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

NUCLEAR WASTE TECHNICAL REVIEW BOARD
FULL BOARD MEETING

SUBJECT: **EXPERIENCE IN NUMERICAL MODELING OF GEOTHERMAL SYSTEMS**

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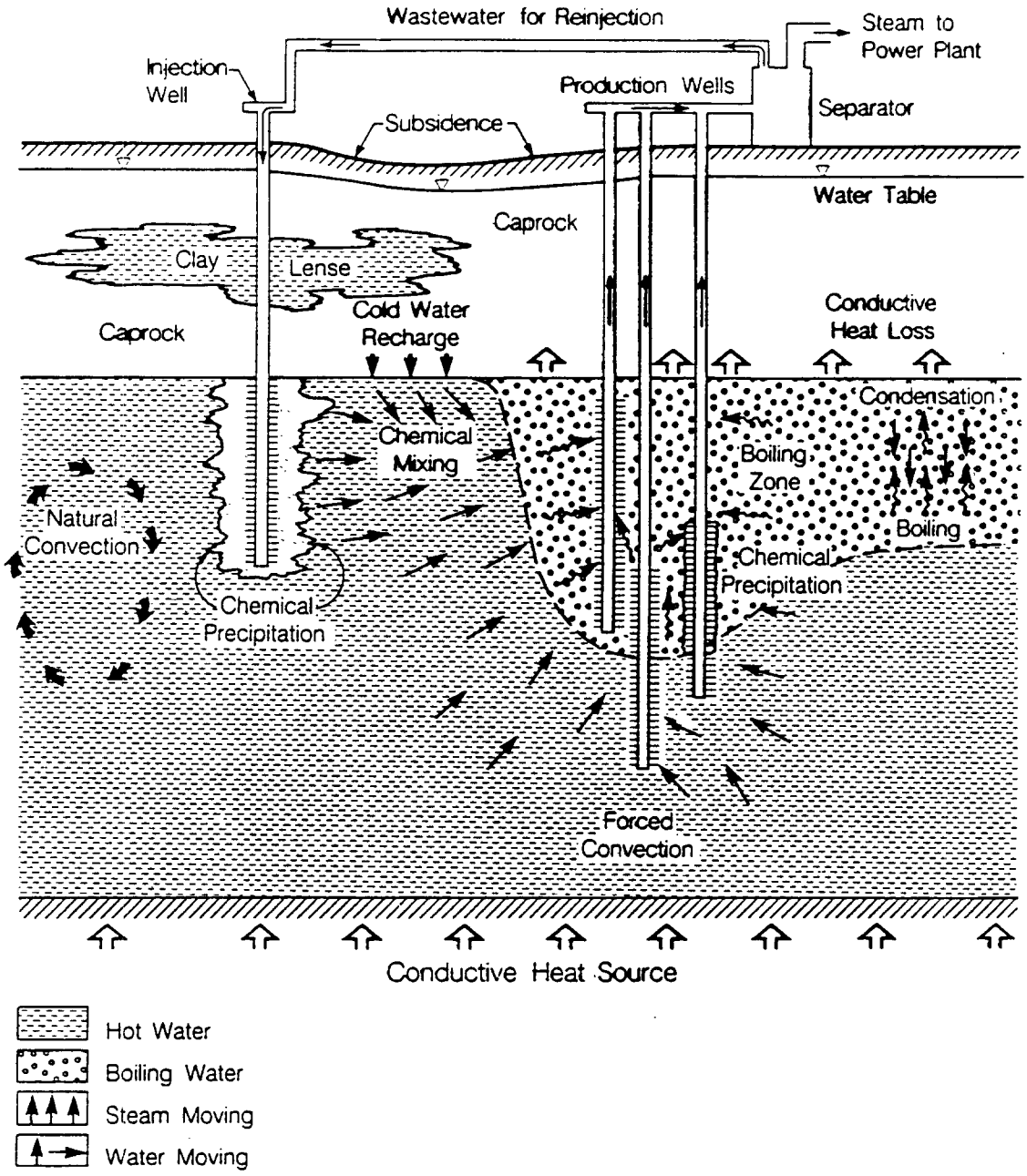
Outline

- Major objectives in modeling of geothermal systems
- General approach in the modeling of geothermal systems
- Available data/history matching
- Major data deficiencies
- Uncertainties and limitations of numerical models
- Olkaria, Kenya, example
- Implications for modeling of Yucca Mountain

