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# A Geologic Systems-Based Classification For Geothermal Energy

Richard J. Erdlac, Jr.
Erdlac Energy Consulting, Midland, Texas

Classification systems are the heart of organizing data and information in a manner that can be used by others in the decision making processes. Very often this information is classified in multiple ways, depending upon the needs and the use of the final classification system. In the case of geothermal energy, multiple classification schemes have been devised to explain and categorize geothermal energy systems. This includes geoexchange, direct use, and power generation from geothermal energy, often being combined in a single classification system.

Several different geothermal classifications presently exist. The simplest and easiest for the public to understand is discussed at the Geo-Heat Center at the Oregon Institute of Technology. This classification is based entirely on temperature ratings of low (<90$^o$C or 194$^o$F), moderate (90$^o$ – 150$^o$C or 194$^o$ – 302$^o$F) and high (>150$^o$C or >302$^o$F), and is loosely tied to the potential uses of the geothermal heat energy.

At least four other classifications also exist. Two classifications were developed at the USGS and are represented in Circular 726 (1975) and Circular 790 (1979). Circular 726 defined three broad categories that included conduction, igneous, and hydrothermal systems, whereas Circular 790 defined five separate categories of conduction, geopressured, igneous, hydrothermal convection, and low-temperature systems. Circular 726 incorporated the geopressured resource within the conductive system, and the igneous system included energy directly from molten systems.

In 2006 and 2007 two variations on these earlier classification systems were suggested by the National Renewable Energy Laboratory (NREL) and the Massachusetts Institute of Technology (MIT) respectively. The deep geothermal category of NREL included all of the conduction-dominated enhanced (engineered) geothermal system (EGS) resource as defined by MIT, which included sedimentary, crystalline basement, and supercritical volcanic EGS rocks. NREL broke hydrothermal into two classifications based on temperature and whether the resource has been identified. Finally, NREL listed co-produced and geopressured resources as related to deep oil and gas wells together whereas MIT broke these resources into two separate categories.

In reviewing these classifications, there appeared to be two good reasons for devising a new geothermal classification that focused on geothermal power development. First, the existing classifications simultaneously combine geological environments, energy resource type, and the mechanism of heat transfer and recovery in a technical potpourri that can make presentation to investors confusing. This approach makes determining cost for geothermal projects more difficult to determine as different geologic environments may impact the cost for energy acquisition. It is also not easy to use the existing classification systems as a general exploration tool that reflects the geologic environment being targeted for energy development.

Second, when looking at developing geothermal energy from sedimentary basins there exists two resource categories that have no easy tie in to the existing classification systems. Co-produced water as an energy resource is very different from stranded water behind pipe and within a target formation. Similarly the stranded hot water may be lithostatic (geopressured), or it may be hydrostatic in nature.

Because of the nature of geothermal energy, the initial geologic activities involving geothermal power production has been focused in active to recently active volcanic systems. Historically this has also linked geothermal energy to the hard rock mining industry. However with the potential of geothermal being developed in soft rock regions due to deep drilling by the oil and gas industry, the need for a different approach to geothermal power classification that would tie geothermal to the geologic environment seemed evident.

In defining a geothermal power classification system, five key parameters were considered important for classifying the resource (Table 1). These include the geologic environment, geologic features, the crustal “heat source”, the resource category, and the rock type in which the geothermal resource is found.

The geologic environment is the simplest of the five categories and the first to be considered. This environment is represented either by the plate margin or intraplate environment. The plate margin environment is broken into three additional environments that include convergent (compressional), divergent (extensional), and transform (strike-slip). The second category is the large scale geologic feature that can be found in either the plate margin or intraplate environment. Thus a volcanic arc complex can be expected to form in a convergent plate margin whereas a pull-apart basin will be within a strike-slip environment. The type of crustal heat source within the plate margin environment is magmatic in origin. The resource category can be classified either as steam or hydromagmatic in nature. Steam references a thermal system where the resource is vapor dominated. The term hydrothermal has been used to describe any hot water or steam resource, though have use the term in a more restrictive sense. To avoid confusion with the idea of hot water from sedimentary basins, the term hydromagmatic is used to restrict water heated by a magmatic source. Finally, the rock type defines the fifth category, is generally considered to be either igneous or sedimentary in nature, and defines the reservoir that is tapped for heat acquisition.

