U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: GEOTHERMAL SYSTEMS AS ANALOGUES TO YUCCA MOUNTAIN: EMPHASIS ON HYDROLOGICAL ASPECTS

PRESENTER: GUDMUNDUR S. BODVARSSON

PRESENTER'S TITLE AND ORGANIZATION: STAFF SCIENTIST
LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA

PRESENTER'S TELEPHONE NUMBER: (510) 486-4789

DENVER, COLORADO
JULY 13-14, 1993

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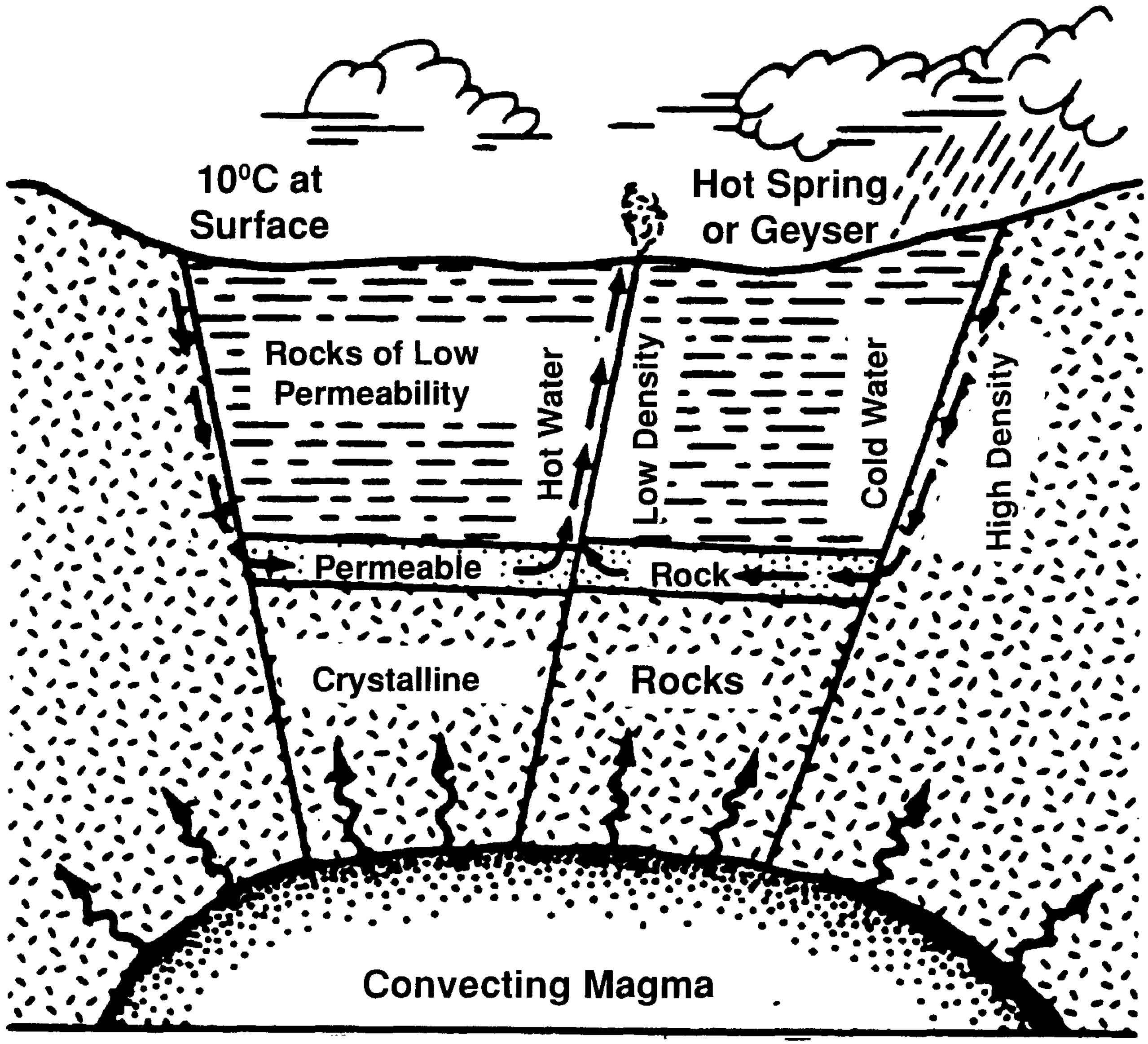
Outline

- General information about geothermal systems
- Classifications and conceptual models of geothermal systems
- Hydrological and thermal aspects of geothermal systems
- Vapor-dominated systems as analogue to Yucca Mountain (with repository)
- Heat transfer in lava flows
- Implications for Yucca Mountain
- Possible geothermal analogue studies

Conceptual Reservoir Model



(After White, 1973)

DCGSAYB2.125.NWTRB/7-13/14-93

Extended-Dry Repository Concept: Issues

- *Exciting* concept (if valid) as it isolates waste from free-flowing water
- Concept *does not* seem very sensitive to some hydrological parameters
- Concept is an *unproven* hypothesis
- Concept is based on *model calculations* without significant "history matching"

Extended-Dry Repository Concept: Possible Failure Modes

- Water flow in fractures ➤ heat pipe
- Fracture/fault-flow from condensation zone through "cold spots" near canisters to water table
- Environmental issues become significant (e.g. high, near-surface temperature; gas outflow, with contaminants; water-level changes; and, temperature contamination in saturated zone)
- Incomplete dry-out due to vapor-pressure lowering effects (adsorption, capillarity, salinity effects)
- Hydrothermal eruption!

