SUMMARY DESCRIPTION OF RESEARCH ACTIVITIES

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The basic goal of the University of Colorado Geothermal Research Program has been to assess, characterize and model the myriad of physical processes occurring in the geothermal environment. While developing an understanding of the fundamental nature of these phenomena we can construct a comprehensive model of the structure of a given geothermal system. Such a result should prove useful in the interpretation of surface geophysical measurements and for the general development of a geothermal field. Our studies spanning the range from heat and mass transfer process in hydrothermal convection anomalies to the possible appearance of dilatancy due to large rates of liquid withdrawal, are carried out by a diverse group of engineers, geophysicists, geologists, seismologists and experts in computation. Much of the effort has been carried out with the cooperation of the geothermal group at Systems, Science and Software, La Jolla, California.

The following summary of activities provides an extremely brief description of the ongoing research programs, their purpose and when appropriate, the results obtained.

Physical Characterization

Black(1) has carried out a subsurface study of the Mesa anomaly in the Imperial Valley. His studies have shown that:

(1) There is a cap of low vertical permeability composed of a large fraction of clay-like material.

(2) Below the cap are relatively compacted, sandy strata with significant permeability.

(3) Fracturing in deeper rock layers, presumably associated with seismic activity increases vertical permeability.

(4) Intersecting fault zones near two wells have produced a chimney of particularly high vertical permeability. Substantial upwelling of hot water from depth occurs here as well as long the linear fault zone to the southeast.

(5) The rising hot water spreads laterally, mostly to the southeast as the fault zone intersects relatively permeable horizontal aquifers.

(6) Reduced salinity of water at depth compared to that in upper levels (0-800m) implies greater circulation and less evaporites in the deeper zone.

Rinehart[2] has considered the presence of faulting in geothermal areas. He has concluded that:

(A) Almost all productive geothermal areas are associated with faulting. Many of these are patterns of ring fractures associated with calderas while others are linear features associated with rift zones.

(B) Fault zones act as conduits for the flow of heated fluid from depth. They can affect the supply of surface water to the system at depth.

Mechanical Models

Rinehart[3] has suggested a possible physical mechanism for the observed cyclic variation in flow rates and water table level associated with saturated porous media subjected to temporal alterations in in-situ stress due to tectonic and tidal forces. Making reasonable assumptions, he argues that a solid block supported by a saturated porous material could move as much as several centimeters due to periodic mechanical loading. This implies that the effective permeability of racture reservoirs can be altered substantially.

Archambeau[a] is currently developing nonl near models of suibsidence due to irreversible pore collapse. included is he possibility *of* structural rock failure (induced seismicity) due to d latancy resulting from high levels of effective stress as pore pressure is reduced.

Heat and Mass Transfer

Kassoy and Zebib[4] examined the effect of a realistic viscosity variation on the onset of convection in a horizontal porous slab. Critical Rayleigh numbers are drastically reduced w/r to the constant property calculation. The roll patterns display relatively high velocities and lairge temperature gradients at depth unlike the symmetric classical profiles.

Kassoy[5] has considered convective flow in a narrow vertical saturated porous slot as a model of mass transfer in a fault zone. The mass flow rates, resulting partly from convection due to pressure head and partly from natural convection, are of the magnitude 10^6 kg/day over an area 0.5 km^2 when the permeability is $10^{-9} cm^2$.

Garg et al.[6] have computed the flow pattern and temperature variation in a horizontal aquifer when fluid is introduced from an intersecting vertical fault zone in which there is hot fluid rising from depth. The solution shows the development of a confined natural convection cell in the aquifer. Hence, in the model considered lateral spillage from the fault zone does not result in simple through flow in the aquifer.

Kassoy and Zebib[b] have extended their work to three-dimensional containers more representative of geothermal areas in highly fractured rock of volcanic origin. The results also portray linear convection patterns in narrow vertical fault zones, and may be used to explain the presence of periodically spaced hot springs along linear fault zones. Kassoy[c] has shown that natural convection instabilities can enhance the vertical fault zone flow described above.

Kassoy [d] has extended his analysis to include lateral spillage into intersecting horizontal aquifers. The pressure and temperature distributions are reminiscent of those found in the Mesa geothermal anomaly. Linear instability at critical a Rayleigh number leads to superimposed closed rolls. These might be used to explain the pair of hot spots at the Mesa anomaly.

Nayfeh[7] et al. have examined two-temperature models of flow in porous media. They conclude that for most geothermal applications the fluid and solid are in local thermal equilibrium.

There has been a major effort to develop useful describing equations for thermally active deformable porous media containing two phase fluids with concentration gradients. This work is summarized in Refs. 6 and 8.

REFERENCES

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7. A. H. Nayfeh et al. - "Heat Exchange in a Fluid Percolating Through Porous Media," Proc. So~.Eng. Sci. Meeting, Austin, Texas, Oct. 1975.

8. T. R. Blake, S. K. Garg, "On the Species Transport Equation for Flow in Porous Media," submitted to Water Resources Research (1975).

*CUMER refers to Mechanical Engineering Report, University of Colorado.

(a) - (d) - Ongoing research activities.