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MAGMA ENERGY

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ABSTRACT

The thermal energy contained in magmatic systems represents a huge potential resource. In the U. S., useful energy contained in molten and partially-molten magma within the upper 10 km of the crust has been estimated at 5 to 50 x 10^{22} J (50,000 to 500,000 Quads). The objective of the Magma Energy Extraction Program is to determine the engineering feasibility of locating, accessing, and utilizing magma as a viable energy resource. This program follows the DOE/OBES-funded Magma Energy Research Project that concluded scientific feasibility of the magma energy concept.

A primary long range goal of this program is to conduct an energy extraction experiment directly in a molten, crustal magma body. Critical to determining engineering feasibility are several key technology tasks: (1) Geophysics - to obtain detailed definition of potential magma targets, (2) Geochemistry/-Materials - to characterize the magma environment and select compatible engineering materials, (3) Drilling - to develop drilling and completion techniques for entry into a magma body, and (4) Energy Extraction - to develop heat extraction technology.

BACKGROUND

Magma, or molten rock, is the ultimate heat source for geothermal reservoirs. In conventional geothermal applications, the energy from magma is tapped indirectly in natural geothermal reservoirs that are associated with certain magma bodies. Many magma sources, however, lack an adequate geothermal field for exploitation. Enormous quantities of energy are stored in magma bodies in the crust. The portion of this energy that can be tapped in conventional geothermal fields is a small fraction of the total energy available in crustal magma bodies. The bulk of this untapped reserve of magma energy would become available if methods were found for extracting energy directly from magma.

Appreciable amounts of magma are believed to exist at depths shallow enough to be directly tapped. In the United States, the magma resource is estimated at 5 to 50 x 10^{22} J within the upper 10 km of the crust. This is equivalent to a 600 to 6,000 year total energy supply for the country. The bulk of this magma resource is in the conterminous western United States. An additional magma resource in the oceanic spreading centers is many times larger.

Magmas range in composition from very hot (1100-1300°C), fluid, basaltic magmas to cooler (800-900°C), viscous, rhyolitic magmas. Magma may occur in large underground pools, in a plexus of dikes, sills, and fractures, or intermittently in isolated dikes and conduits. Evidence for the magma resource is based on geological observations such as: volcanic eruptions, lava flows, caldera collapse, and exhumed or fossilized magma bodies which are frequently associated with mineral deposits. Evidence for magma is also based on geophysical observations such as: leveling data showing tilt and uplift, seismic P-wave delays, seismic S-wave shadowing, and active geophysical methods such as Vibroseis-type P-wave and S-wave reflection seismic techniques.

Previous heat extraction research indicated that most configurations of the magma resource--i.e., basalt/andesite pools, basalt/andesite/-rhyolite matrices of dikes and sills, hot subsolidus plutons--are practical for utilization at energy extraction rates that are comparable to or better than those in conventional geothermal fields. The high temperature of the magma resource (800-1300°C) and the correspondingly high temperatures of the heat-transfer working fluid (300-600°C) lead easily to efficient, conventional techniques for generating electricity. Processes are also available for using this high-quality energy to generate transportable fuels in addition to electricity.

Sandia National Laboratories completed a seven-year study of the scientific feasibility of extracting energy directly from crustal magma bodies. This study examined the problems of locating and drilling into the magma and then extracting useful quantities of energy from the magma. Theoretical calculations with supporting laboratory and field measurements were used to show that there are no fundamental theoretical or physical barriers that prevent the direct extraction of energy from magma. As a result of this study, it was concluded that magma energy utilization is scientifically feasible. Two different scientific review panels agreed with this conclusion.

The current Magma Energy Extraction program is assessing the engineering feasibility of building magma-based power plants. Fundamental technologies required for target location, drilling, materials survivability and energy extraction will be developed. Industry will make the final assessment of commercial feasibility.

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MASTER

MAGMA ENERGY EXTRACTION PROGRAM

OBJECTIVE

Determine the engineering feasibility of extracting energy directly from crustal magma bodies.

Important Questions

- Can magma drilling targets be located using standard geophysical techniques?
- Can magma wells be drilled and completed at depths of 6-7 km?
- Will engineering materials survive the magma environment for several years?
- Can energy be extracted at high rates?
- Is magma energy cost competitive with other energy resources?

FACTORS AFFECTED BY DRILLING FLUID TEMPERATURE

- Fluid Selection
  - Property
  - Degradation
- Tubular Selection
  - Strength
  - Corrosion Rate
- Bit Cooling
- Borehole Stability

BASE CASE WELL

- Wellbore - 12-1/4 in. to 20,000 ft.
- Casing - 9-5/8 in. to 17,000 ft.
- Drillpipe - 5 in. OD, 3/8 in. insulation below 1000 ft.
- Fluid - water
- Flow rate - 350 gpm

CONDITION	BH TEMP°F	MAX TEMP°F	RETURNS TEMP°F
UNINSULATED	1100	1104	93
FULL INSULATED	149	257	208
BASE CASE	264	360	169
FLOW = 200 GPM	390	521	166
FLOW = 500 GPM	198	278	159
INSULATION = 1/8 inch	349	422	158
INSULATION = 3/4 inch	239	348	172
16,000 FT--FULL INS.	101	157	145

GEOCHEMISTRY/MATERIALS

- Magma Characterization
- Materials Compatibility
- Vesiculation Hazards
- Solution Transport

MATERIALS COMPATIBILITY

Goal:

- Evaluate the compatibility of commercially available alloys for use as a heat exchanger material in a volatile-rich rhyolite magma.