Classifications of Geothermal Systems

- **Temperature classification**
  - Low temperature (<100 °C)
  - Medium temperature (100-200 °C)
  - High temperature (>200 °C)

- **Phase classification**
  - Single-phase liquid water
  - Two-phase liquid-dominated (hydrostatic)
  - Two-phase vapor-dominated (vaporstatic)

- **Flow classification**
  - Porous medium
  - Single-fault medium
  - Fractured-rock medium

Vapor-Dominated Systems as Analogues to Yucca Mountain (with Repository)

- Fractured-porous medium with large faults
- Small fracture spacing—large fracture permeabilities (~Darcy)
- Small matrix permeability (~mD)
- Strong capillary pressure effects
- Fracture pressures gas-static
- Water stored in matrix blocks
- Heat source

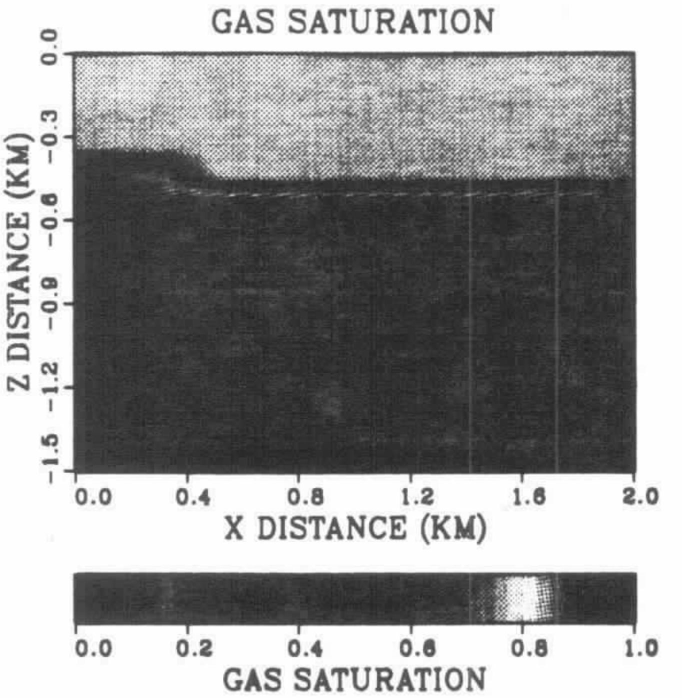
Heat Transfer Mechanisms

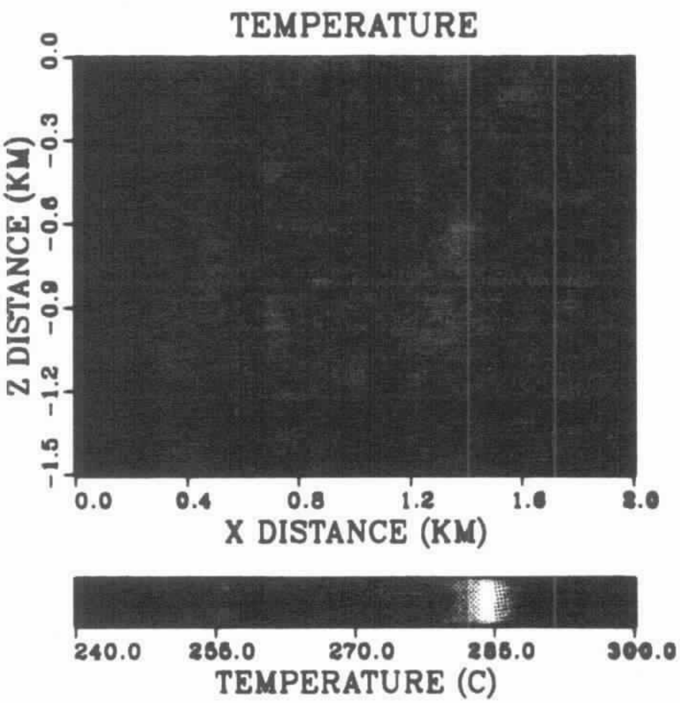
- Conduction
- Convection
- Heat pipes
  - Vapor-dominated
  - Liquid-dominated

Dominant Heat-Transfer Mechanisms

- Single-Phase Systems ➤ Convection
- Two-Phase Systems ➤ Heat Pipes
- Hot-Deep Zones ➤ Conduction

S_{gi} = 25 %, K = 0.1 Darcy, P_c = 0





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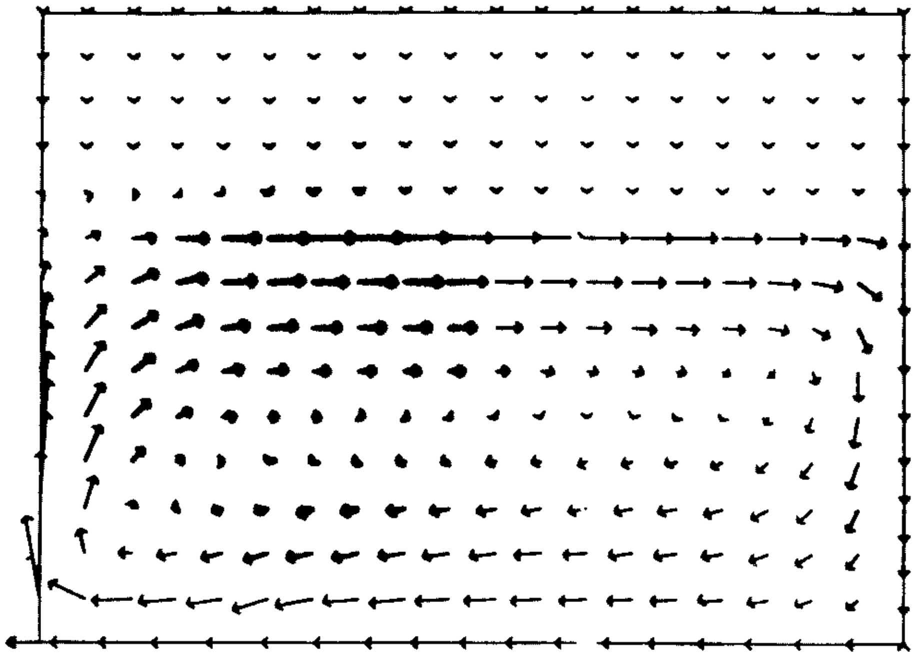
S_{gi} = 25 %, K = 0.1 Darcy, P_c = 0



