Proceedings World Geothermal Congress 2023
Beijing, China, April 17 – 21, 2023

Main Points on Selection of the Best Location for Geothermal Well Drilling

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Keywords: geothermal, well drilling, well site selection, fault, well completion

ABSTRACT

The purpose of geothermal development is withdrawal geothermal energy to serve for energy requirement of human society. Hydrothermal convection could export stronger heat energy than thermal conduction. Therefore, the target of geothermal well drilling should gain hydrothermal fluid rather than a dry hole to be used for heat exchange. How to complete the idea? It is necessary to create a geothermal geological concept model first. Under certain condition in working area, if there is no deep buried aquafer of stratified reservoir you have to look for proper fault or fractures. Rely on a preliminary acquaintance for the concept model from geological investigation and geochemical analysis to design geophysical survey for 2 to 4 profiles using CSAMT sounding method. The target is to find out predicted fault with its occurrence. Then you could design a scenario to drill a well and meet the fault in about 1,400 m depth. The well completion could be in depth of 1,500 m. This well could reach such result that the bottom temperature higher as 40-50°C and the well yields thermal water temperature higher than 37°C of body temperature. Such practice had been completed several dozens of successful wells. For example, 2 wells completed all in 1,600 m depth last year. One of them gets 1,000 m^3/d of 67°C flow, the other gets 840 m^3/d of 43°C flow.

1. HYDROTHERMAL CONVECTION IS STRONGER RATHER THAN THERMAL CONDUCTION

The main current of geothermal development worldwide over hundred more years is hydrothermal type of geothermal resources. Geothermal well site selection after geothermal geological survey hopes always to reach higher temperature and to yield much more thermal fluid. Recent years some geothermal workers unwilling to put in time and energy in geothermal geological survey. They drilled a “dry hole” without water flow. They flatter themselves that said the dry hole was not failure, it could be used for heat exchanger to get heat, and heat pump could increase its efficiency, too. In fact, these are two different philosophy ideas. Hydrothermal fluid provides heat by convection. However, heat exchanger provides heat by heat conduction. There is clear basic concept that hydrothermal convection is rather strong than conduction.

Middle school Physics told us that heat transfer including heat convection, heat conduction and heat radiation. The maximal heat-transfer intensity is heat convection, the secondly is heat conduction, while minimal heat-transfer intensity is heat radiation.

Geothermics textbook showed a diagram for difference between convective heat and conductive heat (Figure 1). The abscissa is permeability, while the ordinate is heat flux. Along with increase of permeability, the maximal conductive heat of strata does never change, as a horizontal line. However, the convective heat was less than conductive heat when very low permeability. But when permeability increasing a little the convective heat flux suddenly sharp increase, exceeded conductive heat. When the minimal permeability for productive reservoir reaches as 10^{-11}cm^2, the convective heat flux has been higher 2.4 times than conductive heat.

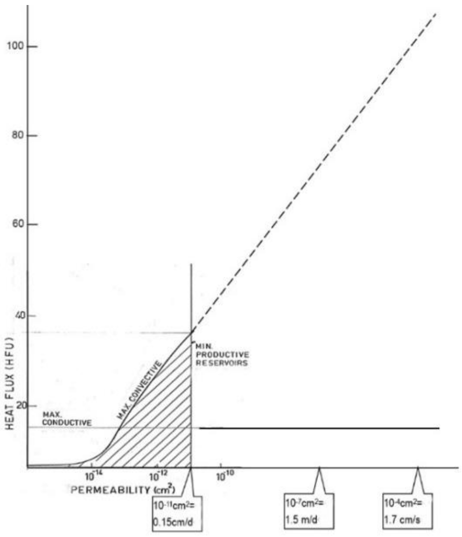

Figure 1: Diagram showing difference between heat convection and conduction

Therefore, from view of efficiency and economy, if there is a certain permeability for the stratum, we should not use conductive heat. Convective heat could provide heat demand more than several times (even more than a dozen times) if comparison to conductive heat.

We can see an example. Beijing Urban geothermal field drilled a well of JR-16 in 1974. The well depth is 1,299 m. It drilled through cold groundwater of Quaternary sediment, and impermeable sandstone and shale of Neogene and Eogene. Then it drilled into fractured karst reservoir of Wumishan group formation of Jixian system and completed the well. Pumping test using submersible pump yielded geothermal water of 56.5°C temperature and 1,341.6 m^3/d water. Corresponding to annual average temperature of 15°C in Beijing, the well yields heat power 2,698 kW. This is the heat power by convective heat. We convers its drilling cost of 48 years ago into present cost, it is CNY 1.95 million. So its cost of heat energy is CNY 723/kW.