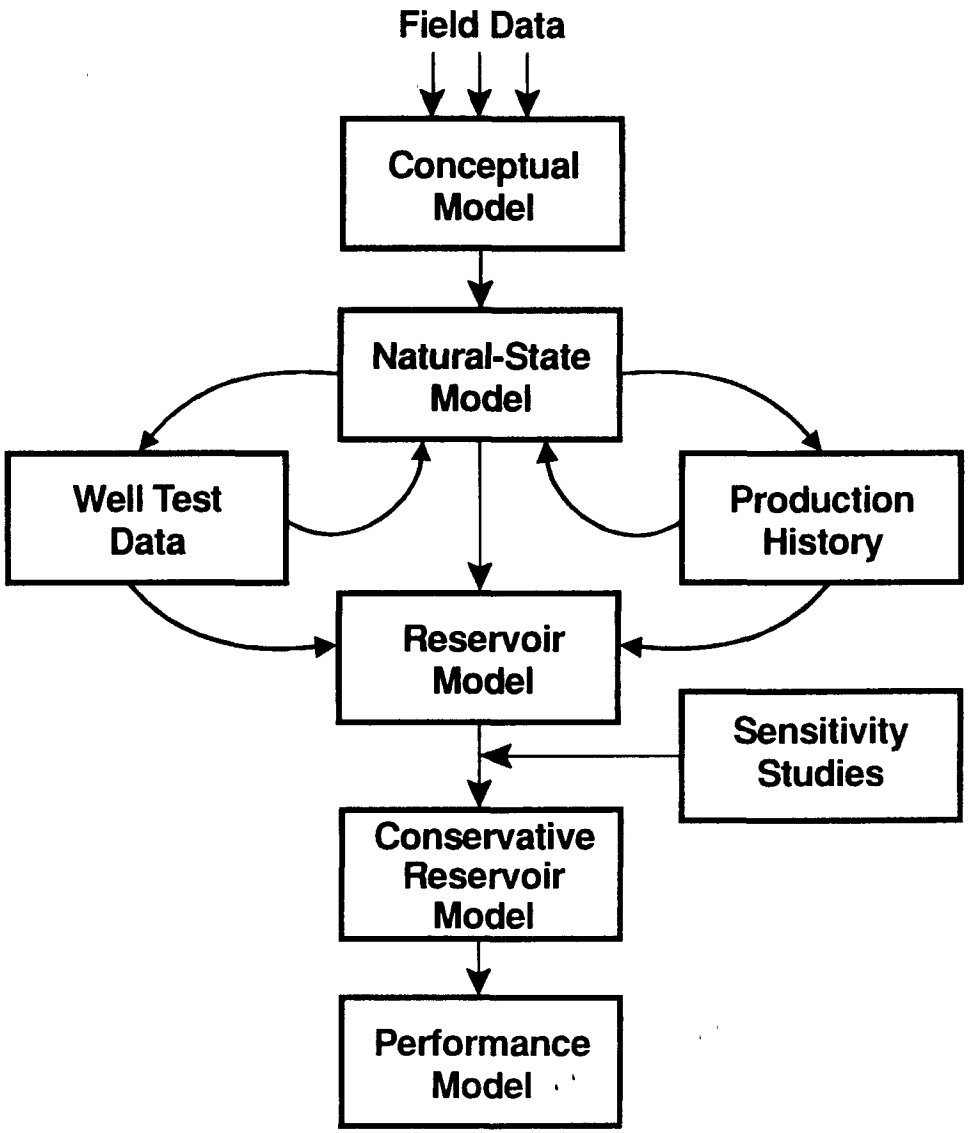
Major Objectives in Modeling Geothermal Systems

- To assess the generating capacity of the system
  - How large a power plant
- To guide in the development of the field
  - Where to drill production wells
  - Where to inject the waste-water
- To predict the future power generation
  - For input into economic forecast models