S_{gi} = 50 %, K = 0.1 Darcy, P_c = 0, $P_{co}2$=1 Bar

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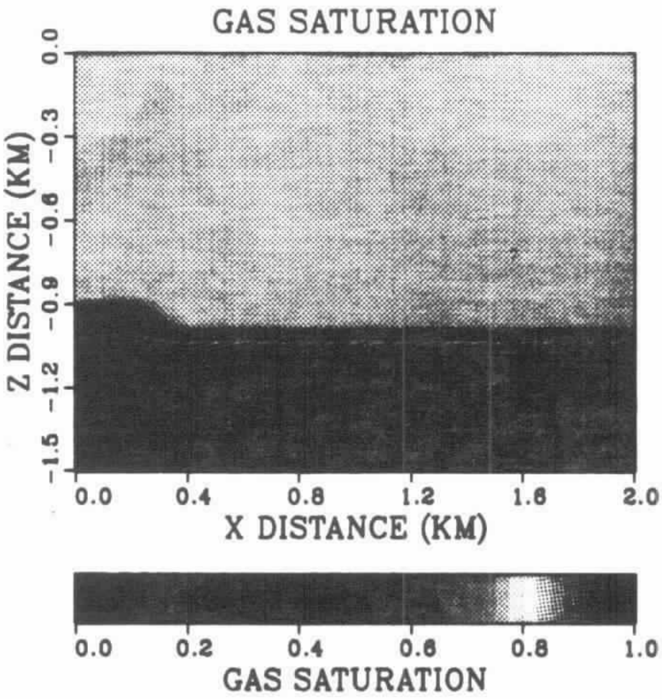

