Convective water circulation in a geothermal Island: Pantelleria (Sicily channel)

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ABSTRACT

Pantelleria, a small volcanic island located in the Sicily channel, contains a water-dominated geothermal field in its southern part. The reservoir, characterized by temperature of about 250 °C, was tapped by a 990 m deep well, which highlighted the existence of deep fluids of marine origin significantly depleted in Ca and Mg and enriched in Si and K due to the interaction with trachytic rocks hosting the geothermal reservoir. Significant temperature inversions with depth are observed between 20 and 100 m b.s.l in five shallow exploratory wells drilled throughout the island. These inversions are due to hot waters which, with temperature up to 110 °C and represented by variable mixtures of meteoric recharge and sea water, flow over a denser and colder sea water from the inner to the external parts of the island. The hydrogeological conceptual model foresees a groundwater circulation characterized by convective flows whose main engine is represented by the geothermal system.

INTRODUCTION

Pantelleria is located in the medium part of the continental rift between Sicily and Tunisia (Fig.1A). It is the emerging part of a submarine volcano 836 m a.s.l and about 1200 m b.s.l. Different volcanic cycles were identified with pyroclastic and lava flow products which are mainly of pantelleritic and trachytic type (Mahood and Hildreth 1986, Civetta *et al*., 1988). Two nested calderas which are related to significant episodes dating back to 50-10 ky, characterize the island morphology. The surface geothermal evidence is represented by fumaroles, mofettes, and hot springs with temperatures up to 98 °C. A geothermal prospecting (Squarci *et al*.,1994, Chierici *et al*., 1995) carried out in the early '90s highlighted the existence of a water dominated reservoir with temperature of about 250 °C in the southern part of the island which was tapped by a 990 m deep exploratory well.

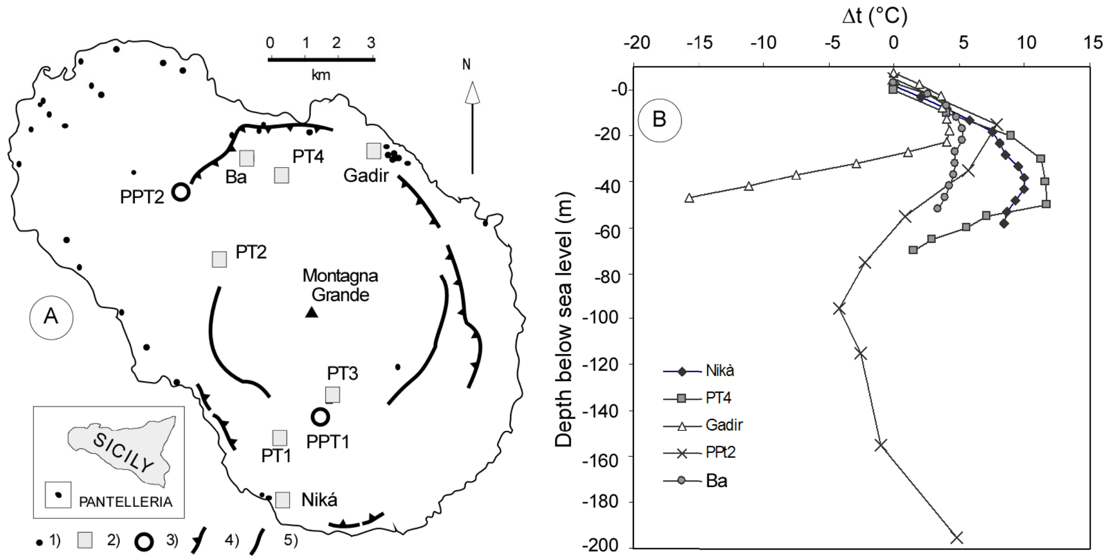

Fig. 1. A) Schematic map of Pantelleria: 1) water wells and springs; 2) shallow exploratory wells; 3) deep geothermal wells; 4) young nested caldera rim; 5) older caldera rim. B) temperature variation with depth with respect to the temperature measured at water level in five exploratory wells.

In-hole temperature measures, carried out in five exploratory wells scattered over the island, together with chemical and isotope sampling and analyses is used to characterize the groundwater circulation within the island.

