Overview of geothermal activities in Morocco

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Abstract

In order to reduce the deficit of its energy balance, several research programs have been undertaken in Morocco for prospecting the possibility of new and renewable energy sources in the country. The temperature is studied by considering either the deep oil well data (1204 values) or data from shallow wells (300 wells and springs). Temperature measurements are treated in a synthetic way for each identified basin. This work allowed also to compare the importance and meanings of the temperature methods and to propose a conceptual model of hydrodynamic operation of the hot water aquifers in Morocco as well as a synthetic diagram explaining the different behaviours of thermal profiles in the investigated wells. In Morocco there are several geothermal anomalies and thermal clues, with occurrence of numerous hot springs and important deep aquifers; thus it could be considered as a real geothermal promising country. However, the present interest is focused on the double use of hot water for both current human needs and enthalpy. Further attention is needed toward a better knowledge and utilisation of this kind of energy, especially in the Northern and probably Southern partof Morocco where high enthalpy is expected to be found.

Keywords: *geothermal, energy sources, well data, conceptual model, enthalpy, Morocco.*

1 Introduction

The evaluation of hydrogeothermal resources of Morocco is mainly done on basis of the knowledge of the temperature, the chemical characteristics of water, the hydrodynamics of the reservoirs and their petrophysical features.

Petroleum wells are always drilled in areas, which are selected on basis of their specific geological and structural framework, wherever located. This exploration technique suffers from the lack of representativity.

Furthermore, research in Morocco showed a noticible influence of the underground water movement on the temperature. The temperature is studied by considering either the deep oil information or shallow one. Temperature measurements are treated in a synthetic way for each identified basin.

2 Geological and hydrostratigraphical studies

Morocco is located in a strategic area at the interaction of several plates (Africa, European, Mediterranean and Atlantic). The structural framework is characterized by transition from the African domain in the southern part of Morocco to Alpine folded structures (Atlasic domain and Rif troughs).

Four main structural units are defined from South to North (Figure 1): Anti-Atlas and Saharian domain corresponds to the Precambrian basement, Atlas corresponds to an Alpine intracontinental range, Mesetas corresponds to stable Paleozoic-Mesozoic basement, Rif represents the Alpine belt around the Western Mediterranean.

The hydrostratigraphical study (Figure 1) of each basin revealed several potential reservoir layers in which the carbonate aquifer of Turonian (Tadla basin and Agadir basin) and Liasic (North-western basin of Morocco and North-Eastern basin) are the most important hot water reservoirs in Morocco (Zarhloule, 1999). These areas are different geologically and hydrogeologically.

