

# *Taller de Geotermica en Mexico*

## **Geothermal Energy – Current Technologies**

presented by

**Paul Brophy,  
President/CEO EGS Inc.**

**Mexico City**

**October 10<sup>th</sup> 2011**

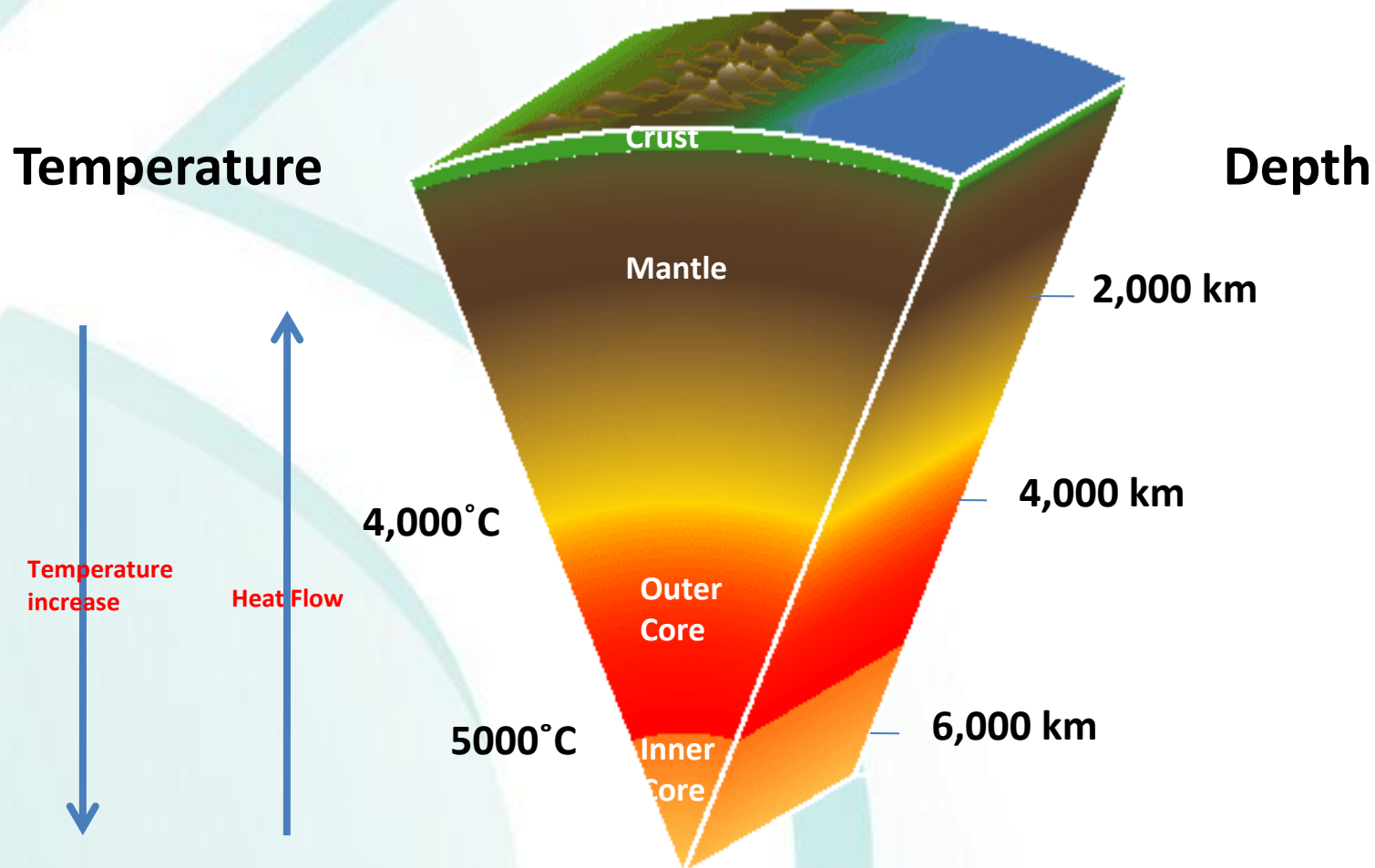


## **Presentation Topics**

- **General Geothermal Discussion**
- **Exploration Approaches and New Technologies**
- **Current U.S. Geothermal Development areas**
- **Caribbean Geothermal Potential**

# Earth Structure and Heat Flow

## Temperatures in the Earth



## *Geothermal Resource Types*

### ➤ **Conventional Hydrothermal (Geothermal) Systems**

- **Liquid/Vapor dominated (electric power)**
- **Direct Use (space heating, industrial processes)**

### ➤ **Earth Heat Systems**

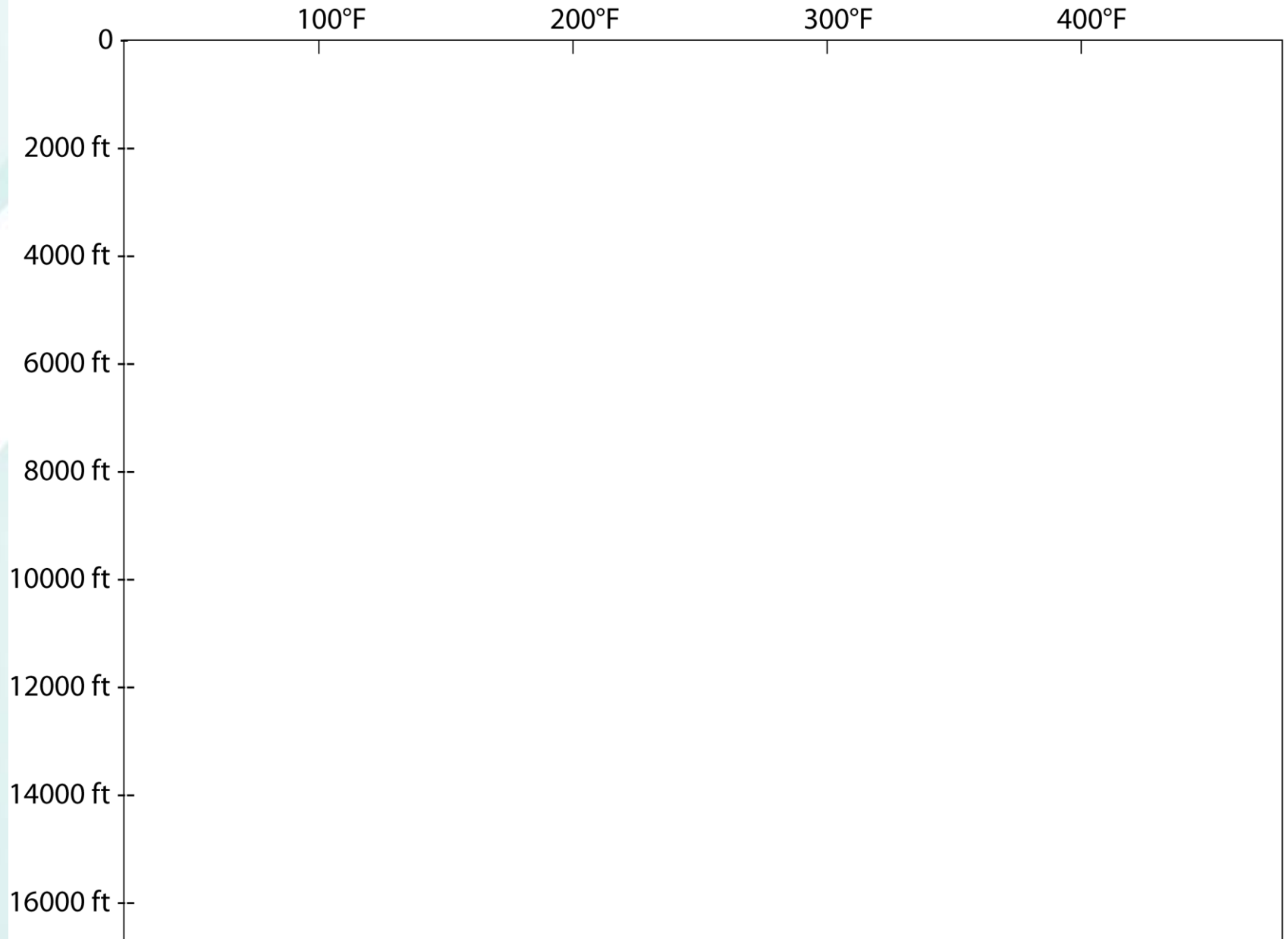
- **Engineered Geothermal Systems (EGS)(electric power)**
- **Geothermal Heat Pumps (residential heating & cooling)**

### ➤ **Deep Sedimentary Basins**

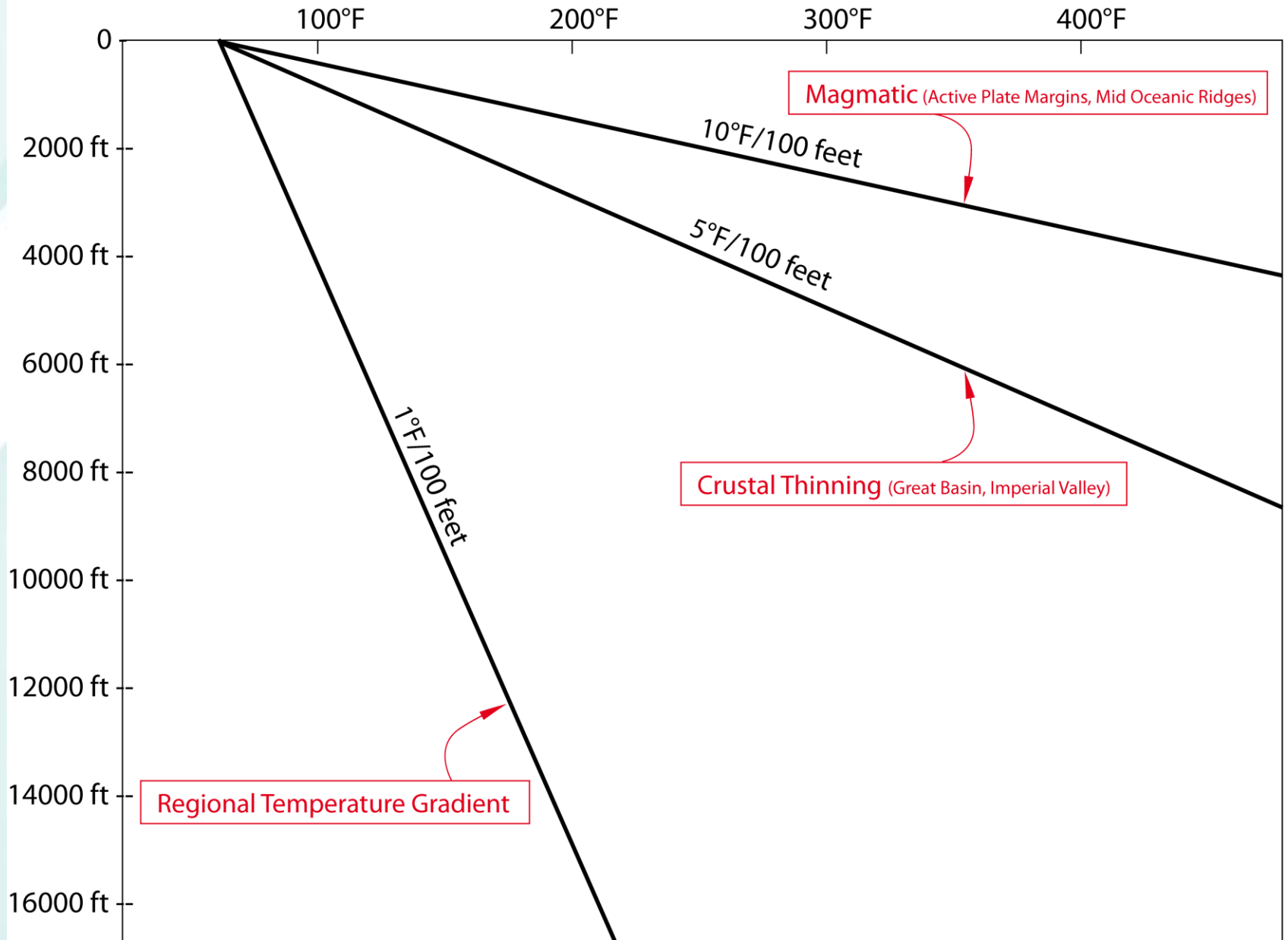
### ➤ **Oil & Gas Wells, Co-production (electric power)**

