Introduction and geochemical aspects of the DESCRAMBLE project

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This project proposes to drill in continental-crust, super-critical geothermal conditions, and to test and demonstrate novel drilling techniques to control gas emissions, the aggressive environment and the high temperature/pressure expected from the deep fluids. ***The project will improve knowledge of deep chemical-physical conditions for predicting and controlling drilling at supercritical conditions.***

PROJECT ACTIVITIES

Section I: Drilling in super-critical conditions.

- Develop procedures for well monitoring and control in order to secure the safety of the well in terms of health and the environment.
- Selection/development of appropriate equipment and material to withstand the harsh downhole conditions.
- Definition/development of drilling procedures.
- Development and testing of a novel logging tool

Section II: Geo-scientific activities to increase knowledge of super-critical wells.

- Geophysical survey and reinterpretation of all data before drilling for a better identification of the drilling target
- Definition of procedures for supercritical fluid handling and sampling.
- Definition of procedures and equipment for the production test.
- Geophysical logs before and during drilling
- Evaluation of petrological characteristics of the rock samples.

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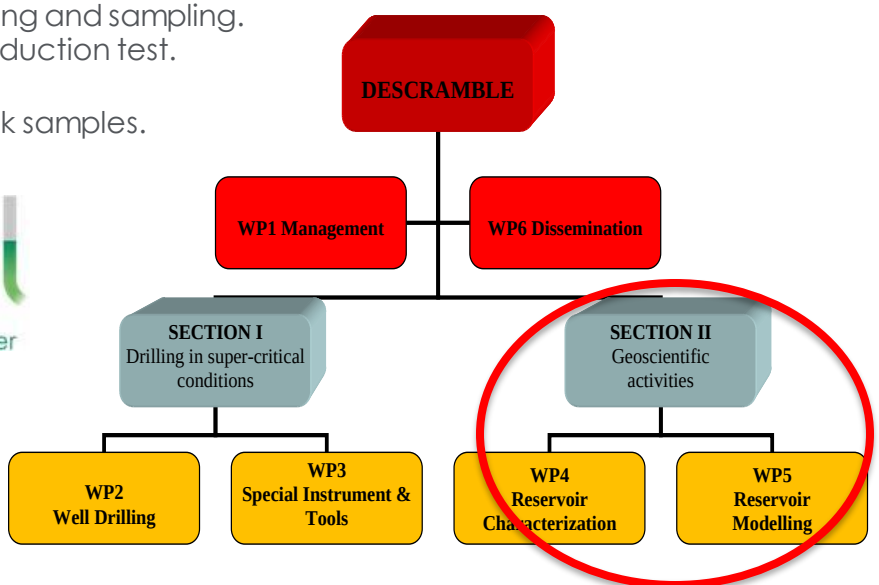