TEMPERATURE PROFILES

Apart from the deep slightly steam producing (4 tons/hour) deep well PPT1, most of the other exploratory wells are characterized by temperature inversion as shown by Fig.1B which reports the temperature variations with depth with respect to that measured at the water table. It is worth to point out that in well PPT2, an exploratory deep well located in the northern part of the island, below the inversion, the temperature increases regularly with depth up to maximum of 126°C at 1000 m (bottom hole), thus indicating mainly an heat flow conductive regime, possibly related to the rock low permeability.

GEOCHEMICAL DATA

Samples were collected from different depths (660 and 990 m) from well PPT1 and during a subsequent production test. The data collected indicate the fluids, of the Na-Cl type, having Cl/Br (meq/L) ratios close to 500, are significantly affected by sea water and, with respect to this, are depleted in Ca and Mg and enriched in Si and K, depending on the dissolution of K-rich rocks and deposition of secondary calcite and clay minerals (Gianelli and Grassi, 2001). Despite other samples collected from the shallow water table mainly in the northern part of the island, water specimens were also collected just above the temperature inversion and at the bottom-hole of wells Bagno dell'Acqua (Ba) and PT4 (Tab.1), the only wells which permitted in-hole sampling.

Tab. 1 Chemical (mg/L) and stable isotope composition (in ‰ vs. V-SMOW) of some water of Pantelleria Island. Numbers in brackets represent the sampling depth, nd=not determined

Sample	Na	K	Ca	Mg	Cl	HCO3	SO4	B(OH)3	SiO2	Li	F	Br	δ18O	δD
Ba(25)	2610	173	121	101	5120	nd	81.8	10.3	99	0.74	5.5	18.9	-3.42	-14.90
Ba(50)	11600	645	101	451	18700	976	596	40	39.2	4.8	3.3	72.6	0.18	4.40
Pt4(140)	4590	221	16.1	34.6	6100	1013	450	23.4	213	1.1	11.4	23.5	-2.71	-12.12
Pt4(180)	11400	611	346	874	18800	769	2120	30.2	223	3.5	7.1	76.6	1.11	8.00
PPT1(660)	3750	500	6.5	0.17	5530	652.7	158	12	311	0.72	26.7	25	-3.17	-17.80
PPT1(990)	5190	623	6.3	0.17	7520	674.7	269	17.1	513	2.9	20.8	30.5	-3.13	-15.80
Local Sea Water	11870	443	461	1410	23401	152	2962	nd	nd	nd	1.2	nd	1.04	8.2

Clear differences exist between the sampled waters. Those from the well bottom, as suggested also by the water stable isotope content, practically coincide with a sea water which undergoes to significant interaction processes with the hosting rocks, whereas the shallower samples are mixtures of sea water and meteoric recharge (δ^{18}O= -5.92 and δ^{2}H= -33.2‰ vs. V-SMOW) affected by a lower degree of interaction as indicated by their K concentration.

FLOW PATTERN

Figure 2A shows a scheme of the possible groundwater circulation of Pantelleria Island and the relations between Na and K for relevant waters. Both temperature and geochemical data concur to indicating a groundwater circulation characterized by a penetration of cold sea water in the aquifer system overlain by a hot water outflow from the inner part of the island towards the coast, thus suggesting a convective pattern. The shallower outward flow could be favoured by permeability contrasts because of possible self sealing phenomena at depth tied to deposition of secondary minerals (Fulignati *et al*., 1997) from the sea water interacting with rocks along pathways of increasing temperature (Gianelli and Grassi, 2001). Considering the Na/K plot (Fig 2B), the shallower hot waters (Ba25 and PT140) would seem to be the mixing products of the water (Ba50 and Pt180) found at depth in the in the shallow exploratory wells and the meteoric component, rather than being significantly affected by the fluids (PT3 and PPT1) found in the southern part of the island, where the geothermal reservoir is located. This could indicate a circulation pattern more complicated than that presented in Fig.2A, in which cells of different size could coexist in the island.