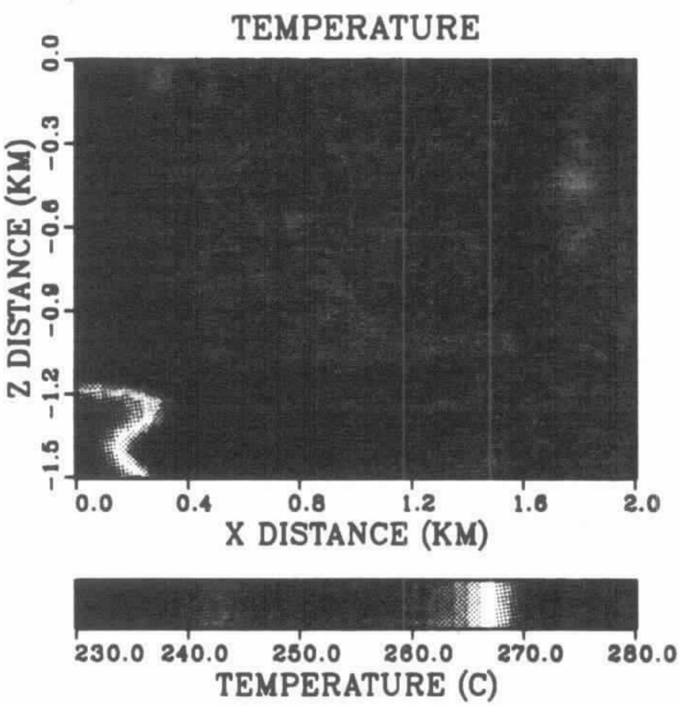

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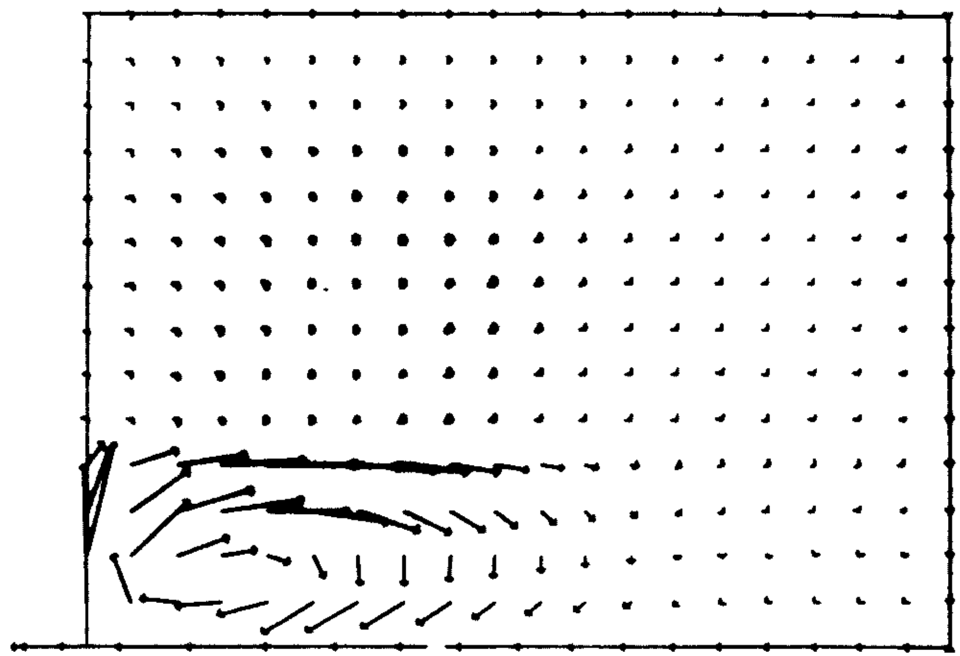
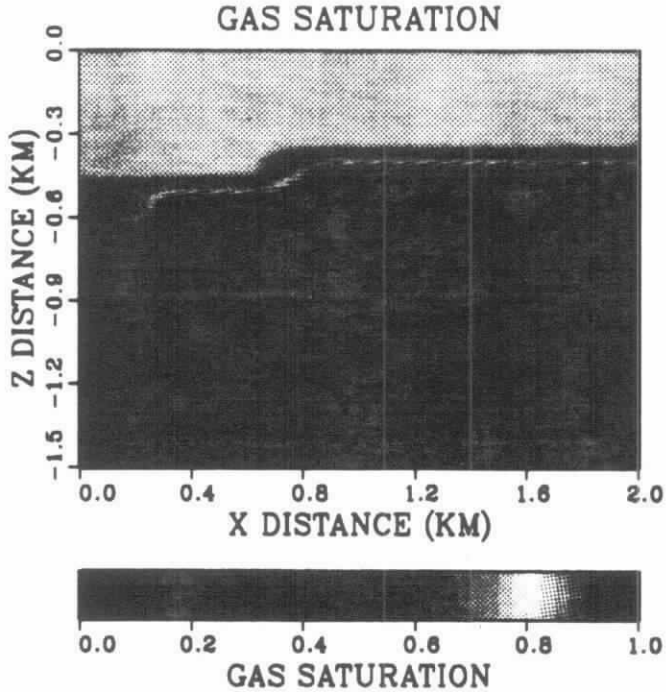
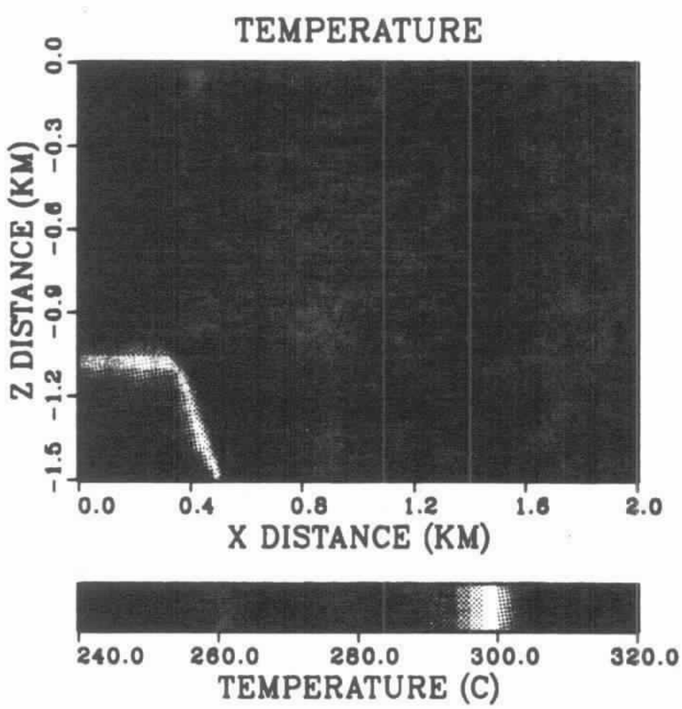
S_{gi} = 50 %, K = 0.1 Darcy, P_c = 0



S_{gi} = 25 %, K = 0.001 Darcy, P_c = 0





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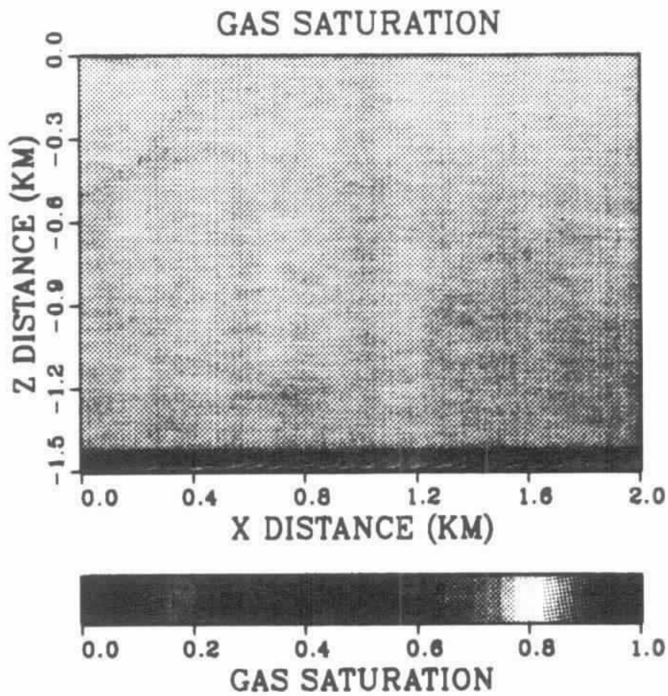
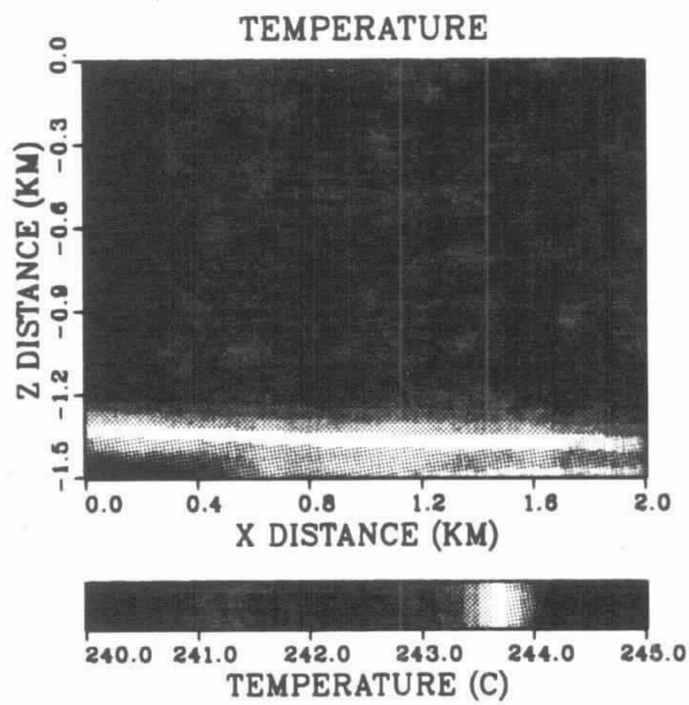
S_{gi} = 70 %, K = 0.1 Darcy, P_c = 0