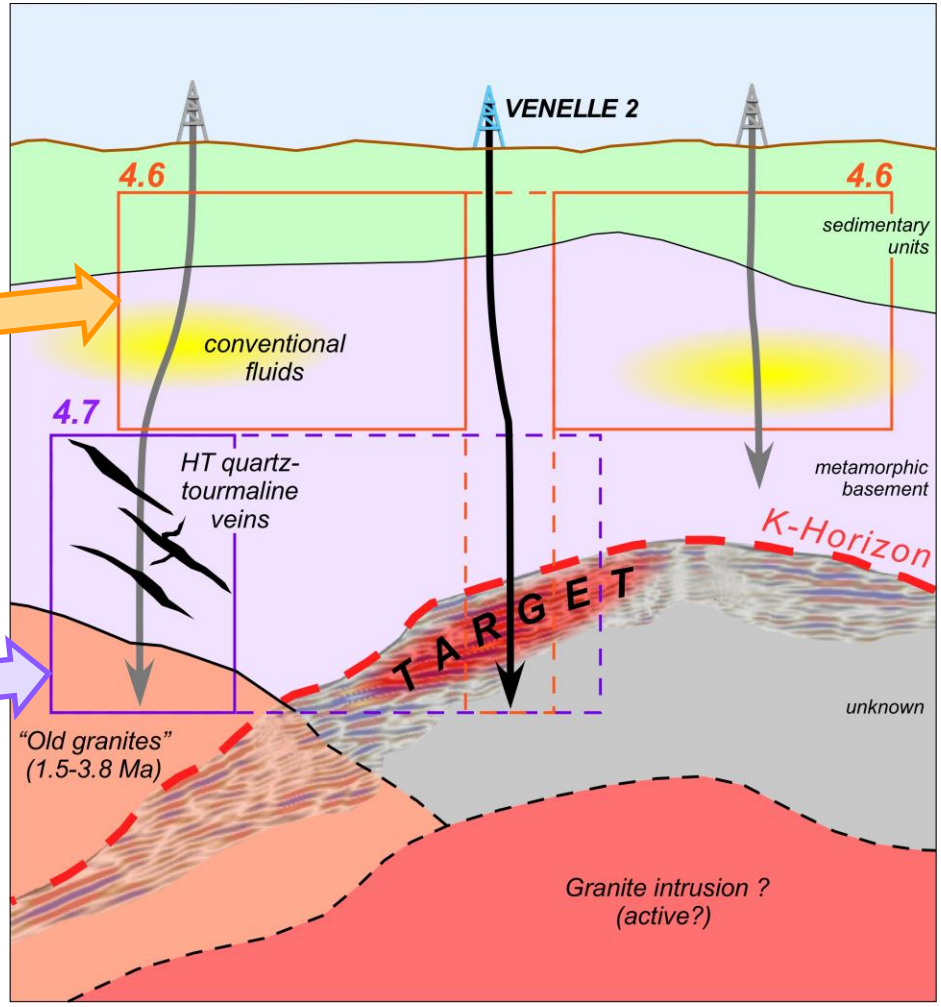
Aims of Tasks 4.6 and 4.7

Task 4.6: Refinement of the physical and geochemical characters of conventional fluids in the Venelle well and nearby area. Characterization of supercritical fluids.

From top, down into the TARGET

Task 4.7: Prediction of P-T-X conditions of supercritical fluids in the Target by the study of fossil proxies: granites, tourmaline veins, metamorphic rocks.

From fossil proxies to P-T-X of fluids in the TARGET

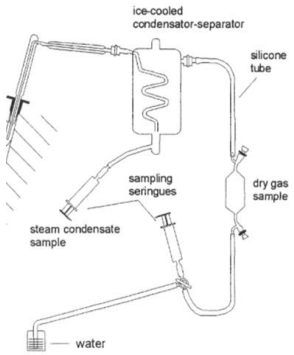


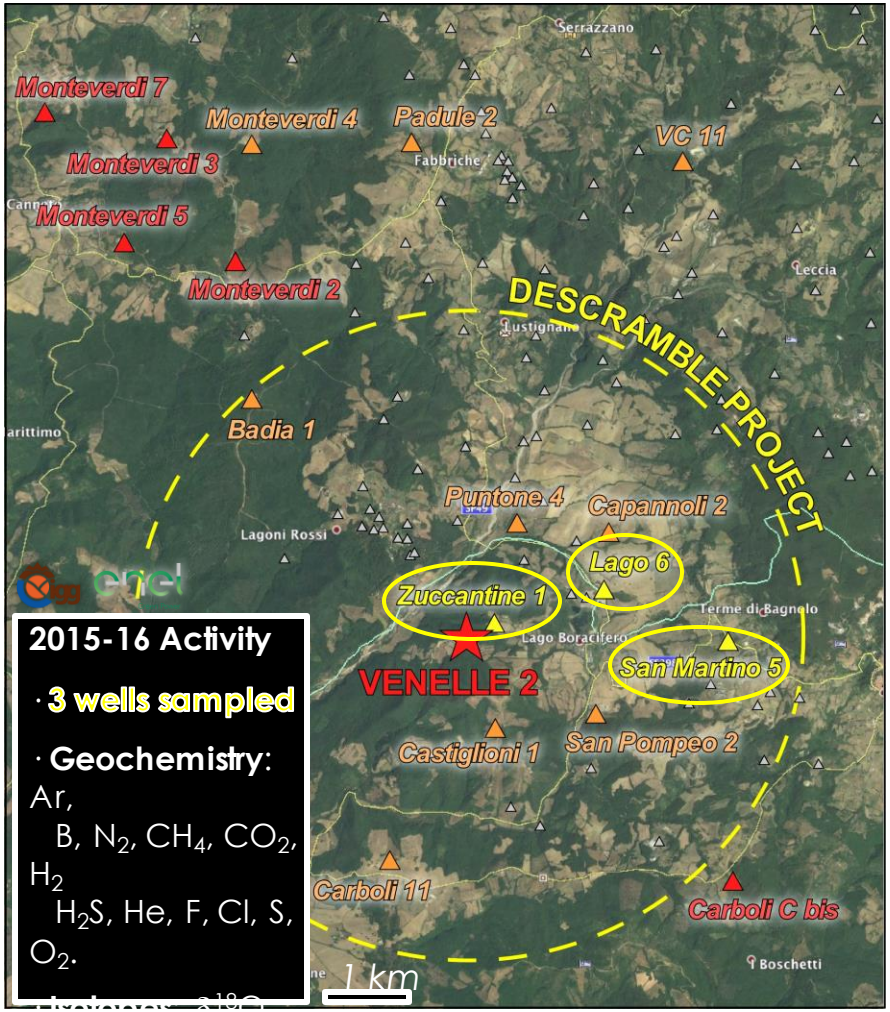
4.6 - Fluid Geochemistry

1 – Intercalibration/testing of sampling and analytical methods.

2 – Characterization of conventional fluids/gases before Venelle well deepening.

