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AN ASSESSMENT OF GEOTHERMAL-RESOURCE POTENTIAL
PASCO BASIN AND VICINITY, WASHINGTON

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ABSTRACT

The geothermal resource potential of the Pasco Basin and vicinity was assessed and found to be limited to the potential occurrence of low-temperature (less than 90°C) geothermal systems. High- and intermediate-temperature systems are believed not to exist because of the apparent lack of a sufficient heat source. Potential low-temperature systems would be hydrothermal convection systems in which meteoric water circulating in the normal heat flow of the region is heated to temperatures of approximately 100°C at depths of approximately 3 km. Potential conduits for the rapid transport of this fluid back toward the surface are faults associated with major anticlines. Should zones of high vertical permeability associated with these faults extend to depths of 2 to 3 km, fluid migrating rapidly upward along the zones could be stored in interbed and interflow zones within the confined aquifer system.

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INTRODUCTION

The Pasco Basin of southeastern Washington is located along the Columbia River north of the confluence of the Walla Walla River. The cities of Richland, Pasco, and Kennewick are located in the southern portion of the basin, while the Hanford Site (being considered for the location of a nuclear waste terminal storage facility) is located toward the basin center. No thermal springs are known to exist within the area; however, the potential exists for low-temperature geothermal reservoirs in the confined aquifer system that is present within the Columbia River Basalt Group. This report evaluates the geothermal resource potential of the Pasco Basin and vicinity, utilizing the existing data base.

GEOLOGIC SETTING

The Pasco Basin is located in the central portion of the Columbia Plateau of southeastern Washington (Figure 1). The Columbia Plateau consists of a series of flood basalts that were extruded during Miocene time over hypothesized Pre-Mesozoic sedimentary and metamorphic rocks (Raymond and Tillson, 1968) through fissures in the eastern portion of the plateau (Swanson and others, 1979). These basalts, collectively referred to as the Columbia River Basalt Group, are subdivided into the Grande Ronde, Wanapum, and Saddle Mountains Basalt Formations. Most of the Columbia River Basalt Group was erupted about 15 million years ago during the extrusion of the Grande Ronde Basalt. However, the youngest flood basalt volcanism ended approximately 6 million years ago with the eruption of the Saddle Mountains Basalt. The only volcanic rocks younger than 6 million years of age that are known to exist on the plateau are intracanyon andesite flows located: (1) northwest of Yakima in the Naches River Canyon, and (2) 80 km east of the Hanford Site in the Snake River Canyon. The State of Washington geologic map (Hunting and others, 1961) identifies these flows as Plio-Pleistocene in age. While these rocks may indicate relatively young magmatic activity on the Columbia Plateau, neither occurrence is considered as indicating the presence of significant localized heat sources for potential geothermal systems in the Pasco Basin and vicinity.

In contrast to highly viscous silicic magmas that form high-level magma chambers in the crust and are commonly associated with geothermal systems, the basalts of the Columbia Plateau typically originate in the mantle or deep crust and rise rapidly to the surface through fissures and vents. Extruded basalts cool rapidly, and basalt remaining within the fissures quickly loses heat to surrounding rock. Thus, the intrusives associated with the Columbia River basalts are not considered as potential heat sources for any modern geothermal systems that might exist within the Pasco Basin.

FIGURE 1. Location of the Major Structural Elements Within and Adjacent to the Pasco Basin (from Gephart and others, 1979).

