The deep reservoir of the Travale geothermal area: mineralogical, geochemical and resistivity data

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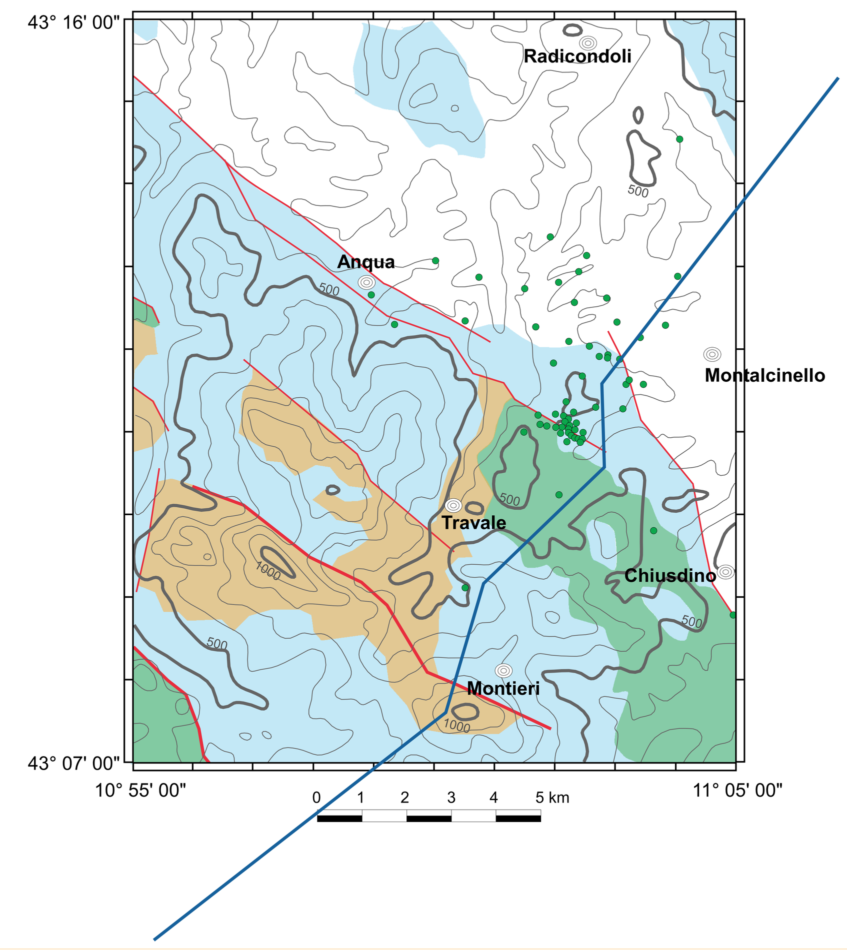
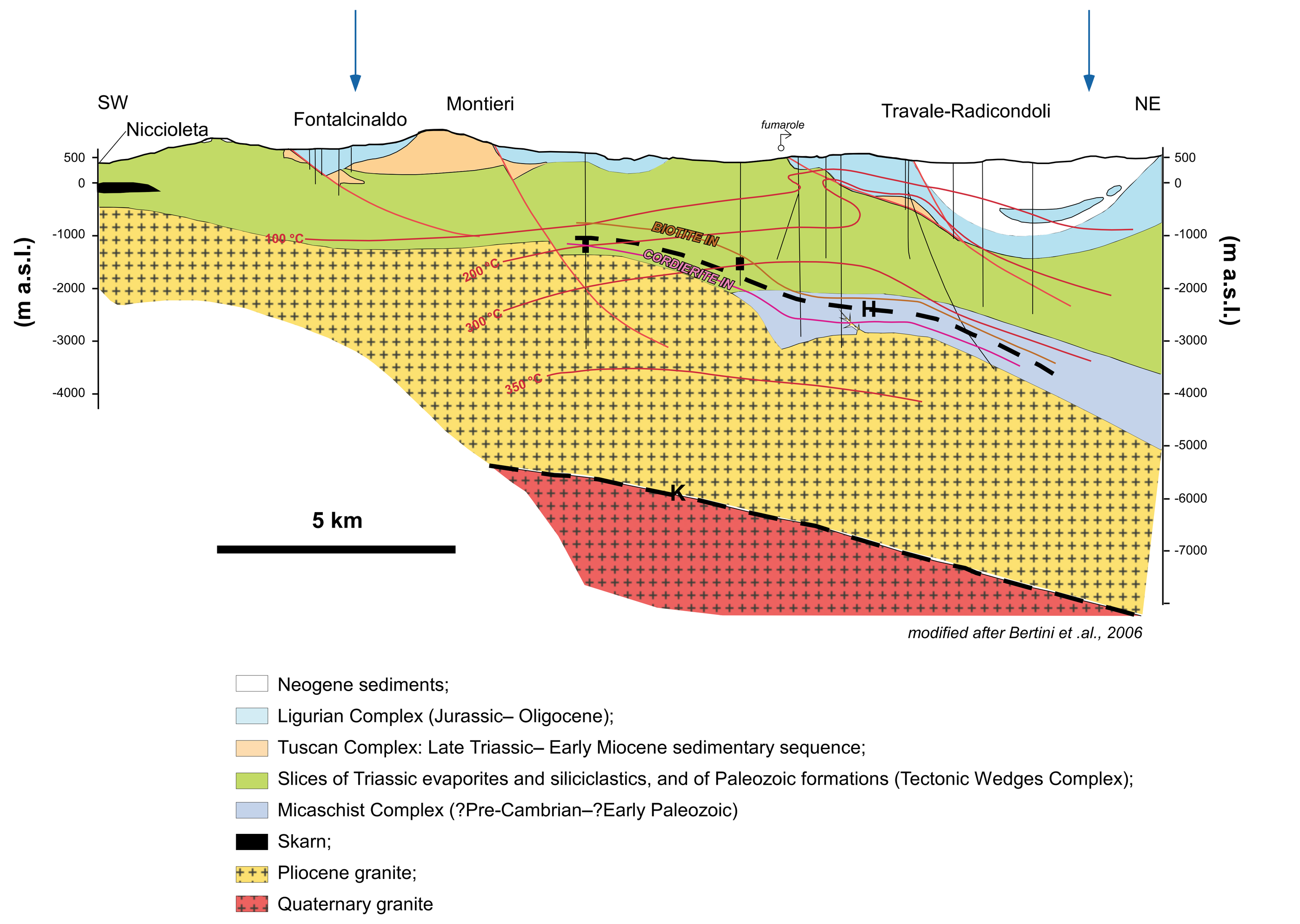
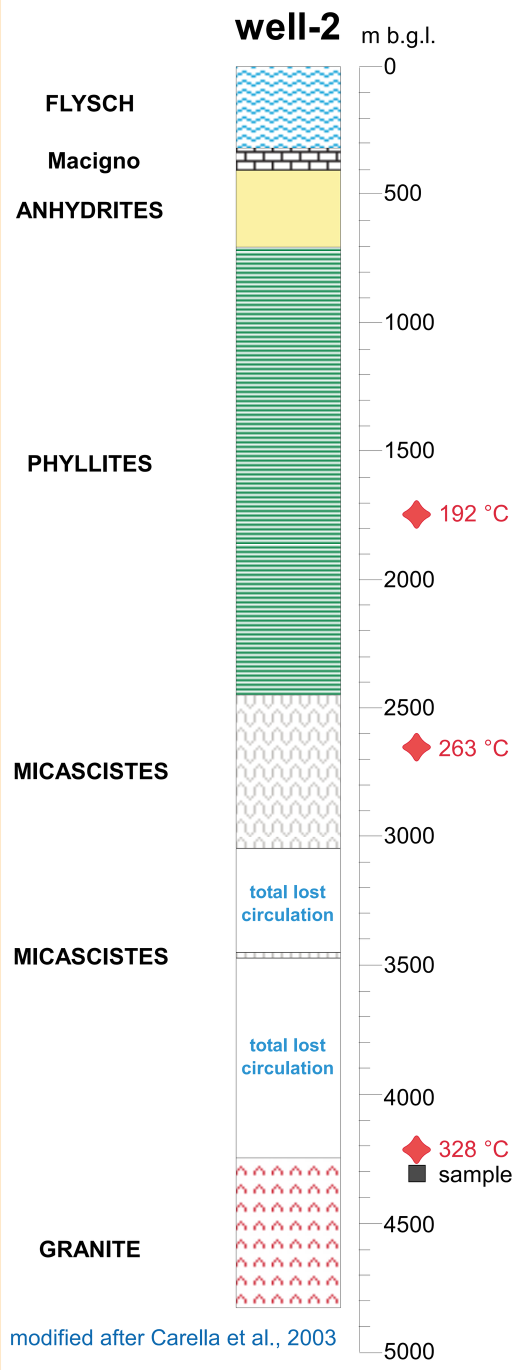
The aim of the present multidisciplinary study is to explain the changes in resistivity observed in the deep reservoir of the Travale area taking into account the lithology and alteration affecting the reservoir rocks, with particular regard to conductive and clay minerals, the physico-chemical characteristics of the fluids, and their distribution and evolution with time. The study is also directed at calibrating petrophysical experiments in order to reproduce realistic physical conditions on a small scale.