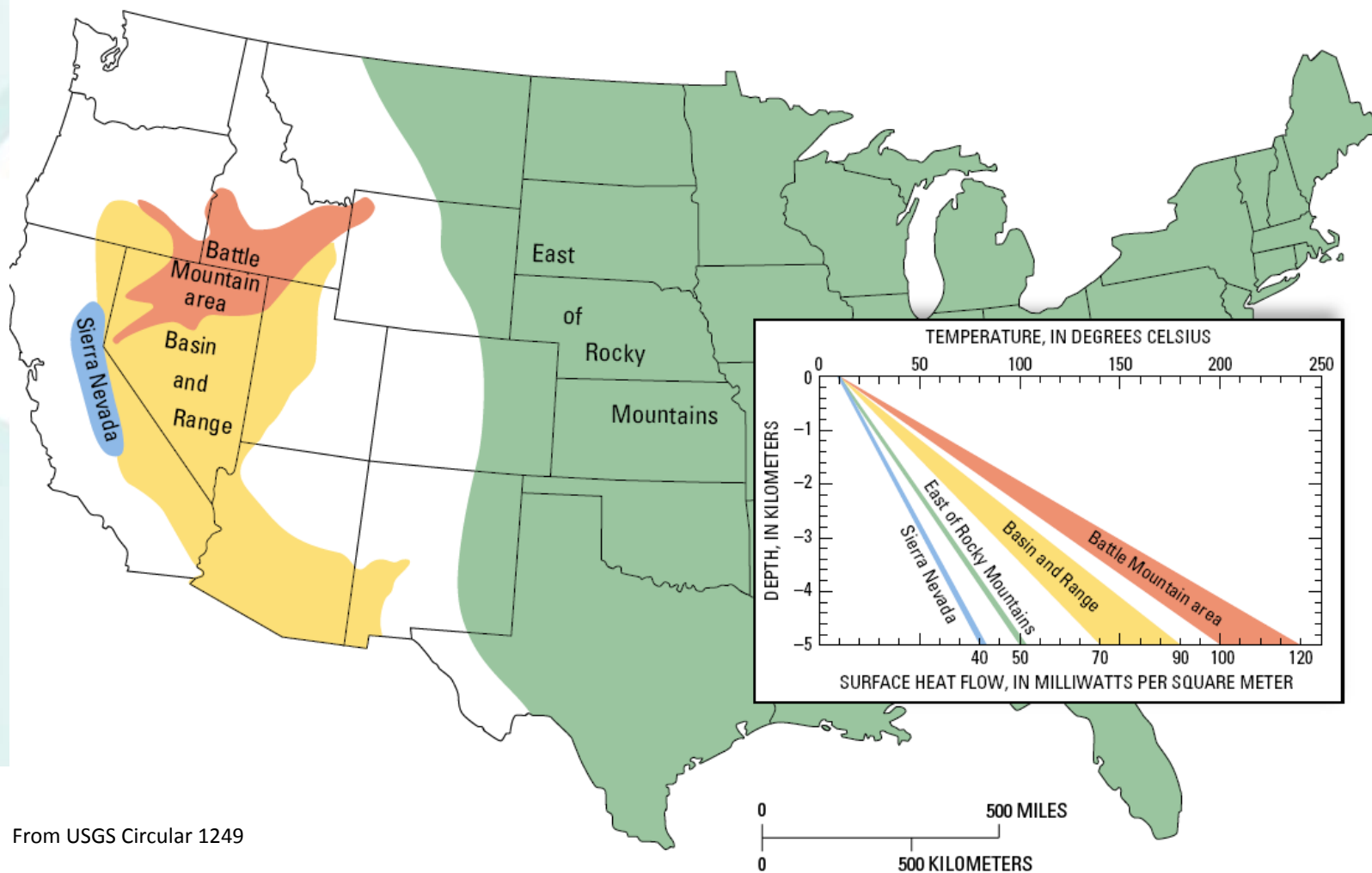
# Hypothetical High-Temperature Conventional Geothermal System

# Schematic Depth-Temperature Plot for Geothermal Resources



# Schematic Depth-Temperature Plot for Geothermal Resources

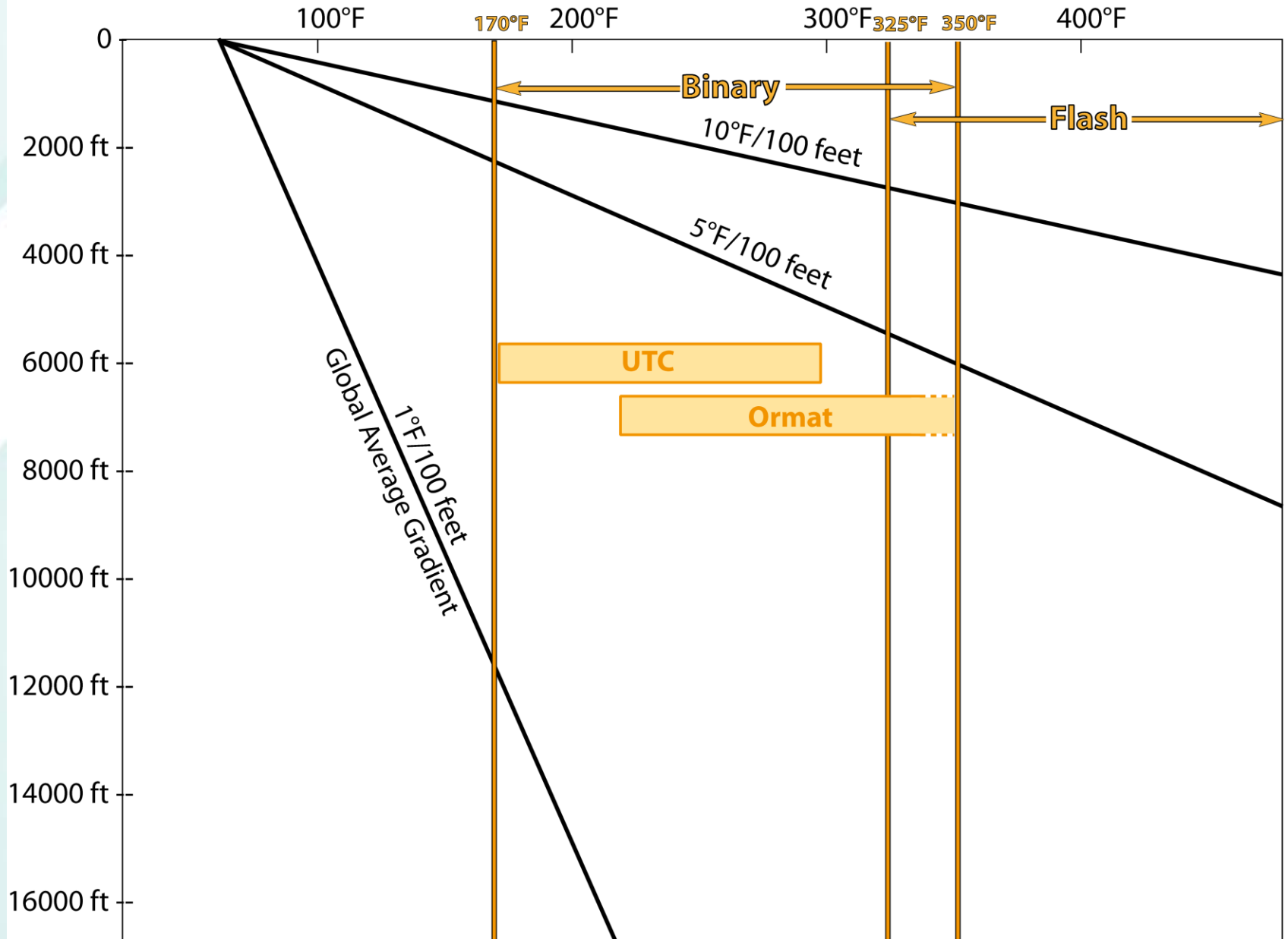




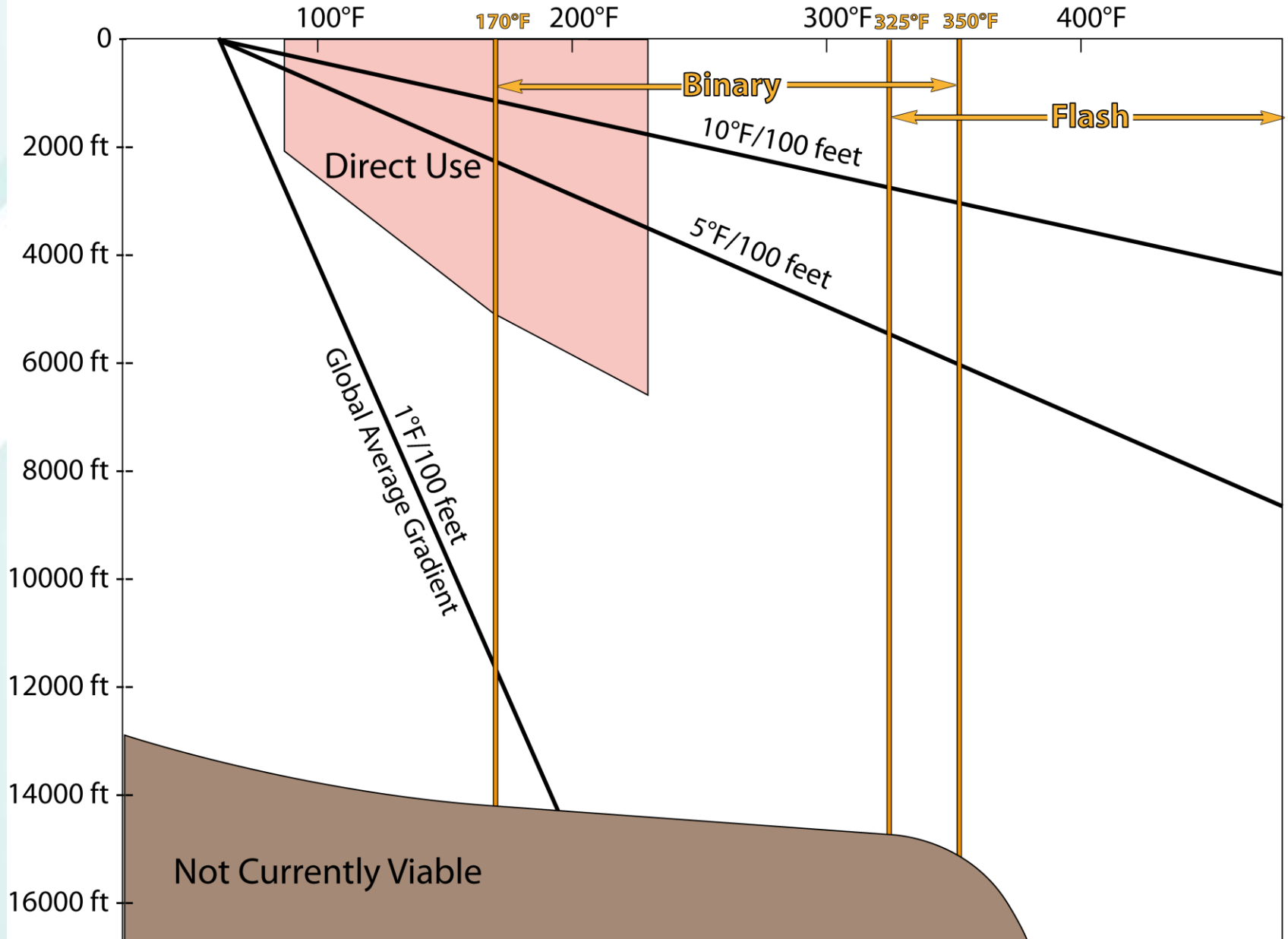
From USGS Circular 1249



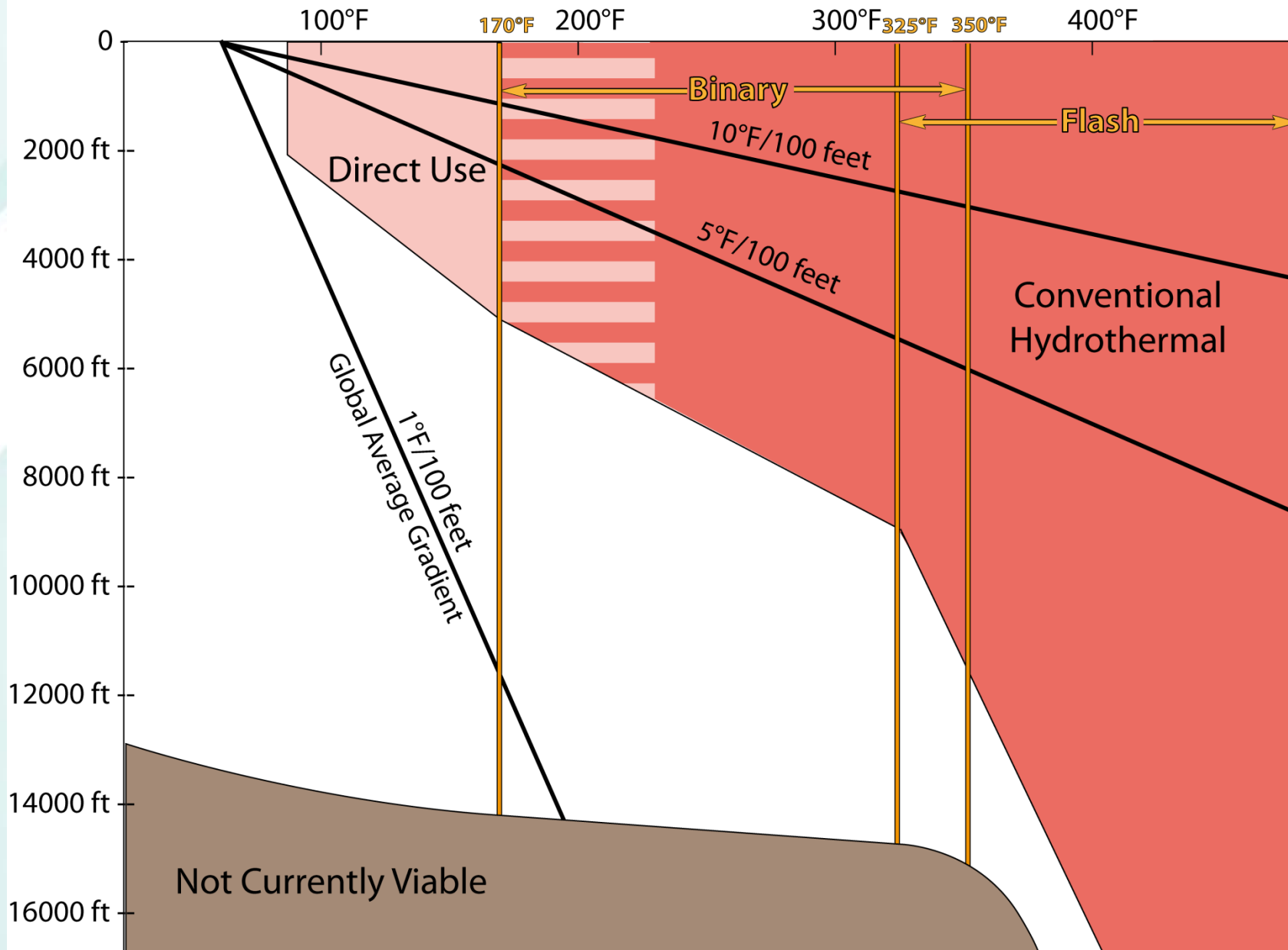
# Schematic Depth-Temperature Plot for Geothermal Resources



