GEOTHERMAL SYSTEM of the CALDERA of PANTELLERIA ISLAND (SICILY CHANNEL)

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Abstract - On the basis of the results of exploration surveys conducted over the last three years (as described in the paper "Geothermal Exploration in Pantelleria Island (Sicily Channel): first results." - R. Chierici et al., 1994), two deep exploratory wells have been drilled in two different structural settings: the first one inside the youngest caldera structure, Caldera Cinque Denti, in the south-western sector of the island, the second outside, close to the northern rim of the same caldera.
Completely different stratigraphic and structural conditions have been encountered in the two wells.
The well PT2 crossed a thick sequence of submarine basalts to a total depth **of** 1200 meters and noted a geothermal gradient **of** about 10 °C / 100 m and low permeability conditions.
The volcanic sequence of this well is characterised by **an** intense hydrothermal alteration with deposition of clay minerals and carbonates. The hydrothermal alteration is very similary to those of the undersea floor hydrothermal system.
The well PT1 passed through pantellerites and trachytes, the typical lavas and pyroclastic sequence of the Pantelleria volcanic complex. intersected to a depth of about **545** m with trachytic-comenditic dykes From about 700 m a subvolcanic body was drilled with a constant composition down to 1103 meters (bottomhole).
The geothermal gradient range from about 35 °C/ 100 m down to about 700 m to only 7 °C /100 m inside the subvolcanic intrusion.
The hydrothermal alteration is mostly developed from aprox 350 m to 700 m. showing the typical distribution of alteration minerals of the geothermal systems (from argillic to propylitic) **an** allowing the identification of some preferential circulation zones.
A fractured productive zone occurs above the subvolcanic intrusion inside the propylitized trachytic lavas.
This productive zone is probably related to the Cinque-Denti Caldera faults and fractures system.

INTRODUCTION

This paper presents the initial results about the stratigraphic sequences, the hydrothermal zoning, and the geothermal results of the Pantelleria exploratory wells 1 and **2** drilled in 1992 and 1993.
The exploratory drilling took place during the Pantelleria Geothermal Exploration Program, Phase 2, promoted by Ente Minerario Siciliano (EMS), the Sicily Mining Board, in the context of the UE program VALOREN and was carried out by CESEN SpA during 1991-1994.

STRATIGRAPHY AND GEOLOGY

Pantelleria Island is the emerged tip of an important undersea volcano with a surface area of about 83 km^2, which is located in a large graben linked with rifting processes which began in the upper Miocene era.
The central part of the volcanic complex is dominated by two nested calderas (Mahood & Hildreth, 1986) and by a volcano-tectonic horst which is evidence of very recent resurgence, (Mahood & Hildreth, 1983; Civetta et al., 1984).
The oldest structure, the "La Vecchia" caldera, was formed about 114 ky ago following a series of ignimbritic and Plinian eruptions, while the most recent structure, the "Cinque Denti" caldera, **Is** the result of the Green Tuff ignimbritc emission which occurred about 45 ky ago.
Since then, the caldera has been the site of intense effusive activity (Monte Gibele volcano), which has partially filled the caldera structure and, later on, was involved in the rise which led to the formation of the Montagna Grande volcano-tectonic horst.
The island is the site of numerous hydrothermal phenomena, such as extensive steaming grounds located on the faults bordering the volcano-tectonic horst and hot springs connected with faults that are associated with regional and volcano-tectonic systems.
At the end of the initial phase of exploration, two wells were drilled: PTI well inside of the caldera structure close to the faults at the southern border of the Montagna Grande horst and PT2 well just outside the caldera in the southern part of the island (Fig. 1).
Reconstruction of the subsoil stratigraphy in the two wells was facilitated by identification of the Green Tuff, which is easily recognised due to its unique petrographic characteristics.
Its outcrops form a continuous cover over the entire island outside of the most recent caldera structure.
The Green Tuff is markedly zoned in composition from pantellerite to trachyte; this zoning was also observed in the subsurface sequences.