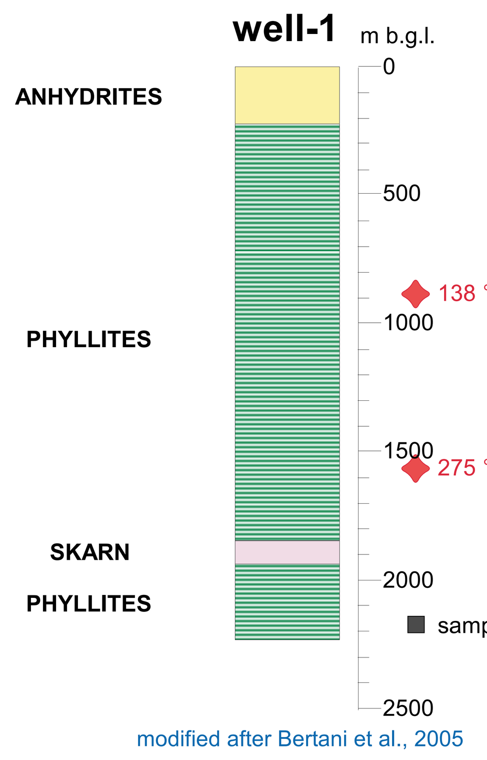
DEEP RESERVOIR

The deep reservoir consists of metamorphic Paleozoic units and younger granite. The metamorphic units include: i) the Phyllitic-Quartzitic Complex (metagreywacke with minor metabasite levels and locally carbonate-siliciclastic metasediments); ii) the Micaschist Complex (almandine-bearing albite micaschist with minor amphibolite); and iii) the Gneiss Complex (gneisses with minor amphibolite layers and rare calc-silicate rocks). Deep drillings have encountered Pliocene-Quaternary granites at depths between ~2 and 4 km below ground level (b.g.l.). All the crystalline units are affected by contact and hydrothermal metamorphism originated by the granite intrusions.