Schematic of Different Physical Processes Occuring in Geothermal Systems



Reservoir Evaluation General Approach



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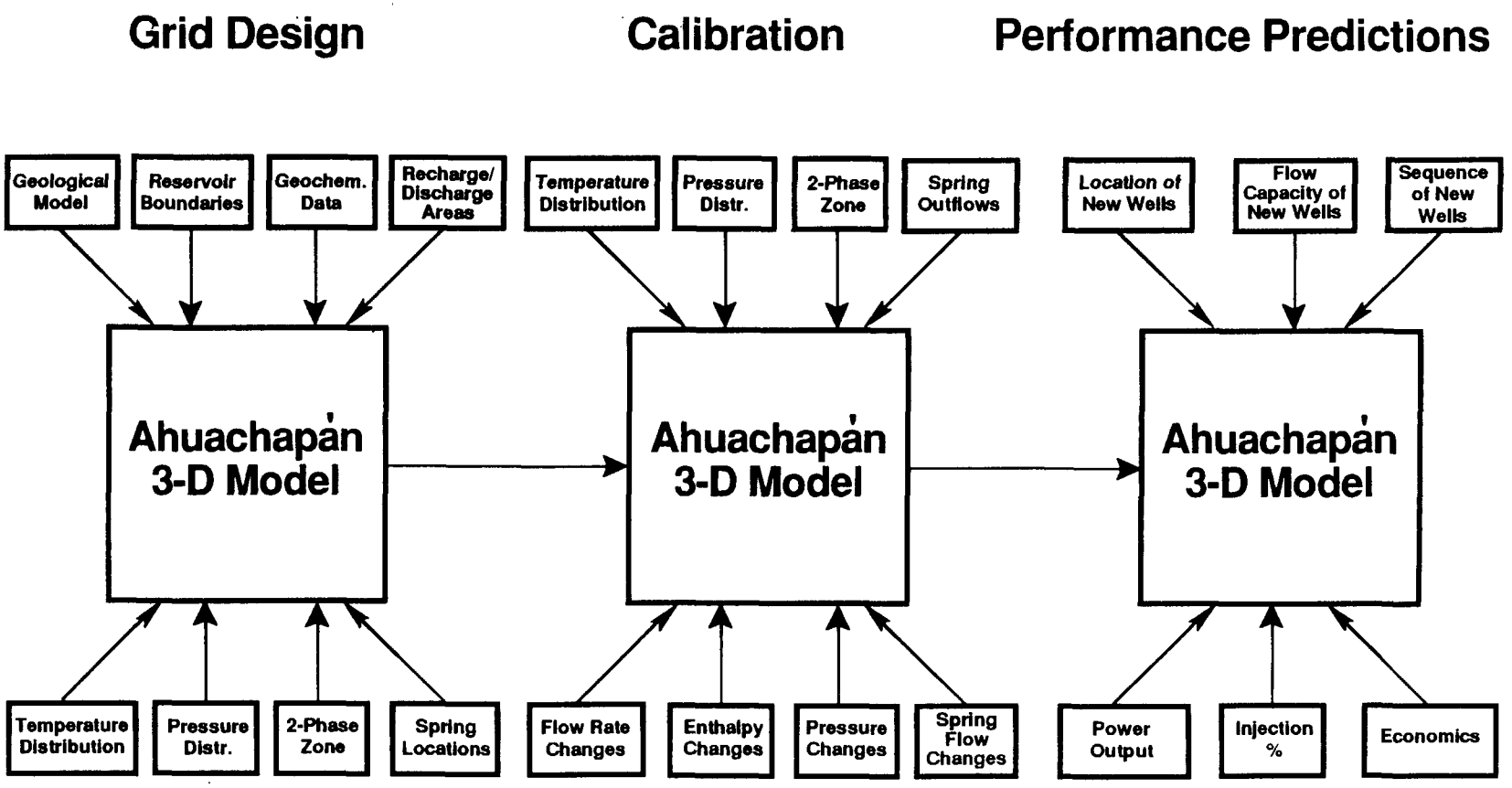
Ahuachapán Model Development



Most Important "Available" Data

- Temperature and pressure distributions in 3D
- Horizontal transmissivity distribution
- Porosities and permeabilities of cores (matrix properties)
- Flow rate, enthalpy, and chemistry histories of production wells
- Injection rates and temperatures
- Reservoir pressure decline
- Repeat gravity surveys