STRATIGRAPHY OF THE PANTELLERIA 1 WELL

The sequence of lavas, pyroclastic flows and subvolcanic rocks crossed by well n. 1 is shown in Fig. 2.
The first 235 m of the well were drilled in a sequence of highly porphyritic trachytic lavas that can be correlated with the intracaldera lavas of Monte Gibele and Montagna Grande.
Between 235 and 295 m the Green Tuff was encountered. It was welded, devitrified, and considerably thicker than observed in outcrops.
Below, a trachytic lava up to a depth of 370 m, is followed by a 130 m thick ignimbritic deposit ranging from trachytic to trachyrhyolithic and thoroughly hydrothermalized. The considerable thickness of this unit suggests that this ignimbritic deposit may be connected with the phases of the generation of the La Vecchia caldera and therefore probably connected with Mahood & Hildreth's Q, P and **F** layers (1986).
For this second ignimbritic unit, as for lhe Green Tuff, the bigger thickening suggests a syncaldcric collapse depositional mechanisms.

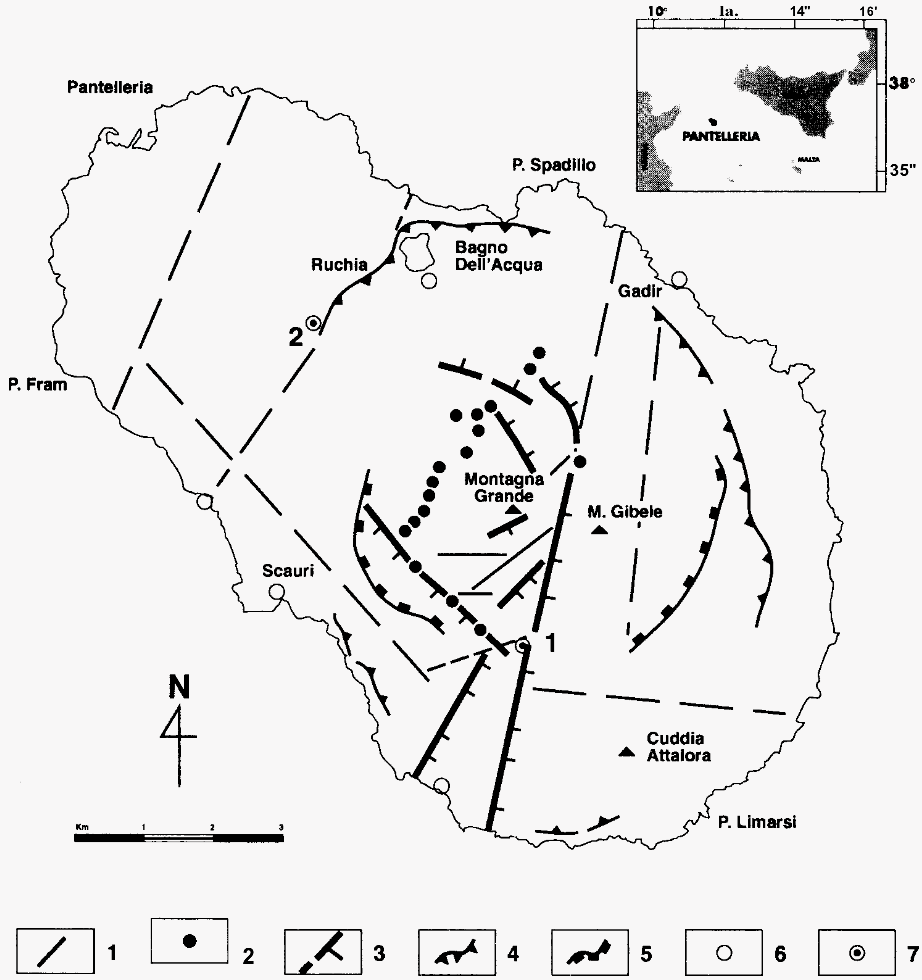

Fig. 1. Volcanic and tectonic sketch map of Pantelleria Island (after Mahood and Hildreth, 1983; Civetta et al., 1988). *1*= Main lineaments; *2*= Eruptive centers (< 6.000 y); *3*= Faults; *4*= Caldera La Vecchia rim; *5*= Caldera Cinque Denti rim; *6*= Thermal spring; *7*= Exploratory well.