3 – Characterization of supercritical fluids sampled in the Target zone (*2017-18*).

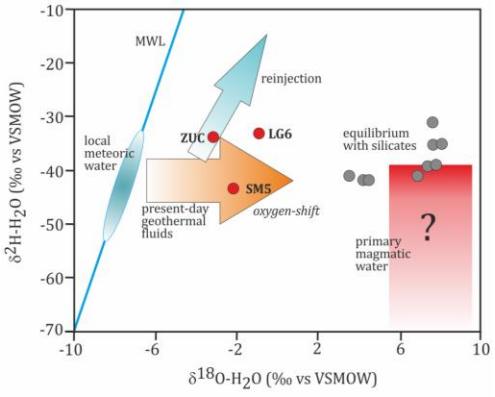


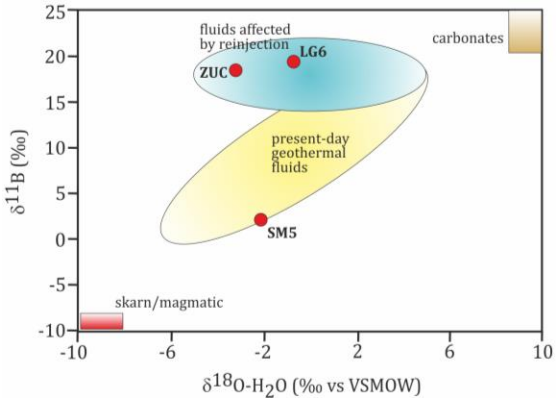


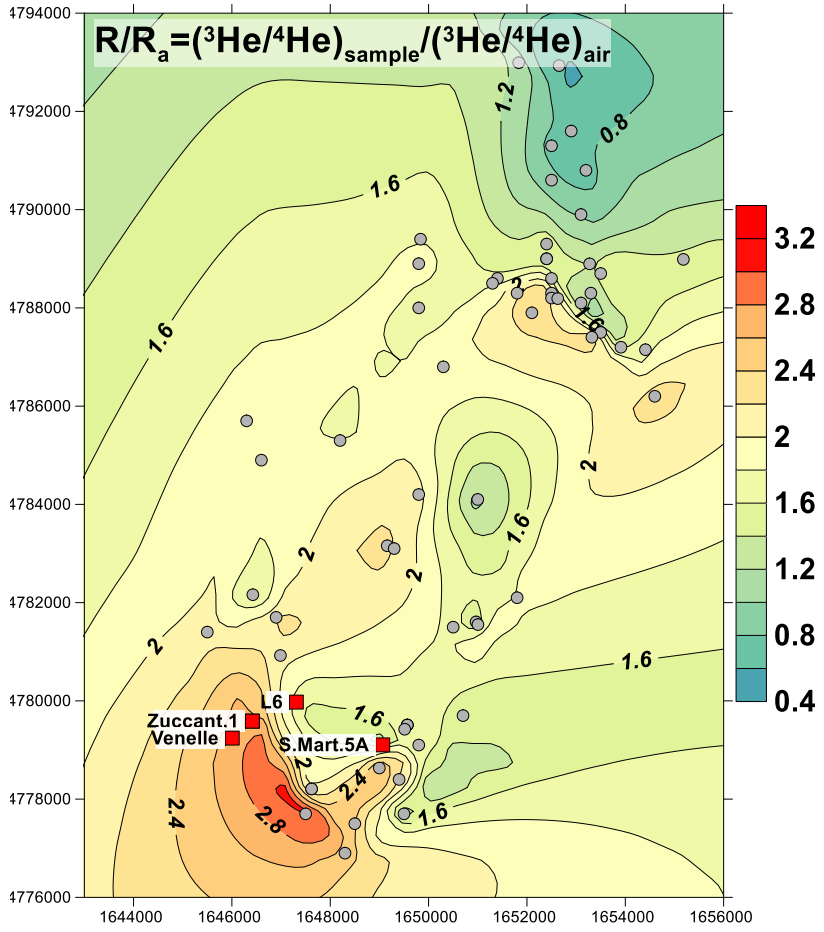
4.6 - Fluid Geochemistry

The main activity of Task 4.6 starts now, with the opening of the Venelle well and its deepening toward the Target zone.

Sampled wells provided geochemical-isotopic parameters that are consistent with the nature of the exploited conventional reservoirs.