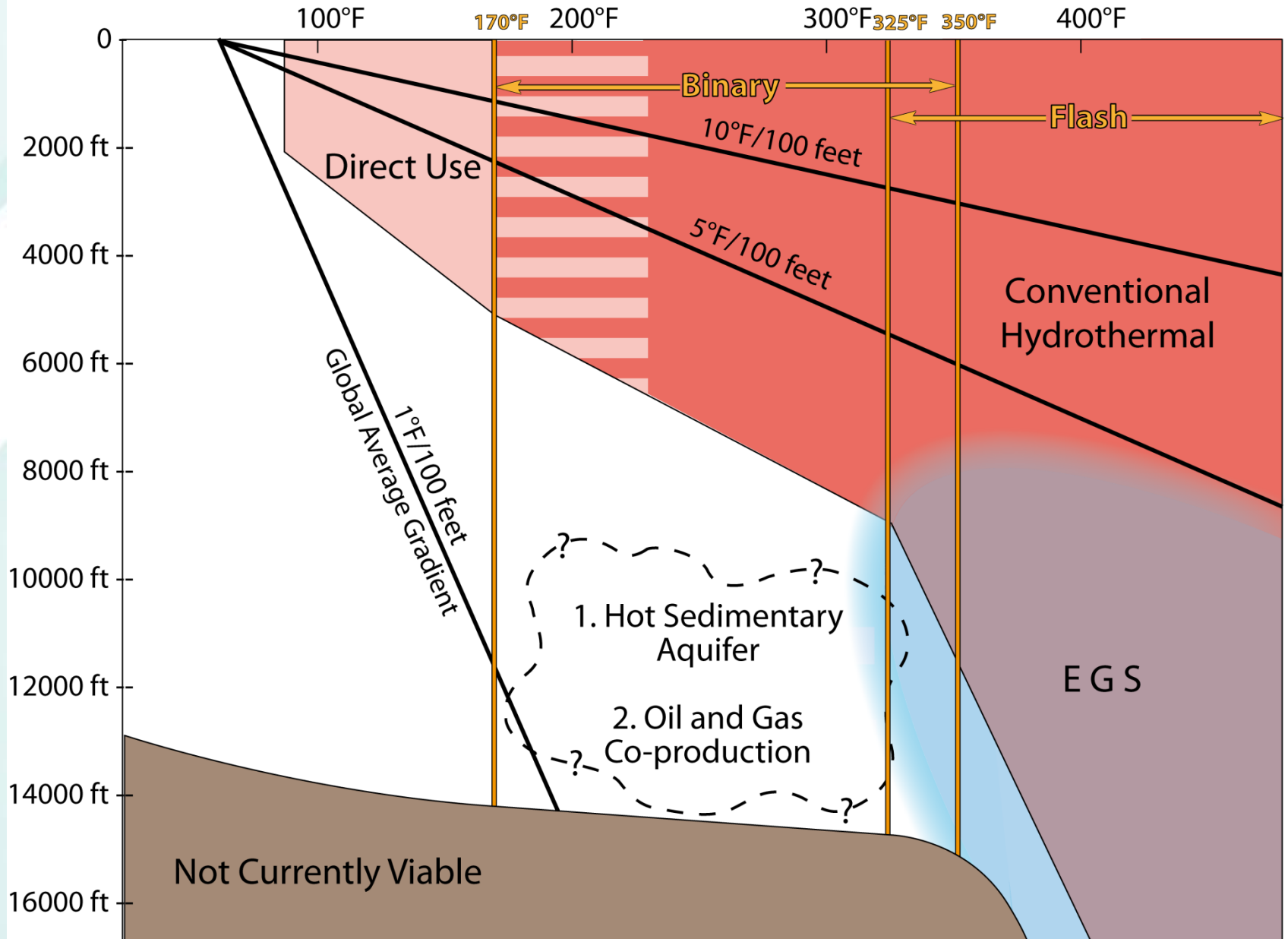
# Schematic Depth-Temperature Plot for Geothermal Resources



# Schematic Depth-Temperature Plot for Geothermal Resources



# Schematic Depth-Temperature Plot for Geothermal Resources



## **Key Exploration Questions**

- **What is the Resource Temperature?**
- **What is the Resource Depth?**
- **What is the Resource Quality?**
- **How large is the Resource (Area Extent)?**
- **How Productive are the Wells?**
- **What are the estimates of Resource Longevity?**

# **Exploration Approach**

- **Remote Sensing Data**
- **Geologic Mapping and Surface Manifestations**
- **Structural Setting**
- **Geochemical Sampling and Analysis**
- **Geophysical Surveys**
- **Exploration Drilling**
  - **Temperature Gradient/Heat Flow**
  - **Exploration (Core) Wells**
- **Production Well Drilling**

# **Remote Sensing Data Types**

- **Multispectral (several relatively broad bands)**
- **Hyper spectral (many narrow bands)**
- **Thermal Infrared (TIR – can be multispectral)**
- **Panchromatic (gray scale – single very broad band)**
- **Radar (microwave)**
- **LIDAR (Light Detection and Ranging - laser)**

# **Geological Mapping**

- **Regional Geologic Mapping**

**Rock Lithology**

**Mapped Faults**

- **Rock Alteration**

**Alteration mineralogy**

**Alteration assemblages**

**Duration of Geothermal Systems**



# *Geochemistry*

- Chemical characteristics of:  
waters, gases, rocks, and soils  
hot springs, fumaroles, springs etc
- Geothermometers  
allows estimation of subsurface  
(reservoir) temp  
silica geothermometers  
cation geothermometers (Na-K-Ca)  
gas geothermometers
- Fluid inclusions
- Isotope analyses
- Tracers

# *Geophysical Techniques*

**Standard:** MT, T-MT, TDEM, Gravity

**Legacy:** Dipole-Dipole, tensor Dipole-Bipole

**Special:** VES, AMT, CSAMT, SP, HEM, Airborne  
magnetics, Precision Ground magnetics,  
Reflection/Refraction Seismics

**Development:** Microgravity, Micro-  
earthquakes, Subsidence

# **Structural Analysis**

- **Regional Structural Analysis**
- **Regional Seismicity,**
- **Stress Field Determinations**
- **Geometry of Fracture systems**
- **Fault Kinematics**
- **Slip Tendency Analysis**

# *New Exploration Technologies*

## Exploration Techniques

- GIS/3D visualization
- LIDAR
- Slip tendency analysis
- He3/He4
- Seismic reflection
- 3D MT

## Exploration Philosophies

- Conceptual modelling
- Blind Deposits

## *3D Visualization – Dixie Valley, NV*

# Structural Analysis

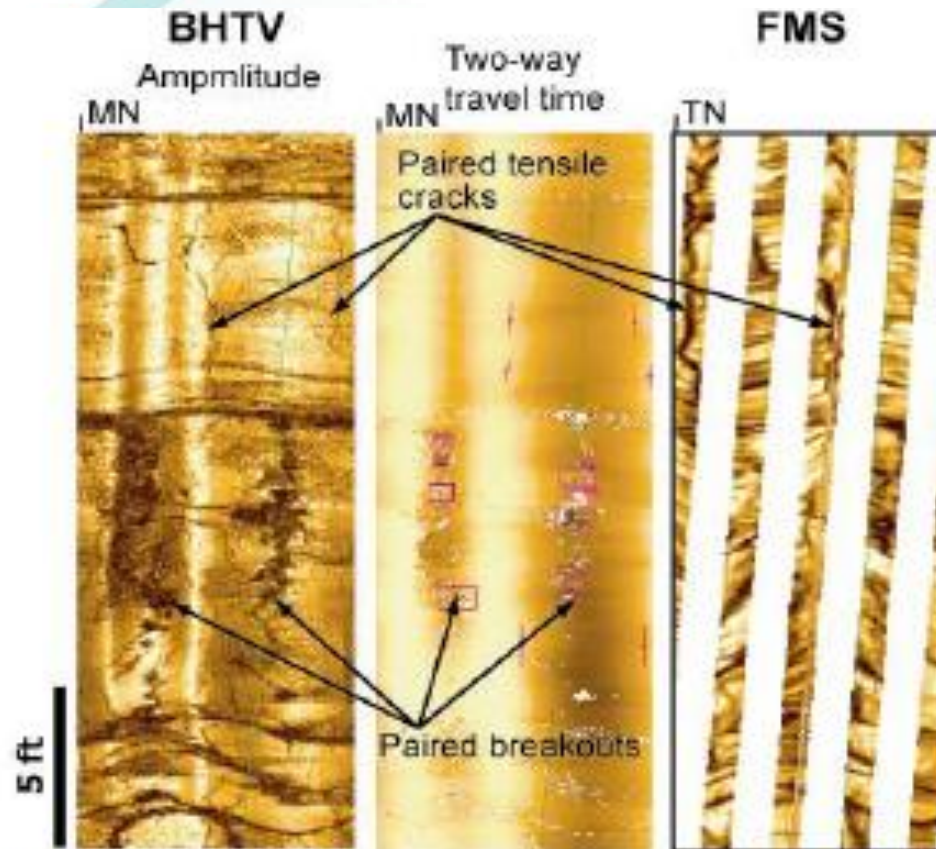
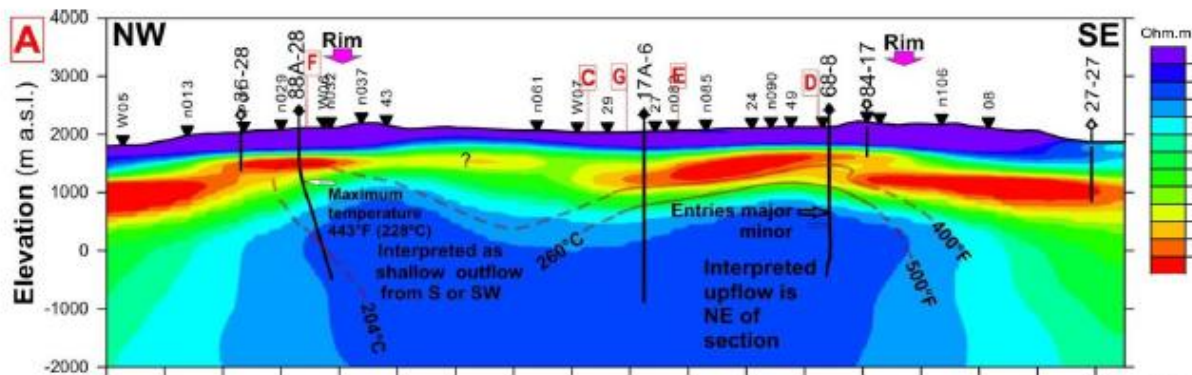


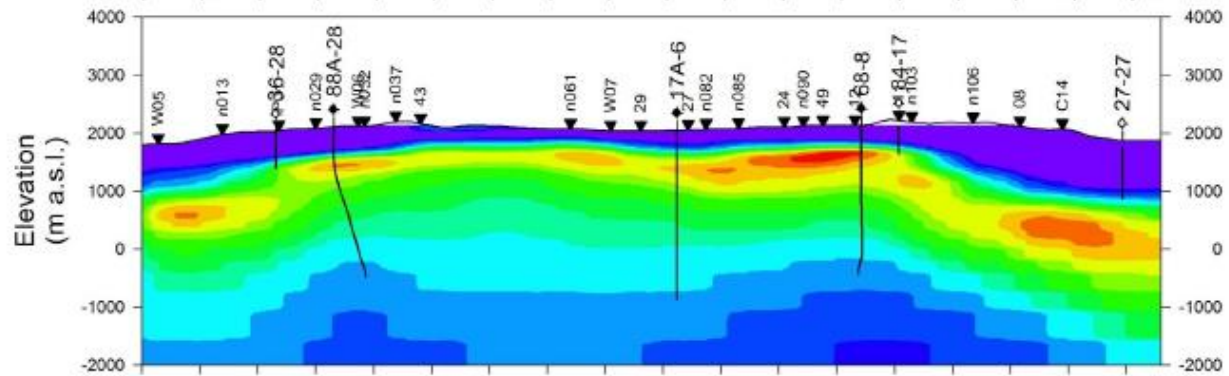
Figure 6: BHTV amplitude and two-way travel time, and FMS image logs of intervals containing borehole wall tensile fractures and breakouts.



