CIRCULATION OF THERMAL WATERS ON PANTELLERIA ISLAND (SICILY CHANNEL, ITALY)

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Kcy words:

Volcanic islands. thermal waters, groundwater circulation, Pantelleria.

Ahstract

Recent geothermal exploration on Pantelleria, a volcanic island within the Sicily Channel. located a water-dominated geothermal field in the southern part of the island. The water-dominated reservoir. characterized by temperatures of around 250 °C. has recently been tapped by a deep producing well (1100 in).
During the survey a large number ofwater samples were collected froin shallow water-wells and some natural manifestations, The analysis of these samples was integrated with geochemical and thermometric observations carried out in exploratory wells scattered over the island.
The data collected. together with the thennodynamic and geochemical characteristics of the deep wells. suggest that the major contribution to the deep fluid comes from the sea. A ground-water circulation model is discussed. This model proposes that the thermal waters. mainly mixtures of meteoric and sea waters. flow towards the coast in the shallow part of the aquifer. and an inflow of colder sea water occurs at depth in the island.

INTRODUCIION

Pantelleria island is a volcanic island located in the Sicily Channel about 100 kin froin Sicily and 70 kin froin Tunisia. About 13 by 8 km in dimensions. the island lies parallel to the still active rift system of the Sicily Channel and represents the emerging part of a submarine volcano. This volcano rises froin a depth of about 1200 m b.s.l. to a maximum elevation of836 m a.s.l at Montagna Grande (Fig.1).

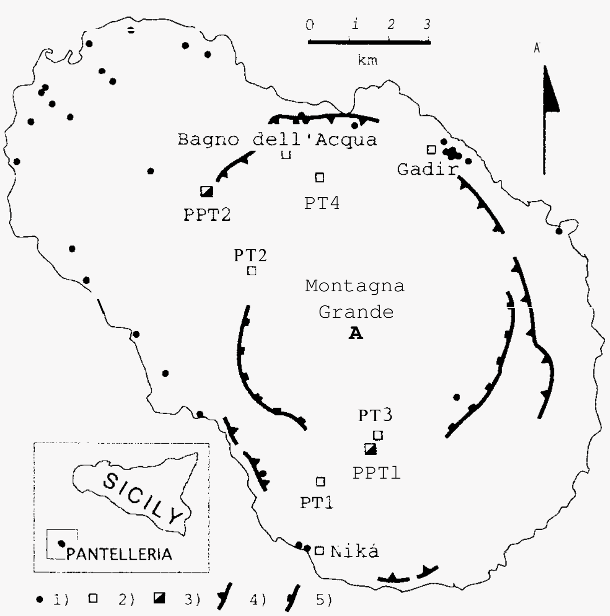

Fig. 1 - Location of the different features. 1) water-wells and springs, 2) shallow exploratory wells, 3) deep exploratory wells. 4) old caldera rim, 5) young caldera rim.

Important thermal manifestations. such as waters with temperatures between 20 and 80 °C. fuinaroles and gas manifestations characterize the island and indicate the existence of interesting geothermal activity. The first geothermal exploration survey on Pantelleria dates hack to the late sixties (Barbier. 1969) when four exploratory boreholes were drilled.
In 1990 a new geothennal exploration project on Pantelleria island was carried out by CESEN sponsored by the European Union and the Sicily Mining Hoard (Chierici *et al.*, submitted). During this project. geological. geophysical aiid geochemical osbervations carried out, also in four new 180-400 m deep exploratory wells. indicated that the most promising geothermal zone was in the southern-central part of Pantelleria (Squarci *et al.*,in press). This was confirmed by drilling two deep (1100-1200 m b.g.l.) exploratory wells. The well located in the southern-central part of the island (Fig. 1), which tapped some producing fractures, is characterized by a temperature of250 °C at 750 m b.g.l.; the well drilled in the north-western part of the island revealed a very low permeability and has a temperature of 127 °C at 950 in b.g.l. The geophysical and geochemical data collected from the exploratory wells. shallow water-wells and natural manifestations have provided important information on the ground-water circulation on Pantelleria island.