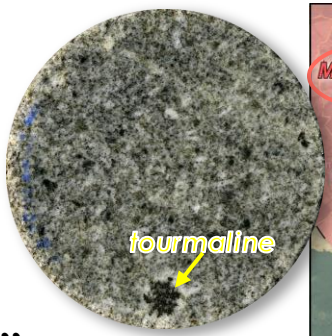




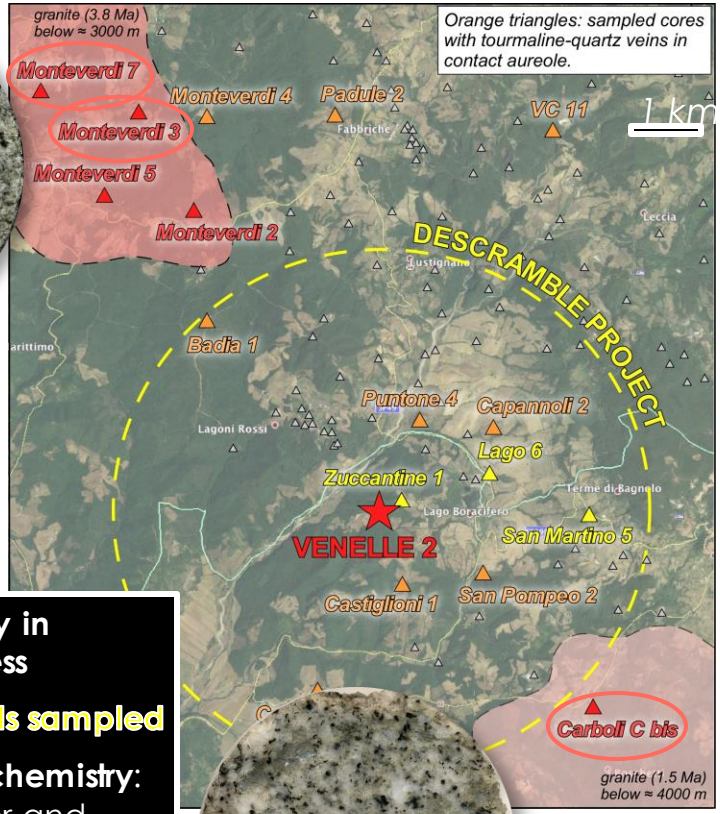
4.7 - Granite intrusions

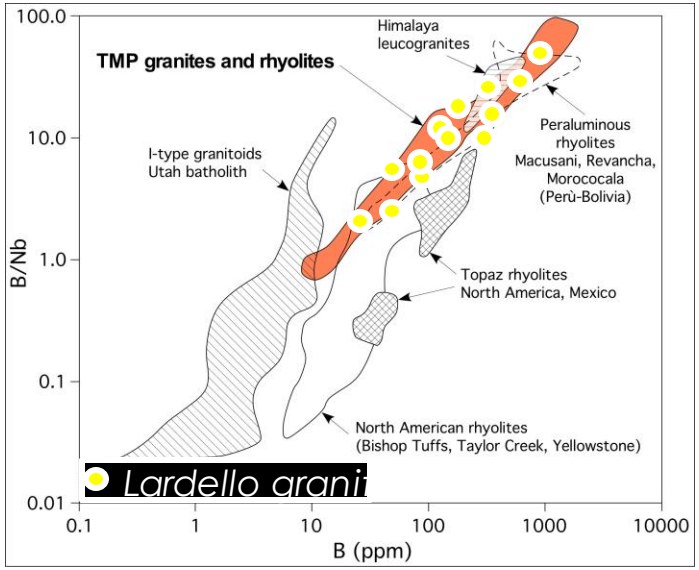
Peraluminous, silicic granites produced by the crystallization of crustal melts.

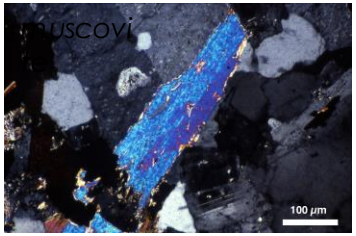
Magma was very rich in boron (*tourmaline*) and quite rich in other "volatiles" and "fluxes" like fluorine, lithium and, of course, water.



Monteverdi 3 well granite core slab. 3860 m; 3.8 Ma







U-Pb dating on zircons is in progress in collaboration with Geneva University

Activity in progress

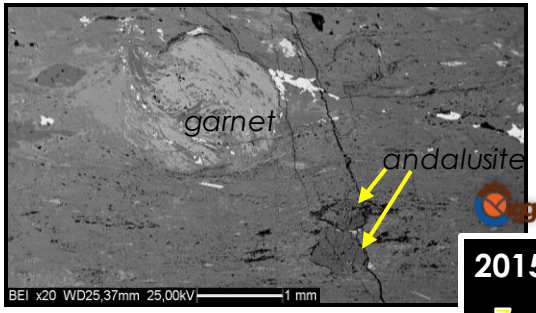
- **3 wells sampled**
- **Geochemistry**: Major and trace elements.
- **Isotopes**: Sr, Nd, Pb