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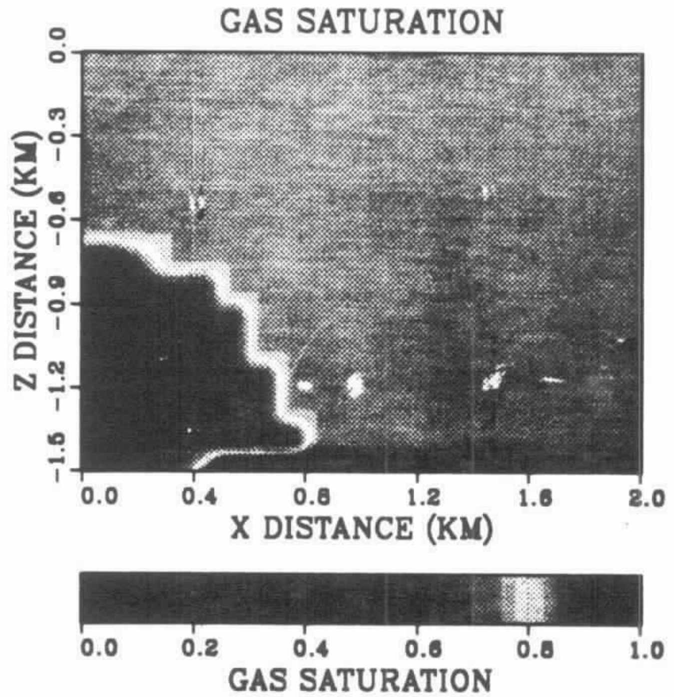
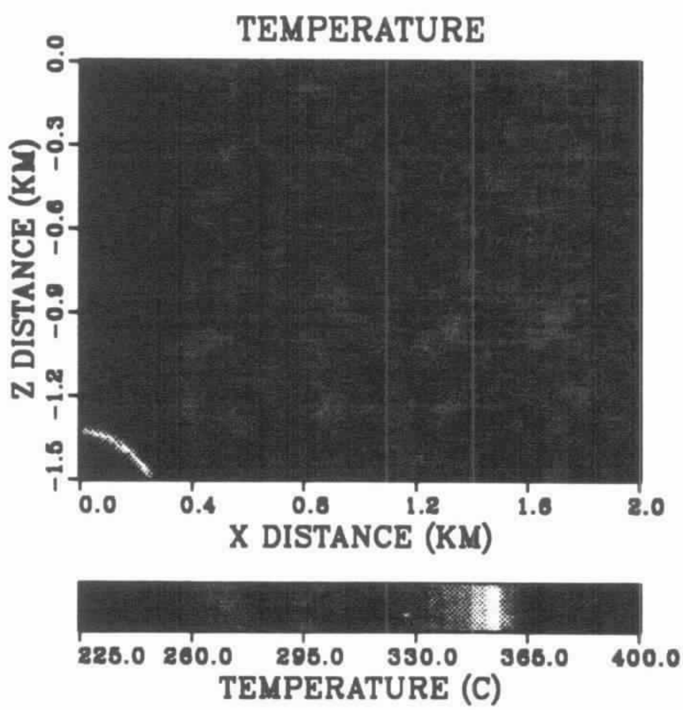
S_{gi} = 75 %, K = 0.1 Darcy, P_c = 0





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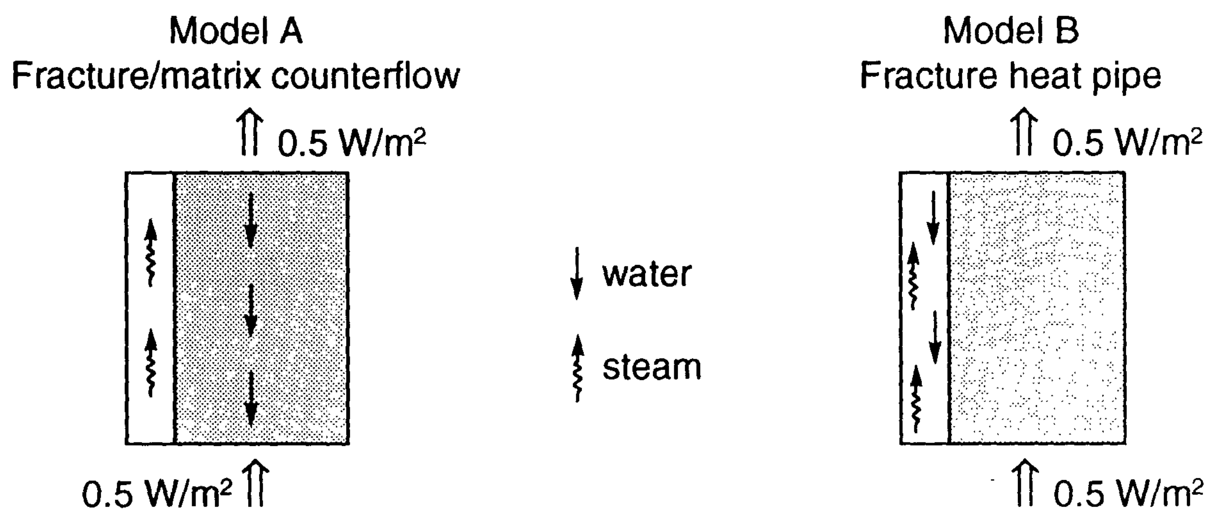
Heat Pipes in Vapor-Dominated Systems



