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Notes on the physical nature of geothermal resources

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Exploitable geothermal resources occur in several forms. For the purpose of legal definition and resource regulation the details of origin and geological setting are not important. These notes will attempt to describe the physical characteristics and the typical form and lateral extent of geothermal resources, which will be divided into four categories:

Flowing springs

Hydrothermal systems

Sedimentary aquifers

Hot dry rock

Flowing springs

About 60 thermal springs are known in Canada, almost all in the western mountains, in the Provinces of Alberta and British Columbia and in the Yukon and Northwest Territories (Souther 1975, McDonald et al. 1978). The maximum temperature recorded in these springs is 82°C, and springs having temperatures as low as 8°C are regarded as 'thermal', since they are warmer than the average temperature of the surrounding ground. Flow rates range from small seeps to 4400 l/min.

In the natural state the spring water drains to a creek and eventually to a river, cooling to the atmosphere and mixing with cold water. A large spring is often surrounded by an area a few tens of metres across, in which climate is severely modified, resulting in luxurious growth of trees, ferns, flowers and mosses. Even the small seeps often support highly coloured patches of moss, lichen or algae. Some springs deposit rock formations of spectacular shape and colour, and these may easily be damaged or destroyed by careless visitors or rock collectors. Some springs are on privately owned land, some on crown land, and some in National or Provincial Parks. In the more travelled areas springs have been exploited to create spas and tourist facilities, as at Banf, Harrison, Lakelse, Jasper, Radium, Fairmont, Lower Liard Crossing, etc. In remote areas springs are still in the natural condition except for the results of occasional visits by trappers, etc.

Hydrothermal Systems

Hydrothermal systems are associated with some types of recent volcanic activity, and so are restricted to British Columbia and the Yukon Territory. They consist of bodies of hot water, possibly with some steam, occupying the pores or cracks in a mass of rock. The systems are confined laterally and above by adjacent masses of relatively non-porous and impermeable rock. Within the system water is circulating under convective drive. There is usually some leakage to the surface in the form of hot springs, or, in other countries, fumaroles and geysers. There is also usually a recharge system whereby cold surface water circulates close to hot intrusive rock.

The tops of hydrothermal systems are commonly 100m to 1000m below the surface. The lateral extent is typically 1km to 10km, although some systems or groups of systems extend considerably further, e.g. Larderello, Italy. Thus the systems may underlie several parcels of land surface. They have natural boundaries that may be sharp or diffuse and that are so far entirely unknown in Canada. The exploitable product is hot water or steam, which may not fall within the definition of any mineral product that is now regulated or defined for ownership rights. Exploitation is achieved by drilling wells from the surface and by piping away the water or steam at high temperature and pressure, commonly over 200°C and 2000 kPa. Exploitation at one well will draw down the pressure around it to a distance that depends on the permeability, thickness and recharge characteristics of the reservoir and will normally be 50 to 150m. Thus a well can adversely affect a neighbouring area, analogous to oil or gas production. Reinjection of spent water may be practised, but there are risks of cooling the system unless the reinjection is some distance from the production. Reinjection could adversely effect a neighbouring area.

Because of the dynamic nature of the hydrothermal system, as it is presently understood, the system is to some extent renewable. This extent probably varies from slightly to almost completely, but accumulated experience is nowhere long enough to provide any example of a depleted system. The longest continuous exploitation is at Wairakei, New Zealand, a period of about 27 years.

Sedimentary Aquifers

Sedimentary aquifers occur in layered sandstones and carbonate rocks, which may be flat-lying or folded and inclined. The same rocks could also contain oil or gas reservoirs. The aquifers consist of hot water occupying pores between the sand grains or within reef limestones, and the pore space is typically 5% to 20% of the total volume. The aquifers are usually confined above and below by impermeable rocks, but they may extend laterally for several hundred kilometres. There may be very slow (typically 1-5 m/yr) lateral movement of the water through the permeable rock or faster flow through fractures, giving rise to springs on the margins of the basins. Only those springs in highly folded and fractured areas are noticeably warmer than normal, e.g. Banf, Jasper. Recharge areas are normally on high ground at the margins of the basin, e.g. the Rocky Mountains.

Because the high temperature of the water depends on normal geothermal gradients, the useful aquifers are 1.5km or more below the surface. Lateral boundaries are seldom sharp or well defined, and since the lateral extent is so large, they will always be divided by legal rather than physical boundaries. Exploitation is achieved by drilling wells from the surface, commonly one for production and one for reinjection, these being placed about 1 km apart. As exploitation advances beyond the demonstration stage, these pairs of wells will develop into patterns of many wells. Since each production well has an area of pressure draw-down around it, and each reinjection well has an area of cooling around it, the spacing of these wells will need to be regulated for optimum energy recovery. The cooled water from a reinjection well will eventually appear at adjacent production wells, and the life of a system depends on the thickness and porosity of the aquifers, the spacing of the wells and the rate of use of the hot water. Typical lifetimes will be 30-40 yrs. The energy is not renewable, except in time periods an order of magnitude greater.

Hot Dry Rock

Hot dry rock systems are associated with some types of recent volcanic activity or with large masses of older rocks containing a high level of diffuse radioactive elements but no ore-grade uranium deposits.

A hot dry rock system has no associated water for use as a heat carrier. The rock is drilled and fractured and artificial circulation loops are established. Water is introduced artificially from the surface through one drill-hole and is recovered through another hole in the form of hot water and steam. The two holes are typically 100m apart.

The technology for the use of hot dry rock is in its infancy, and techniques for detecting the dry energy source are not well developed, so that this form of geothermal energy will probably not become widespread until after the use of hydrothermal systems and sedimentary aquifers has become well established. The Yukon Territory and the Province of British Columbia are the most probable areas for hot dry rock, but the Maritime Provinces, Newfoundland and Quebec may have such resources.

There is great variety in the size, shape and depth of hot dry rock systems. Physical boundaries can only be defined by some arbitrary temperature level, which may depend on the application of the energy. Legal boundaries will probably predominate. Adverse affect on neighbouring territory must be considered.

Since the definition of a hot dry rock resource depends only on temperature the magnitude of the resource depends entirely on economic factors. Hot rock resources exist everywhere beneath the surface if it can be reached at a cost that is competitive with alternate sources. Thus in the long term (50 yrs) hot dry rock may become the dominant form of geothermal energy.