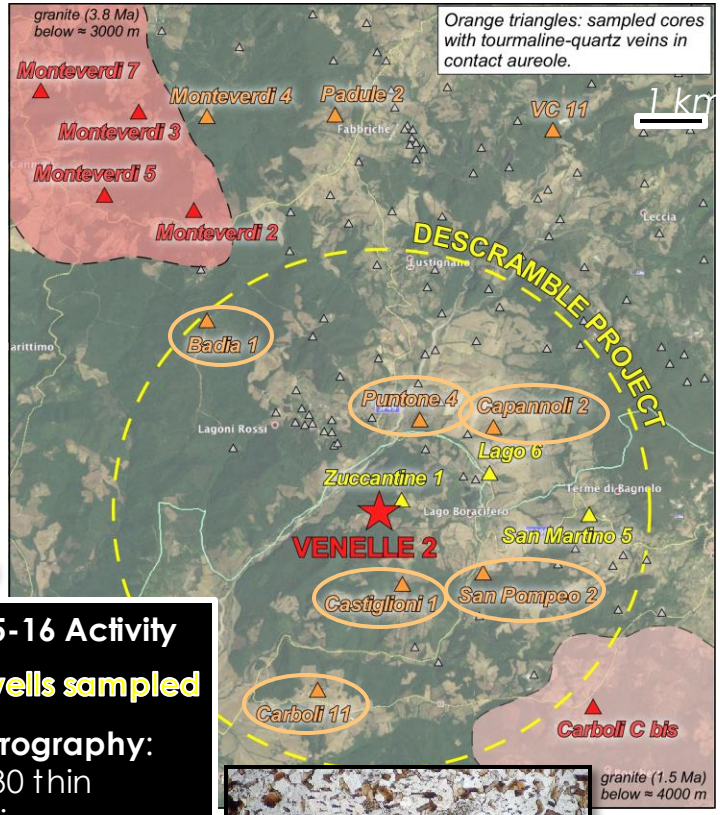
Carboli C bis well granite core slab. 4200 m; 1.5 Ma

4.7 – Metamorphic rocks

Below 2300 m depth Bt-rich micaschists and amphibolites are widespread. The common occurrence of andalusite, cordierite and garnet porphyroblasts is typical of contact aureoles surrounding granite plutons in Tuscany.

A detailed EPMA study coupled with ^{40}Ar-^{39}Ar dating is in progress to determine P-T conditions and age of contact metamorphism.



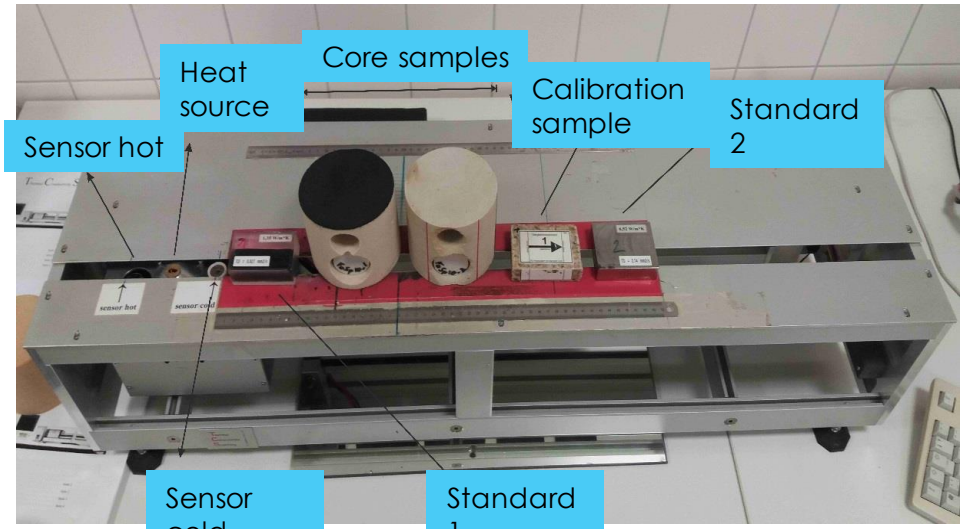


2015-16 Activity

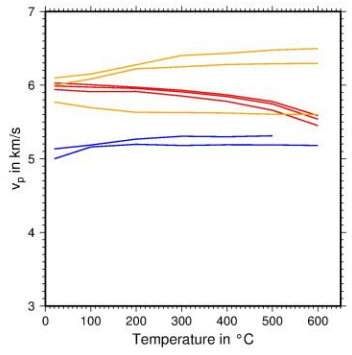
- **7 wells sampled**
- **Petrography**: ≈ 30 thin sections from cores; depth range: 1000-3700 m

4.7 – Petrophysics

Petrophysical analyses evidenced heterogeneous thermal conductivities within the metamorphic basement that have been considered for the numerical modeling. Petrophysical experiment was successfully conducted in a multi-anvil pressure apparatus to determine the pressure and temperature effects on the seismic velocities.



P-wave velocity vs.



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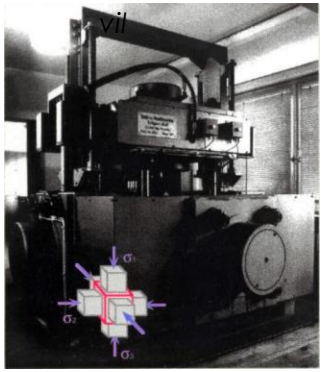


2015-16 Activity

- **6 wells sampled**
- **12 cores**

- **Thermal conductivity**: Conductivity tensors, anisotropy, porosity.