Technical drilling problems prevented thorough knowledge of the interval between 500 and 600 metres in depth. The drill cuttings recovered only at 545-550 metres show an association of trachytic lavas and subvolcanic trachytic peralkaline rocks (aegirina, anorthoclase and cossyrite-bearing rocks).

Between 600 and 715 m in depth, lithology still appears to be composed of trachytic lavas which are intensely brecciated, (core sampled at 600 m) and intersected with comenditic dykes as depth increases.

The stratigraphic succession below 715 m is completely different as a subvolcanic body with a homogeneous trachytic-comenditic composition (peralkaline microsyenite) is found down to bottomhole at a depth of 1100 metres.

This subvolcanic body shows a progressive increase in mean crystall size as depth increases; it appears to be thoroughly hydrothermalized only up to a depth of about 850 m, while it is practically unchanged toward the bottomhole. The deepest core sample clearly reveals that the composition of the body is mixed.

It contains femic trachytic magmatic inclusions, which are indicative of mixing processes between the comenditic trachyte and a trachyte with a higher femic mineral content which also has a peralkaline imprint.

Pantelleria 1 well:

The intra-caldera situation is the most interesting from the geothermal point of view (Fig. 2).

The thermal anomaly is conspicuous, reaching aprox. 250°C at a depth of 700 m and 270°C at 1000 m.

The geothermal-hydrothermal system begins to develop at the water table which is present at a depth of about 270 m within a unit represented by the Green Tuff and by trachytic lavas below it, affected by intense argillification and silicification.

This argillified layer reaches a depth of 400 m and is characterized by extensive deposition of secondary minerals of the smectite, silica, and sulphur groups.

The argillic zone at the surface is followed by a phyllitic zone of originally ignimbritic lithologies with a trachytic composition; in this layer phyllosilicates belonging to the chlorite group, mixed layers minerals, chloryte-smectite, adularia, pyrite, calcite, albite and quarz are stabilized. This zone, together with the one above it, represents the self-sealing cover of the geothermal field; the circulation which is currently active is developed at lower levels, below 500 metres.