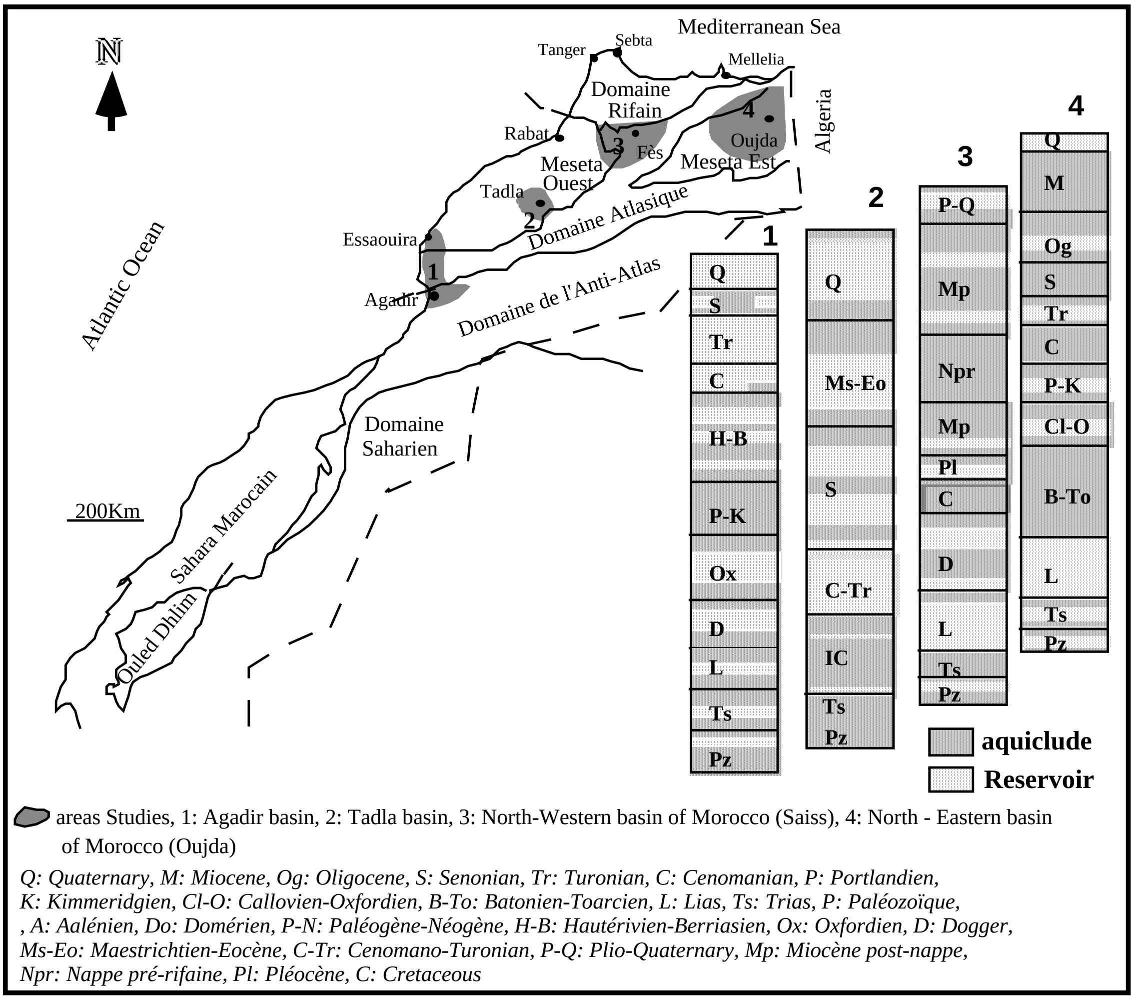
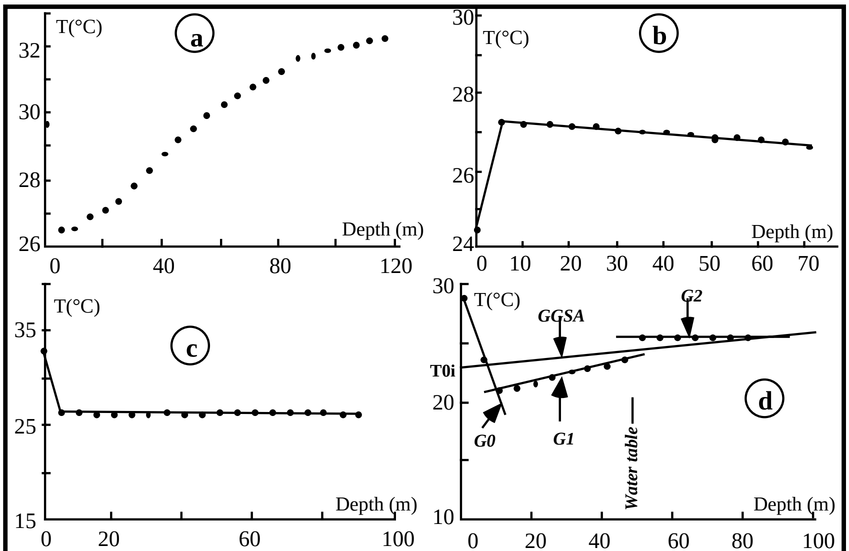


Figure 1: Simplified geological map of Morocco with the study zones and the hydrostratigraphical logs.

3 Shallow geothermal prospection in Morocco

A shallow temperature measurements program has been launched to estimate the natural geothermal gradient in these areas, to determine the principal thermal anomalies, to identify the main thermal indices, and to characterize the recharge, discharge and potential mixing limits of the aquifers (Zarhloule et al., 1998, 2001).