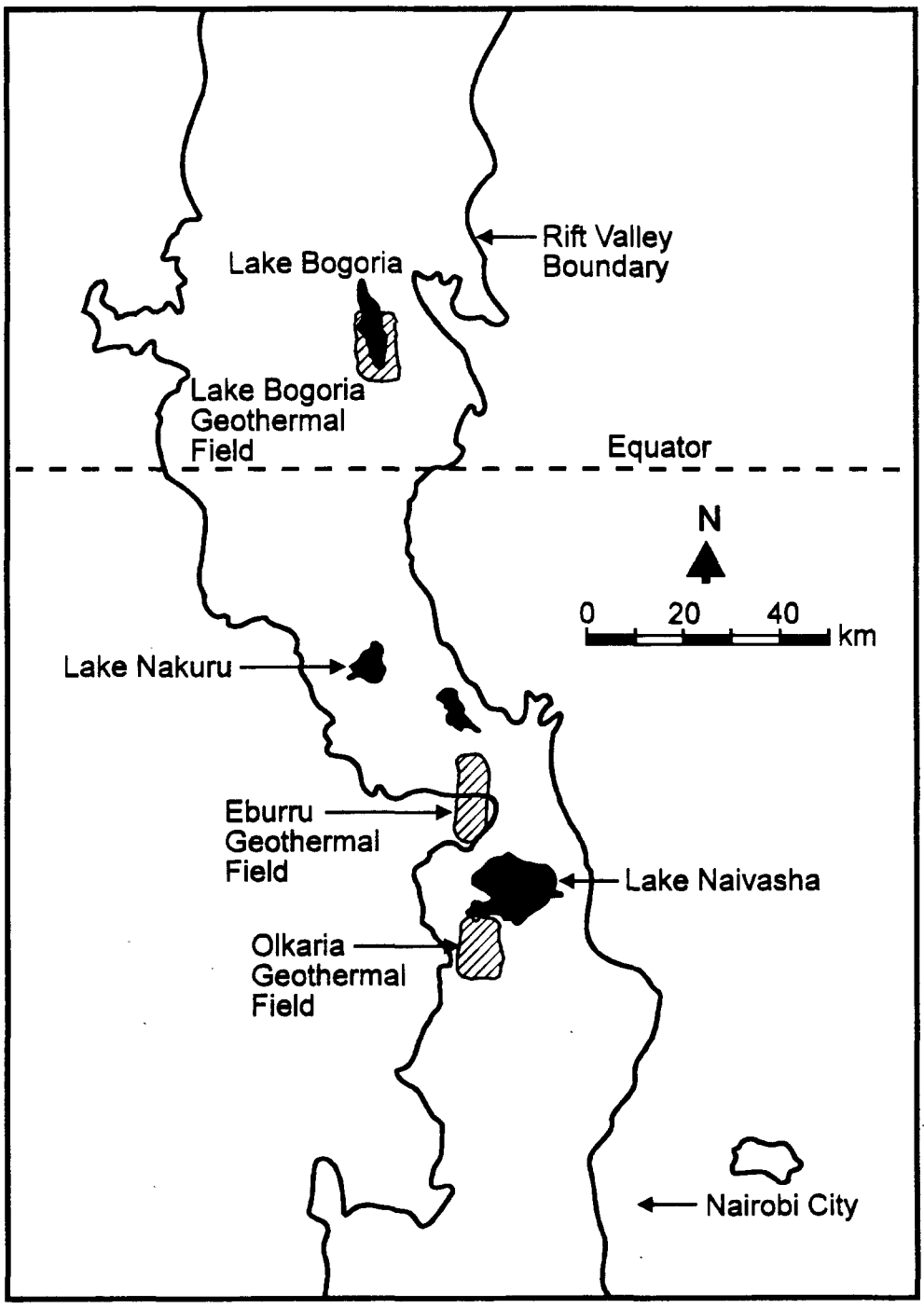
Most Important "Missing" Data

- Reservoir thickness
- In-place liquid saturation (vapor-dominated system)
- Vertical transmissivities
- Relative permeability and capillary pressure curves