HYDROGEOLOGIC SETTING

The hydrogeologic setting of the Pasco Basin is dominated by both a structural and topographic basin. The basin subsided as basalt accumulated, resulting in the youngest basalt being located in the lower, central area of the basin while the oldest basalt is exposed at the topographically higher basin edge. This simple basin structure is made more complex by the presence of numerous east-southeast striking folds (Figure 1). The folds are generally asymmetrical anticlines and synclines in which the northern limb of the anticlines is the steeper limb. The anticlines form prominent topographic ridges with flanks that are faulted and warped by secondary folds. The synclines are generally filled with sediment of the Hanford and Ringold Formations and are concealed beneath the surface. Two major anticlines, the Saddle Mountains and Rattlesnake Hills, define the northern and southern limits of the Pasco Basin, respectively. Other anticlines, including the Umtanum Ridge-Gable Mountain and the Yakima Ridge structures, plunge gently eastward into the Pasco Basin. Within this setting are two aquifer systems: An unconfined system within the overlying sediments, and a confined system within the basalt and associated sedimentary interbeds (Gephart and others, 1979).

The unconfined aquifer (Figure 2) extends downward from the water table to either the relatively impermeable, lower member of the Ringold Formation or to the top of the basalt, and is over 60 m thick in the Cold Creek syncline. This aquifer is not a geothermal reservoir even though reported temperature measurements (Korosec and Schuster, 1980) are an indication of the presence of thermal water. The aquifer has been thermally contaminated as a result of artificial recharge of warm waste water through disposal ponds at the Hanford Site (Gephart and others, 1979). The effects of this recharge are well documented as widespread increases in the elevation of the water table and increased concentrations of tritium in the aquifer water. The temperature measurements taken in the zone must be avoided when evaluating the geothermal potential of the area.

The confined aquifer (Figure 2) exists within the Columbia River Basalt Group. The basalt flows are generally dense and impermeable; however, zones of relatively high horizontal permeability exist along flow contacts or interflow zones where vesicularity and flow brecciation have resulted in increased permeabilities and within sedimentary interbeds of the Ellensburg Formation. The interbed zones have hydraulic conductivities that range from 10^{-1} to 10^1 m/d and are considered poor to moderate groundwater producers. Most interflow zones have hydraulic conductivities of approximately 10^{-1} to 10^{-4} m/d; however, the largest hydraulic conductivities for these zones are 10^1 to 10^3 m/d. The interflow zones are moderate to excellent groundwater producers. The thick, columnar basalt sections that separate interflow zones and sedimentary interbeds act as aquitards to vertical groundwater movement and have

