



Introduction

Geothermal exploration on Milos island started in 1971 by the Institute of Geological and Mining Research/Exploration of Greece (IGME) with the following exploration surveys:

- Geological mapping
- Mapping of thermal manifestations
- Soil and water sampling and geochemical analysis
- Thermal gradient mapping by drilling shallow boreholes (50-80m depth)
- Schlumberger resistivity surveys by IGME and CGG in 1972-1973
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- Drilling the first two deep wells MA1 and MZ1 in 1975-1976

The above information was complemented in 1977, by ENEL, which carried out on behalf of the Public Power Corporation of Greece the following surveys:

- Volcanologic, hydrogeologic, thermal, stratigraphic and structural features
- Geochemical investigation sampling hot springs, shallow and deep wells
- Logging and testing deep wells MA1 and MZ1

In 1981, deep wells M1, M2 and M3 were drilled by the Public Power Corporation in Zefyria plain, reaching depths 900-1350 m. The project was supported by the European Commission.

Between 1982 and 1984, a gravity survey and additional DC-Schlumberger resistivity surveys were carried out by the Institute of Geological and Mining Research on behalf of the Public Power Corporation of Greece. These surveys were part of a wider project on Milos geothermal exploration, which was supported by the European Commission, and also included volcanologic, petrologic, mineralogical, tectonic and geomorphologic studies.

Between 1985 and 1987 the European Commission supported a series of geophysical investigations on the island including MT soundings by 4 European teams (Technical University of Braunschweig, BRGM, University of Edinburgh, and the University of Frankfurt), monitoring of micro earthquakes by RWTH-Aachen, the Institute de Physique du Globe de Paris and BRGM, as well as self potential and magnetic surveys by IGME.

In 1991 CRES estimated the conductive heat flow over the island of Milos, by integrating the temperature gradients near the surface.

During the summers of 1996-1999 sampling and analysis of submarine springs near Milos coast was done by scientists from the National History Museum of London, the National University of Athens, the University of Nottingham, the Scottish Universities Environmental Research Centre, the College of Staten Island, the University of London and the University of Bristol.

Results: Geology

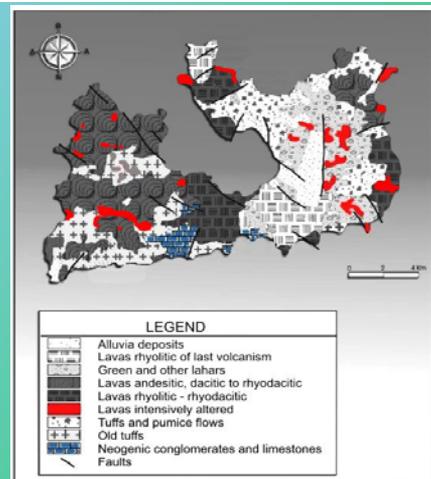


Figure 1. Geology and main faults of Milos island. (adapted from Drakoulis et al. 2005)



Figure 2. Thermal manifestations on Milos island. (adapted from Fytikas 1977)

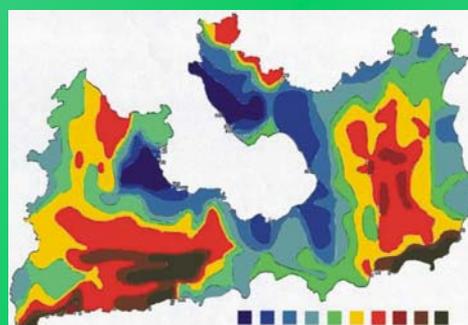


Figure 3. Top of basement depth on Milos as derived from interpreting gravity data. (adapted from Public Power Corporation 1986)

Results: Deep Wells

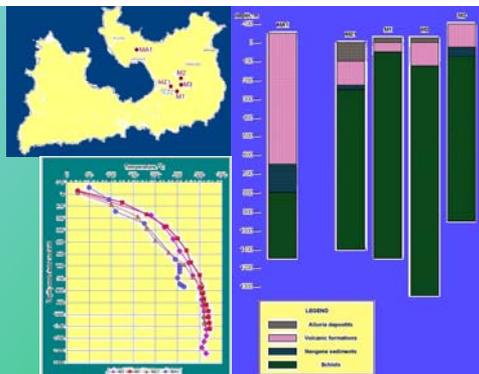


Figure 4. Deep wells: location, stratigraphy and static temperature profiles

Results: Geochemistry



Figure 9. Distribution of main water types on Milos and Kimolos islands.