The temperature data from depths between 15 and 500 m of 250 wells have been analysed. The temperature measurements were made at 5m depth intervals using portable thermistor probe equipment with 0.01°C resolution. The shallow temperature data allowed to establish a thermal profile for each investigated well, assumed to be in thermal equilibrium. Thermal behaviour is changing from well to another (Figure 2) as well as within the same well (Figure 3). Lateral and vertical temperature assessment seems to be affected principally by the depth of water table, water temperature and the well location within the hydrodynamic frame. The temperature values of water range from 18 to 55.5°C.



a/ positive gradient; b/ negative gradient, c/ no gradient,
d/ main slop breaks in the thermal profile, GGSA. apparent shallow geothermal gradient, G1. Thermal gradient between the groundwater level and the limit of surface-effect influences, G2.Thermal gradient between the groundwater level and the bottom of well, T0i. Interception temperature

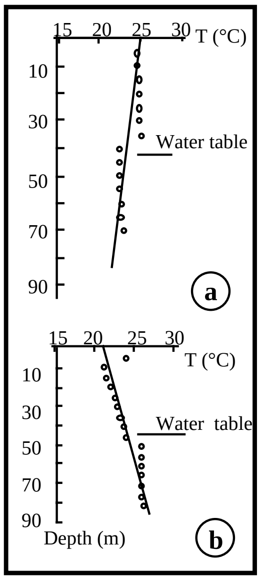


Figure 2: The different types of geothermal gradient; Figure 3: Effect of hydrodynamism on thermal behaviour.

The bottom shallow wells temperature values are plotted against depth (Figure 4) showing a rather important disturbed points either for highs or lows. Giving the fact that normal temperature can be considered, at a given depth, as the one in agreement with the regional geothermal gradient, noticably higher and lower values at the same depth should be considered as anomalous. Negative anomalies correspond to the recharge zone of each aquifer with topographic highs and infiltration meteoric cold water, whereas positive anomalies correspond to the shallow upcoming hot water and to the more or less well defined disharge zones.

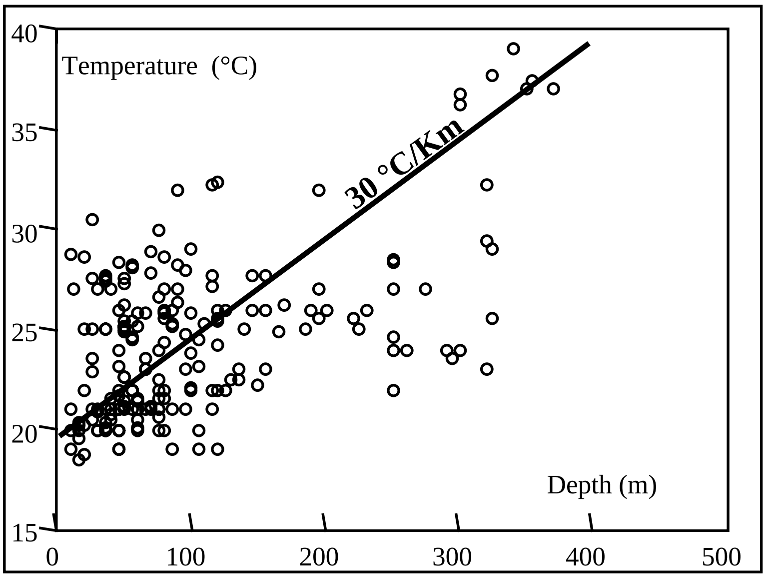


Figure 4: Bottom shallow hydrogeological wells temperature V.S depth.

The main thermals clues (80) (Figure 5) and the principal thermal anomalies that coincide with the zone of artesianism of Turonian and Liasic aquifers have been identified, as well as the potential mixing limit of the aquifers systems (Zarhloule, 1999).

