GEOPHYSICAL EXPLORATION FOR HOT DRY ROCK IN THE MIDCONTINENT

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The midcontinent of North America is commonly characterized as a stable cratonic area which has undergone only slow, broad vertical movements over the past several hundreds of millions of years. This is an unfertile area for hot dry rock (HDR) exploration, but recent geophysical and geological studies testify to the contemporary tectonism of limited areas within the midcontinent and the possibility of localized thermal anomalies, which may serve as sites for HDR exploration. HDR as an energy resource in the midcontinent is particularly appealing because of the high population density and the increasing demand on conventional energy sources.

Surface manifestations of potential midcontinent HDR sites are negligible, therefore geophysical techniques supplemented by deep drilling are necessary for HDR exploration. Within the past few years, gravity and magnetic data covering broad areas of the midcontinent have been observed, compiled, and in some cases filtered to enhance particular attributes of the anomaly fields. These maps and data are proving useful in mapping tectonic/lithologic regimes, which serve as guides to localize more detailed geophysical/geological studies. In addition, increasing availability of the results of deep drilling are providing new insight into the structure, geologic history, and geophysical parameters of the midcontinent - information which is critical to effective HDR exploration.

Five generalized models of exploration targets for midcontinent HDR sites have been identified: 1) radiogenic heat sources, 2) conductivity-enhanced normal geothermal gradients, 3) residual magmatic heat, 4) sub-upper crustal sources, and 5) hydrothermal-generated thermal gradients. These models are illustrated schematically in Fig. A-13.

Radiogenic heat sources localized in intrusives of sufficient volume and concentration of heat-producing radioisotopes are potentially viable HDR sites particularly where they are covered by a thermally insulating sedimentary rock blanket. Potential radiogenic heat sources include both felsic (e.g., Wolf River Batholith) and alkalic (e.g., Coldwell Complex) intrusives. Felsic intrusives are commonly characterized by gravity minima of the order of a few tens of milligals and negative magnetic anomalies. A typical example is the 1500 m.y. old granite pluton drilled over a vertical range of nearly 1 km in northern Illinois. Analyses of the core indicate an abnormally high U and Th content and a mean heat generation of roughly 40×10^{-13} cal/cm^3 sec. The three-dimensional configuration of this pluton has been determined by analysis of the associated gravity minimum and more poorly defined magnetic minimum. In contrast, recent studies in the midcontinent show that other felsic plutons are associated with relatively high magnetite contents resulting in strong localized magnetic anomalies. Available evidence suggests that the gravity signature of these high-magnetite felsic plutons is nil or slightly positive. Felsic plutons in the midcontinent are associated with Precambrian orogenic regimes (e.g., Penokean Foldbelt) as well as anorogenic areas (e.g., Central Province). Alkalic intrusives, which are marked by intense positive gravity and magnetic anomalies, occur with Proterozoic rifts (e.g., Coldwell Complex) and with major structurally disturbed zones (e.g., 38th Parallel Lineament).

An example of a potential radiogenic heat source in the basement of a cratonic basin associated with a gravity minimum has been investigated in the southeastern portion of the Michigan Basin. A residual Bouguer gravity of -25 mgals amplitude has been isolated over a portion of the Basin underlain by Grenville Province basement rocks. The gravity minimum is associated with a