Heat flow per unit area $Q_h = q_m \bullet L = \frac{k}{\mu} \rho \frac{\Delta P}{\Delta z} \bullet L$

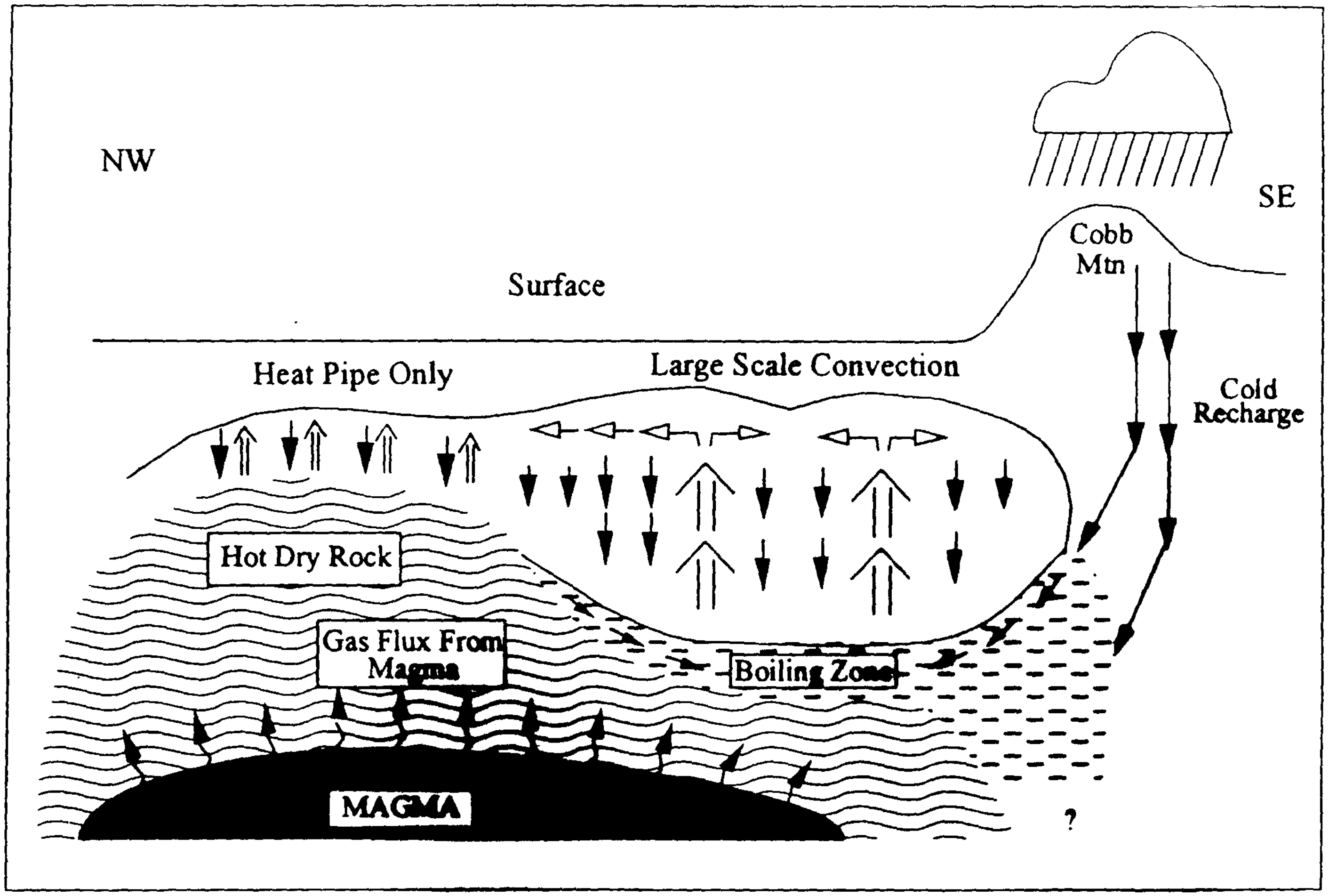
$$\frac{\Delta P}{\Delta z} = \frac{Q_h \mu}{k \rho L}$$

Model A: $\frac{\Delta P}{\Delta z} = \frac{0.5 \bullet 10^{-4}}{10^{-18} \bullet 10^{3} \bullet 2 \bullet 10^{6}} = .25 \bullet 10^{5}\ \mathrm{pa/m}$

$\Rightarrow$ heat pipe must be present in the fractures.