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

At Pantelleria the exposed rocks are mainly represented by lavas and pyroclastic deposits, mostly made up of pantellerites and trachytes, and, subordinately, of alkali basalts.
The island has been affected by intense volcanic, tectonic and volcano-tectonic activity. with a frequency of 13 ± 6 ky for the major eruptive cycles (Mahood and Hildreth. 1986; Civetta *et al.*,1988). Two submarine eruptions occurred in the last century in the vicinity of the island.
Two nested calderas are found the island. the younger of these. with a diameter of 6 km, being the dominant topographic feature.
The structural setting of Pantelleria is defined mainly by faults aiid fractures that follow the regional N-S and NE-SW trends.
Most of the volcanic products cropping out on the island are significantly fractured. with fractures of a few decimeters in some cases. The lava flows generally exhibit a higher degree of fracturing than the tuffs. even though the tuff formations are locally crossed by large fractures that can act as important ground-water circulation pathways. as in the case of Bagno dell'Acqua well (Barbier. 1969). In this well, which has a transmissivity of 0.15 m^2/s, consistent circulation losses were observed in correspondence to an ignimbrite layer.
Precipitation is generally scarce on the island. The mean annual precipitation depth recorded in the period 1951-1988 was **441** mm, with an estimated actual evapo-transpiration in the range 350 - 400 mm (Gianelli *et al.*, 1991). Meteoric recharge is low on Pantelleria .

IN HOLE - TEMPERATURE OBSERVATIONS

Figure 1 shows the locatioii of the different water-points (water-wells. springs, exploration wells). **All** the water-wells are drilled into the shallowest part of the water-table. which is generally located a few meters a.s.l., and cannot he used to obtain data on temperature distribution at depth. The temperature distribution at depth has been investigated by carrying out in-hole temperature measurements in the shallow exploratory wells (Squarci *et al.*, in press; Bellani *et al.*, submitted)scattered over the island.
With the exception of wells Pt1 and Pt3. which have particular temperature conditions (Bellani et al., submitted). all the other exploration wells drilled to depths in the range 50-80 m b.s.l.. are characterized by temperature profiles as shown in Fig. 2. This figure reports the temperature profiles for wells Pt4 and Nika'.

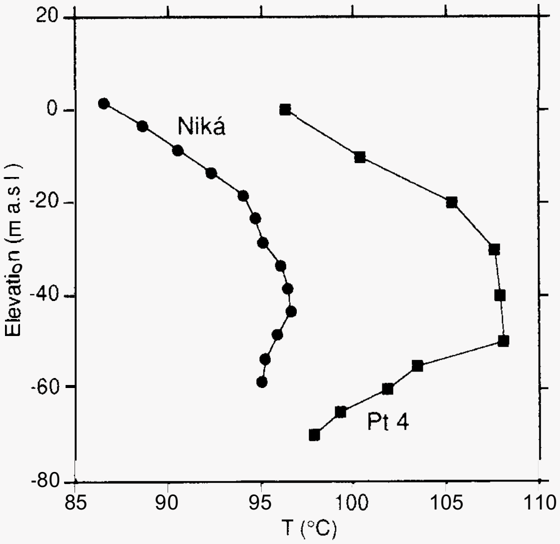

Fig. 2 -Temperature profiles with depth for two shallow exploratory wells.

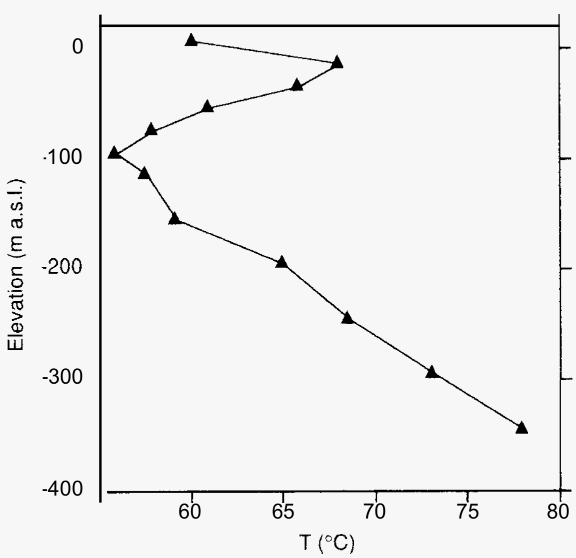

Fig. 3 - Temperature profile for the deep exploratory well PPT2

Temperature inversions with depth are not confined to the wells close to the coast, but have also been observed in the deep exploratory well PPT2 drilled in the north- western part of the island. Figure 3 reports the temperature distribution to a depth of 400 m b.s.l for this well. An abrupt increase in temperature characterizes the shallowest part of the aquifer system below sea level, and overlies a colder zone whose temperature then increases more or less monotonically with depth.
The temperature inversions seem to be common on Pantelleria island.