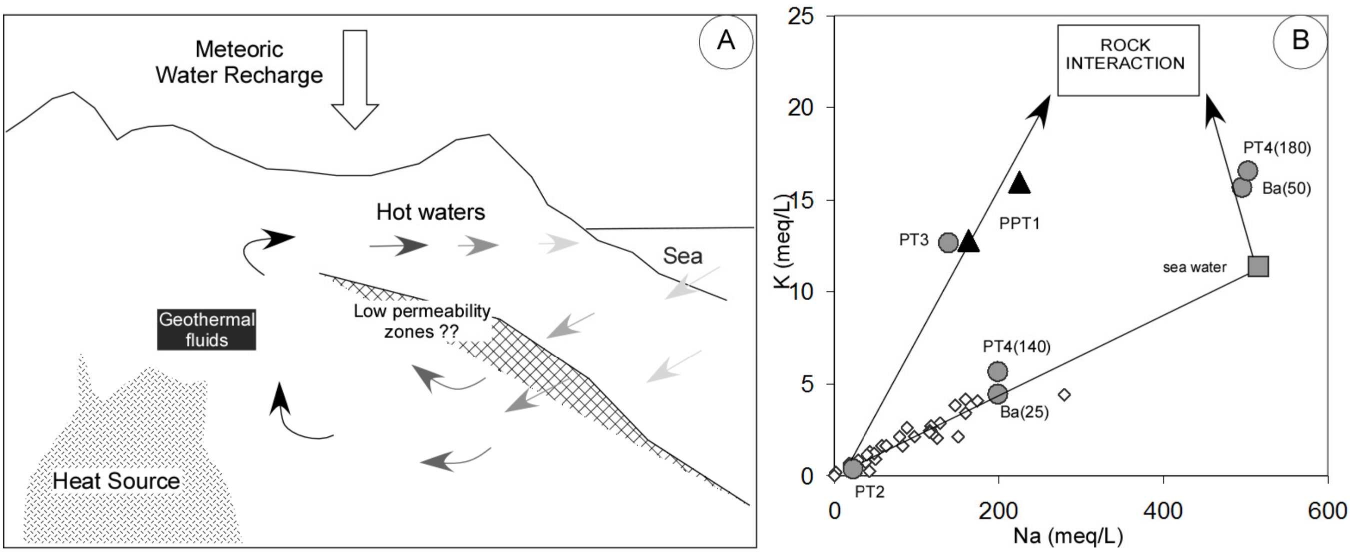

Fig. 2 A) Schematic groundwater circulation model of Pantelleria Island and B) Na/K diagram for some significant waters. Small diamonds = shallow domestic water wells, circles = shallow exploratory wells, triangles = well PPT1. Numbers in brackets represent the sampling depth.

DRIVING FORCES

Both temperature and water salinity can affect water density whose gradients are the main driving mechanism of convective flow. In atoll islands the observed (Swarz, 1958; Sornein and Guy, 1993) convective circulations are considered to be maintained by a remnant geothermal gradient rather than by salinity contrasts. In Mururoa island, for example, a weak geothermal gradient of about 20 °C/km linked to an heat flux of only 47 mW/m^2 seems to be the main driving factor of convective flow (Henry *et al*., 1996), whereas salinity is considered to play a minor role (Leclerc *et al.*, 2000). Otherwise, a simple rough evaluation of the density variations induced by temperature and salinity, allows to highlight that variations of only 10°C (in the field 20-100°C), commonly found in a high temperature geothermal island like Pantelleria, correspond to salinity differences of about 6000 mg/L, that is certainly a large solute amount. On this basis we believe that in Pantelleria island, characterized by a geothermal gradient of 115 °C/km and an heat flux of 460 mW/m^2 (Bellani *et al*., 1995), the main driving force of the convective circulation is the temperature differences associated to the existing geothermal system.

CONCLUSION

Based on different factors Pantelleria island can be considered an example of groundwater convective circulation. The existence of a high temperature geothermal reservoir containing waters of marine origin, the presence in the surrounding aquifer system of temperature inversions in correspondence with lighter hot mixtures of intermediate salinity overlying a colder and denser sea water suggest, in fact, inward and upward movements of sea water. The latter, receiving then contribution from the local recharge, is discharged back to the sea. The convective flow of sea water and its possible mixtures is driven by density gradients mainly related temperature contrasts connected to the existence of the geothermal reservoir which, in our opinion, represent the main engine of the convective system.

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