Hydroshearing and Hydrofracturing – What's the Difference?

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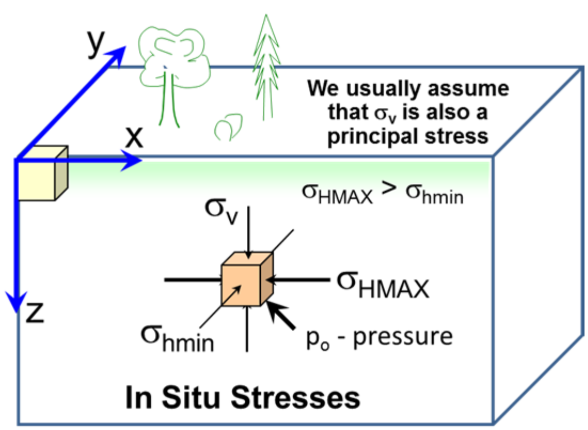
Deep geothermal energy extraction requires a method to take heat from the rock and bring it to the surface where it can be used. In wet geothermal reservoirs, there is hot fluid that can be produced, usually without the need for well stimulation methods. This is because the rock mass is permeable enough (pores and natural fractures) to withdraw fluid, strip the thermal energy at surface, and reinject the fluid at a different wellbore. Generally, high quality geothermal resources are considered to be wet reservoirs, and there are such reservoirs in BC and YK, and deep in the sedimentary basins of Alberta and Saskatchewan. In hot dry rock geothermal development, there is little porosity and insufficient permeability to allow circulation of fluids at economic rates, so the rock mass must be stimulated. This stimulation is done by hydroshearing or hydrofracturing (hydraulic fracturing).

STRESSES IN THE EARTH

Hydroshearing can be done without hydrofracturing, but not the other way around, because hydrofracturing is always accompanied by a component of hydroshearing. We can understand this only by understanding something about stresses and pore pressures. In the earth, the natural stress state is highly compressive, and the three principal stresses are different from one another, so natural shear stresses exist in the rock mass. We usually call these stresses in the ground

- The vertical stress (taken as a principal stress) σ_v
- The major principal horizontal stress σ_{HMAX}
- The minor principal horizontal stress σ_{hmin}

These three principal compressive stresses are oriented at 90° to each other, and in the fluid-filled pore space and natural fractures, there is also a pore pressure, usually referred to as p_o (initial pressure).