GEOLOGIC TIME SCALE			GEOLOGIC CHARACTERISTICS					HYDROGEOLOGY		
ERA	PERIOD	EPOCH	RADIOGENIC DATE YEARS BEFORE PRESENT	STRATIGRAPHIC	BED OR FLOW UNIT	GENERAL LITHOLOGIC CHARACTER	AVERAGE THICKNESS IN FEET	HYDROLOGIC CHARACTER	AQUIFER	
CENOZOIC	QUATERNARY	HOLOCENE	6,600	ALLUVIUM COLLUVIUM & EOLIAN SEDIMENTS		SANDS, SILTS, GRAVELS, & CLAYS MODIFIED BY WIND EROSION	DUNES TO 50	OCUR EVERYWHERE ABOVE THE WATER TABLE.	DRY	
			10,000							
		PLEISTOCENE	12,500	GLACIOFLUVIAL SANDS & GRAVELS (HANFORD FORMATION)	TOUCHET SILTS	FINE-GRAINED FACIES OF THE GLACIOFLUVIAL DEPOSITS. BEDDED IN QUIET WATER		OCUR ABOVE THE WATER TABLE EXCEPT BETWEEN THE HIGH TERRACE PLATEAUS & THE COLUMBIA RIVER. HAS VERY HIGH TRANSMISSIVITY & STORAGE.	OCCASIONALLY AN UNCONFINED AQUIFER OR DRY	
			>12,000		PASCO GRAVELS	PREDOMINANTLY COARSE-GRAINED GRAVELS. COBBLES & SANDS WITH CUT & FILL STRUCTURE	0-400			
			<18,000							
			40,000		PALOUSE SOIL	CALCAREOUS SAND & SILT EOLIAN DEPOSIT MAINLY DERIVED FROM RINGOLD FORMATION	0-80	ABOVE WATER TABLE WHEN PRESENT.	DRY	
	TERTIARY	PLIOCENE	1,000,000	RINGOLD FORMATION	UPPER RINGOLD	LOCALLY CAPPED BY CALICHE. MOSTLY WELL-BEDDED FLUVIAL SILTS & SANDS WITH SOME GRAVELS		SANDS & GRAVEL BEDS HAVE VERY HIGH HYDRAULIC CONDUCTIVITY & STORAGE. SOME BEDS OF SILTY CLAY OR CLAY ARE ESSENTIALLY IMPERMEABLE.	UNCONFINED AQUIFER	
					MIDDLE RINGOLD	SANDS & GRAVELS WELL-SORTED, COMPACT, BUT VARIABLY CEMENTED	0-400		AQUICLUDE	
					LOWER RINGOLD	SILTS & CLAYS WITH INTERBEDDED GRAVELS & SANDS CLAY IS CHARACTERISTICLY BLUE, BUT MAY BE GREEN, BROWN, OR TAN	0-400			
		MIOCENE	4,000,000	COLUMBIA RIVER BASALT GROUP	SADDLE MOUNTAINS	BASALT FLOWS WITH INTERFLOW ZONES. SEVERAL SEDIMENTARY INTERBEDS OF ELLENSBURG FORMATION ARE PRESENT	900	FLOWS ARE DENSE WITH LOW- HYDRAULIC CONDUCTIVITY.. INTERFLOWS & INTERBEDS HAVE HIGHER HYDRAULIC CONDUCTIVITY AND TRANSMISSIVITY.	CONFINED AQUIFERS	
			5,500,000		WANAPUM	BASALT FLOWS WITH INTERFLOW ZONES. FEW INTERBEDS OF ELLENSBURG FORMATION ARE PRESENT	1,000			
			11,000,000 15,000,000		GRANDE RONDE	BASALT FLOWS WITH INTERFLOW ZONES. INTERBEDS OF ELLENSBURG FORMATION ARE INFREQUENT AND VERY THIN WHEN PRESENT.	3,000			

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FIGURE 2. Hydrogeologic Column for the Rocks Beneath the Pasco Basin
(from Gephart and others, 1979).

estimated vertical conductivities ranging from 10^{-4} to 10^{-7} m/d. Structural complexity also influences permeability and folds may act as barriers to groundwater movement, or joints and faults may greatly increase vertical permeability.

According to the most recently published conceptual model of the Pasco Basin confined aquifer system (Gephart and others, 1979), groundwater movement in the confined aquifer is from recharge areas surrounding the basin toward discharge areas downstream from the Hanford Site along the Columbia River (Figure 1). Recharge enters the system where precipitation and stream runoff infiltrate into the basalts and associated interbeds exposed around the basin margins. Groundwater movement is assumed to be downward along formation boundaries, toward the center of the basin and along the Columbia River toward downstream discharge areas. Locally, this movement is modified by folds, tectonic fractures associated with major anticlines, and distribution of hydraulic head within the aquifer.

Characteristics of the confined aquifer system are of major significance to assessment of the geothermal resource potential of the Pasco Basin for several reasons. First, all meaningful measurements of the subsurface thermal regime are made within this system. Second, the vertical circulation component of potential geothermal systems must occur within the confined system. Third, if reservoirs of geothermally heated water exist within the confined aquifer, then the hydraulic properties of the reservoirs would be determined by the characteristics of the aquifer.

THERMAL SETTING

The thermal data used to evaluate the Pasco Basin and vicinity were obtained from Korosec and Schuster (1980) and Rockwell Hanford Operations (Rockwell) data, and were selected to incorporate only the most reliable data available. Groundwater flow and artificially induced recharge appear to substantially influence many reported measurements, and insofar as possible, these measurements were avoided.