GEOCHEMICAL INDICATIONS

The geochemical characteristics of the thermal waters of Pantelleria. as well as the geothermometric aspects. have been discussed by Dongarra *et al.* (1983) and Squarci et *al.* (in press). Recent data, mainly collected from the exploratory wells in 1993, are integrated with the previous observations in this paper.
Most of the thermal waters of Pantelleria are of the Na-Cl type, with TDS values in the range of 1-29 g/l. Only two samples are of the Ca-HCO_3 type with salinity of 0.1-0.3 g/l. The presence of Na-HCO_3 type waters on the island has recently been revealed by the exploratory well Pt2 that tapped a perched aquifer characterized by a tritium content of 15 T.U. Tritium is generally low or absent in the Cl rich waters (Squarci *et al.*,in press).
The thermal waters of Pantelleria are generally characterized by a very low Ca-Mg content, due to alkaline-earth carbonate precipitation, and by a bicarbonate enrichment (Dongarra' *et al.*, 1983) that is probably related to CO_2 dissolution in groundwater. CO_2 represents up to 99% ofthe the non-condensable gas manifestations on the island.
In December 1993 samples were collected of the water entrained (PPTle) in the vapour produced froin well PPTl during a production test. Samples (PPTla. PPTlb) were also collected from different depths of this well six months before the test and prior to well stimulation. Of all the wells characterized by temperature inversions. the two shallow exploratory wells Pt4 and Bagno dell'Acqua. are the only ones that permit the use of a sampler. Water samples were collected in these wells in correspondence to the maximum observed temperature (Bal.Pt4a) and to the bottom-hole (Ba2.Pt4b). All the water samples are Na-Cl in composition. The salinity of these waters increases froin 11-15 g/l (PPtla. PPTlb. Bal. E4a) to about *35* g/l (Ba2. E4b). reaching a maximum value of30 g/l for sample PPTle.

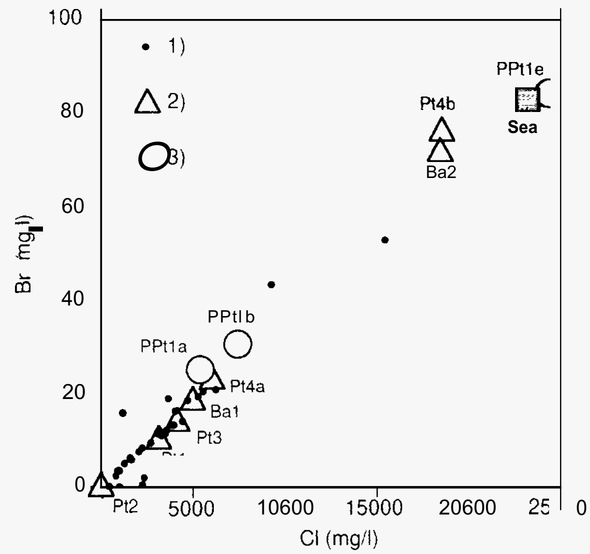

Fig. 4 - Br vs. Cl for: 1) water wells, 2) shallow exploratory wells. 3) well PPT1. PPTla. PPTl b indicate water sample collected at different depths from well PPTI prior to well-stimulation: PPTle refers to the water entrained in the vapour produced by this well during a production test. Bal and Pt4a indicate water samples collected in correspondence to the maximum observed temperature and Ba2 and Pt4b to the bottom-hole of wells Bagno dell'Acqua and Pt4 respectively.