Approach:

- Experimentally react commercial alloys in a volatile-bearing rhyolite magma (conditions - 850C, 200 MPa) and with a hydrous rhyolite glass at normal operating conditions (500C, 50 MPa), followed by characterization of the metal-melt (glass) interface.

RESULTS:

- Magma characterization studies have been completed for shallow magma at Long Valley, Coso, and Kilauea.
- Experimental procedures were developed for compatibility testing of commercial alloys in volatile-bearing rhyolite magma
- Oxidation, not sulfidation, is the main corrosion problem for all alloys in a volatile-rich rhyolitic magma.
- Nickel-base superalloys have very good chemical resistance and strength in a rhyolitic magmatic environment (850C, 200 MPa).
- Reaction rates between alloys and silicates are significantly reduced at normal operating conditions (500C, 50 MPa).
- Hydrous rhyolite glass crystallizes at normal operating conditions (500C, 50 MPa) yielding anhydrous silicates and a vapor phase.

DISSOLUTION/TRANSPORT KINETICS

Goals:

- To predict silicate dissolution rates and solution composition in a direct contact heat exchanger system.
- To evaluate the potential for loss of permeability due to precipitation of secondary minerals.

Approach:

- Measure dissolution rates for crystalline phases at normal heat exchanger operating conditions (500C, 50 MPa).
- Build a theoretical framework for extrapolating the existing low-temperature dissolution data to higher temperatures.

RATES OF MINERAL GROWTH AND DISSOLUTION

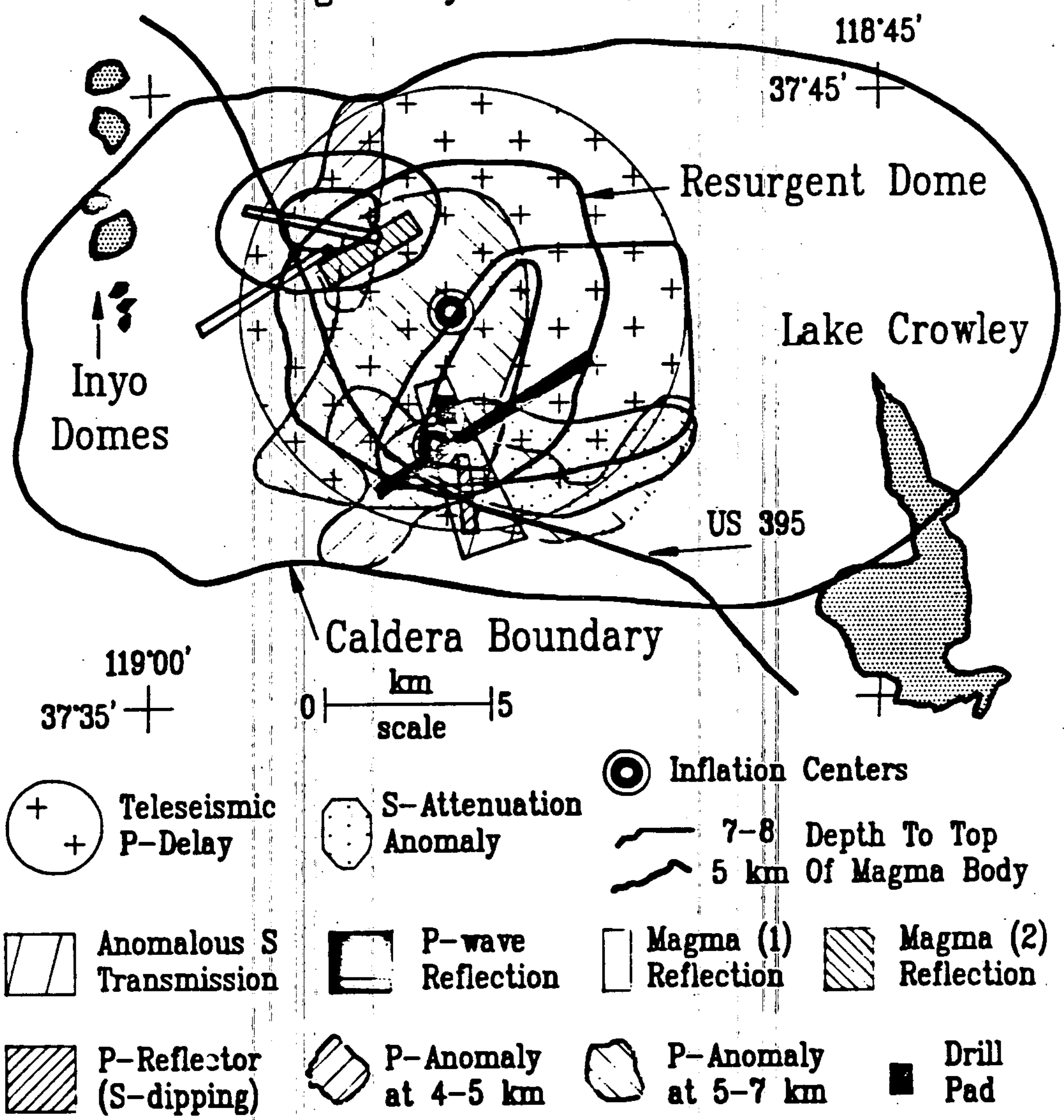
- Theory: Predicting the mechanism and magnitude of rates at T and P
- Experiment:
  (1) Hydrothermal Autoclave: rates and activation energies at T and P
  (2) Benchtop Experiments:
    (a) pH-dependence of rates
    (b) Role of mineral defects in controlling rates
    (c) Molecular mechanisms and transition state