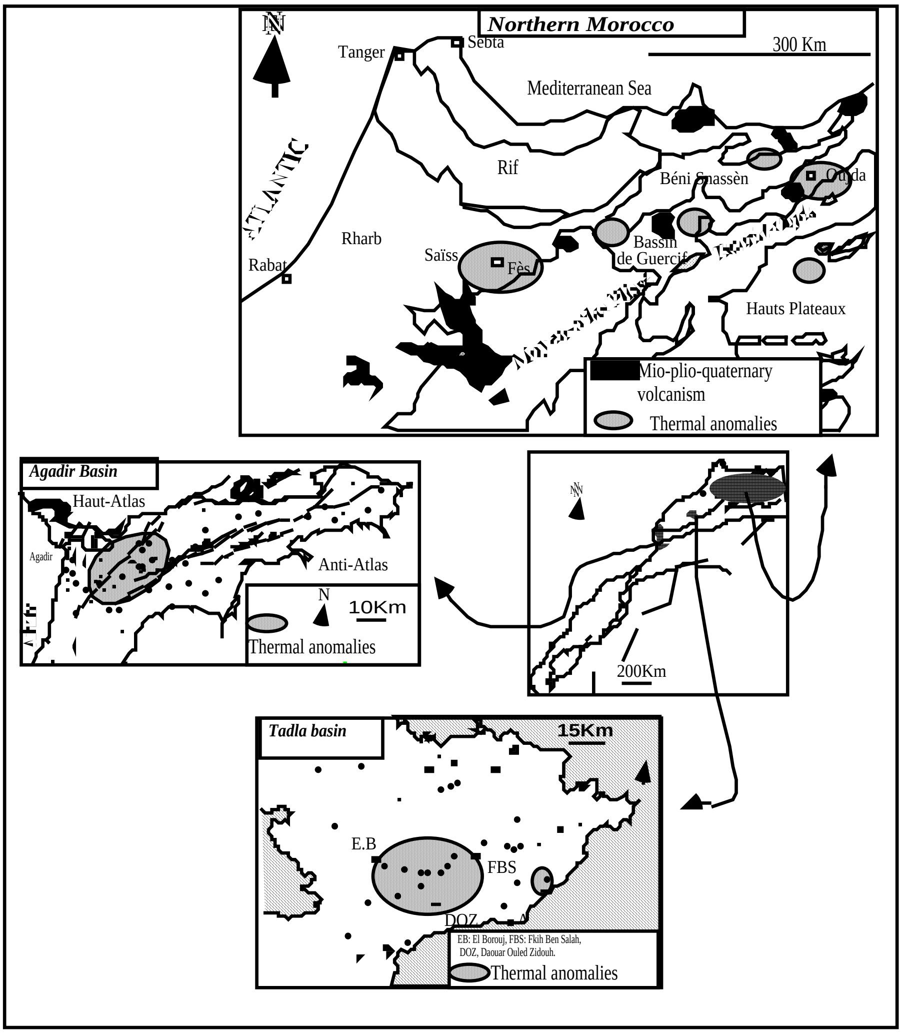


Figure 5: Map of shallow thermal anomalies areas in Morocco.

4 Geothermal gradient map of Morocco: Temperature data from oil wells

In order to improve the knowledge of these structural domains, the geothermal data will be compared with the geological and geophysical features. The aim of this work is to establish the first geothermal gradient map for the whole of Morocco (Figure 6), by using data obtained from the numerous petroleum exploration wells that exist in the country (Zarhloule, 1999, Zarhloule et al., 1999). These offer several temperature values, measured either by logging or testing surveys. Both the corrected bottom-hole temperature (BHT) and the drill-stem test temperature (DST) are used to construct the geothermal gradient map. A total of 410 wells provided 1204 temperature values from a depth range of 120-4500 m and subdivided as follows: 1126 BHT and 78 DST.

The geothermal gradient ranges from 16 to 41°C/km. The geothermal anomalies are related to deeper hydrodynamic, recent tectonic, volcanism or to the elevation of the Moho.