Then we can see a new example of conductive heat. Beijing sub-center spent CNY 10 more million to drill a hole of 2,745 m depth in 2021, called test well of mid-deep geothermal downhole heat exchange. The well bottom temperature is 60°C. Yield test combined with heat pump lasted for more than 60 days. The maximal heat power is 660 kW. Its stable yield of heat power is 550 kW. Therefore, its cost of heat energy is CNY 18,182/kW. This cost of conductive heat is 25 times higher than above convective heat.

Why we said these? We need emphasize that geothermal well drilling has to select best well site by earnest geothermal geological survey in order to complete a convective geothermal well. Formerly, if someone designed and drilled a dry hole, he would feel ashamed for his failure. But present someone designed and drilled a dry hole he would not recognize his technical failure. On the contrary he said it could be “innovation” to use as heat transfer by heat exchange. He is able to invite “experts” to appraise his project and to give him a tall hat as “implemented breakthrough”. Thus, he gained honorable “achievement” even more than a high yield hydrothermal well. But I believe that the real geothermal exploration workers would tune up one’s nose.

2. CONCEPT MODEL OF HYDROTHERMAL TYPE RESERVOIR

You wanted to drill a hydrothermal type geothermal well, you have to understand such hydrothermal reservoir for its geothermal geological condition which buried where of underground. So, we have to find out such condition by geological measures. It is to say that when you select a well site for drilling you have already created a preliminary geothermal geological concept model, so that you could make correct decision.

Hydrothermal type of reservoir is divided into two types: stratified reservoir and zonal banding fractured reservoir.

2.1 Concept Model of Stratified Reservoir

Under large-middle sedimentary basins there are buried permeable aquifer (karst limestone and coarse sandy conglomerate etc. to form stratified reservoir. Its overlying impermeable strata forms cap-rock.

Within a stratified reservoir condition the well site selection and drilling design are simple relatively. Because almost anywhere could be drilled for a well. It is just some deference in reservoir temperature affected by different thermal gradient. However, we can see such fact from developed geothermal fields that if the well drilled nearby a fault in the basin depression, it would yield relative higher temperature and rich water.

2.2 Concept Model of Zonal Banding Fractured Reservoir

Geological stratigraphic distribution in some region there is only granite body or impermeable aquifuge of very thick metamorphic rocks etc. So there is only fault zone could cut and break such rock body or strata to create channel for hydrothermal convection. Thus they form a zonal banding fractured reservoir. Then its overlaying rocks which uninfluenced to be as caprock.

Without stratified reservoir condition does not equal inexistence of hydrothermal type geothermal resources.

Evolution process of long geological history existed anywhere. It left a certain scale fault in rock bodies and strata, or a small scale of fracture paralleled with fault which formed by faulting. Field geological survey should measure typical fracture plane and fault. Then analyze crustal stress field to recognize fractural system. Then carry out geophysical survey to find out the fault or bigger fracture. Usually, small fracture with extension shear feature could have ability yielding water. Therefore, they all form zonal banding fractured reservoir.

3. Geothermal Drilling has to Find out and Recognize Fault Correctly to Get Success

Successful geothermal well drilling need yield both heat and water. “Heat” will not be problem. Such geological condition exists anywhere. When drilling depth increase, geothermal gradient will make temperature increase, too. But the “water” condition needs a certain geological structure background. However, if there is geological fault, we would meet water no problem. At stratified reservoir condition the fault zoon will own higher temperature and rich water. At zonal banding fractured reservoir, the fault zoon will be unique and best condition for water yield.

3.1 Geological Investigation and Survey

Geological investigation and survey needs read reginal geological map first to see if any reginal fault zoon passed through. Fault is regional geo-stress effected vestige of deformation. There are 4 directions of fracture plane under intact stress field (Figure 2).