In the phyllitic zone within the thick ignimbritic unit, we

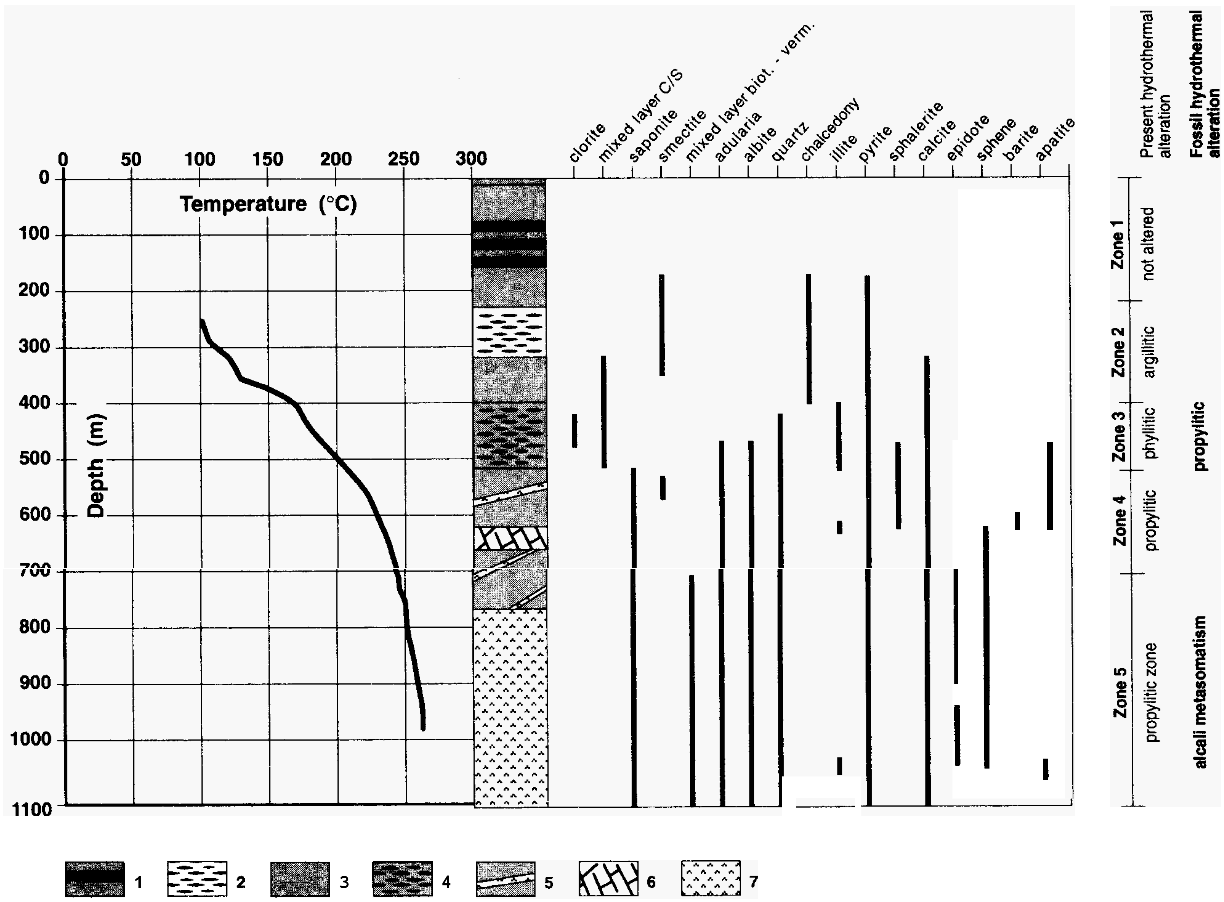

Fig. 2. Alteration minerals distribution and hydrothermal zoning of **Pantelleria exploratory well 1 (295 m.** a.s.l.). *1*= **M. Gibele and Montagna Grande lavas (trachytic** and **comenditic);** *2*= **Green Tuff;** *3*= **trachytic lavas;** *4*= **trachyrhyolitic ignimbrites;** *5*= **trachytic lavas intersected by comenditic dykes;** *6*= **production zone;** *7*= **peralkaline microsyenite.**

find coexistence of relatively high temperature hydrothermal minerals (adularia, chlorite) with low temperature minerals (mixed layers). This paragenesis and the composition of the chlorites (Cathelineau's geothermometer) indicate temperatures at least 40°C higher than those which can be measured today.

This indicate a drop of thermality over time at this depths and a reduction of permeability due to extensive processes of self-sealing in the ignimbrite, originally highly permeable, both by porosity and fracturing.

The area of active circulation which was revealed by the well develops below the 500 metre level, down to a depth of 700 - 750 metres in fractured trachytic lavas which are intersected by trachytic and comendytic dykes. Hydrothermal paragenesis is represented by an association of the propylitic type with adularia, quarz, albite, pyrite, blende, titanite, apatite and phyllosilicates of the smectite group, and saponites. Below 750 metres, inside the subvolcanic peralkaline microsyenite body, hydrothermal paragenesis varies toward higher temperatures and phyllosilicates are stabilized with mixed layers, biotite-vermiculite, epidote and albite.

Pervasive penetration of the hydrothermal system inside the subvolcanic body occurs at about 1000 metres. Below this depth, the secondary minerals seems to decrease, even though albitization and alteration of primary feldspars into saponites can be observed all the way down to the bottomhole.

On the other hand, this fact is consistent with the temperatures which have been measured and with the stabilized thermometric profile, showing a lower temperature gradient, evidence of circulation of fluids within the subvolcanic body.

Newly formed biotite, which has now been transformed into mixed layers of biotite-vermiculite, epidote (in reaction to calcite), and rare traces of secondary actinolitic amphibole, present in the upper part of the subvolcanic body, seem to indicate that in the past hydrothermal circulation conditions involved a higher temperature than at present (>300°C); as a result, in the intrusive body, too, there is a tendency toward lower temperatures than those attained in the past.