The Br vs. Cl plot shown in Fig. 4 indicates that the waters in the island are mixtures. in different proportions. of meteoric and sea water. Apart from two water-wells that have intermediate characteristics, most of the waters. which come from the shallowest part ofthe unconfined aquifer. seem to be mainly influenced by the meteoric watrr component. The meteoric component. which practically coincides with the tritium-rich water of well PT2. is also prevailing in some exploratory wells such as Pt1 and Pt3 and seem to influence to a significant extent the waters Bal. E4a. PPt1 and PPt1b.
From figure 4 it would appear that sea water is the only component of the water entrained in the vapour delivered by well PPTl during the production test. and represents almost 80 % of the mixtures collected in correspondence to the bottom-hole of wells Pt4 and Bagno dell'Acqua.
The water PPTle and samples Ba2 and Pt4b are close to the local sea-water isotopic composition in Fig. 5, which shows δD vs. $\delta^{18}O$ for the considered waters. as well as the central Mediterranean meteoric line (MCML). Although a certain scattering of water-points is observed in this figure. a number of water samples fit along the line representing the mixing between the meteoric water and the sea water. However. this line is also influenced by evaporation processes that arc probably a result of the flow of thermal groundwater under unconfined conditions. These processes. highlighted by the plot of δD vs. Cl content in Fig. 6, produce isotopically heavier waters and shift samples Ba2 and Pt4b towards the sea-water point in Fig. 5. Both mixing with sea-water and evaporation processes influence the isotopic composition of groundwater circulation at Pantelleria.
The geochemical information indicates that there are significant differences between the shallow hotter and deep colder waters of Bagno dell'Acqua and PT4 wells. the deeper circulation being mainly represented by sea water. The sea-water penetration into the island can be considered responsible for the temperature inversion normally observed at depth at Pantelleria. Assuming that sample PPTle is representative of the geothermal fluids. the sea-water should also be the major component ofthe geothermal reservoir.

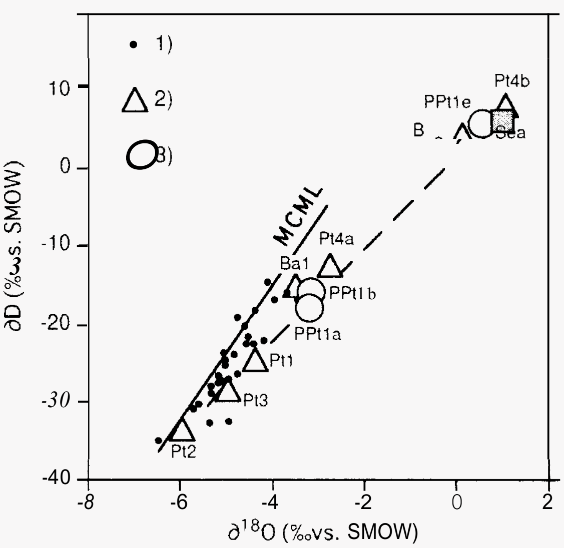

Fig. 5 - ∂D vs. $\partial^{18}O$ for the different waters. 1) Water wells, 2) shallow exploratory wells. 3) ucll PPTI. For explanation of numbers, see text or Fig.4

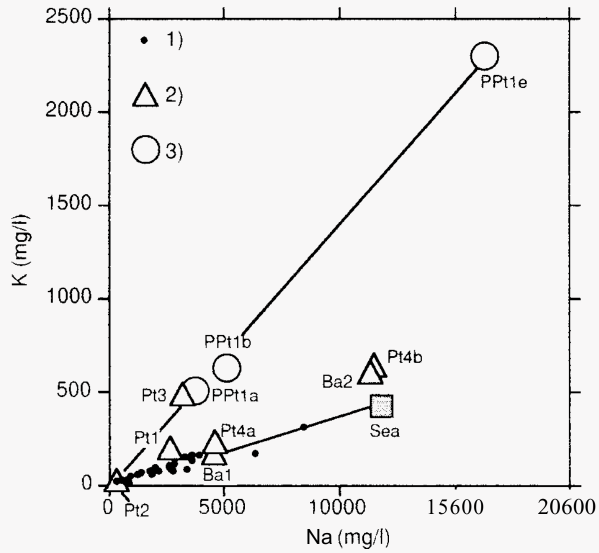

Fig. 7 - ti vs. Na for : 1) water wells, 2) shallow exploratory wells, 3) well PPTI. For explanation of numbers, see text or Fig.4.