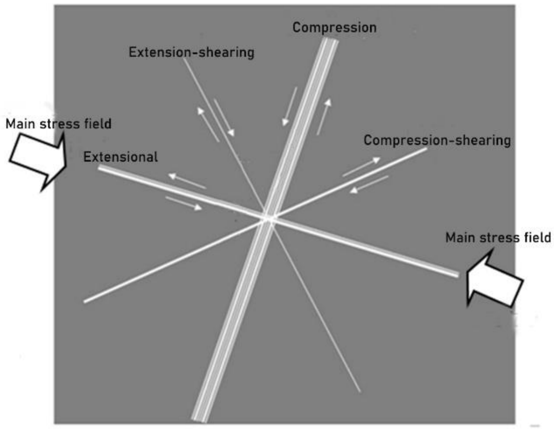

Figure 2: 4 directions of fracture plane under intact stress field

Direction along with main stress is extensional fracture plane. A direction is perpendicular to main stress, that is compression fracture plane. There will be other two directions of oblique crossing, they are compression-shearing and extension-shearing fracture planes respectively (Figure 2). Compression fracture plane appears largest scale usually. It owns superiority of conducting deep heat source. Extensional fracture plane owns superiority of conducting water at shallow depth. However, extension-shearing fracture plane owns superiority of conducting both heat and water, because it extends far away and cuts deeper.

Geological survey for well site selection purpose does not need geological mapping with large scale. But have to measure occurrence of different fracture planes, in order to recognize their different mechanical property. Then we could draw the outline of preliminary geothermal geological conceptual model. Therefore, we could create a scenery for layout of geophysical survey, i. e. which fault we want to find out, and where could be a potential well site.

3.2 Geochemical Survey

Collect typical water samples from different water body in working area. It includes hot spring (never mind if none), deep well, shallow well, stream, lake etc. We needs detect water chemistry for 11 items: K、Na、Ca、Mg、HCO_3、CO_3、SO_4、Cl、SiO_2、F and pH. Then geochemical study could provide many useful geothermal information.

3.2.1 Water Type

Chemical type of cold water is HCO_3-Ca.Mg. But geothermal water is rather different. Its dominated cation is Na, while dominated anion is Cl and SO_4. Chemical type between both is mixed type of cold and geothermal waters (Figure 3). According to these we could distinguish which sample had more geothermal information, and where is its distribution roughly.

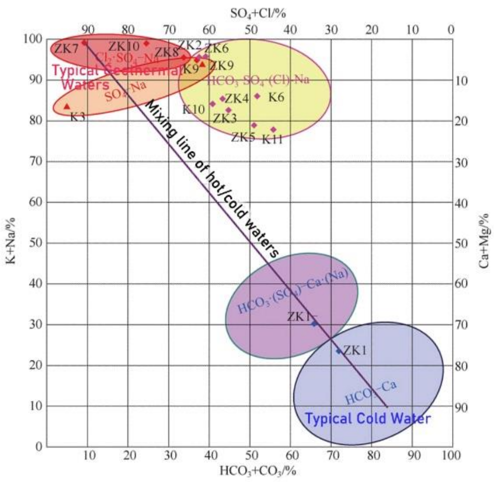

Figure 3: Lenglier-Ludwig diagram of Quman geothermal water

3.2.2 Geothermometry

We can use K-Mg geothermometer and SiO_2 geothermometer to calculate potential subsurface temperature. The temperature of SiO_2 geothermometer represents a maximal temperature at the location during process of geological history. Because it is sole that hot water could dissolve SiO_2 mineral to a certain concentration at corresponding temperature. While the temperature of K-Mg geothermometer could be as accessible temperature by drilling.

3.2.3 Special Constituent

SiO_2 and F can be as special constituent of geothermal water. There is higher concentration in geothermal water. While its concentration is very low in cold water. So, it could indicate the way for seek geothermal water.

3.3 Geophysical Survey

Geophysical survey is essential key point for geothermal exploration. Deep subsurface geology has to be detected rely on geophysical survey. There are many methods for geophysical survey. They are electric, magnetic, gravity, artificial seismic wave etc. methods. And each type method has further disaggregated classification. For geothermal purpose of seeking fault magneto-telluric and artificial seismic wave methods could be best choice.

3.3.1 Controllable Source Audio Magneto-Telluric Sounding Method (CSAMT)

Magneto-telluric method uses two electric and magnetic components to detect low anomaly of resistivity. While high temperature and rich water all show low resistivity. Among this classification, audio magneto-telluric sounding (AMT) could detect to 1,500 m depth about. It shows slightly limited. Magneto-telluric sounding (MT) could detect to 10 km depth. But it reduced precision for suitable drilling depth of 0-3,000 m. So controllable source audio magneto-telluric sounding method (CSAMT) detecting to 3,000 m depth is best suitable for geothermal well drilling. It increases detecting precision by transmission gain of artificial source. The only disadvantage is not suitable for serious electric magnetic interference area i. e. high voltage power.