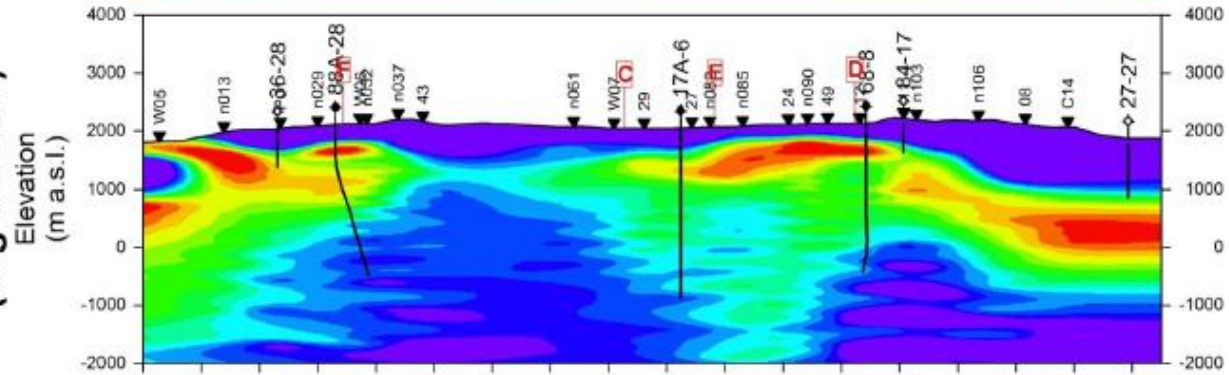
**3D**  
Zxy, no Hz



**2D**  
TM + TE

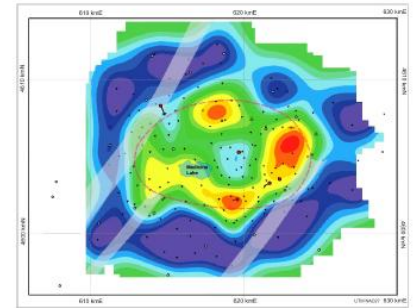


**1D**  
(avg smooth)

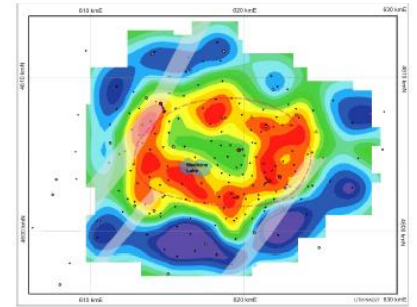


From Cumming and Mackie, 2010

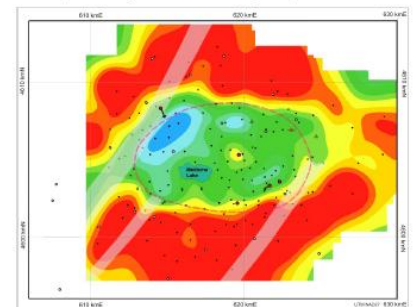
Distance (Km)



1700m asl



1600m asl



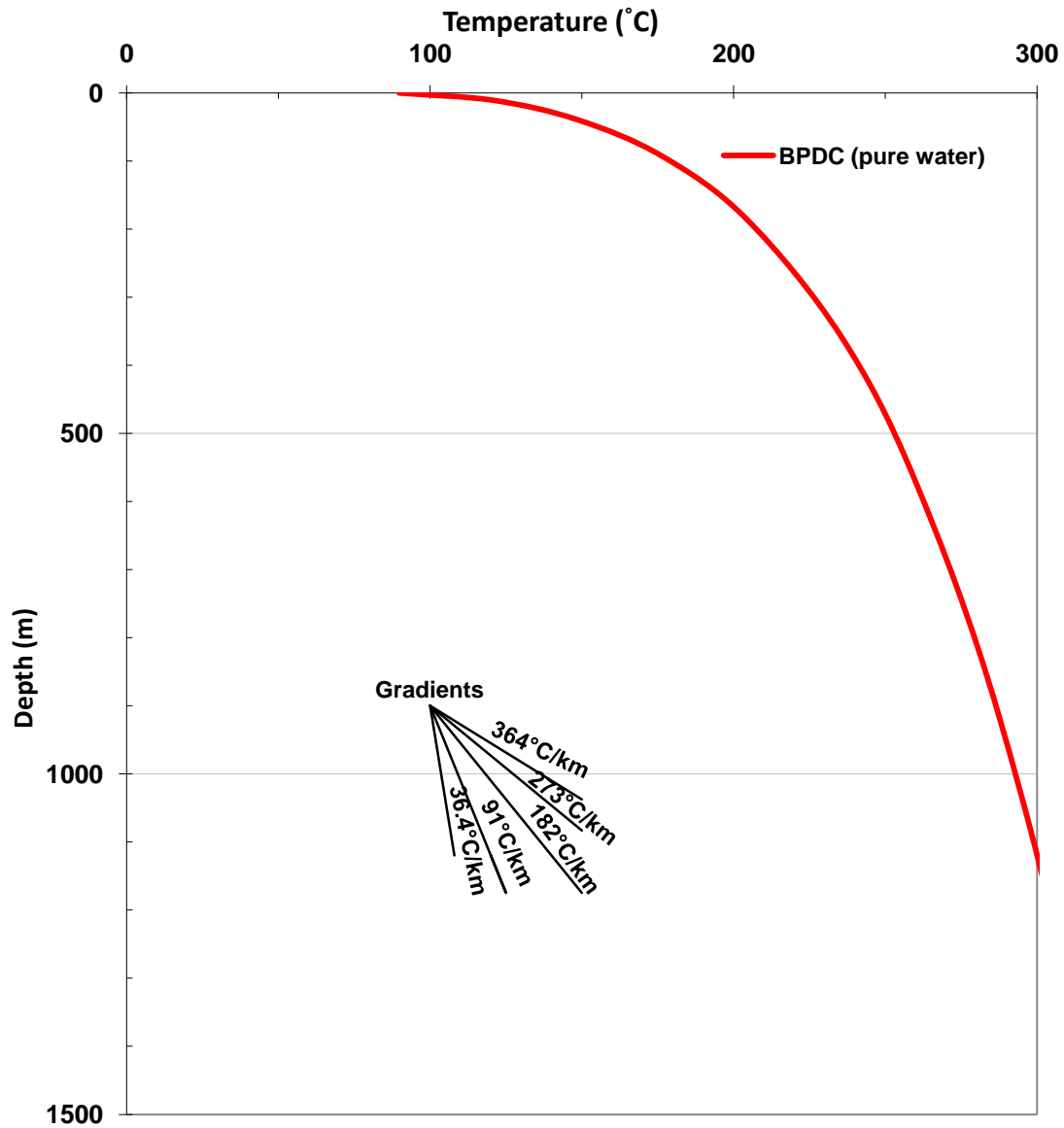
1500m asl

# *Exploration Drilling*

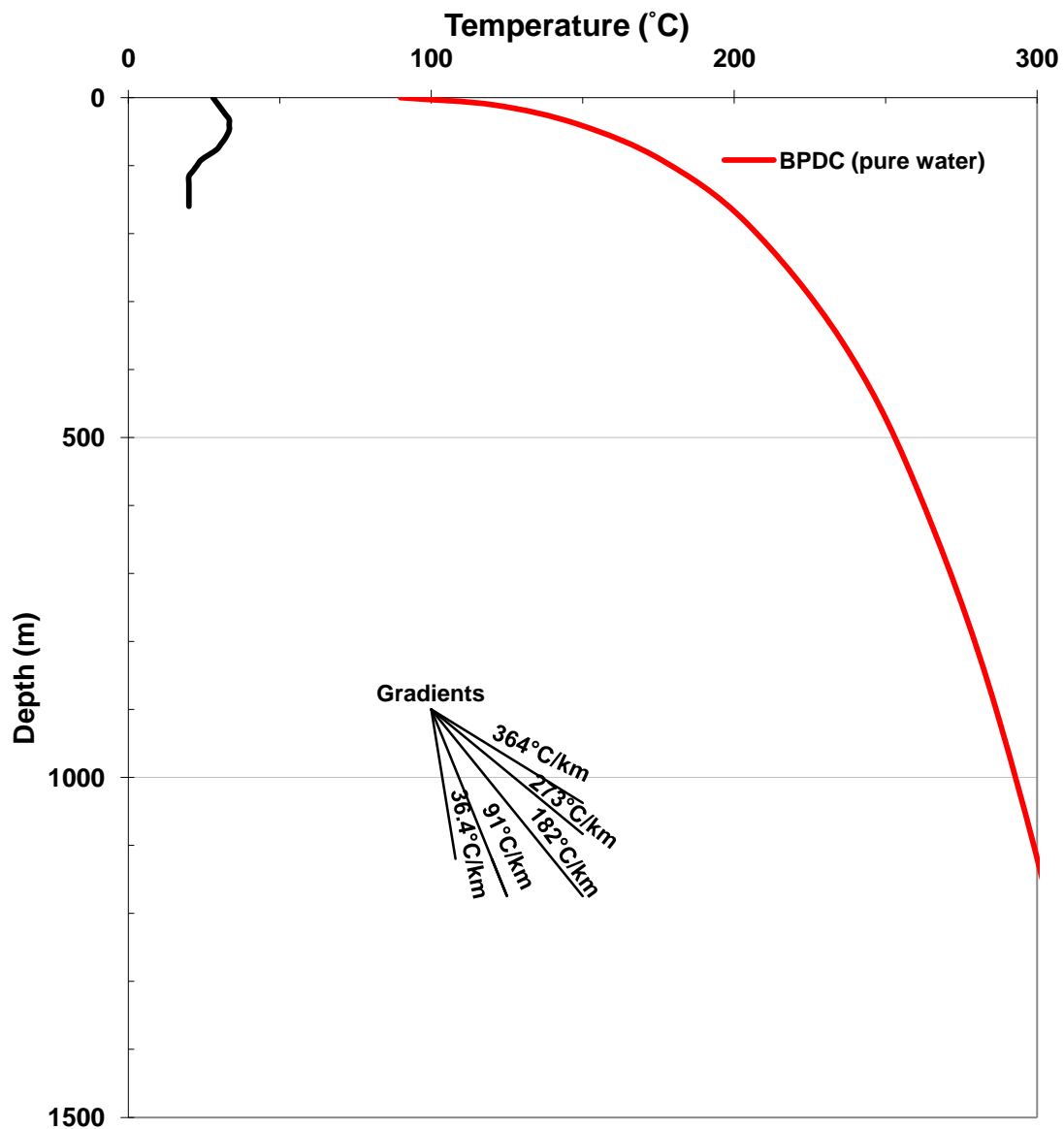
- **Temperature Gradient (Heat Flow) Holes**
  - historically 300 or 500 ft in depth
  - Increased to 1000 feet
- **Slim (Core) Holes**
  - Large diameter core holes – for flow testing and resource quality
  - Smaller diameter core holes for resource temperature
  - Designed in upper section to be converted to production well
- **Exploration/Development Wells**
  - Sized to be capable of flow testing
  - Sized to be capable of limited production
  - Designed and sized to be converted to production, if successful.