Geothermal Analogue Studies

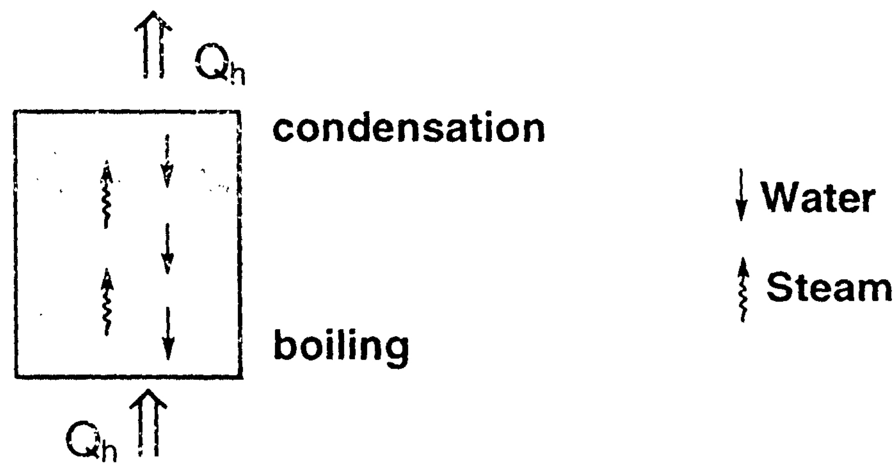
- May be the only way to determine the likely heat-transfer modes and thermal regime at Yucca Mountain
- May help to better understand two-phase flow in fractures and give better understanding of conditions under which heat-pipes develop
- May help to understand the role of fracture fillings, of the fluid chemistry, and of the matrix blocks on mass and heat flow
- Propose to drill corehole at the geysers that penetrates both the typical reservoir and the underlying "hot, dry" zone


NW
SE
Surface
Cobb
Mtn
Heat Pipe Only
Large Scale Convection
Cold
Recharge
Hot Dry Rock
Gas Flux From
Magma
Boiling Zone
MAGMA
?

Conclusions

- Heat pipes are the "preferred" heat transfer mechanism in two-phase geothermal systems
- Conduction-dominated zones may be present in deep-hot vapor-saturated systems
- Heat pipes develop in "preferential" fracture/fault zones that are spaced on the order of 100 m apart
- Heater tests are not likely to fully resolve the issue of likely thermal regimes at Yucca Mountain
- Geothermal analogue studies of vapor-dominated reservoirs are *essential* for reliable predictions of future thermal regimes at Yucca Mountain

Heat-pipe

- 

- **Most efficient heat transfer mechanism (smallest temperature difference)**

- **Can be either vapor- or liquid-dominated (pressure gradient vapor- or hydro-static**

Implications for Thermal Loading at Yucca Mountain

- Geothermal experience suggests that heat pipes will develop in fractures at Yucca Mountain, hence, temperatures may remain near 100°C.
- Geothermal experience suggests that if total dry-out takes place hydrothermal eruptions *may conceivably* occur.

Vapor-Dominated Heat Pipes at The Geysers

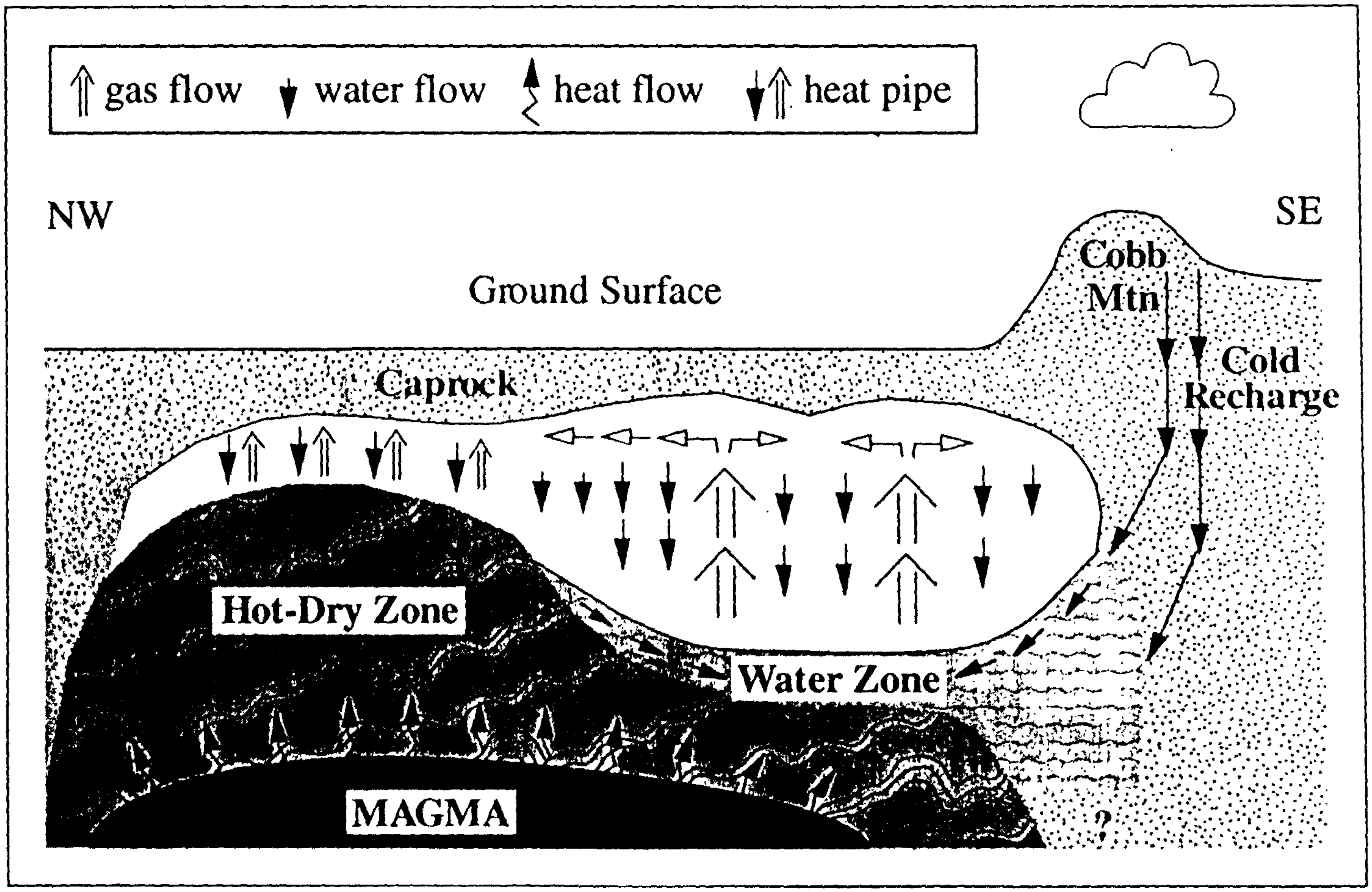
- Indirect data suggest that the heat transfer controlling heat pipes are spaced some 100 m apart including
  - major steam entries encountered during drilling
  - effective fracture spacing inferred from history matching with 30 years of reservoir performance data