SAMPLE DESCRIPTION

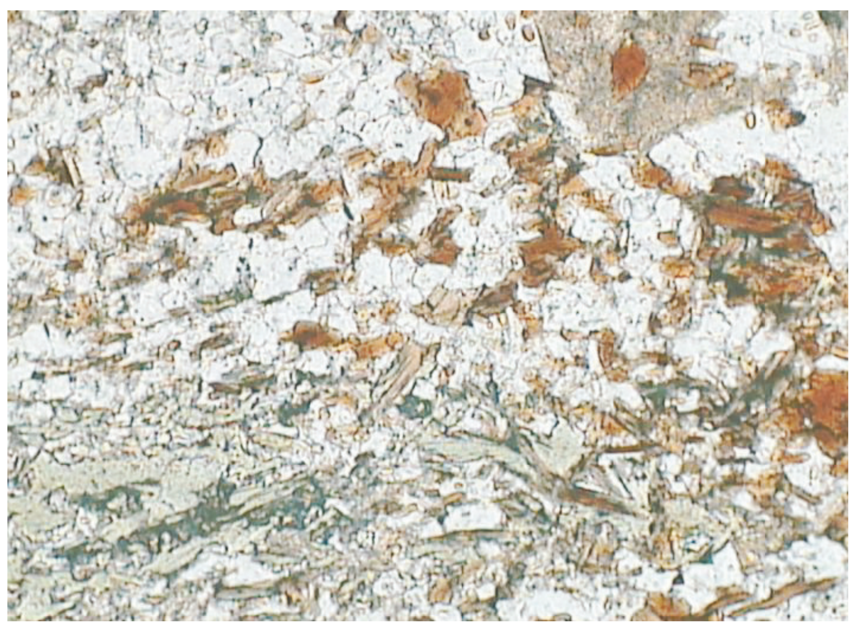
The **well-1** sample is characterised by a lens of quartz folded inside the phillites affected by thermo-metamorphism (a granitic body is suggested at 3 km of depth). The sample is located between two fracture zones and it is roughly coincident with H-horizon location.

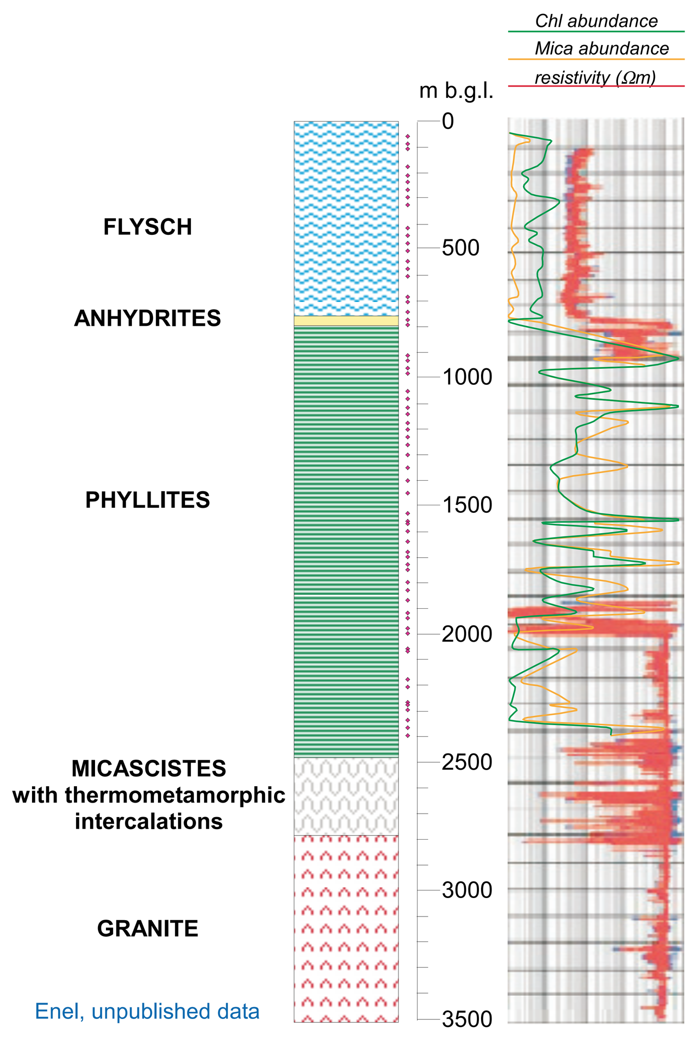
Four types of fluid inclusions occur in the sample: polyphase (LVHS), threephase (VL-c), biphase (LV-NaCa) and monophase (V-c) inclusions. The fluid inclusion chronology was reconstructed taking into account the relative relationship between fluid inclusions trails and microthermometric data.