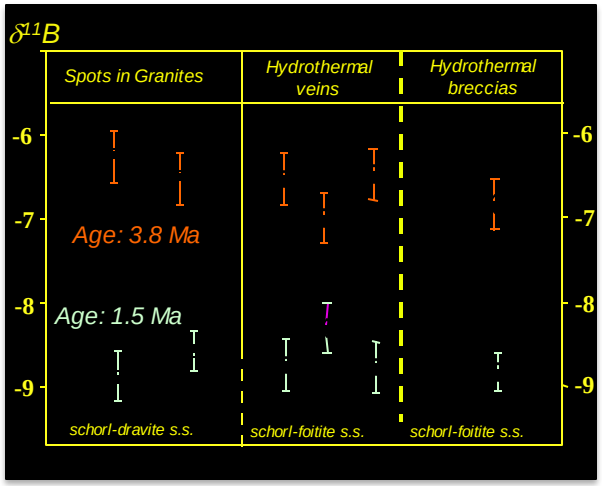
Thermal conductivity tensors for seven core samples and the associated anisotropy factors Kxz Kyz

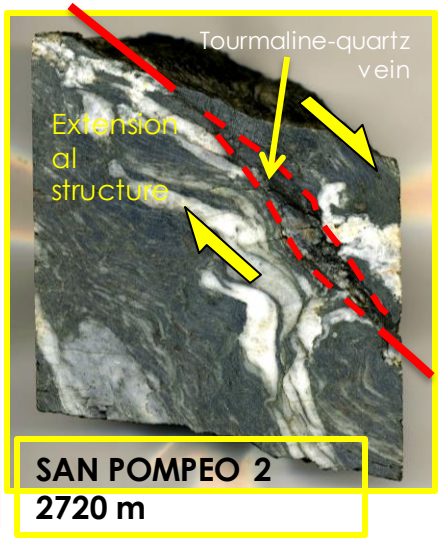
Core sample	$\lambda_{m,dry}$ [W m^{-1} K^{-1}]	$\lambda_{m,sat}$ [W m^{-1} K^{-1}]	$K_{xz\ dry}$	$K_{yz\ dry}$
C11#9	2.59 0 0 0 2.51 0 0 0 2.95	3.22 0 0 0 3.42 0 0 0 3.86	1.1360	1.1679
P4B#7	1.70 0 0 0 1.76 0 0 0 2.08	2.15 0 0 0 2.21 0 0 0 2.50	1.2231	1.1792
C11A#14	4.33 0 0 0 2.95 0 0 0 4.83	4.97 0 0 0 3.42 0 0 0 5.32	1.1143	1.6270
C11A#19	3.71 0 0 0 3.68 0 0 0 4.03	3.76 0 0 0 3.67 0 0 0 4.36	1.0881	1.0948
SP#18	2.29 0 0 0 2.16 0 0 0 3.09	3.07 0 0 0 3.13 0 0 0 4.39	1.3339	1.4148
SP#10	/	2.98 0 0 3.09	/	/
CAS#3	2.37 0 0 0 2.79 0 0 0 2.69	2.40 0 0 0 2.48 0 0 0 2.14	1.1207	0.9681