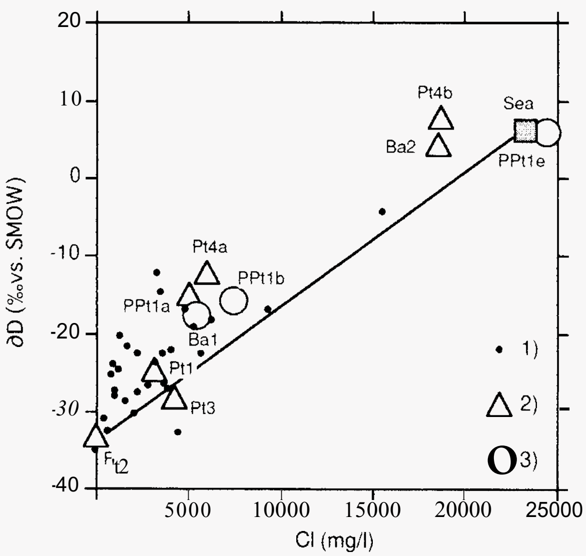

Fig. 6 - ∂D vs. Cl for the therinal waters of Pantellerla island. 1) Water wells. 2) shallow exploratory wells. 3) well PPTI. For explanation of nuinbers. see text or Fig.4.

Figure 7 reports K vs. Na for all the water samples. It is interesting to note that the geothermal waters (PPt1e, PPt1a, PPt1b and Pt3) till along a straight line evidencing an enrichment in K. Most of the water samples, on the other hand, plot along a line indicating a direct mixing between the meteoric component and sea-water. Samples Ba2 and Pt4b, which plot close to sea-water, are slightly enriched in ti. These trends could indicate that water from the sea and/or mixtures of this water with the meteoric component, after penetrating the island at depth, started to interact with the rocks, acquiring K as a result of the higher temperatures occurring along their circulation pathways.

GROUND-WATER CIRCULATION MODEL AND CONCLUSION

Figure 8 reports a possible groundwater circulation inodel for Pantelleria island.

The shallowest part of the aquifer system is mainly characterized by mixtures of the meteoric recharge and the sea-water that flow froin the inner part of the island towards the coast. This thennal circulation overlies a colder, more saline tluid that seems to be mainly represented by **sea** water or mixtures of this water with the meteoric component. According to the temperature indications this colder circulation should flow into the island where it interacts with the host rocks as a result of high teinperature conditions existing on its route within the island.

According to this model. and considering also the low meteoric water recharge estimated for the island, the major source of water for the geothermal resenoir should be the sea-water as it seems to he suggested also by the entrained water in the vapour produced by well PPTI. Contributions to the geothermal reservoir froin meteoric water are also possible.

More geothermal wells are expected to he drilled at Pantelleria. In-hole temperature data and geochemical observations will better clarify the groundwater circulation model of this island.

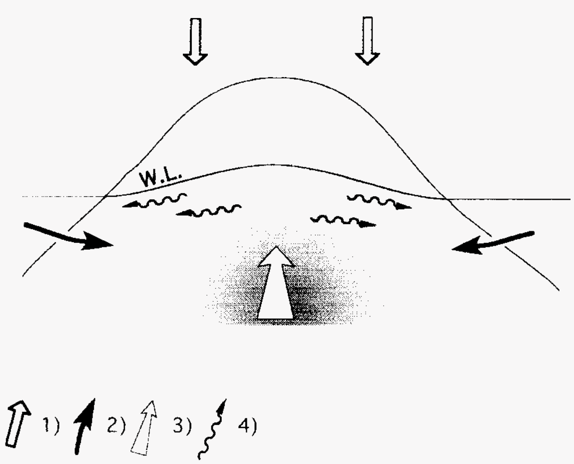

Fig. 8 - Ground water circulation model for Pantelleria island. 1) meteoric recharge, 2) sea water, 3) deep geothermal fluid, 4) mixtures. W.L. = water level.

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