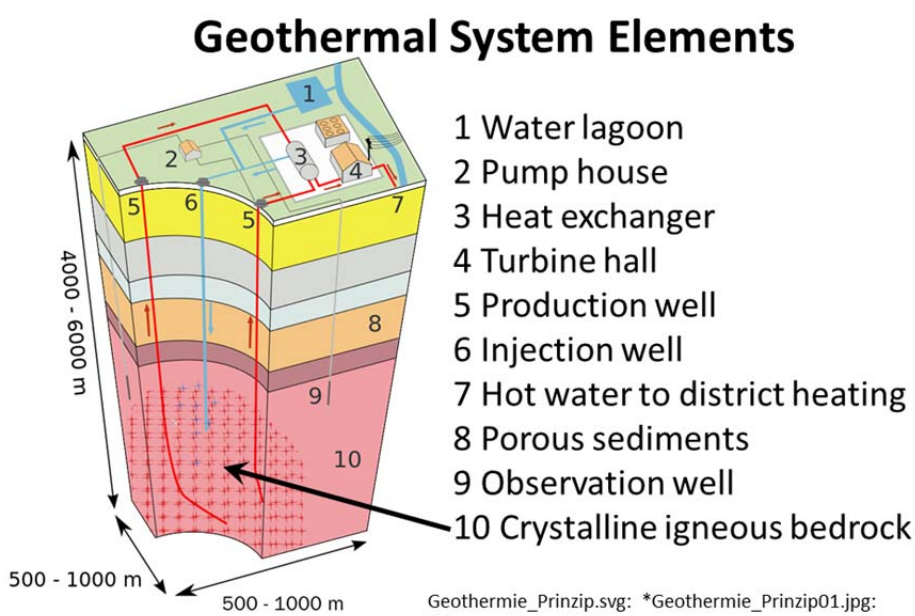
NATURAL FRACTURES IN DEEP CRYSTALLINE ROCK MASSES

The rock mass at depth that must be stimulated to implement heat recovery is naturally fractured, and these are called joints. If the rock mass is an crystalline rock (igneous or metamorphic), these joints arose during the cooling of the rock and the slow process of erosion that brought the rock closer to the earth's surface, and was affected by the tectonic stresses. Joints usually occur in regular patterns, but they can also appear almost random in orientation and length. Joints are easily seen at the surface where weathering and stress relief have opened and exaggerated the natural fractures. However, these joints are largely closed at greater depths because of the high compressive stresses, so the permeability is too low to allow circulation of fluids for heat extraction.

The following figure shows joints in an igneous crystalline rock at the surface, and in deep mines and core holes, natural fractures can also be seen and studied.

https://s3.amazonaws.com/gs-geo-images/acceb8bb-c2e2-4115-bcf9-eb347a30d847.jpg

It is possible to increase the permeability of an igneous rock mass by injecting a fluid under high pressure into the deep rock mass (10 in the next figure), called hydroshearing or hydrofracturing.

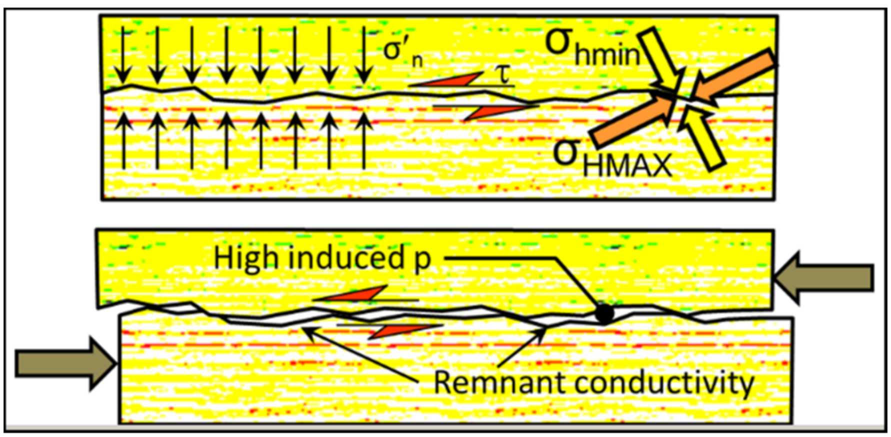


From Wikipedia

Geothermie_Prinzip.svg: *Geothermie_Prinzip01.jpg: "Siemens Pressebild" http://www.siemens.comderivative

HYDROSHEARING

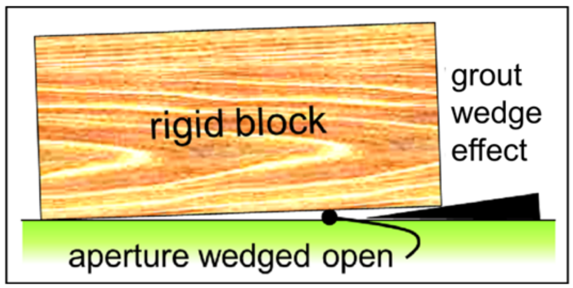
Suppose we slowly increase the pore pressure in the rock mass around one of the deep wells by gradually increasing the injection rate. The principal stresses shown in the first figure do not change substantially, and at some point, because the stresses are different in different directions, favorably oriented joints will slip. This is because the increase in pressure counteracts the compressive stress holding the joint tightly together. When slip happens, the rock surfaces across the joints are displaced, usually by a millimeter or less. Because the joint surface is rough, this slip also opens some additional space which stays open after injection is stopped because the slip is not reversible: it is like pushing a brick along a table; when you stop pushing, the brick stays where it is. The process is shown in the figure below, and the opening of additional space, labeled remnant conductivity, is called "shear dilation", which is the dominant mechanism in hydroshearing. By maintaining the injection pressure at a suitable level, or perhaps by increasing it slowly, a zone of hydroshearing will slowly grow around the injection point, increasing the rock mass permeability around the well. However, hydroshearing only opens some of the joints, and the increase in fluid conductivity may be limited in terms of the size of the region affected around the wellbore, and the amount of dilation the joints may experience.