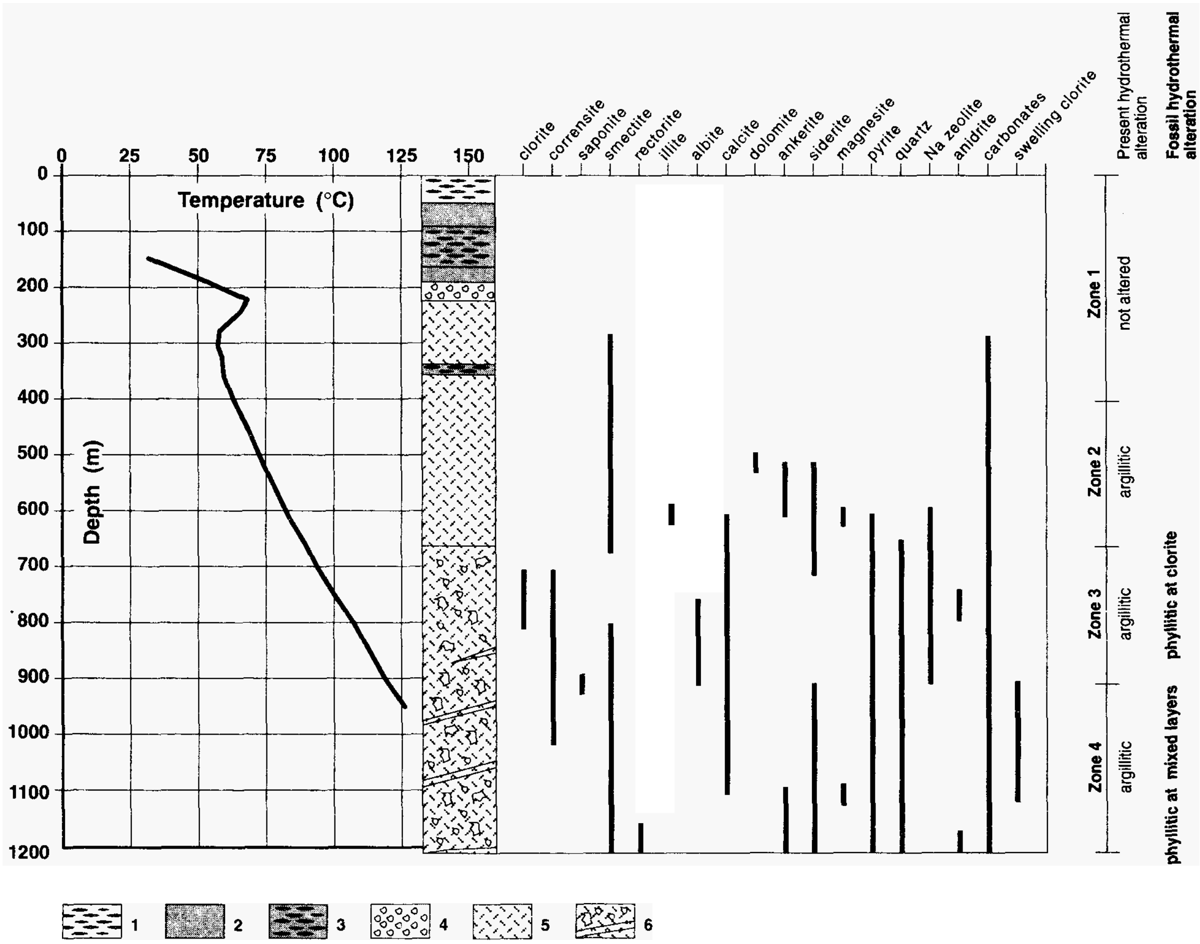

Fig. 3. Alteration minerals distribution and hydrothermal zoning of Pantelleria exploratory well 2 (205 m. a.s.l.). *1*= Green Tuff; *2*= trachytic-comenditic **lavas;** *3*= trachyrhyolitic ignimbrites: *4*= alkali-basaltic scoriae: *5*= alkali-basalts: *6*= basaltic hyaloclastites crossed by basaltic dykes.