Hydrothermal Eruptions

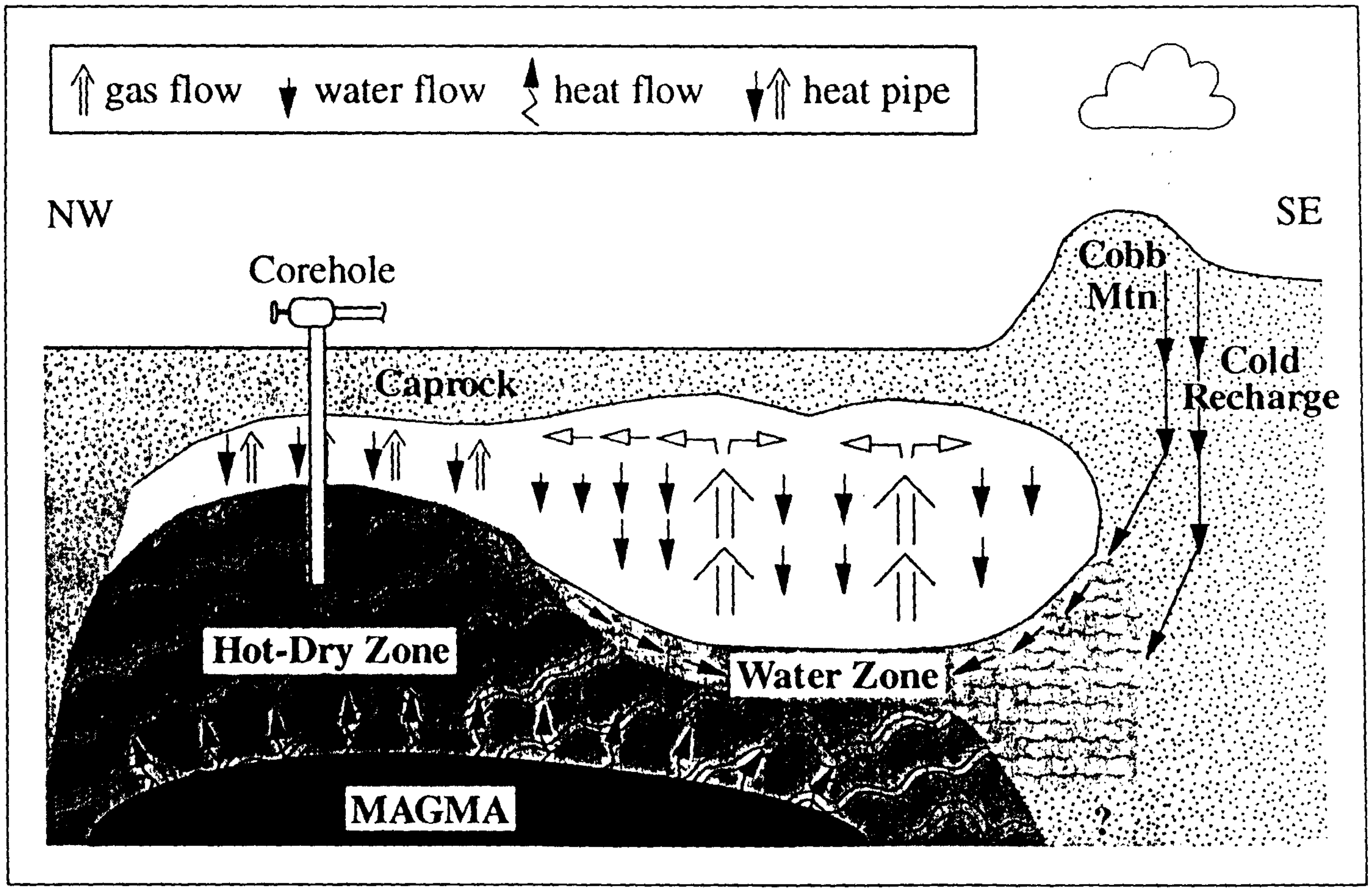
- "Typical features of the Taupo Volcanic Zone high-temperature geothermal fields"
- "In the undisturbed systems, major deep-seated eruptions, originating as deep as 400 meters below ground surface, can be expected every few thousand years, while small shallow focus events occur years apart"
- "These large magnitude eruptions produced vents from 50 to 250 meters in diameter and deposits that cover 5 to 10 km^2."
- "... as hydrothermal eruptions are characteristic of high temperature fields, their destructive potential should be considered in any development proposal

Bixley and Browne (1988)

Conceptual Model of The Geysers



Proposed Corehole at The Geysers



Lava Cooling at Westman Islands