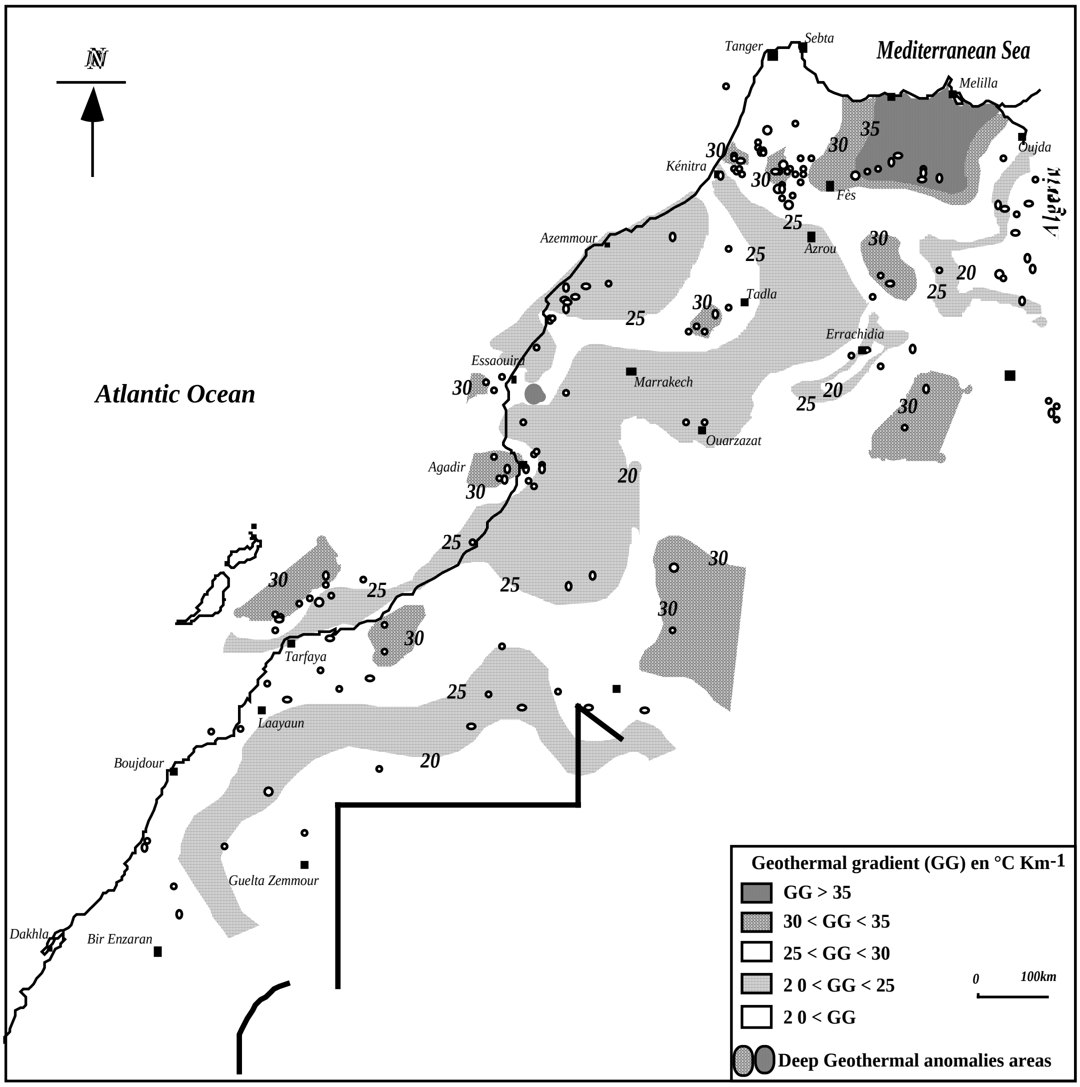


Figure 6: Deep geothermal gradient map of Morocco.

5 Geochemistry of thermal springs

The study covers the entire Northern part of Morocco and includes the most important hot springs (47). Through lack of the deep data in the Northern Morocco basin, a geochemical study has been undertaken in order to evaluate underground temperature, to determine the origin-reservoir, to approach the origin-reservoir lithology and to characterize the Liasic aquifer from which the hot springs emerge. Chemical analysis of springs is used to determined the reservoir temperature and mixing of shallow cold water with deep hot water.

Measured temperature of hot springs ranges from 21 to 54°C and disharge rates from 2.5 to 40 l/s. Geothermometers applied are: silica (Fournier et Rowe, 1966; Arnorson et al., 1983); Na/K (Fournier, 1979; Truesdell, 1976; Michard, 1979; Arnorson et al., 1983; Arnorson, 1983), Na-K-Ca (Fournier and Truesdell, 1973), Na-K-Ca-Mg (Fournier and Potter, 1979), Mg/Li (Kharaka and Mariner, 1986) and Na/Li (Fouillac and Michard, 1981). Temperatures estimated by those geothermometers are plotted against the measured values to evaluate the applicability of the geothermometers use. Only the silica geothermometers seem to give plausible values. Alkaline geothermometers used for the thermal springs are not reliable for prospecting, inasmuch as the chemical composition is greatly affected by the enormous dilution with the shallow cold water and probably affected by interaction with the evaporitic rocks that are ubiquitous in the basin.

The application of Giggenbach method (Giggenbach, 1986) to springs revealed that the waters result from mixing of deep water with shallow cold water. In this case the reservoir deep temperature is given by the mixing model.