The injection pressure that is maintained during hydroshearing by continuous pumping is close to the minimum stress in the ground (usually σ_{hmin}), perhaps 95 to 99% of its value – so $p_{inj} \approx \sigma_{hmin}$. During hydroshearing, the flow rate and pressure are carefully monitored to sustain the shearing process and allow it to propagate slowly outward. Each shear displacement event shown above is not a gradual process; it takes place as a "stick-slip" event accompanied by the emission of small bursts of seismic energy, called microseisms, or microseismic activity. These are like earthquakes, but because they generally are never felt at the surface, they are called "microseismic events". The propagation of the hydrosheared zone can be tracked as it moves outward by recording and mapping these microseismic events, so it is possible to learn a great deal about how the deep rock mass reacts. This information, along with pressure and flow rates over time, aids in the design of future activities and decisions as to whether hydroshearing or hydrofracturing is the better option in particular cases.

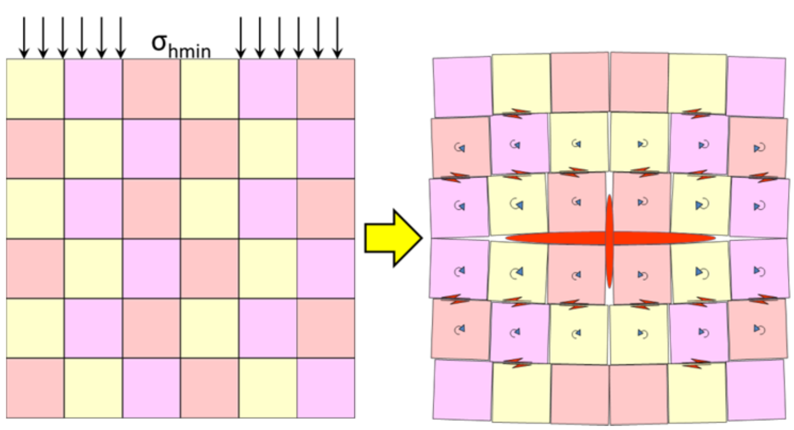
HYDROFRACTURE

Hydrofracturing, also called "hydrofracking" or just "fracking", is a little bit different than hydroshearing. In this process, the injection pressure is deliberately and usually suddenly brought well above the minimum stress in the ground ($p_{inj} > \sigma_{hmin}$) so that the joints in the right orientation are opened, a process of physical "wedging" by the fluid pressure. We differentiate clearly between natural and "induced" fractures, although in competent but jointed rock the latter are simply joints that have been opened by the high injection pressure. This process is widely used in the petroleum industry to increase the productivity of oil and gas wells. To enhance and maintain the beneficial effects, it is common to also place a granular agent such as quartz sand or artificial ceramic beads to hold the fracture open, a process called "propping", and the granular material is called a "proppant" because it "props" open the fractures after the injection ceases. This is also similar to what Civil Engineers may do in a fractured rock mass under a hydroelectric dam: they inject a fine-grained cement grout or a polymer at hydraulic fracture pressures, greater than σ_{hmin}, so the grout can be forced far into the rock mass and help seal the joints.