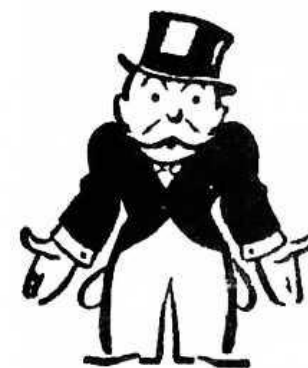
## Wowie-Zowie #1 Corehole Temperature Gradient Data



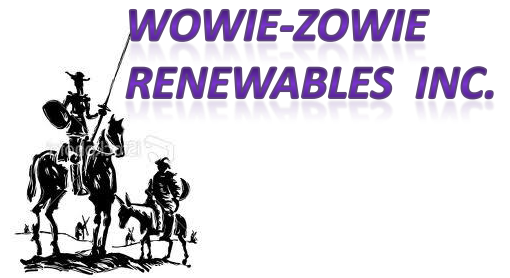
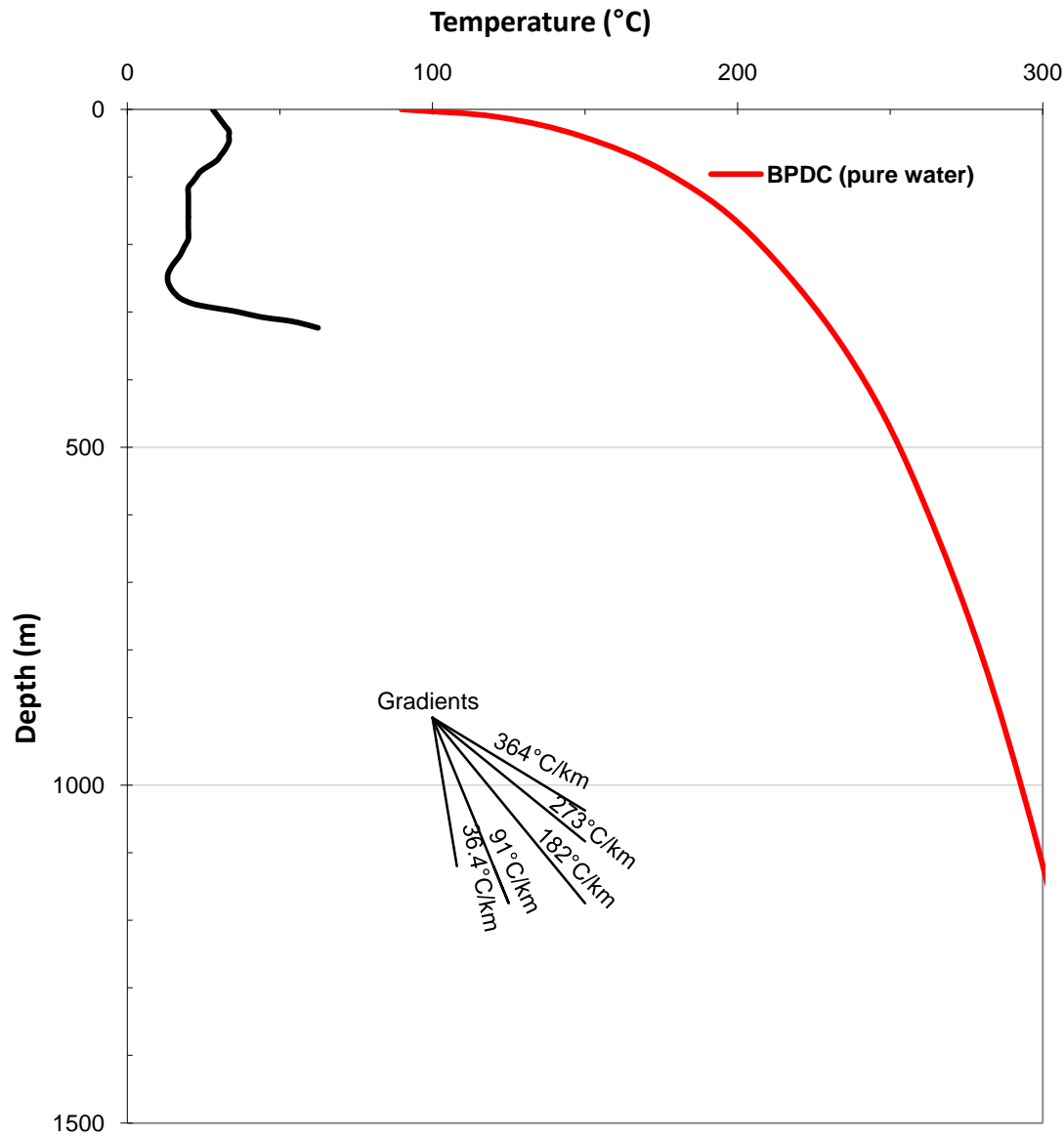
# Wowie-Zowie #1 Corehole Temperature Gradient Data