3.3.2 Artificial Seismic Wave Methods

Artificial seismic wave methods using 2-D or 3-D could detect occurrence for fault plane. Its disadvantage is not possible showing high temperature and rich water. High temperature geothermal exploration in volcanic region uses artificial seismic wave methods usually. Because its fracture distribution does not be controlled by geo-stress field but by physical principle of “heating expands and cooling contracts”.

3.4 Well Drilling Should be Drill on the Upfaulted Block of Fault

According to combined geological, geochemical and geophysical survey we can recognize a draft geothermal geological concept model. So, we can select well drilling site then. It should be on the upfaulted block of fault to insure good enrichment of heat and water. Design a certain depth for example 1,500 m to meet the fault. So we could get proper increased geo-temperature and suitable well depth for sustainable exploitation.

3.4.1 Well Has to be Drilled on the Upfaulted Block of Fault

Along with drilling the well temperature will increase stably before touching the fault. And the more accessing a fault the more hot. This is correct measure to reach ideal geothermal yield. Because the drilling target is the “source” of geothermal.

3.4.2 Well Location is not Suitable to Select in the Central Geophysical Anomaly

The low resistivity anomaly in geophysical survey shows a location of fault usually. But the fault is not standing vertically. Fault has its dip direction and dip angle. If well site selected at the center of anomaly, then drilling would penetrate the fault soon, and then drill into the down block. It will cause no longer increasing of temperature, on the contrary cooling. The drilled hole can be used for its shallow part only, but not for deep part. Because it drilled the “flowthrough” but not for “source” of geothermal. That is the end of geothermal convective flow.

3.4.3 Never Drill a Well at the Downfaulted Block of a Fault

When a well drilled at the downfaulted block the well temperature will increase slowly. And the more deep drilling the more slow increasing. Such well drilling will failure. It is not possible to reach geothermal “flowthrough” or “source”.

4. TWO NEW EXAMPLES FOR WELL DRILLED IN IMPERMEABLE STRATA

Experienced geothermal exploration drilling for several decades, even for a dead zone without thermal manifestation our geothermal well drilling all got successful results. Author published a monograph of *Hot Spring Under Your Feet*. It summarized successful experience as this paper explained. Just at the year of 2021 we drilled two successful new geothermal wells.

4.1 Manguangmai of Jinghong City in Yunnan Province

Local geological team drilled a well. They selected the wellsite according to a link line between hot spring and a geothermal well. The well drilled to 1,100 m in depth. The temperature is 31°C, but no water yield.

Looked up regional geological data. Locality belongs to geothermal anomaly area. Its heat flow is 65 mW/m^2. Working area distributed whole granite. Geotectonic belongs to outskirts of the zigzag structure system. Working area is controlled by south-north direction tectonics. There is a fault at southern side but possible extend to north.

Carried out CSAMT sounding by 2 profiles. All 80 measuring points with interval of 50m have a total length 4,000 m. The detected depth is 3,000 m. Interpreted result shows 2 faults passing through south to north (Figure 4).