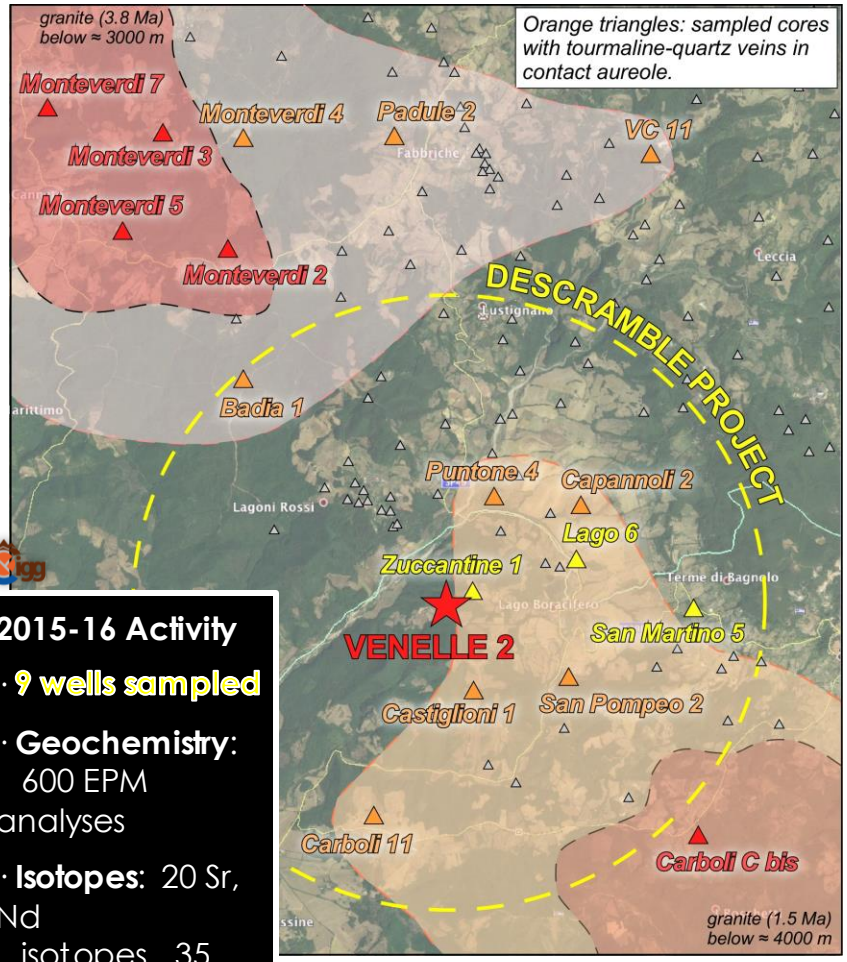
4.7 – HT Veins: geochemistry

Tourmaline from HT veins has light boron and heavy oxygen isotope composition consistent with an origin by magmatic fluids.

Differences in d^{11}B and Sr-Nd isotopes are consistent with the composition of nearest granite intrusion







2015-16 Activity

- **9 wells sampled**
- **Geochemistry**: 600 EPM analyses
- **Isotopes**: 20 Sr, Nd isotopes, 35 $\delta^{18}O$.

4.7 – HT Veins: Fluid Inclusions

Two main types of fluids: 1) high-salinity or hypersaline fluids (up to 34 wt% NaCl equiv.) of magmatic origin; 2) aqueous-carbonic fluids derived by contact metamorphism reactions.

P-T conditions during inclusion trapping, estimated from fluid inclusion isochores, are around 740 bars (i.e. lithostatic) and 500°C for San Pompeo 2 - 2270.

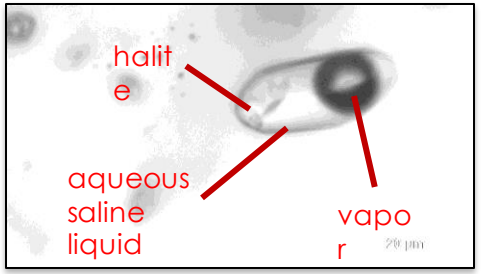
For Carboli 11 - 3455 sample the estimated trapping T is lower, around 425°C, whereas P varies from lithostatic values, around 1000 bars, to hydrostatic pressure about 350 bars.

2015-16 Activity

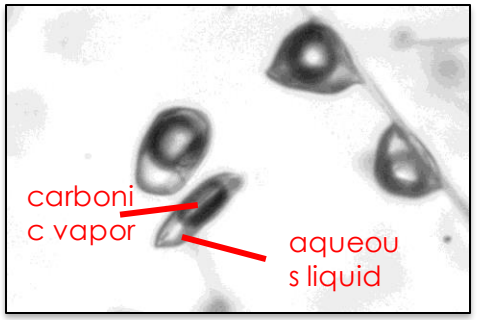
- **2 wells sampled**
- **Microthermometry**: 100s analyses
- **geochemistry**: Micro Raman and LA-ICPMS analyses for major ant

Coexisting aqueous-carbonic and ipersaline (brine) f.i.

Ipersaline fluid inclusions : H_2O + NaCl (~30 wt.% NaCl equiv.)



Aqueous-(carbonic) fluid inclusions: H_2O + NaCl + CO_2 (± CH_4 ± N_2). CO_2: 1-6 mol. % NaCl: 0-4.4 wt.%