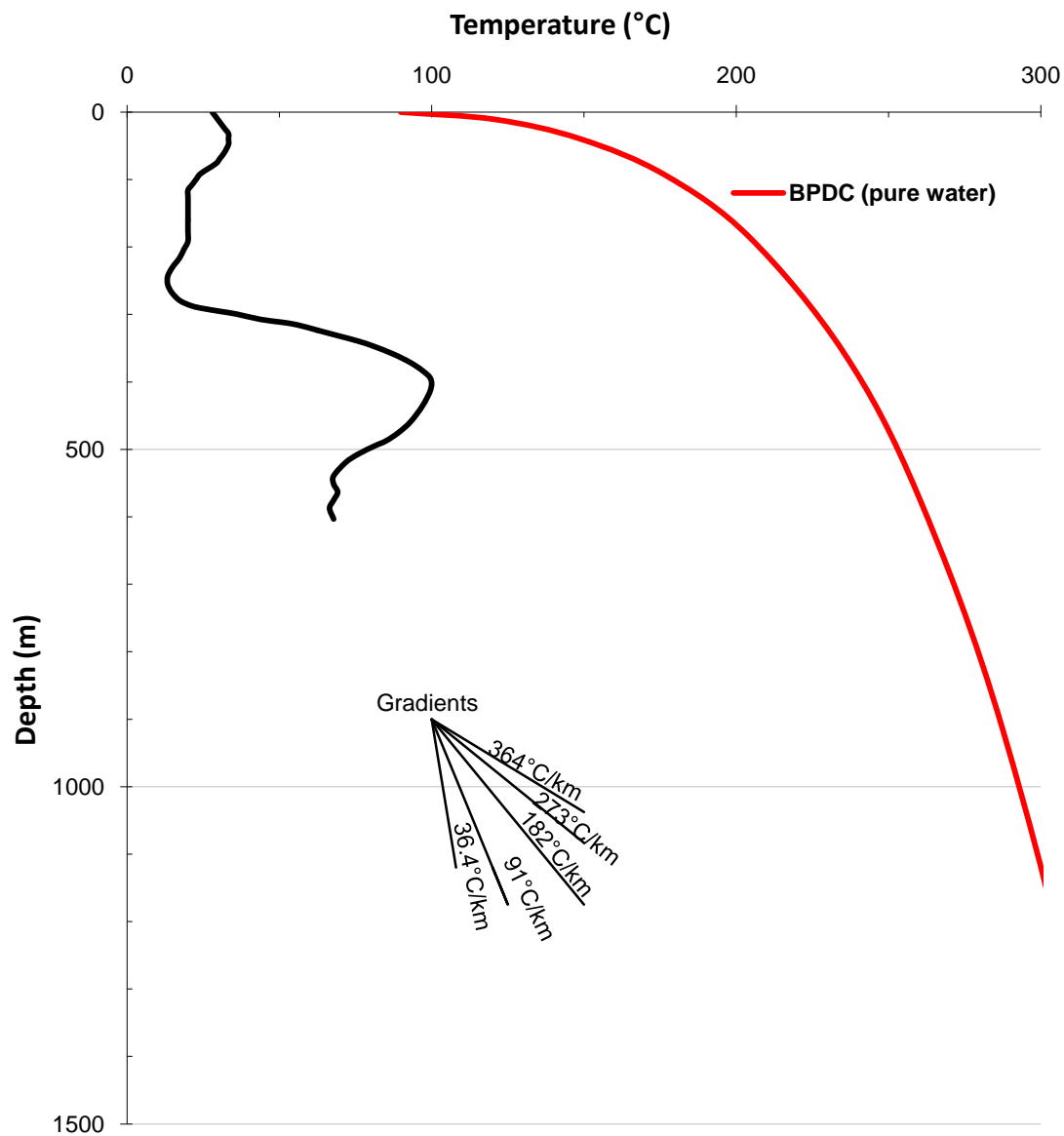
**WOWIE-ZOWIE  
RENEWABLES INC.**



# Wowie-Zowie #1 Corehole Temperature Gradient Data

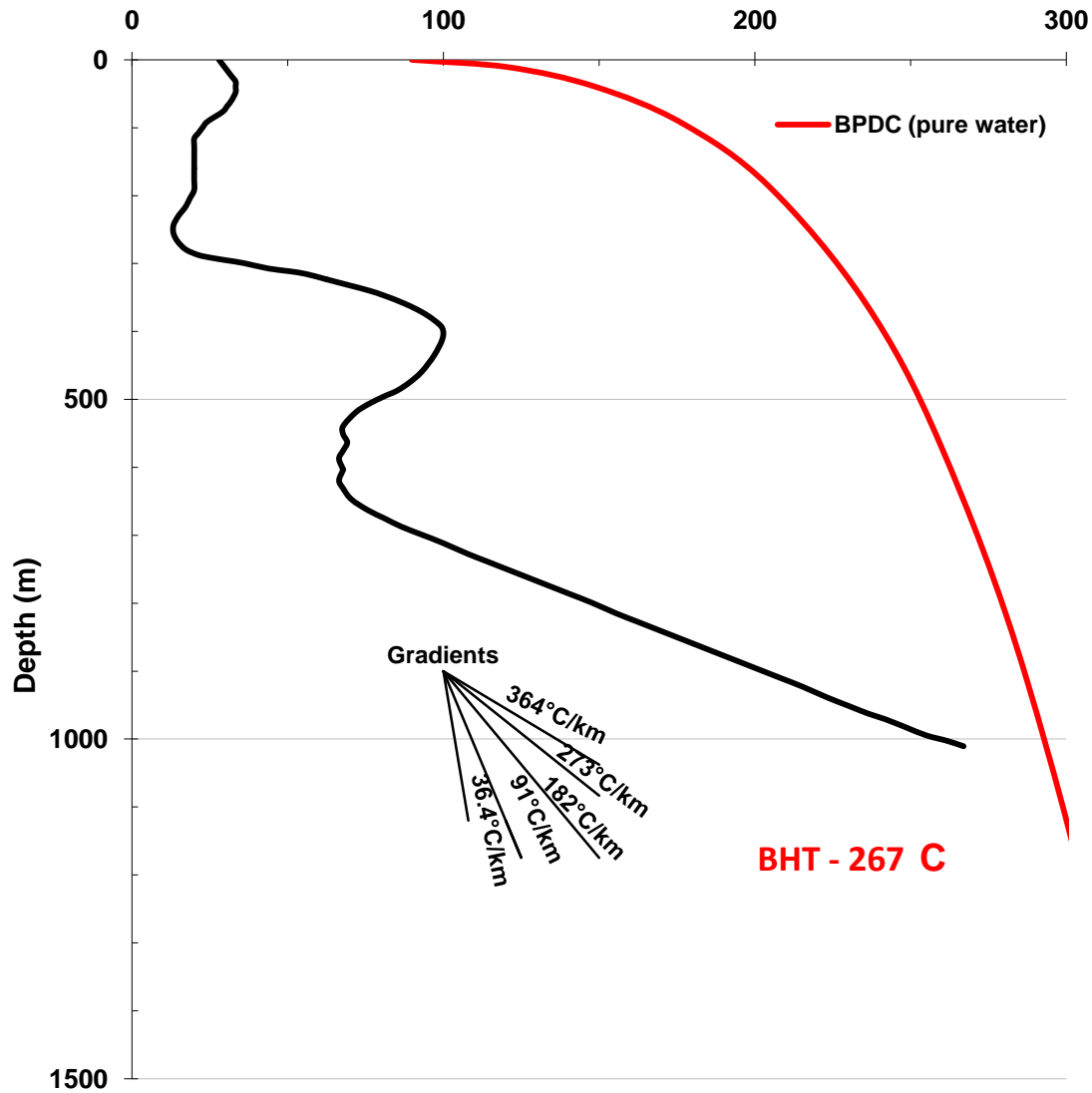


# Wowie-Zowie #1 Corehole Temperature Gradient Data



# Wowie-Zowie #1 Corehole Temperature Gradient Data

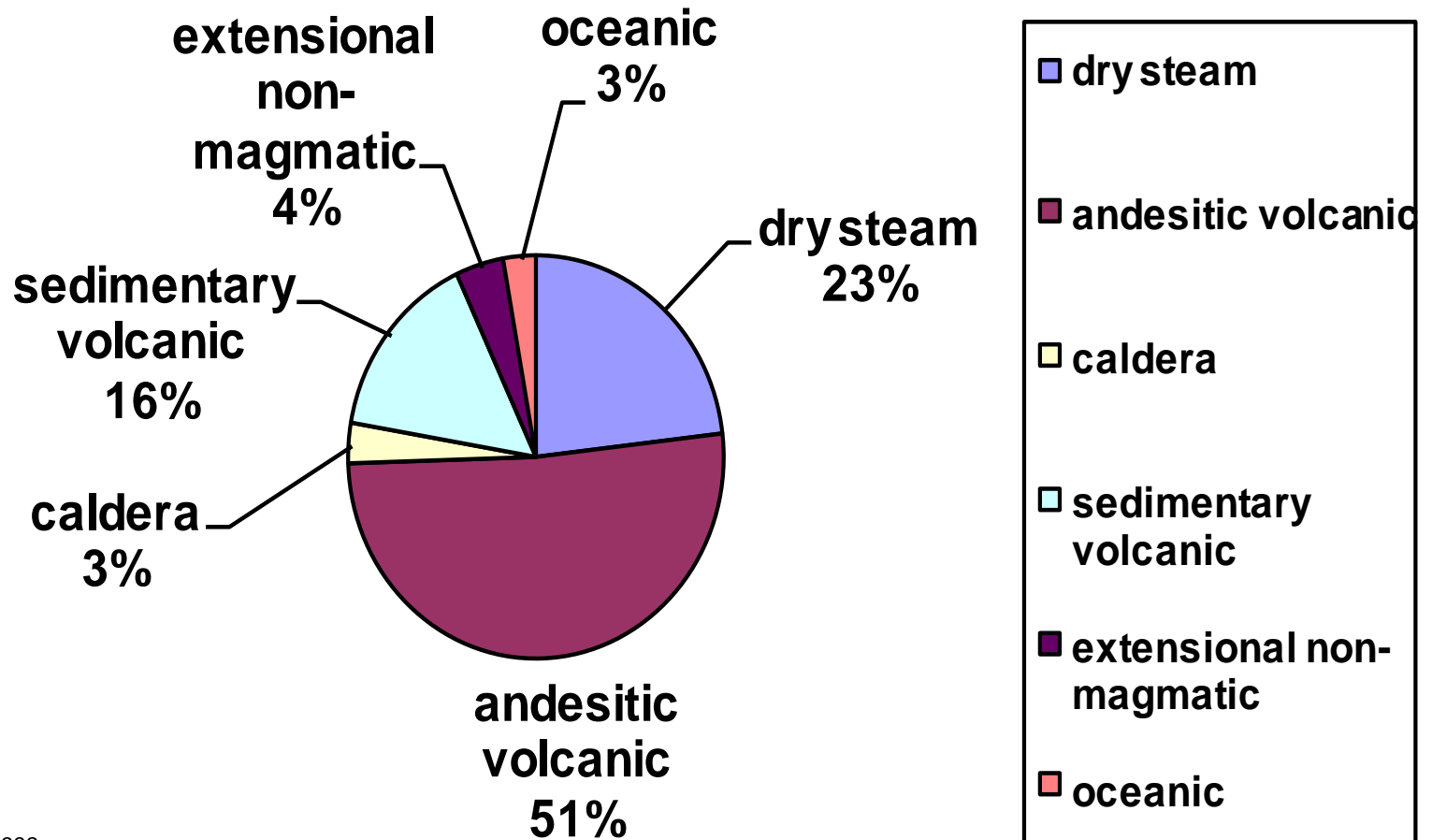
Temperature (°C)



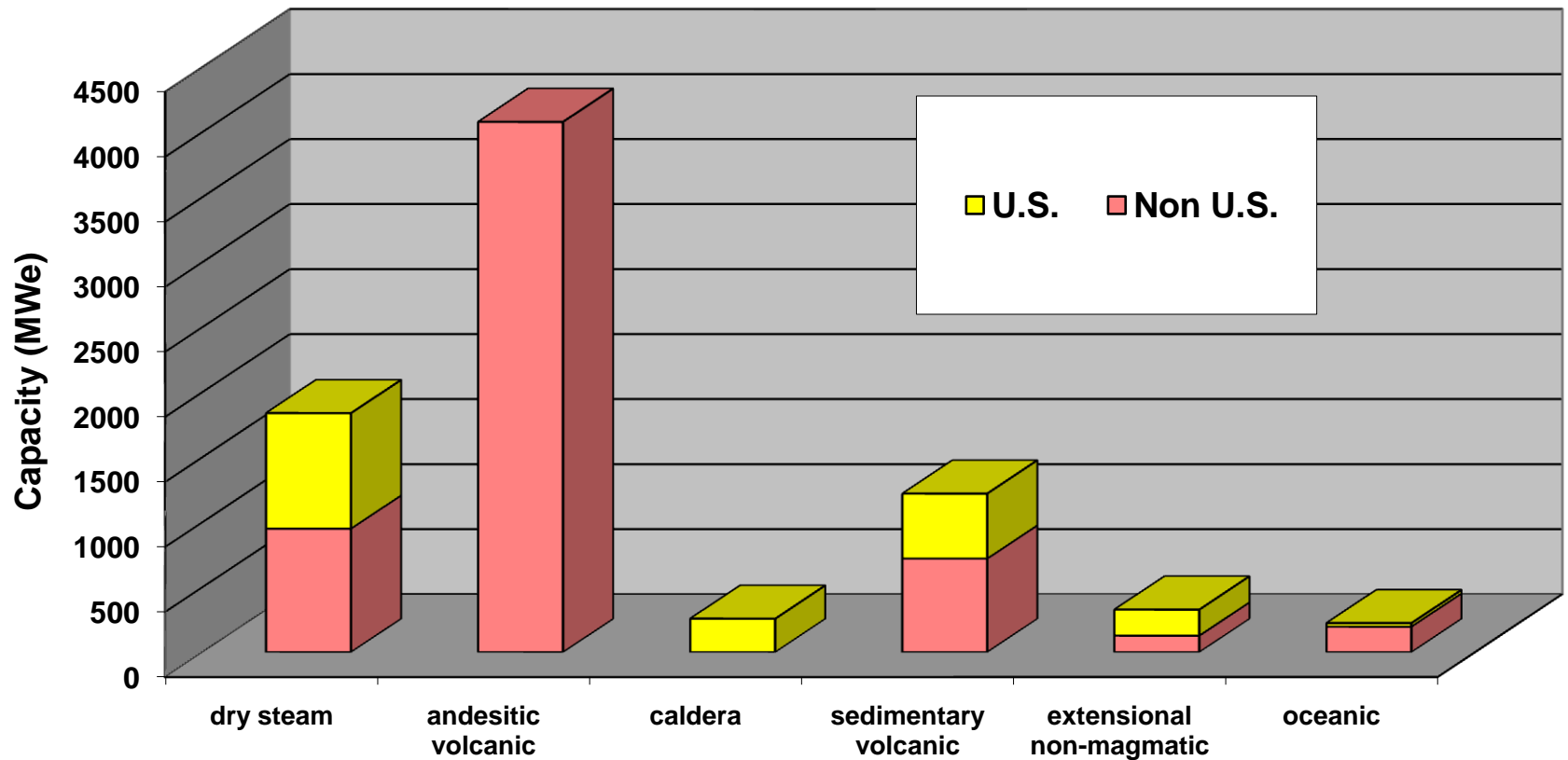


# **Current U.S. Geothermal Development Areas**

# Worldwide Geothermal Resources



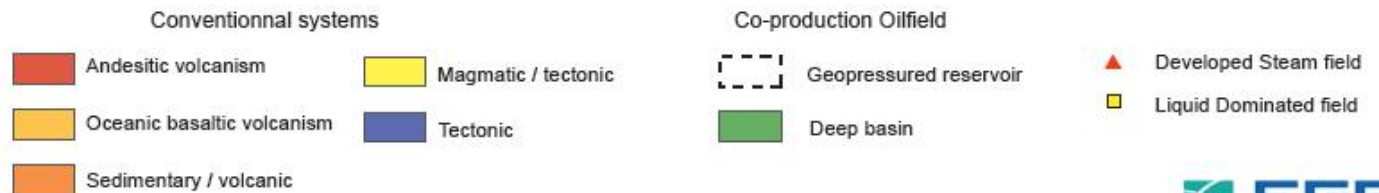
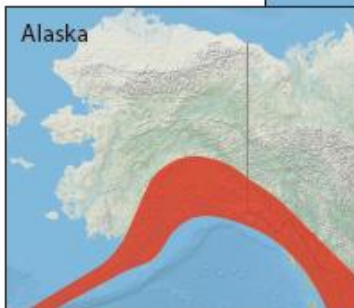
# U.S. Proportion of World Geothermal Resources