Pantelleria 2 well:

The well presents decidedly lower temperatures at equal depths in respect to the Pantelleria 1 well and completely different facies of hydrothermal alteration due to both the lower temperature of the geothermal system in this side of the volcanic complex and the different lithology (basaltic) of the hydrothermalized sequence (Fig. 3).

The temperature is about 100°C lower at equal depths, reaching a maximum of 125°C at a depth of 950 metres. The thermometric profile shows an absence of convective zones, as temperature increases regularly with depth.

It contains argillic alteration mineralogy that is consistent with the current downhole temperatures. The mineralogy of alteration is dominated by clays and carbonates and is controlled by the originally basaltic lithology.

This argillitic zone appears superimposed on a chlorite phyllitic fossil zone between 700 and 900 metres in depth and a phyllitic fossil zone with mixed layers between 900 metres and the bottomhole.

The hydrothermal facies is, as we have already mentioned, dominated by clay minerals and iron and magnesium carbonates, siderite, ankerite, and dolomite.

STRATIGRAPHY OF THE PANTELLERIA 2 WELL

The different structural location, outside of the caldera, of this second well is reflected in a stratigraphic succession completely different from that of the well I (Fig. 3).

The first few metres of the well pass through the Green Tuff, which is composed mainly of pantellerite (Agpaitic Index 1.33-1.38) with a level of pumice at its base with composition and paragenesis similar to those of the ignimbrite, Below there are 35 metres of trachytic-comenditic lavas (Agpaitic Index 1.01), and still deeper, 90 metres of pantelleritic ignimbrites (Agpaitic Index 1.04). This second layer of ignimbrite may be correlated to the second ignimbritic layer of well 1, which has similar petrographic and mineralogical characteristics, and may therefore represent the caldera forming unit of the La Vecchia Caldera.

At the base of this unit there are several tens of metres of vesiculated, subaphiric pumices, with a pantelleritic-trachytic Composition.

Note that both ignimbritic layers outside the caldera have pantelleritic compositions.

Below 190 m in depth, there is a change in the lithology of the subsoil units, with a prevalence of basaltic rocks in the succession.

The first basaltic interval is represented by alkali-basaltic scoriae, which is porphyritic with clinopyroxene, plagioclase, and oxidized olivine that was deposited in a subaerial environment. Below there is a thick layer, approximately 100 metres, of basaltic alkaline lavas with hawaiitic tendencies, probably partly from a subaerial environment and partly from a submarine environment.

The basaltic sequence is interrupted by a few metres of submarine vitrophyric, trachytic and comenditic lavas crossing between 330 and 350 metres in depth.

Below, from 350 to 700 metres, there is a monotonous succession formed of submarine basaltic lavas with interlayering of subordinate hyalocastites.

Hyalocastic lithologies with a composition which is probably more evolved, possibly hawaiitic, predominate between a depth of 700 m and the bottomhole at 1200 metres, intersected by numerous subvolcanic gabbroid bodies possibly tabular intrusions (dykes) which become more frequent as depth increases.

The well ends in a strongly altered subvolcanic body of intermediate composition.

SOME REMARKS

Reconstruction of the wells stratigraphy reveals the difference between the two geological environments which characterize the volcanic complex: the intra-caldera and extra-caldera sectors.

The different composition of the volcanic products as compared to the intra-caldera and extracaldera ones, is connected to the fact that the intracaldera feeding systems are directly connected with the magmatic chamber of the volcanic complex.

In the magma chamber low pressure differentiation processes produce trachytes and rhyolites from basaltic magmas (Civetta et al., 1988).

This process prevents the rise of the basalts on the vertical of the magma chamber.

Outside of the calderic collapse structure, which is an obvious reflection on the surface of the emptying of the magma chamber during large scale eruptions, the absence of light masses, represented by molten trachytes and rhyolites residing in the chamber, permits the basaltic magmas to reach the surface.

Inside the caldera, the stratigraphic sequence seems to include succession of three volcanic cycles; the oldest, which is closed by the eruption culminated with the collapse of the La Vecchia caldera approximately 114 ky ago; an intermediate cycle ended by the eruption of the Green Tuff, and a more recent one which includes the products that filled the Cinque Denti caldera.