The **well-2** sample is a granular syenogranite, characterised by Kfs, Pl, Qtz, Bt, Ms, Crd, with Ap, Zrc, Mon, Ilm, Tur as accessories (Dini et al., 2005).

The proposed age is 2.25±0.04 My based on $^{40}Ar/^{39}Ar$ method on biotite (Gianelli & Laurenzi, 2001).

The sample has only one type of fluid inclusions (VL-c) occurring along transgranular trails.





XRD

X-ray diffraction was carried out on one well in the Travale area (63 cutting samples in 2400 m of drilled depth) to identify the types of minerals present, their relative abundance and to compare the mineral characterisation with resistivity values.

The Phyllitic-Quartzitic Complex is characterised by clay minerals (chlorite and mica types), quartz, plagioclase, calcite, anhydrite and rare dolomite: the relative abundance of these minerals is not homogeneous throughout the complex.

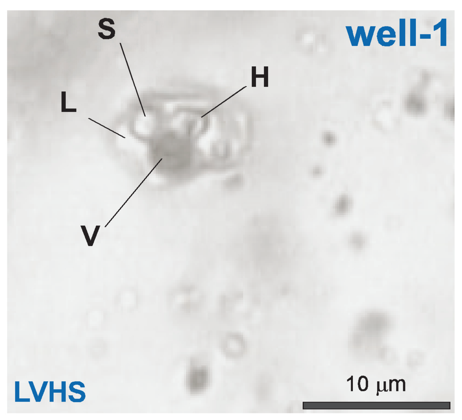
A clear correlation between the abundance of clay minerals and a change in resistivity was not observed.

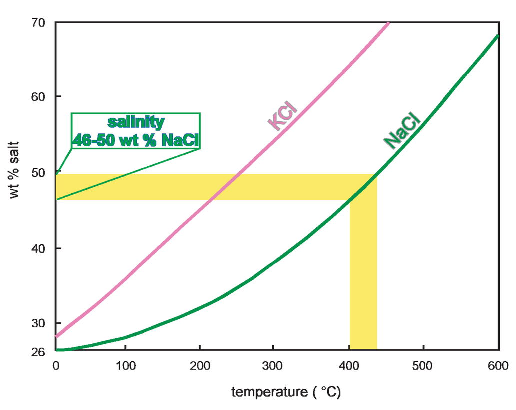
FLUID INCLUSIONS

Four types of fluid inclusions have been recognised:

- polyphase (LVHS);
- threephase (VL-c);
- biphase (LV-NaCa);
- monophase (V-c).

polyphase inclusions (LVHS): liquid + vapour + halite (H) + an unknown solid (S) that not dissolve upon heating.