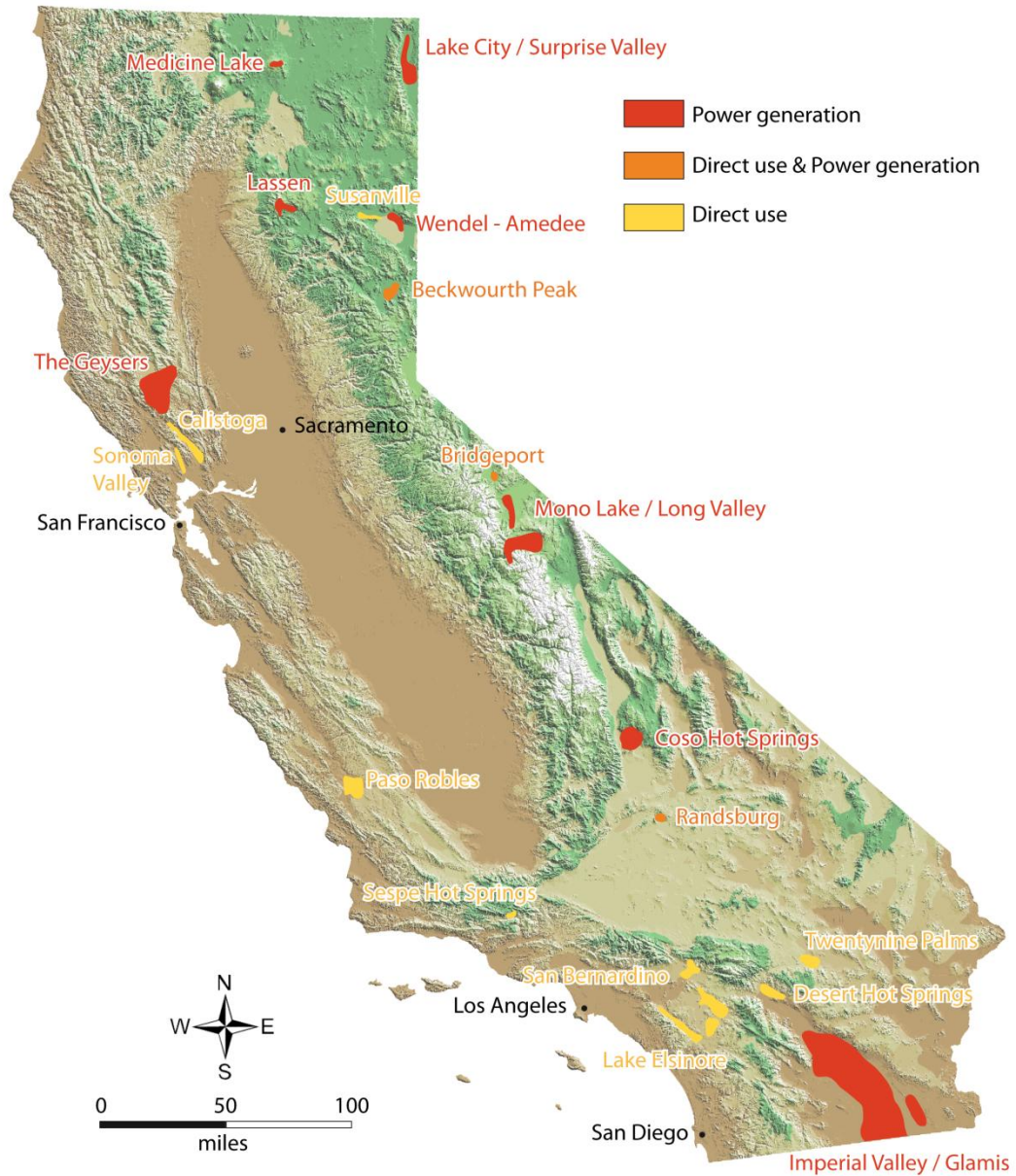
Brophy, 2008



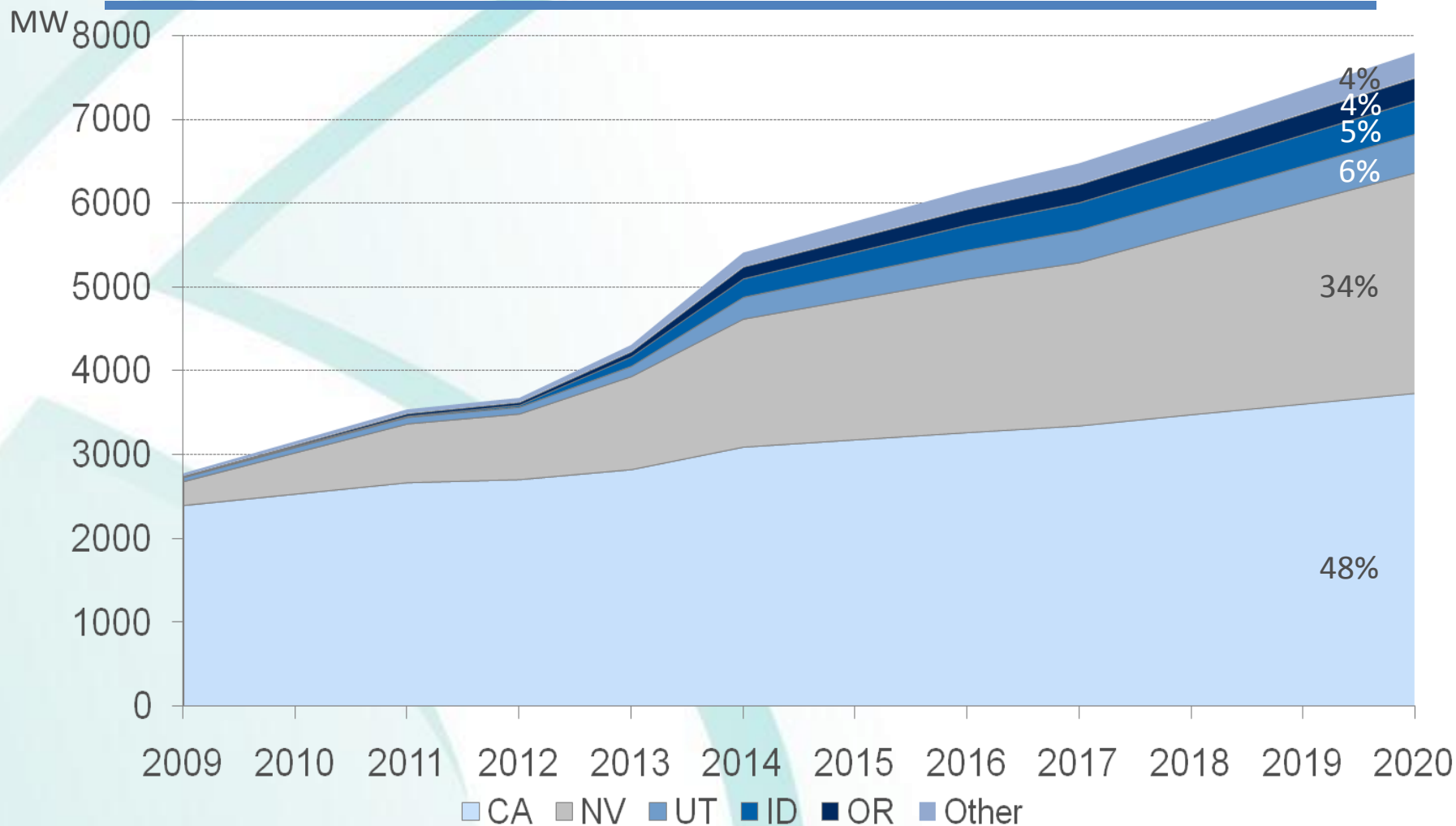
## Potential Geothermal Provinces of the United States



# Geothermal Resources in California



# US Geothermal Forecast to 2020



Note:

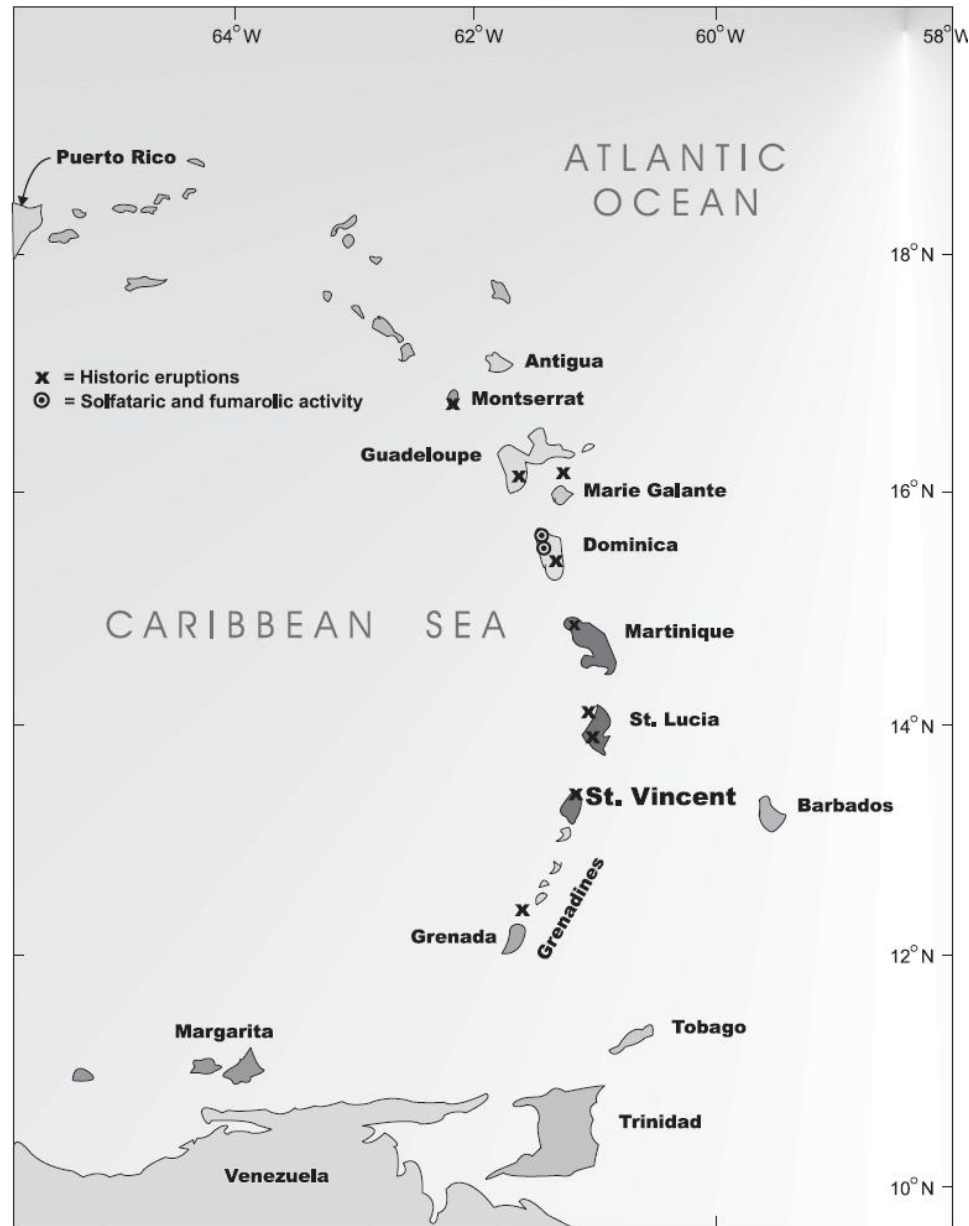
Source: New Energy Finance



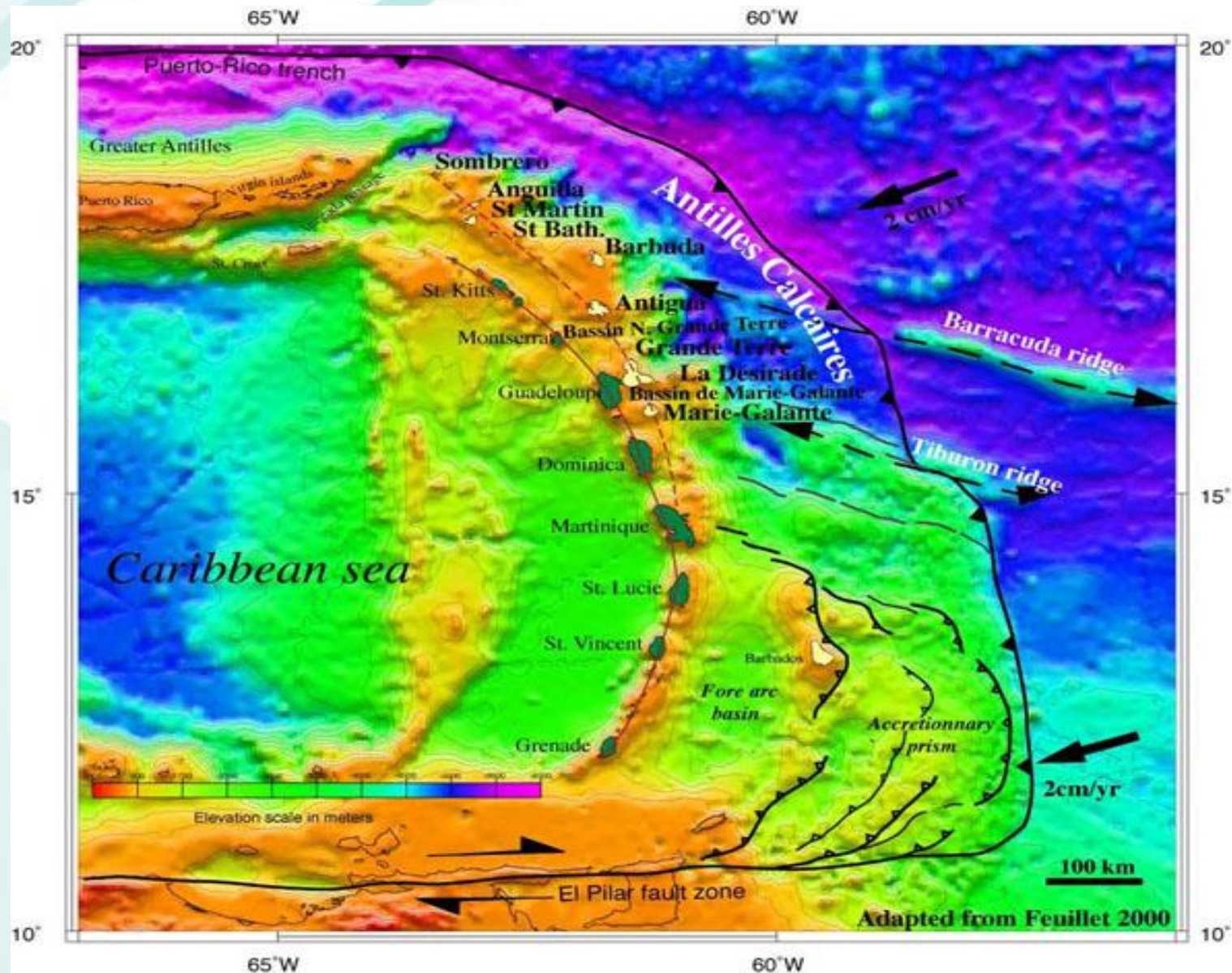
# ***Geothermal Development in The Caribbean Islands***



# Islands of the Caribbean



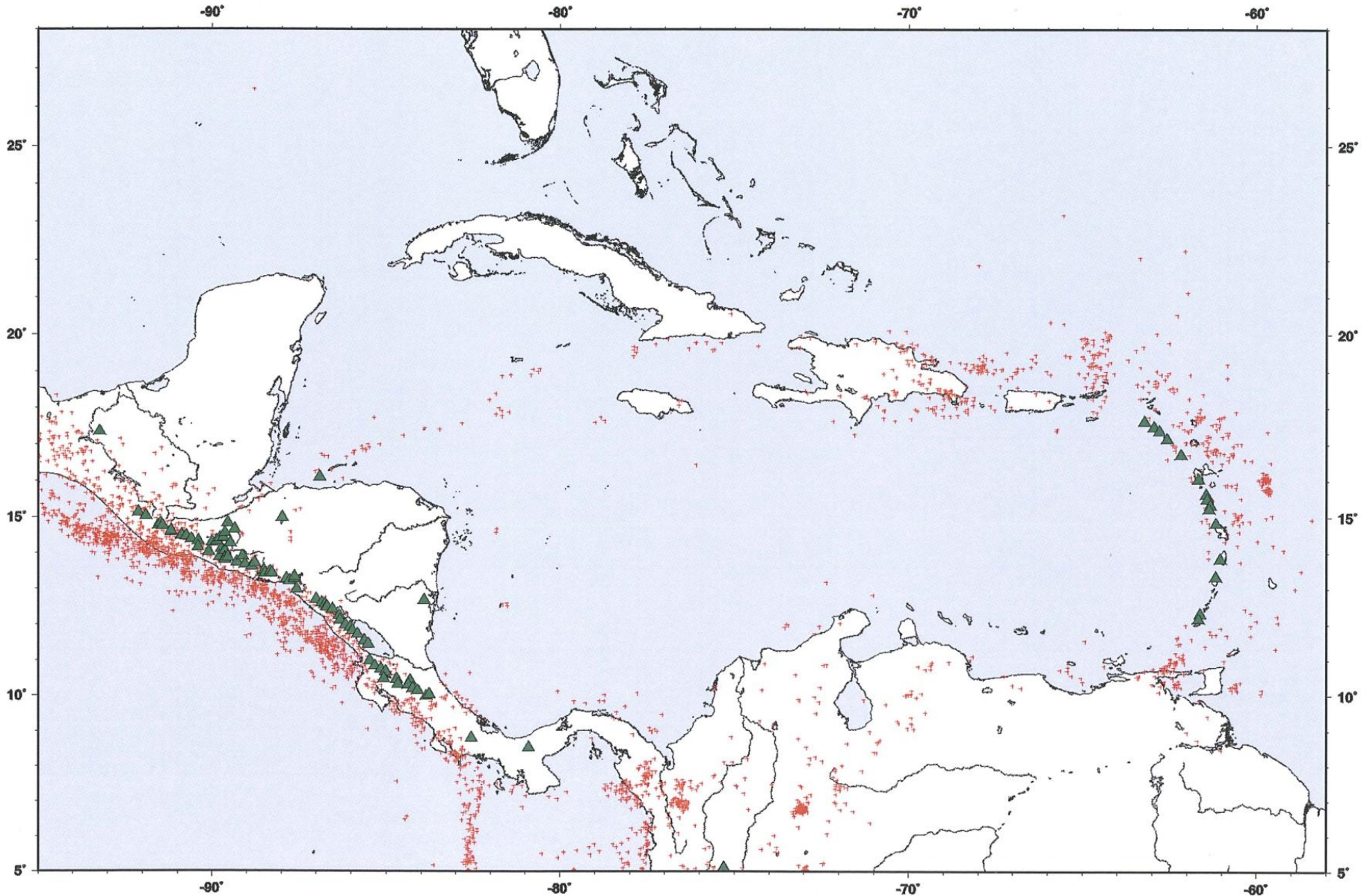
# Regional Tectonics of the Caribbean





# Volcano and Earthquake Data from the Caribbean

Earthquakes and Volcanoes in the Caribbean Region



Nevis,  
Your oer skirts  
show your faults.