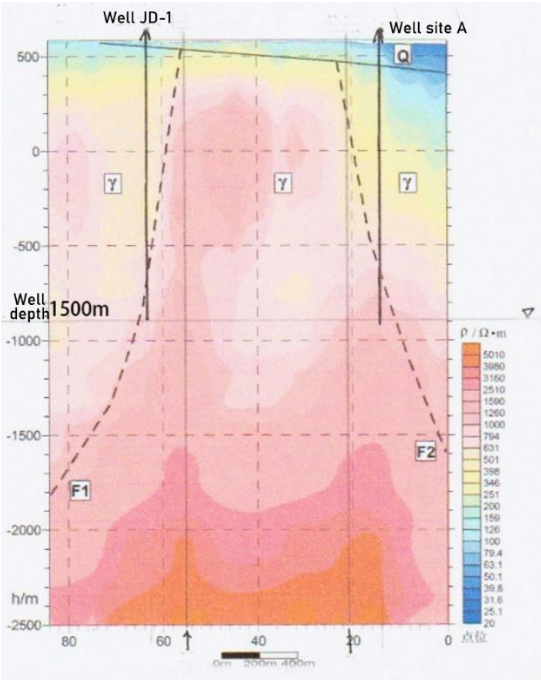

Figure 4: CSAMT interpreted result showing 2 faults

Due to the eastern fault closes to the runway of airport nearly. It is no possible to be used for well drilling. But the western fault has out of the boundary for owner. However, let the owner to extend its land acquisition then selected the well drilling site (Figure 4). Design the well to drill 1,500 m in depth. The local geothermal gradient is about 3°C/100m. The drilling will reach to the fault at 1,400 m depth. Well bottom temperature could be 45°C. Plus local normal temperature (average annual air temperature) of 20°C, the well temperature could be 65°C. The actual well completion temperature is 57°C and water yield 1,000 m^3/d.

4.2 Shiqiao of Fumin County in Yunnan Province

The Fumin county in Yunnan province implements the village promotion project. Shiqiao village of Xinfu town created Eco Leisure Park including homestay residential tourism and hot spring tour. But its hot spring is fake now. The village director asked provincial hydrogeological prospecting institute for service. MT sounding was carried out for one profile with detect depth of 2,000 m. Then well drilling started. They said the well will be completed successfully. Even said if no production of hot water you do not need pay for drilling. The well drilled to 2,400 m depth. There is some proper temperature. They think it would yield 100m^3/d water at least. However, the pumping showed no water even pump pipe has deep to 2,400 m.

The village is eager to complete the well. They invited us to drill the well. Looked up regional geological data. There are faults intersected in working area. Geological strata are Jurassic and Permian. If we want to drill a stratified reservoir it needs drill through Permian basalt to about 2,000-2,500 m depth to reach limestone of Permian-Carboniferous system. If we design to drill a fault zoon it is not necessary to drill so deeper. Local heat flow is about 60 mW/m^2 which close to normal. Design to drill 1,500 m we will get ideal hot water.

Field geological investigation has found a large fault with NNW direction. The dip direction is NEE and dip angle is ∠76° (Figure 5). This fault within working area increases successful confidence. And it provided geophysical survey layout more precise.

Figure 5: NNW fault at south of Shiqiao

CSAMT was carried out for 2 profiles. All 84 measuring points with interval of 50m have a total length 4,300 m. The detected depth is 3,000 m. Interpreted result shows 2 faults parallelly in NNW direction. They dip towards NEE with a dip angle ∠72° (Figure 6). Interpreted the west fault is just the known fault as in Fig 5. It located at north as extension from Fig 5. We selected the well drilling site as the village's favor locality. The well design to reach fault at 1,300 m depth. According to the fault's dip angle of ∠72° the well site should move 325 m eastward. Designed well depth is 1,600 m. At this depth the drilling would meet only Jurassic tuff at all. We will get geothermal water from the fault zoon. Well completion reached the fault at 1,380 m depth. Well depth is near 1,600 m depth. Pumping test completed the index of contract appointed. Water yields 500m^3/d with a temperature of 41°C. And its maximum water yield 840m^3/d and highest temperature 43°C.

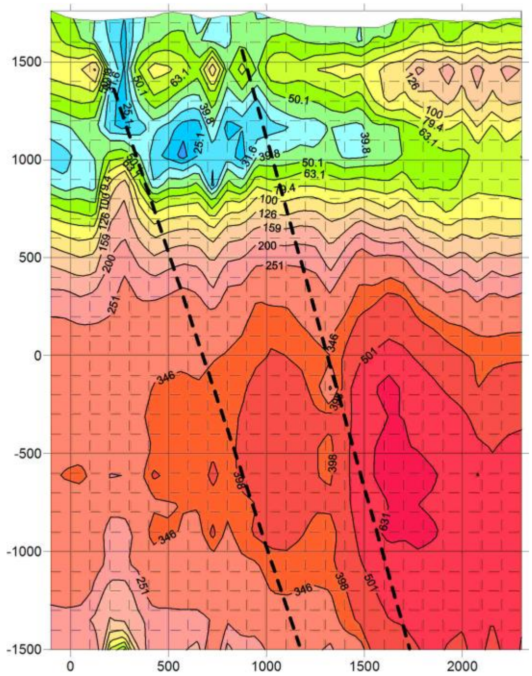

Figure 6: CSAMT interpreted 2 faults in Shiqiao

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