat source, therapeutic properties and their potential as a source of energy. In the last ten years several studies have been done on the shallow thermal wells in the Jiza region, Central Jordan.

As a result of these studies theories on several possible heat sources were presented to explain the presence of the high-temperature water especially in the Zara-Zarqa Ma'in and Jiza regions. The presence of the Late Cenozoic basaltic lavas in the Zara-Zarqa Ma'in areas led earlier investigators (Bender, 1974; Abu Ajameih, 1980) to conclude that the thermal water is heated by a crustal magma body or solidified hot pluton that represents the intrusive roots of the lavas. But the radiometric-age determinations show that the lavas are too old (1.8 ±.1 million year) and of too small volume, less than 1 km^3 (Duffield, et al., 1987). Also, the chemistry of the thermal water suggests that it is probably equilibrated with crustal rocks of about 110°C (Truesdell et al., 1983). Therefore, a magmatic heat source for this thermal water seems unlikely.

Hakki and Teimeh (1981) related the hottest springs in the Zara-Zarqa Ma'in to the highest intensity of shearing in the area, friction associated with lateral movement along faults. Galanis et al. (1986) concluded that the heat flow in Zara-Zarqa Ma'in area is high ($\leq$ 472 mW/m^2) and that the area of the highest heat flow is associated with the Zarqa Ma'in fault zone rather than the local basaltic eruptions.

Salameh (1986) suggested a heat stowing horizon consisting partly of dry sandstone overlain by marls with heat conductivities of only about half that of wet sandstone results in a temperature gradient of about twice the gradient of the whole sequence, maintaining herewith a constant heat flow.

Myslil (1988) re-evaluated the heat flow data presented by Galanis (1986) and included recent data and presented a temperature gradient map and identified two favourable zones for future exploration. The most favourable area was the eastern escarpment of the Dead Sea Rift and the second area was the region near the border with Syria and Iraq.

An alternative hypothesis that the waters are heated during deep circulation through crust with normal to slightly elevated geothermal gradients appears more likely. Isotopic and chemical properties of the thermal water indicate an origin in the Paleozoic sandstones, which extend to depths of 2,500-3,500 m below the level of the Jordanian plateau. The geothermal gradient in these sandstones is normal, thus circulation to 2.5-3 km could produce the estimated temperature of about 100°C. By this model, deep circulation in nearly flat lying Paleozoic sandstones is directed upwards along the deep faults to feed the hot springs and wells. This suggests that a widespread resource of moderate temperature thermal water exists in the Paleozoic sandstones of Jordan. The Zara-Zarqa Ma'in thermal field is controlled by tectonic forces, so the feeding system follows the vertical faults, which acts as conduits for the rapid ascent of hot waters from deep confined aquifers. This up flow can feed laterally some permeable layers where aquifers can be developed on more or less large characteristic temperature curves with rapid increase of temperature followed by an inversion of the gradient. It is well represented on the temperature profile of the GTZ-3 well (1100m) in the Zara area, where the out flow seems to be localized at the depth interval from 242.5 to 318.5 m, which lies in the Triassic sandstone. The temperature decreases from 55.4°C in the out flow zone to 51°C in the down hole. Therefore, the only way to find hotter water is to intercept the vertical feeding system (faults). Truesdell et al. (1979, 1983) concluded that the Zarqa Ma'in and Zara springs, are fed by deep circulating water. The maximum temperature of this water at depth is about 110°C cooling down during ascendance and by mixing with shallower cold water before it discharges as thermal springs. This interpretation for the heat source is similar to that reported by Mazor et al. (1980) for many thermal springs elsewhere in the western side of the Dead Sea Rift and appear to reflect a regional similar geothermal regime along this major structural zone.

Between the years 2002-2007 three geothermal studies were carried out and concentrated on shallow thermal wells in Central Jordan for heat source and possible future utilization. During the years 2001-2003, NRA conducted a study on the thermal wells in the Jiza region (Jaser, 2002). In the course of this work geological, hydrogeological, hydrochemical and geophysical investigations were made. The main outcome of this study is that the thermal water in the area is a result of a mixing process between different types of water (meteoric origin) and the highest temperature predicted by using mineral saturation index for the deep aquifer is about 115°C.

Sawarieh (2005) presented a detailed hydrogeological and hydrochemical study on thermal water in Central Jordan. The study concluded that the thermal water in shallow thermal wells in the Jiza region results from mixing between the thermal chloride water of the lower aquifer complex with the bicarbonate water of the upper aquifer complex via conduits (faults) raising water temperature in the vicinity of these faults.

In the years 2004-2005, a joint venture project was carried out by West Japan Engineering Consultants, Inc. and GeothermEx, Inc., USA to evaluate all the available data related to the geothermal fluids in Jordan. In this study all available geophysical, hydrochemical and hydrogeological data were re-evaluated. The study concentrated on the shallow thermal wells in central Jordan and presented a model explaining the presence of the thermal water in these wells with convection within the upper aquifer without any mixing with the lower aquifer water. This suggests a deep drilling in the area between the two faults (Zarqa Ma'in and Daba'a) to get hotter water from the deep sandstones through the up flow zone of the Daba'a fault.

4. THERMAL WATER UTILZATION

The known thermal water sources in Jordan belong to low-enthalpy thermal heat sources. Power generation is unlikely to be possible in Jordan except in the north-eastern parts of Jordan where high geothermal temperatures have been reported in oil wells.