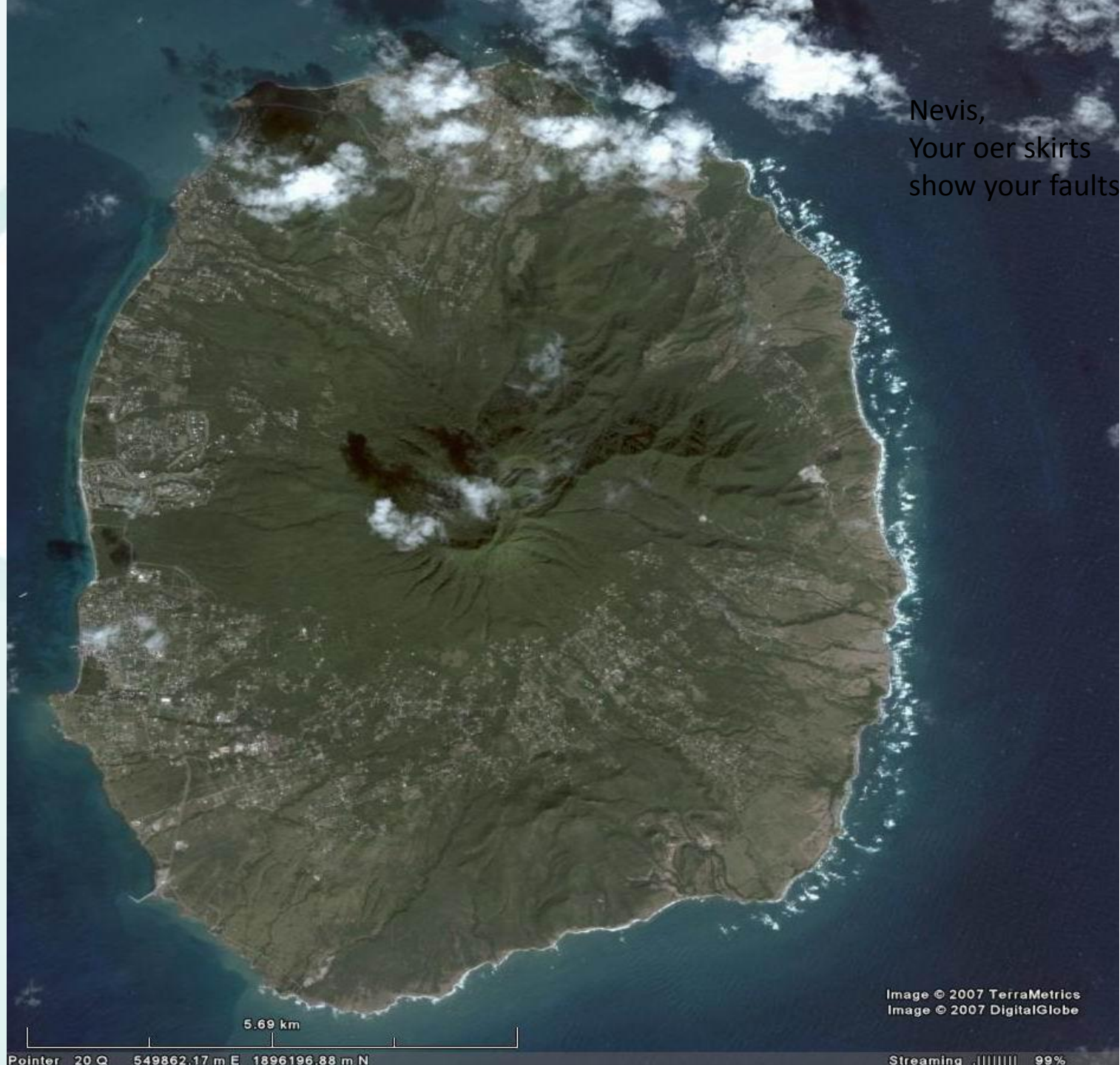


Image © 2007 TerraMetrics  
Image © 2007 DigitalGlobe

5.69 km

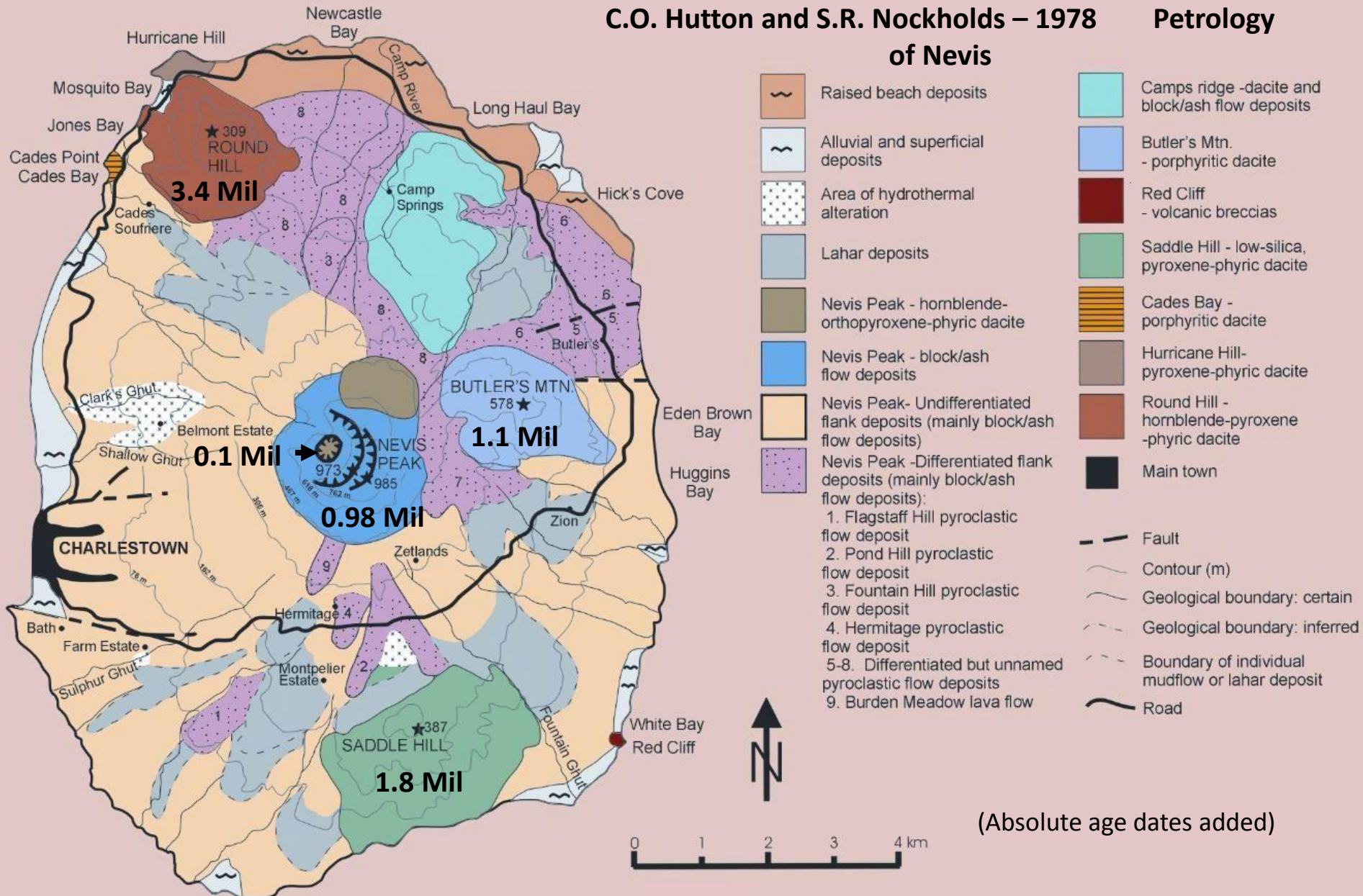
Pointer 20 Q 549862.17 m E 1896196.88 m N

Streaming .||||||| 99%



# C.O. Hutton and S.R. Nockholds – 1978 of Nevis

## Petrology









## *Southern Portion of Montserrat*

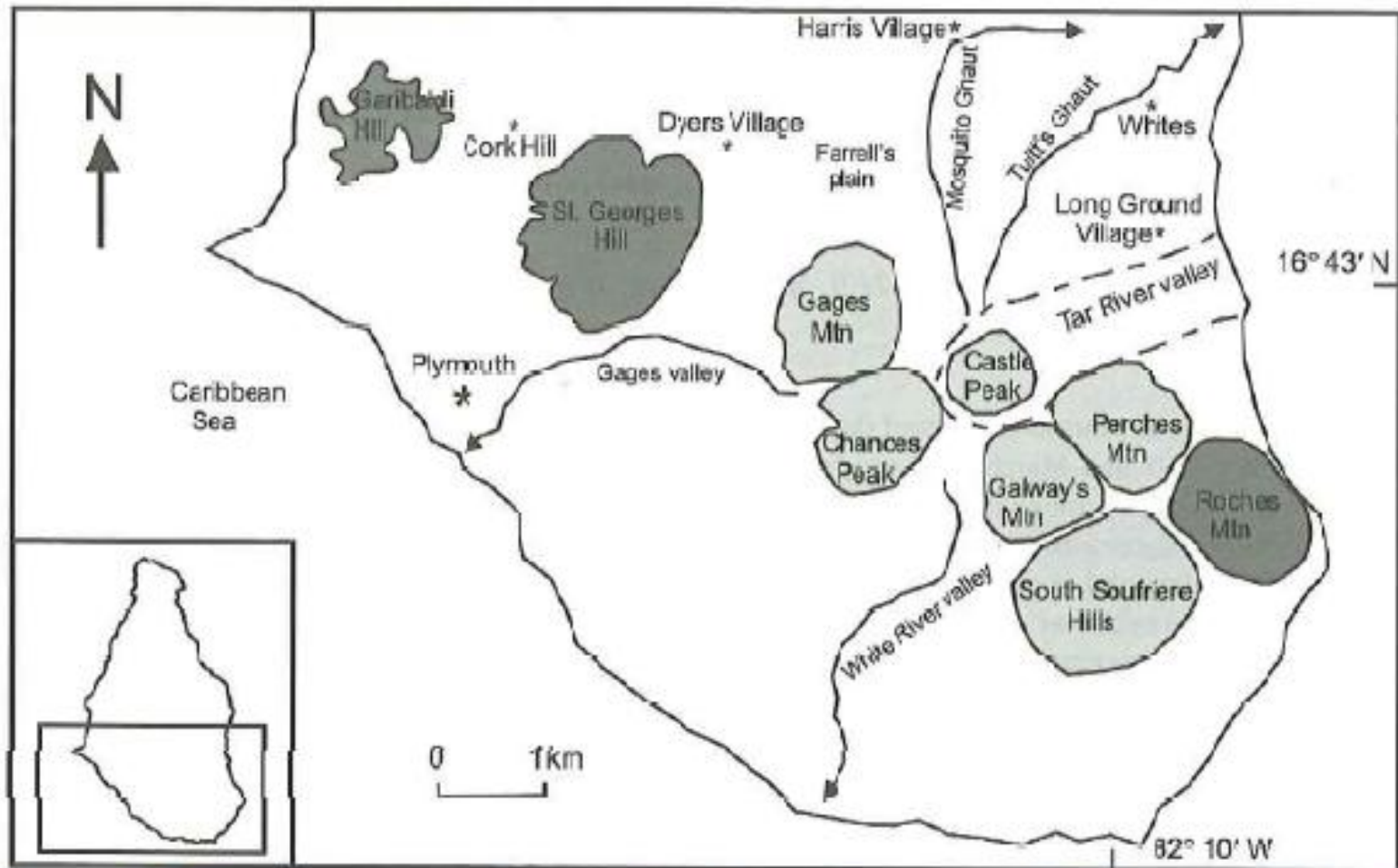


Figure 2.6 Eruptive center alignment in the southern part of Montserrat island.

# *Geothermal Development on Montserrat*

