THE EXTRACTION OF HYDRO-GEOTHERMAL ENERGY FROM FAULT CONTROLLED SYSTEMS

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Introduction

Hydro-geothermal is the use of natural resources of hot water in the sub-surface. Sedimentary reservoir formations for hydro-geothermal projects are siliciclastic rocks like sandstones, arkoses, greywackes, and conglomerates as well as carbonates like limestones and dolomites. Only for limited regions in the world the primary or the secondary porosity (fracture and/or karst porosity) is such that deep ground water for geothermal use can be directly pumped from the reservoir formation. With the Permian Slochteren Formation, the Triassic Buntsandstein, the Lower Cretaceous sandstones and Tertiary sands, The Netherlands have such high porosity and high permeability formations (Lokhorst & Wong 2007). However, in most cases the permeability of reservoir formations is not sufficient for economically interesting pumping rates in the range of 40, 60, 80 or even more litres/sec. In this case fault systems are helpful for the development of sedimentary reservoir formations for hydro-geothermal use.

Functionality of fault systems

To describe the functionality of fault systems in hydro-geothermal, the drainage of a peat-bog can be used as a “model”. A peat-bog contains plenty of water and seems to be a good reservoir for pumping water. However, if larger amounts of water should be extracted by the aid of a high-capacity pump, soon problems will arise because of insufficient inflow rates. To reach a high production rate it is much better to dig first a long, wide and deep drainage channel into the peat-bog and then to hold the high-capacity pump into the drainage channel. The peat-bog can be compared with a rock formation with good but not sufficient reservoir properties for high-capacity pumping and the drainage channel with a fault system showing a significantly higher and sufficient permeability for high-production rate water extraction.

Most fault systems, particularly larger ones, are accompanied by lateral damage zones. The width of the damage zone is one of the key factors which define the productivity of the damage zone for high-capacity pumping. The width largely depends on fault displacement with a trend of having wider damage zones along faults with larger displacements (Hull 1988, Evans 1990). However, further fault parameters controlling the width of damage zones, for instance the fault geometry – planar or listric fault-planes, fault bends –, the geometry of en échelon fault arrays with linking damage zones or cross cutting relationships with other faults.

Still keeping our “model” of a drainage channel in a peat-bog in mind, the depth of the drainage channel, i.e. the vertical reach of the damage zone, is defined by the thickness of the reservoir formation. However, in many cases the thickness of the reservoir formation only defines the minimal vertical reach of a damage zone. As soon as reservoir formations in the hanging wall of a fault coming into contact with reservoir formations in the foot wall, the vertical reach of the damage zone increases significantly. Juxtaposition diagrams or Allan diagrams which relate formation thicknesses with fault offsets may identify such sections with maximal vertical reach of damage zones along fault systems (Allan 1989, Knipe 1997).

The length of a fault system, i.e. its lateral stretch, largely depends on the fault type – normal, wrench or thrust – and the fault offset. Larger faults are generally in favour of hydro-geothermal projects. However, faults with large offsets frequently develop fault cores which concentrate the deformation and reduce
the cross fault permeability due to clay smear and the growth of phyllosilicates. The reduction of the cross-fault permeability due to clay smears can be estimated by the calculation of values for the shale gouge ratio (SGR) or the clay smear potential (CSP) amongst others (Yielding et al. 1997).

Particularly along active faults the development of a fault core can significantly reduce the permeability of damage zones. Most deep ground waters are highly mineralized. Fracture porosity will soon be reduced due to mineral precipitation, if ongoing deformation does not mechanically counteract the sealing of fractures due to mineral precipitation by breaking up of mineral-seals or the generation of new fractures (Goyal & Kassoy 1977).

In general active faults are the primary target for hydro-geothermal use because of mechanical processes for fracturing rock that work against the mineral deposition associated with highly mineralized geothermal fluids. Active faults can be recognized directly by their surface expressions, i.e. fault-scars, or their influence on the development of the landscape and the surface drainage network. Also ongoing seismicity undoubtedly indicates active faults. In cases, also reflection seismic lines and 3D reflection seismic surveys combined with remote sensing data facilitate the detection of active faults.