Heat flow (Figure 3) and thermal gradient (Figure 4) data within the study area range from 47 to 64 mW/m² and 35° to 45°C/km, respectively. Heat flow values are generally toward the low end of the 55 to 70 mW/m² range reported by Korosec and Schuster (1980) as normal. Most measured thermal gradients are also within the normal range of 35° to 45°C/km. Gradient data calculated using bottom hole temperatures tend to vary over a wider range, but most values are between 33° to 47°C/km. Exceptions to the normal conditions noted above were reported for three

● HEAT FLOW VALUES IN mW/m²

FIGURE 3. Heat Flow in the Pasco Basin (from Blackwell, 1980).

EXPLANATION

- ROCKWELL DATA
- BLACKWELL (1980)
- ▲ KROSEC AND SCHUSTER (1980)
(MEASURED GRADIENT/CALCULATED GRADIENT)

ALL VALUES IN °C/KM

FIGURE 4. Temperature Gradient Measurements for the Pasco Basin and Vicinity.

holes within the Hanford Site with gradients of 490 to 500°C/km, and a group of five wells northeast of the basin (near the town of Bruce) where both measured and calculated gradients are consistently above normal (400 to 900°C/km). Further investigation of the causes of these elevated gradients is warranted.

Temperature measurements in deep holes are an indication that the thermal gradients remain constant or decrease slightly with depth. A temperature on the order of 100°C has been measured at a depth of 2,980 m in hole RSH-1 near the Hanford Site. Temperatures of this magnitude are expected at depth, but if water from a depth of 3 km could be rapidly transported back toward the surface, a potential for low-temperature geothermal systems may exist within the basin.

There is no indication that a localized heat source is present within the Pasco Basin or that the region is characterized by anomalously high heat flow. For comparison, regional heat flow values in areas of high geothermal resource potential such as the Oregon Cascades, southern Idaho, the Imperial Valley, and the Rio Grande Rift average over 100 mW/m² and much of western United States ranges from 60 to 90 mW/m² (Blackwell, 1981, and Sass and Lachenbruch, 1979). In the presence of a localized heat source, heat flow values and gradients might be several times greater and vary significantly over short distances. In the Pasco Basin the available thermal data are limited, but no such variations are apparent.

DISCUSSION

The potential for occurrence of high- and intermediate-temperature geothermal systems in the Pasco Basin is judged to be insignificant because neither localized heat sources nor high heat flow from the mantle are available as potential heat sources. Both geologic and thermal evidence support this conclusion. However, there is potential for low-temperature hydrothermal convection systems within the basin.

Deep drilling in the Pasco Basin has confirmed the presence of fluid temperatures of approximately 100°C at depths approaching 3 km. Water at these depths entered the confined aquifer system where older basalts and interbeds are exposed around the edges of the basin. Circulation of the fluid to depth is believed to occur along interflow and interbed zones in the basalt. Water is heated along the flow path in the normal heat flow of the region. At depth, the water reaches ambient lithospheric temperatures and is not anomalous. However, rapid vertical migration of the geothermally heated water toward the surface and into near-surface aquifers could result in quantities of the thermal water being stored at reasonable drilling depths.

The zones of high vertical permeability required for the deep circulation model described above are an important, and unquantified, factor in the geothermal resource potential of the Pasco Basin. The structures

most likely to provide the necessary conduits for deep thermal waters are faults associated with the northwest striking folds shown in Figure 1. If zones of vertical permeability are associated with these faults, and if the faults extend to depths sufficient to intersect the deep thermal water, then the potential for vertical migration exists. However, vertical migration could only occur where hydraulic head decreases upward along such a fault zone.

Assuming an initial temperature of approximately 100°C, the temperature of the potential geothermal systems described above are not likely to be greater than 40°C. This estimate is based on the assumption that cooling and cold water mixing will occur along the flow path. At the present time there have been no known discoveries of systems like those described. However, the model presented above defines the structurally complex, folded areas as the zones of greatest potential.

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