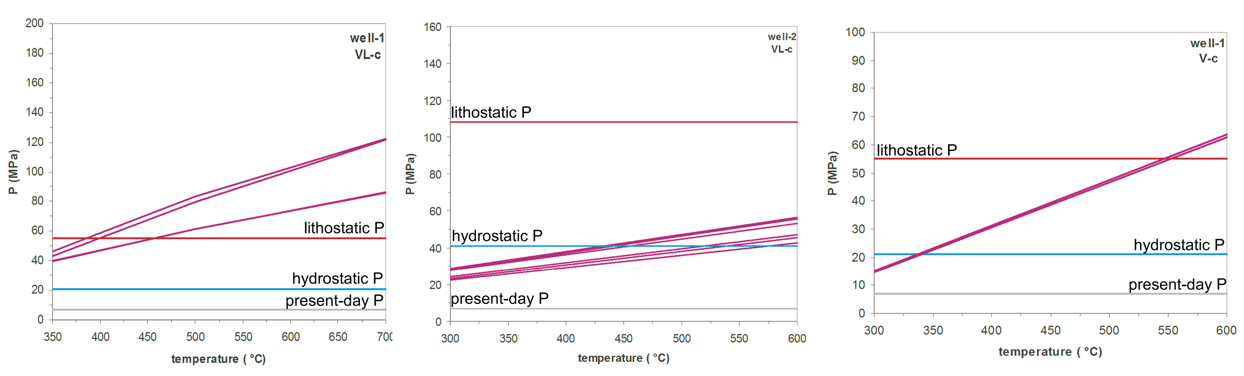


	Th	TmH	TmS
well-1 (LVHS)	248/420 299 (14)	402-436 414 (9)	>550

three-phase inclusions (VL-c): carbonic gas + carbonic liquid + liquid water. Microthermometry shows the presence of CO_2 and an another gas (presumibly CH_4).

	$TmCO_2$	Tmcla	$ThCO_{2\,(v)}$	$ThTOT_{(v)}$
well-2 (VL-C)	-58.8/-57.0 -57.8 (68)	10.0/11.5 10.8 (28)	15.0/25.5 22.5 (22)	202/246 226 (10)
well-1 (VL-c)	-58.5/-58.1 -58.2 (8)	0.1/9.0 6.0 (5)	23.5/24.0 23.7 (3)	366
well-1 (V-c)	-57.2/-57.1 -57.2 (2)	3.5/6.0 4.9 (4)	-	345/370 360 (3)

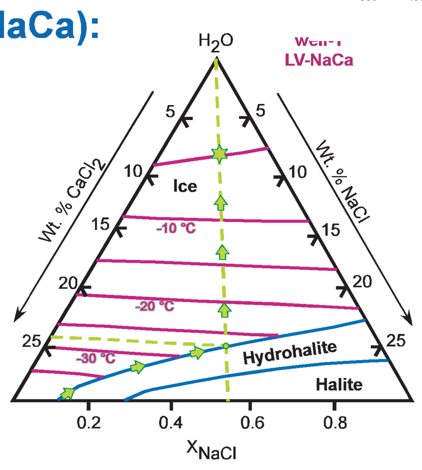
monophase inclusions (V-c): vapour, but in a few cases may contain small amounts of liquid.