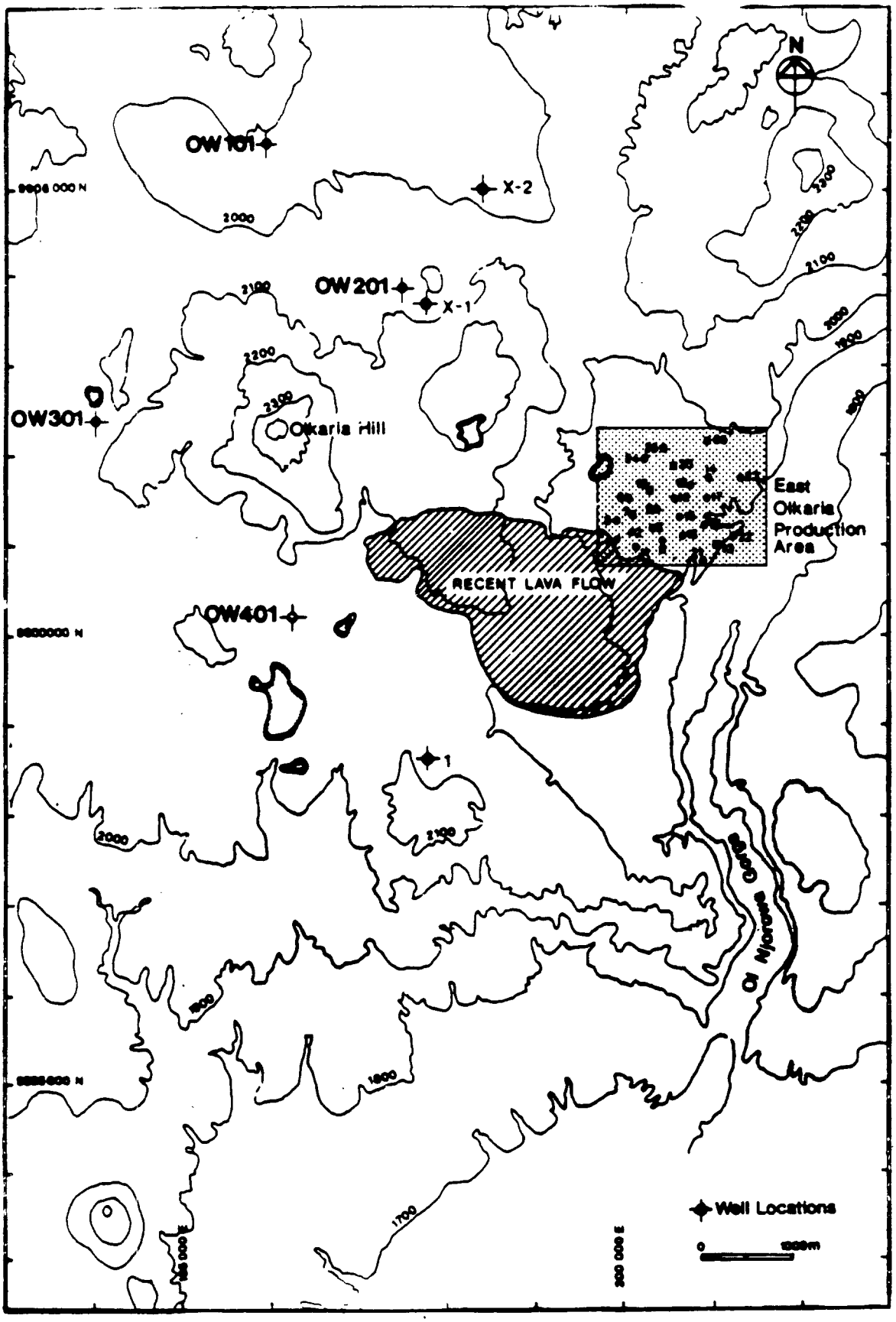
History Matching: Iterative Matching of Natural-State and Exploitation Data

- Temperature and pressure distribution (natural state)
- Horizontal transmissivity distributions
- Exploitation histories of production wells
  - Flow-rate histories
  - Enthalpy histories
  - Chemical concentration histories (non-condensible gases, chlorides, etc.)
- Pressure decline at observation wells
- Repeat gravity surveys (development of two-phase zones)

Location of the Olkaria Geothermal Field in the Rift Valley



Olkaria Geothermal Field



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Uncertainties and Limitations of Numerical Models

- Depend on
  - Realiability of the conceptual model
  - Importance of the "missing" data
  - Quantity and quality of the "history match" data
  - Modeler
- Generally, can predict reasonably and reliably the power generation of a geothermal system with significant exploitation history
- Predictions of chemical transport in geothermal systems are very uncertain

Conclusions

- Numerical modeling of multi-phase, multi-component systems is very complex
  - Unless verified, results, are only *unproven* hypothesis
- Experience from geothermal modeling shows many examples of *poor* hypothesis, with power plants running at fraction of installed capacity
- Current methodology in modeling geothermal systems is solid and generally yields reasonable predictions for extraction rates; hence, for power output
- The modeling of chemical or heat transport is much less certain than for modeling geothermal systems because of the lack of understanding of processes and the geohydrological structure