6 Synthetic geothermal approach and conclusion

Geothermal studies of sedimentary basin have revealed lateral as well as vertical variations in the temperature fields. These variations are commonly interpreted as resulting from thermal conductivity heterogeneities or local variations in basement heat flow. Variations many also result from groundwater flow systems. The movement of water in deep aquifers can significantly perturb the local underground temperature distribution in sedimentary basins (Zarhloule, 1994).

In sedimentary basins of Morocco, the treatment and the compilation of geological, geophysical and hydro-geothermal data allowed the construction of a conceptual model showing the relationships between topography, hydrodynamism, chemistry and temperature of all hot aquifers in Morocco (Figure 7).

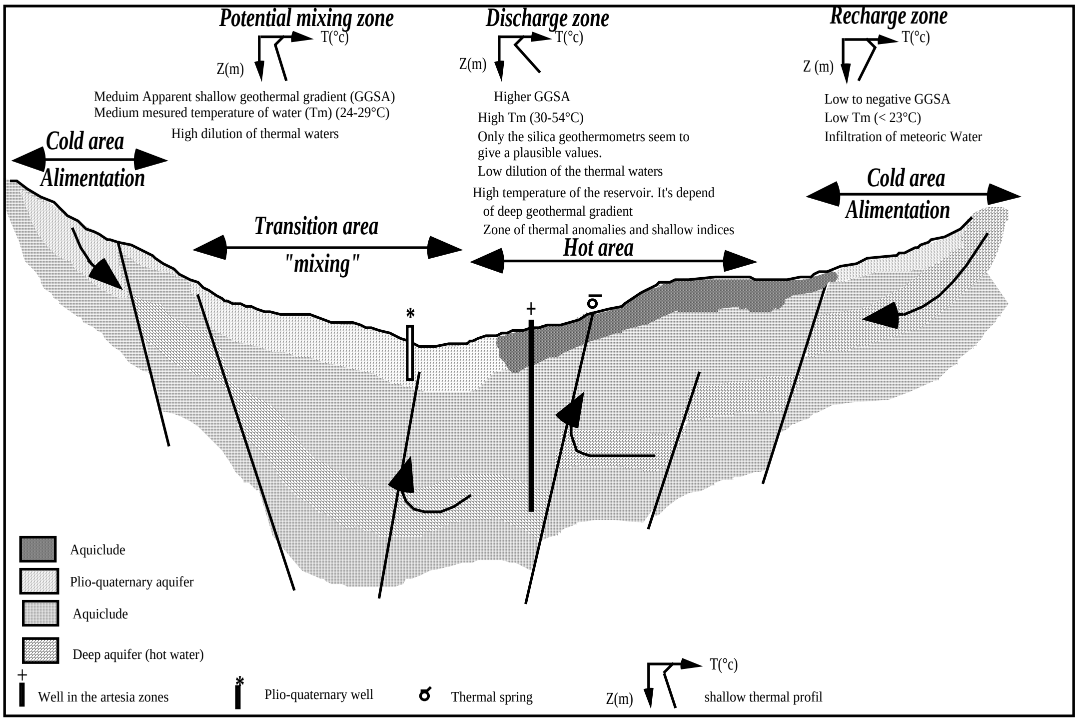


Figure 7: Conceptual model of circulation of hot water of the different aquifers in Morocco: relationship between hydrodynamism, temperature, chemistry and topography (schematic section).

The recharge zones are characterized by shallow cold water, low apparent geothermal gradient, negative anomalies and high topography. The waters are mainly HCO_3-Ca-Mg type, resulting from the great influence of carbonate rocks.

The discharge zones are characterized by shallow hot water, high apparent geothermal gradient, positive anomalies and low topography. The hot springs are general Ca (Mg)-SO_4 (Cl) or Ca (Mg)-HCO_3 type, resulting from the main influence of evaporitic rocks.

The middle of the basin shows a low apparent geothermal gradient. However, the communication between the deep and the shallow aquifers found expression in a potentiel mixing zone, with hot water and high apparent geothermal gradient.

In general the shallow geothermal gradient is high near hot springs. Hot springs represent discharge from a deep reservoir and upward moving growndwater flow. The upward moving water may come from the centre of the basin and the discharge zone may be related to the hydrologic limit of the aquifer or to the existence of faults or fractures.

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