The trachytic-comenditic sub volcanic body and its train of apophysis are of uncertain age and stratigraphic position; the body cuts through the lavas that predate formation of the La Vecchia Caldera.

Its chemical composition makes it similar to the products of the most recent cycle of activity (Monte Gibele formation) and therefore it would seem to be a relatively recent body.

Further support for this interpretation can only be obtained if geochronological studies are carried out on the subsurface units.

The new information demonstrated by the subsurface geology outside of the caldera seem equally important.

The well demonstrates that the volume of pantellerites, trachytes and evolved magmas is limited and concentrated in a relatively short and recent period **of** volcanic activity that formed the surface part of the volcanic pile (200 metres).

The rest of the volcanic sequence appears to be basaltic, erupted in a subaerial environment, in the upper part of the sequence, and in a submarine environment in the lower one.

This lower part is mostly hyaloclastitic, completely altered and impermeable and is probably linked to the opening phases of the Pantelleria rift.

THE GEOTHERMAL SYSTEM OF PANTELLERIA ISLAND

The wells constitute the first direct source of information on the island's underground hydrothermal system.

The intra-caldera and extra-caldera hydrothermal systems appear completely different due to their relative positions with respect to the magma chamber.

The chlorite zone between 700 and 900 metres in depth is, however, characterized by calcite. The presence of calcite in this zone only would seem to suggest that temperatures were high enough to exceed the range of stability of the iron carbonates; siderite is stable between 37°C and about 135°C (Browne & Ellis, 1970).

On the whole, the studied formations, in particular the hyaloclastitic formations and the submarine basaltic lavas, appear to be completely impermeable due to intense transformation into low temperature hydrothermal minerals, clays and carbonates.

A layer involved, in the past, in the circulation of high enthalpy fluids is present, corresponding to an area interested by the injection of basaltic dikes.

GENERAL CONSIDERATIONS

Comparison of the hydrothermal situations in the two wells reveals a clear difference between the inside and the outside of the caldera. An active geothermal system is present inside the caldera, in lavas which are permeable due to fracturing. This represents the reservoir of the Pantelleria geothermal field.

This reservoir extends down to the outer part of a subvolcanic body.

The geothermal system underlies altered ignimbrites that are impermeable due to self-sealing processes.

These formations were, in the past, the site of intense hydrothermal circulation at higher temperatures than those currently present, as evidenced by the mineralogical paragenesis present in the ignimbritic formation.

The Pantelleria hydrothermal system is therefore slowly cooling down and probably moving downward. The driving force of the hydrothermal system is the magma chamber of the volcanic complex and its apophysis, represented by the subvulcanic bodies found in the Pantelleria 1 well.

The areas which show evidence of permeability and productivity are characterised by abundant deposits of adularia, a secondary mineral which is an index of permeability in various geothermal systems (Browne & Ellis, 1970).

The results of drilling clearly indicate that the most promising areas for future geothermal exploration at shallow depths on this island are restricted to the area inside the caldera, where the thermal anomaly associated with the magma chamber is most intense and closest to the surface.

The geothermal system appears strongly controlled by the caldera volcano-tectonic activity. The hydrothermal circulation develop along the caldera faults and the direct faults which border the volcano-tectonic resurgent horst of Montagna Grande.

Outside the caldera there is a lesser thermal anomaly and fluid circulation conditions are less favourable due to a subsurface lithostratigraphy characterised by hyaloclastitic and submarine lavic basaltic formations that are completely impervious.

Moreover, the low temperature of this part of the volcanic complex hinders the development of brittle fracturing in formations that have been made plastic by argillification.

Future plans for exploration and exploitation of the Pantelleria geothermal field must take into account that the island's subsurface includes subvolcanic bodies with a syenitic and granitic composition at shallow depths. These are probably present throughout the caldera, as is clearly demonstrated by the abundance of these rocks among the lithics present in the different pyroclastic formations of the volcanic complex and their outcrops at the base of the Montagna Grande volcano-tectonic horst.

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