REACTION RATES ARE STRONGLY AFFECTED BY:

1. Temperature (very large, measurable)
2. Variations in Mechanism
   (a) Solution Composition (40x)
   (b) Defect Concentration (unevaluated, potentially large)
   (c) Hydrodynamics (evaluated theoretically)

Geophysical Evidence For Magma:

Long Valley Caldera, California



WHY LONG VALLEY?

* Result of study of 22 U. S. sites
* Potential magma targets have been identified
* Other than Mt. St. Helens, largest recent surface deformation in the U. S.
* Most studied caldera system in the U. S.
* KGRA where industry is currently drilling exploratory wells.

WHY DRILL NOW?

* Bulk of reasonable surface geophysics has been done-have reached point of diminishing returns
* Geophysical inverse techniques are not unique - difficult to reach a consensus
* Drilling is next logical step - obtain important new data

WHY THE RESURGENT DOME?

* Peak of the uplift
* Locus of most of the shallow seismic anomalies
* Reduced environmental problems

MAGMA ENERGY OBJECTIVES LONG VALLEY WELL

. Determine nature of geophysical anomaly

. Verify existence of magma

. Test new drilling technology

. Evaluate engineering materials

. Confirm energy extraction calculations

CRITICAL PROGRAMMATIC EXPERIMENTS

. Temperature and heat flow measurements

. Fluid and gas sampling

. In situ stress measurements

. Physical and chemical analysis of limited core samples near the well bottom

. Permeability measurements

. Passive and active seismic observations

SCIENTIFIC OBJECTIVES (EXAMPLES)

. Understanding relationship between seismicity and deformation

. Discrimination among proposed models for observed deformation

. Local and regional crustal structure studies

. Direct observation of source processes

. Relation of pore pressure changes to seismicity, deformation, and temperature changes

. Direct observation of geochemical processes and alteration of shallow crustal rocks

. Understanding system dynamics for use in predicting system evolution

POSSIBLE CSDP SCIENTIFIC ADD-ONS

EXPERIMENT
1. Absolute In Situ Stress:

(i) Hydrofrac
(ii) Acoustic Emission of Core Samples
(iii) Core Relaxation

PURPOSE
Orientation and magnitude of stress field: confirm/deny deformation models

EXPERIMENT
2. Stress Changes: (same methods)

PURPOSE
Changes in magnitude of stress with time: examine magmatic inflation process

EXPERIMENT
3. Acoustic Televiewer

PURPOSE
Fracture logging and borehole breakout analyses (stress field orientation)

EXPERIMENT
4. Temperature Logging/Heat Flow/Changes with Time

PURPOSE
Thermal signature of magmatic injection and earthquake swarms

EXPERIMENT
5. Passive Downhole Triaxial Seismometer

PURPOSE
Local crustal structure to depths of 10 km using local and regional earthquakes and teleseisms; investigate 3-D structure in vicinity of wellbore, near-surface attenuation.

EXPERIMENT
6. Active seismology

PURPOSE
Surface-to-borehole, borehole-to-borehole, borehole-to-surface; investigate high frequency seismic structure and attenuation in vicinity of wellbore

EXPERIMENT
7. Fluid/Gas Sampling

PURPOSE

Understand geochemistry of pore fluids and gases

EXPERIMENT

8. Core Studies

PURPOSE

Physical and chemical properties of core: alteration geochemistry, deformation mechanism, permeability, porosity, composition, etc.

EXPERIMENT

9. Vertical Electromagnetic Profile

PURPOSE

Determine deep electrical structure independent of surface hydrothermal conductors

EXPERIMENT

10. Pore Pressure Monitoring

PURPOSE

Use well as strainmeter to record deep deformation of caldera with time

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