Thermal springs have been used in bathing and in irrigation since ancient times. Recently, several hotels (spas) were constructed on the thermal springs' sites. The experiments carried out on the curative ability of the thermal water in Jordan show the ability of this water in treating several diseases

(Salameh et al., 1991). Several research projects are running now on utilizing thermal water in fish farming and green houses.

Because Jordan is one of the ten poorest countries in the world, thermal water is used after desalination and treatment for domestic use, mainly drinking.

The future outlook for thermal water utilization in Jordan suggests the following uses:

1. Space heating in constructions nears the geothermal sources;

2. Doubles systems for air conditioning and heating in big constructions like the Queen Alia Airport and the spas;

3. Protected agricultural activities (greenhouses to produce flowers, mushrooms and strawberries for examples);

4. Fish farming projects to provide the local market with fresh fish;

5. Constructing big and modern spas for medical treatment and relaxation, like the one built in the Zarqa Ma'in area;

6. Continue the investigations to find hotter water sources for power generation.

REFERENCES

Abed, A.M., 1982: *Geology of Jordan* (in Arabic). Al- Nahda El-Islamih Library. Amman, Jordan, 232 pp.

Abu Ajameih, M., 1980: *The geothermal resources of Zarqa Ma'in and Zara*. NRA, Amman, report on phase-1 of geothermal energy project in Jordan, 82 pp.

Bayer, H.J., Hotzl, H., Jado, A.R., Roscher, B., and Voggenreiter, W., 1988: Sedimentary and structural evolution of the northwest Arabian Red Sea margin. *Tectonophysics, 153*, 137-152.

Bender, F., 1974: *Geology of Jordan*. Contribution of the Regional Geology of the Earth, Borntraeger, Berlin, 196 pp.

Duffield, W., Edwin, A., McKee, H., Salem, F. and Teimeh, M.,1987: *K-AR ages, chemical composition, and geothermal significance of Cenozoic basalt near the Jordan Rift.* NRA, Amman, technical report.

Freund, R., Zak, I., and Goldberg, M., 1970: The shear along the Dead Sea Rift. *Philosophical Transactions of the Royal Society of London, Ser. A267*, 107-130.

Galanis, S. P., Sass, J. H., Munroe, R. J., and Abu Ajameih, M., 1986: Heat flow at Zarqa Ma'in and Zara and a geothermal reconnaissance of Jordan. USGS.

Gass, I.G., 1979: Evolutionary model for the Pan-African crystalline basement. In: *Evolution and mineralization of the Arabian-Nubian Shield. Bulletin of the Institute of Applied Geology, Jeddah, 1,* 11-20.

Girdler, R.W. and Styles, P., 1982: Comments on ' The Gulf of Aden: Structure and evolution of a young ocean basin and continental margin' by J. R. Cochran. *J. Geophys. Res., 87*, 6761-6763.

Hakki, W., and Teimeh, M., 1981: *The geology of Zarqa Ma'in and Zara areas.* NRA, Amman.

Jaser, D., and the project staff, 2002: *Preliminary results of the geology and structures, geophysics, geochemistry and hydrological works in the course of the NRA - Geothermal project - Central Jordan.*

Mazor, E., Levitte, D., Truesdell, A.H., Healy, J., and Nissenbaum, A., 1980: Mixing models and ionic geothermometers applied to warm water (up to 60°C) springs: Jordan Rift Valley, Israel. *J. Hydrology, 45,* 1-19.

Myslil, V., 1988: *Report on evaluation of geothermal potential of Jordan.* Geological Survey, Prague, Czechoslovakia, Strojexport Prague.

Purser, B.H., and Hoetzl, H., 1988: The sedimentary evolution of the Red Sea rift: A comparison of the northwest (Egyptian) and northeast (Saudi Arabian) margins. *Tectonophysics, 153,* 193-208.

Quennell, A.M., 1956: Tectonics of the Dead Sea Rift. *Proceedings of the 20th Intern. Geological. Congress, Mexico, Ass. Deserv. Geol. Africanos,* 385-403.

Salameh, E., and Udluft, P., 1985: The hydrodynamic pattern of the central part of Jordan. *Geol. Jahrbuch, C38,* 39-53.

Salameh, E., 1986: The reason of elevated temperature in the lower aquifer complex in Central Jordan. Ground water in semiarid and arid regions. *Proceedings of the International Congress, 1, Amman, Jordan, 1986.*

Salameh, E., Rimawi, O., and Hamed, K.H., 1991: *Curative thermal and mineral water in Jordan.* Jordan University, Amman, Water Resources Centre, Issue 15.

Salameh, E., and Bannayan, H., 1993: *Water resources of Jordan - Present status and future potentials.* Friedrich Ebert Stiftung, Amman.

Sawarieh, A., 2005: *Heat sources of the groundwater in the Zara-Zarqa Ma'in-Jiza area, Central Jordan.* University of Karlsruhe, Germany, PhD thesis, 166 pp.

Truesdell, A. H., 1979: *Final report on the chemistry and the geothermal energy possibilities of Zarqa Ma'in–Zara hot springs, Jordan.* USGS, Menlo Park, California, USA, unpupl. report.

Truesdell, A., Duffield, W., and Abu Ajamieh, M., 1983: Origin and heat source of thermal waters at Zarqa Ma'in and Zara, Jordan. *Extended abstracts of 4th Internat. Symposium on Water-Rock Interactions, Misasa, Japan, 1983,* 508-811.