The intraplate environment consists of various geologic features that include mantle plumes or hot spots, extensional terrain, cratonic basins, passive margin basins, and the basement complex. While the majority of heat comes from deep within the earth's mantle, the nature of the intraplate environment allows for an expansion of the crustal heat source into either magmatic, thermal gradient, radiogenic heat, or possibly a combination of these sources. The magmatic heat source is associated with mantle plumes or regional extensional terrain. The thermal gradient would dominate within cratonic and passive margin basins where conduction and heat advection are highly active. The radiogenic source, along with conduction, has greater dominance within the basement complex. Steam and hydromagmatic resources would dominate within the igneous and sedimentary rock associated with mantle plumes or regional extension. Cratonic and passive margin basins would have stranded (geopressured and hydrostatic) and co-produced hot water resources within the sedimentary rock that dominates the basins. Finally, the basement complex is the realm of the hot dry rock resource and would generally be igneous in its rock type.

**Table 1**

<table>
<tr><th colspan="6">Proposed Geothermal Power Classification System</th></tr>
<tr><th colspan="2">Geologic Environment</th><th>Geologic Feature</th><th>Crustal Heat Source</th><th>Resource Category</th><th>Rock Type</th></tr>
<tr><td rowspan="9">Plate Margin Environment</td><td rowspan="4">Convergent (Compressional)</td><td>Back Arc Basins</td><td rowspan="4">Magmatic</td><td rowspan="4">Steam<br>Hydromagmatic</td><td rowspan="4">Igneous<br>Sedimentary</td></tr>
<tr><td>Volcanic Arc Complex</td></tr>
<tr><td>Continental Volcanism</td></tr>
<tr><td>Intrusive Complex</td></tr>
<tr><td rowspan="2">Divergent (Extensional)</td><td>Volcanic Spreading Center</td><td rowspan="2">Magmatic</td><td rowspan="2">Steam<br>Hydromagmatic</td><td rowspan="2">Igneous<br>Sedimentary</td></tr>
<tr><td>Rift Systems</td></tr>
<tr><td rowspan="3">Transform (Strike-Slip)</td><td>Pull-Apart Basins</td><td rowspan="3">Magmatic</td><td rowspan="3">Steam<br>Hydromagmatic</td><td rowspan="3">Igneous<br>Sedimentary</td></tr>
<tr><td>Transtensional Faults</td></tr>
<tr><td>Volcanic / Magmatic Centers</td></tr>
<tr><td colspan="2" rowspan="7">Intraplate Environment</td><td>Mantle Plumes (Hot Spots)</td><td rowspan="2">Magmatic</td><td rowspan="2">Steam<br>Hydromagmatic</td><td rowspan="2">Igneous<br>Sedimentary</td></tr>
<tr><td>Extensional Terrain</td></tr>
<tr><td rowspan="2">Cratonic Basins</td><td rowspan="4">Thermal Gradient</td><td>Stranded</td><td rowspan="4">Sedimentary</td></tr>
<tr><td>Geopressured</td></tr>
<tr><td rowspan="2">Passive Margin Basins</td><td>Hydrostatic</td></tr>
<tr><td>Co-Produced</td></tr>
<tr><td>Basement Complex</td><td>Radiogenic</td><td>Hot Dry Rock</td><td>Igneous</td></tr>
</table>

So long as geothermal energy remained in the realm of volcanic and ore body environments, existing classifications have sufficed for geothermal development. However expansion to sedimentary basins requires a reconceptualization of classification that is more encompassing in its geologic realm. Similarly the mixed potpourri of various geologic, engineering, and resource terminology makes expansion of existing classifications into sedimentary basins cumbersome. Thus the proposed geothermal power classification system (Table 1) is a first step in developing a scheme that is defined by specific key geologic parameters that organize pertinent data into a more fluid and functional manner, one that can hopefully begin to be used as an exploration tool as well.

This systematic, descriptive approach is not necessarily the definitive answer to geothermal data organization. For example heat transfer mechanisms were not included in this discussion. The presence or absence of other surface or subsurface features affecting or resulting from geothermal activity in various geologic environments was not discussed. While the broad categories of igneous and sedimentary rocks was mentioned as related to geologic features, a detailed break down of the rock strata (i.e. limestone, sandstone, andesite, rhyolite, etc.) is necessary for a more complete classification. Neither has permeability and porosity variations within the various target rock types been presented. However this is a first step in defining a category for geothermal energy for power generation that starts from first principles, those being the environment defined by geology.