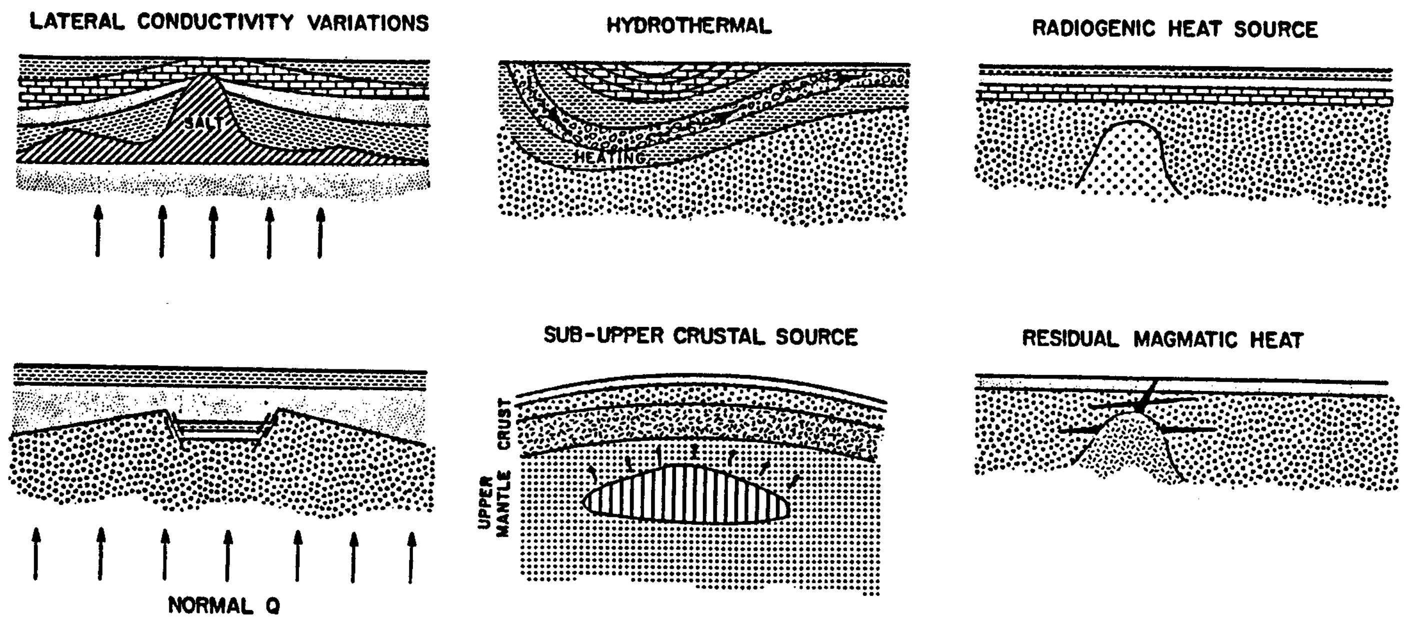

Fig. A-13.

Models of exploration targets for midcontinent HDR sites.

magnetic minimum ringed by a discontinuous positive anomaly. Geologic cross sections of the anomaly area prepared from well logs show that the gravity minimum cannot be due to increased thickness of evaporite deposits and evidence is lacking to explain the minimum with an increased thickness of low-density clastic sedimentary rocks. The thickness of low thermal conductivity shale within the basin over the basement anomaly source is approximately 400 m. The configuration of the hypothesized felsic source of the geophysical anomaly has been determined by modeling as an inverted cone, which is elliptical in horizontal cross section and reaches to a depth of roughly 8 km.

Channelling of heat through higher conductivity rocks can result in locally high geothermal gradients in a regionally normal heat flow field. Rock types that have significantly higher thermal conductivities with respect to the sedimentary rock overburden include evaporites and crystalline basement rocks. Thus salt diapirs (e.g., Gulf Coast Salt Domes), which are characterized by strong negative gravity anomalies, may perturb the local normal thermal gradients as will basement horsts and anticlines (e.g., Howell Anticline) within sedimentary basins. Basement uplifts are commonly, but not necessarily, associated with positive gravity and magnetic anomalies. Buried basement rifts and their related grabens (e.g., Reelfoot Rift) commonly involve marked relief of the basement crystalline rocks with the infilling sedimentary rocks. Thus abnormal thermal gradients caused by "channelling" are possible in the Mississippi Embayment, particularly near the head of the Embayment where geophysical/geological evidence indicate the presence of an ancient rift zone, which is undergoing recent tectonic activity (New Madrid Seismic Zone) as a result of the ambient stress field operating on this ancient zone of weakness. In a similar way, other Middle-to-Late Proterozoic rift zones, which occur extensively throughout the midcontinent, are of potential interest to HDR exploration. The geophysical signatures of these ancient rifts are varied depending upon the degree of crustal disruption and graben development, but generally the crust is thickened and linear trends of positive gravity and magnetic anomalies mark the location of mafic intrusive/extrusive rocks.

Potential residual magmatic heat sources include young (< 1 m.y.) upper crustal intrusions. Relatively small volume, anorogenic, alkalic intrusions are found within the Phanerozoic sedimentary rocks of the midcontinent along the 38th Parallel Lineament and the Gulf Coast region. Calculations indicate that these intrusives cool rapidly and thus would contribute no useful residual heat beyond 1 m.y. However, the youngest of these intrusions, which are manifested in positive gravity and magnetic anomalies, is approximately 70 m.y. Thus, residual magmatic heat is an unlikely source of HDR resources unless very recent intrusions can be located.

Sub-upper crustal sources involve anomalously high, lower crustal or upper mantle temperatures sustained for a sufficient period of time to cause surface thermal anomalies. Mass transport processes within the mantle, which lead to these temperature anomalies may be observed indirectly by the effect they have upon upper mantle and crustal structure and properties. Based upon geological/geophysical evidence, the Mississippi Embayment is the most commonly cited candidate in the midcontinent for relatively recent (Mesozoic) involvement in processes involving mass transport within the mantle. A long-wavelength magnetic minimum over the Embayment may be a result of an upwarp of the Curie Point isotherm suggesting post-Mesozoic activity, but other explanations for the anomaly are plausible and recent analyses place the observed high heat flow in the Embayment under serious question.

Anomalously high local upper crustal temperatures in the midcontinent may be caused by heat transfer through ground-water movements caused by nonthermal induced convection. The prominent thermal anomaly in western Nebraska is believed to have this origin. Water heated in the lower reaches of the Denver Basin is driven upward in permeable horizons into the subsurface of the panhandle of Nebraska. The components which are required for the development of this type of thermal anomaly include structural attributes of sedimentary basins which are amenable to investigation by geophysical methods.

Consideration of the possible models for HDR exploration on sites in the midcontinent shows that geophysical techniques, particularly gravity and magnetic methods on a reconnaissance basis, are useful in delimiting localized areas for more detailed investigation and analysis.