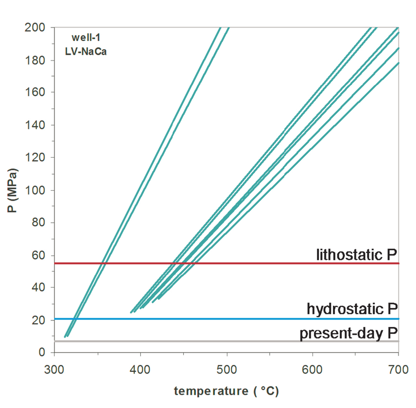


biphase inclusions (LV-NaCa): liquid + vapour

Te measurements shows the presence other salts than NaCl

salt-water system H_2O-NaCl-$CaCl_2$



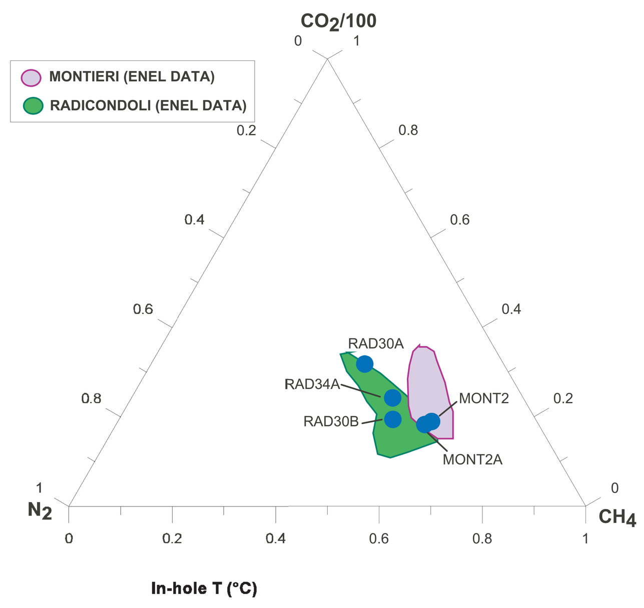


	Te	TmH_1	TmIce	$ThTOT_{(l)}$
well-1 (LV-NaCa)	-60.0/-51.0	-27.0/-26.5 -26.9 (4)	-5.7/-3.5 -4.7 (10)	312/417 387 (11)

A multi-stage fluid circulation was proposed, consisting of an early magmatic stage characterised by high-salinity fluids of magmatic origin, and vapours and liquids resulting from heating of the Paleozoic rocks during contact metamorphism. The hydrothermal stage that follows is characterised by low- to high-salinity aqueous fluids with vapours produced by boiling processes. The high salinities can be explained by the interaction of these fluids with evaporites and/or connate waters.

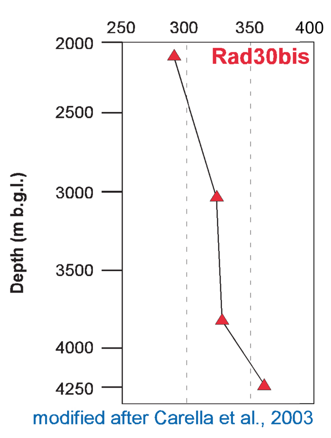
GEOTHERMAL FLUIDS

The present-day geothermal fluid is superheated steam with similar gas/steam ratios.(4.8-8.7 % wt.).



CO_2 is the main gas compound (91.0-94.8 % vol.), followed by CH_4 (1.2-3.0 % vol.), H_2S (1.6-2.9 % vol.), H_2 (0.7-2.2 % vol.) and N_2 (0.8-1.3 % vol.). He, Ar, O_2 and CO are always lower than 0.1 % vol.

The steam condensates are characterized by high amounts of HCO_3^-, NH_4 and B (up to 439, 145 and 101 mg/kg, respectively).



	GT1	GT2	GT3	GT4
Mont2	251	212	375	246
Mont2A	243	266	391	246
Rad30A	237	260	355	270
Rad30bis	223	270	335	250
Rad34A	214	248	366	257

GT1=D'Amore & Panichi (1980);
GT2=Bertrami et al. (1985);
GT3=Giggenbach (1991);
GT4=Giggenbach (1993).

CONCLUSIONS

Since the state of the geothermal fluid produced cannot explain the observed reduction in resistivity, the latter could be related to the abundance and type of i) heterogeneities in the reservoir rocks, ii) the abundance and type of alteration minerals, and iii) the presence of brines similar to those evidenced by the fluid inclusion study, whose interconnection would be sufficient to produce electrolytic conduction.

In order to reproduce realistic physical conditions on a small scale, we propose petro-physical measurements at:

i) the present-day reservoir conditions (**H-horizon**): low-P and low-salinity
ii) the **K-horizon** condition representing a potential deep-seated reservoir hosting a fluid in a supercritical state (Bertini et al., 2006): high-P, high-T, high-salinity, and gas-bearing fluids.

Fluid	T (°C)	P (MPa)
H_2O + NaCl (*)	300-350	3-7 (vaporstatic) 25-40 (hydrostatic)
H_2O + NaCl (^)	350-500	40-100 (lithostatic)
H_2O + NaCl + CO_2 + CH_4 (°)	350-500	40-100 (lithostatic)

(*) 0-1 wt % NaCl eq.
(^) up to 50 wt % NaCl eq.
(°) up to 50 wt % NaCl eq., pure CO_2 or CO_2 + CH_4 mixture 50:50 (molar)

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