Results: Geophysical surveys

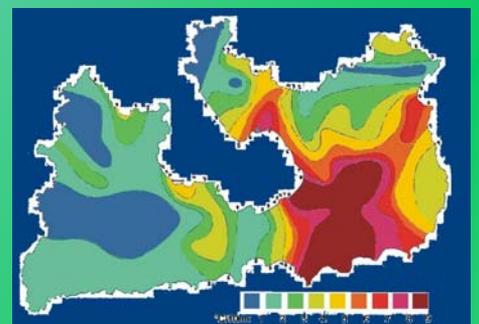


Figure 5. Temperature gradients in °C/10m on Milos. (adapted from IGME map)

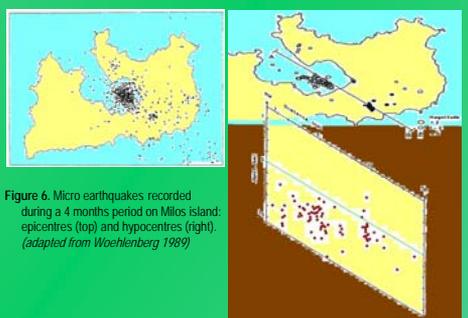


Figure 6. Micro earthquakes recorded during a 4 months period on Milos island: epicenters (top) and hypocenters (right). (adapted from Wohlenberg 1989)



Figure 7. DC-Schlumberger resistivity survey: apparent resistivity map for AB/2 = 1000m, which corresponds to electric current penetration down to 700m.



Figure 8. MT resistivity surveys: apparent resistivity map at 1Hz, which corresponds to electric current penetration down to 1000m.

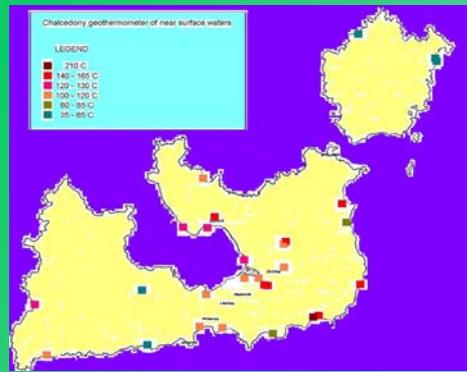


Figure 10. Expected temperatures of intermediate depth waters below Milos and Kimolos islands, as derived from chalcodony geothermometer.

Conclusions

The presence of geothermal alteration in the surface, geothermal gradients and geoelectric soundings indicate that the entire island should be of geothermal interest in terms of medium and high enthalpy resources.

Shallow water table present within the alluvia deposits and the volcanic formations contains warm water, the temperature of which is higher in Vouvalia (50-100°C), where the most recent volcanic activity took place. The origin of these waters points to deeper water bearing formations of 80-165°C beneath the east half of island and the south western part of west island.

Altered tuffs (argillic alteration) are impermeable formations forming a cap rock for the deeper reservoir encountered within the neogene sediments. They are responsible for the extremely low apparent resistivity measured east and south east of inner Milos bay (Zefyria plain and Vouvalia).

Neogene sediments have high permeability and if encountered at sufficient depth and have sufficient thickness (up to 150-200m) they form a geothermal reservoir of expected temperature within the range 100-250°C. Most promising areas are in and around the inner Milos bay, including Adamas area in the north where well MA1 is located and Vouvalia area in the south.

The metamorphic basement comprises green schists of extremely low permeability. However, in the vicinity of active faults where fracture permeability has been created and maintained by seismic activity, hot water is present of 310-325°C temperature and 75,000-80,000 TDS salinity of 45,000 ppm chloride. Deep wells intersecting these faults yield 20-45 kg/s fluids of high enthalpy (two phase water and steam), sufficient to produce 2.5-10.0 MWe per well. As the basement outcrops only to a limited area at the south-eastern coast of Milos, its faults are hidden and their location must be determined by geophysical surveys, as they should be the targets for deep exploratory and production wells. Temperatures higher than 300°C are encountered below 1 km depth. The best geophysical method able to locate these faults down to 3-5 km depth is the 'reflection seismics' one.

Geochemical data and resistivity surveys (both DC-Schlumberger and MT) indicate the presence of an active hydrothermal system beneath the east part of the island. Regarding its extent in other parts of the island, MT data indicate promising areas also near the coast southwest of Milos bay. There is also some sparse geochemical evidence of the presence of geothermal fluids of intermediate temperature at the south-western part of the island.

Seismic and micro-seismic activity is ongoing with hypocenters distribution beneath the inner part of Milos bay, extending towards the north in Adamas and nearby area, and towards southeast and east towards the east part of the island. This seismic activity indicates the maintenance of open fractures in the above areas, which form the flow path of rising deeper geothermal fluids of temperature 300-325°C. These fluids are expected to rise from ~5 km depth. The area with the highest heat flow from depth is located southeast of Milos bay, coinciding with the surface presence of the rhyolitic lava domes and lava flows of the most recent volcanism, where the majority of thermal manifestations (hot soil and fumaroles) are also encountered.

Further geophysical exploration needs

Objectives of future surveys:

- Thickness of neogene sediments
- Location of main fault zones down to 3 km

Proposed methods:

- AAMT with 3-D inversion in the entire island & Milos bay
- Reflection seismics

References

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