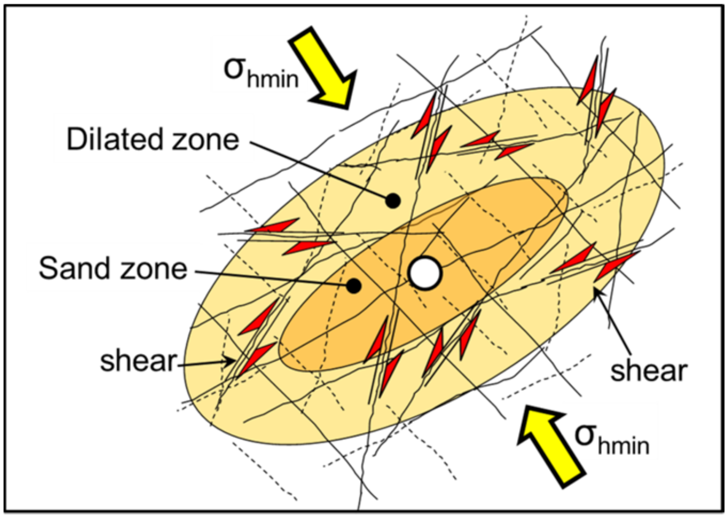


Of course, for geothermal development, it is necessary to improve the permeability, so the propping material that is added to the hydrofracturing fluid during high pressure injection is coarse-grained. Then, the propped fractures retain a high fluid conductivity, and the overall permeability of the rock mass is enhanced. It is possible, with proper fluid design and aggressive injection, to open joints and prop them to distances of about 100-150 m from the injection point. Much more than this requires such large volumes of fluid and proppant that it may not be economical.

During hydrofracturing, high pressures are not confined to the region where the joints are propped open. Pressures propagate far in advance of the propped zone, so in advance of the zone being propped, hydroshearing is taking place. This is well known because large hydrofracturing processes in the oil and gas industry have been carefully monitored for microseismicity, and it is clear that the microseismicity is far in advance, perhaps several hundred meters, of the zone that is wedged and propped. Also, because the rock mass is composed of rock blocks that are quite rigid (granite and gneiss), when a fracture is wedged open, it generates movements in the surrounding rock far from the proppant. This effect is shown in the figure below, a simple model of a blocky rock mass.



Forcing open a fracture near the injection point leads to rock block slip and joint opening far from the propped region (shown in red), and this effect, combined with the even more distant hydroshearing, leads to a stimulated zone that is much larger than the propped zone. Of course, the natural fractures are not so regular as in an array of child's blocks, but the processes of hydrofracturing and hydroshearing are the same. A more realistic figure of the stimulated zone is shown below.



Here, the darker central zone is the limit of the propped zone, and the lighter ellipse delineates the extent of the zone of shear dilation, the hydrosheared zone. The length and orientation of the major axis of the stimulated zone is a key design factor in placing hydraulic fractures, and it almost invariably lies close to 90° to the minimum stress direction. Different strata will respond differently because of differences in the extent and openness of the natural fractures, the difference and directions in the natural stresses, differences in the mechanical properties of the rock, and differences in the rate and properties of the injected fluid. These must be understood to achieve good results in geothermal stimulation of low permeability igneous rock masses, and in linking adjacent wellbores. Also, how can one increase the extent of the hydrosheared zone? That is a story for another day. But remember, success in geothermal development depends on economic and effective drilling and accessing the energy, whether it is hot fluids in permeable rock or the heat in hot dry rocks. With ingenuity, we will access the great amount of heat at depth in an economic manner, sustainable, and highly useful in our cold climate.

THE AUTHOR

Maurice is a teacher and researcher in the University of Waterloo, and is interested in the geomechanics of anything deeper than 200 m. He may be contacted at mauriced@uwaterloo.ca. Maurice and several colleagues, Dipanjan Basu and Roydon Fraser, are investigating the potential for hot dry rock geothermal deep in the crystalline rocks that underlie many northern communities such as Yellowknife, Cambridge Bay and Iqaluit.