Most interesting are faults which are actively deforming as tensile or trans-tensile fractures. In these cases newly formed fractures have the tendency to stay open and, thus, increase the fracture porosity and, most likely, the permeability of the damage zone. To recognize such fault systems it is necessary to know something about the recent tectonic stress field, at least the stress regime and the orientation of maximum horizontal normal stress should be known. By the aid of this information it can be estimated whether a fault has the tendency to open or to slip under the recent tectonic stress field. Most interesting are those faults indicating a high dilation and/or slip tendency (Ferrill et al. 1999).

Examples

Examples for the use of fault systems in hydro-geothermal are numerous. In the Upper Rhine Graben, Germany, the two existing hydro-geothermal power plants near Landau and Bruchsal pump hot water from damage zones along master faults. In Larderello fluid circulation is linked to active NW-SE striking normal faults. In the Great Basis in the western US, Faulds et al. (2005, 2010) described several hydro-geothermal systems linked to actively deforming fault systems. Also for the western part of Turkey most hydro-geothermal systems are related to active faults. All these examples indicate the importance of active normal, dip-slip and wrench faults for hydro-geothermal projects.

Fault systems in the Netherlands

Within the Netherlands, several fault systems are present. The most commonly known is the area around Roermond: the Peel Boundary Fault at the northern border of the Roer Valley Graben in the provinces of Noord-Brabant en Limburg. This fault zone currently shows seismicity at different depths, ranging from a few kilometres up to 30 km (KNMI, 2011). The area around Voerendaal in southern Limburg is also known for its earthquakes, indicating active faulting. Within the Mid-Netherlands Fault Zone, several earthquakes have occurred since measuring started in the Bilt in 1904. This indicates that other regions besides the Roer Valley Graben in the southern part of the Netherlands are also still active. For example in 1997 a tectonic earthquake with a magnitude of 2.0 occurred at Beverwijk.

As can be seen in figure 1, the major fault trends are NW-SE. This trend probably dates back to mid-Paleozoic times when Avalonia collided against Laurussia (De Jager 2007). The second most commonly fault trend is aligned NE-SW to ENE-WSW which established during the Early Permian (Ziegler 1988,1990a). During rifting and later inversion, pre existing faults were reactivated several times and these trends can still be observed in the younger sediments.

The faults in the Netherlands are not of a clear Andersonian nature. Most faults have also undergone sinistral or dextral displacement in the past. It is expected that several fault zones, or fault sections, are still actively deforming as oblique normal faults as the stress orientation is not everywhere aligned with the fault orientation.
Geothermal reservoirs

Within the Netherlands, several formations are of interest for the extraction of geothermal energy. These include the Slochteren Formation, the Main Buntsandstein, the sandstones of the Lower Cretaceous and sandstones of the Tertiary. These formations are well known from the oil and gas exploration. The quality of the reservoir determines the amount of geothermal water which can be extracted. With this respect porosity and especially permeability are very important. In large areas of the Netherlands, the primary porosity and permeability of the named reservoirs are insufficient for an economical feasible project. Within these regions, the appliance of a fault-controlled hydro-geothermal system might well increase the flow rate which can be extracted. In such a way, the use of a hydro-geothermal system instead of a more conventional aquifer-type geothermal system, can make the difference between a feasible or an infeasible project.

Conclusions

In summary, hydro-geothermal depends on the availability of natural hot water reservoirs in the deep sub-surface which allows persistent high-capacity pumping. For this purpose large active fault systems with large damage zones developed in thick reservoir formations are the primary target. Most likely they guarantee high permeabilities and efficient heat exchange in highly fractured rocks which is needed for the energy gain from hydro-geothermal heat extraction from the deep sub-surface. Large geothermal fault systems are present within the Netherlands. A hydro-geothermal type of project would increase the feasibility in several areas of the Netherlands.

References