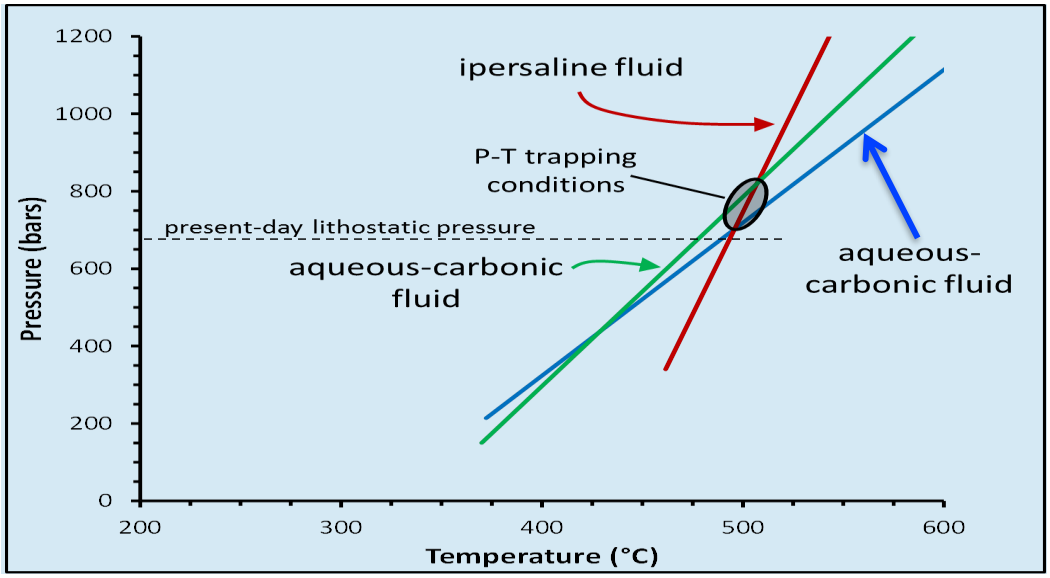


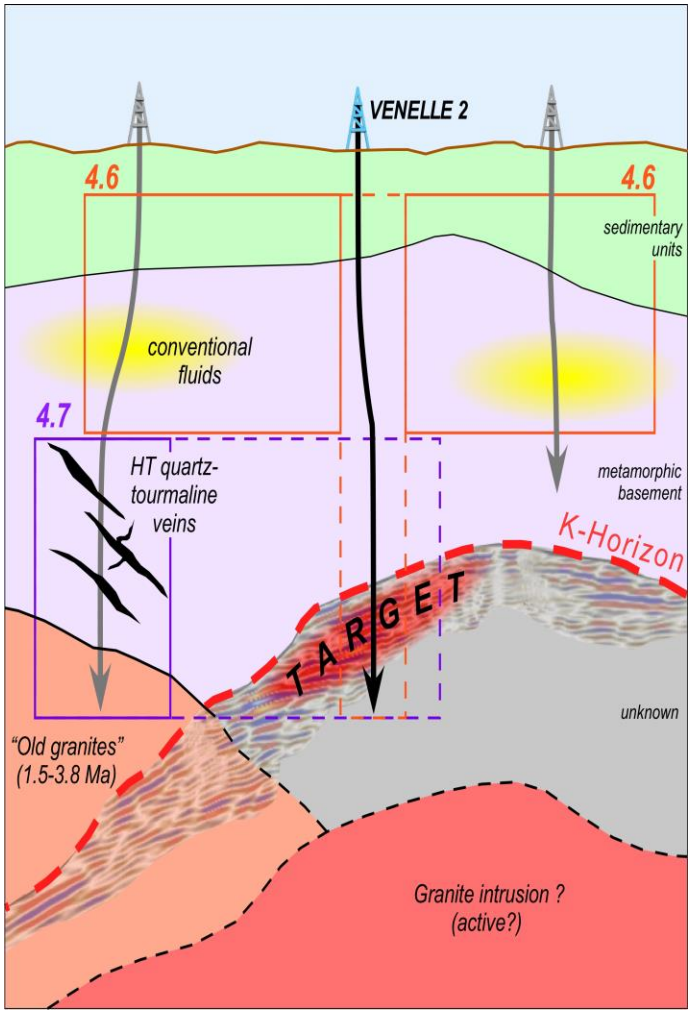
Predicting Target fluid's P-T-X

P range: variable, 350-740 bars

T range: 400-500 °C

X parameters: B-rich saline fluids associated with aqueous-carbonic fluids. Distinct isotopic signature.





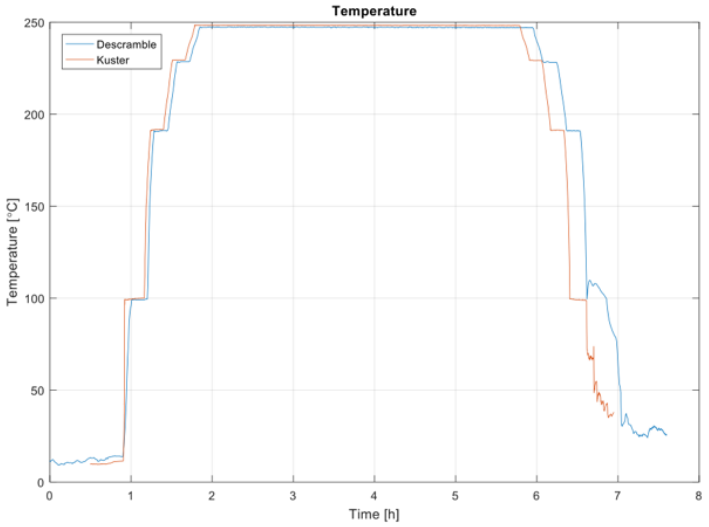
New designed T&P logging tool

A new tool for measuring temperature and pressure at supercritical conditions has been designed and developed by SINTEF

Main features:

- Electronics, sensors and batteries operate within the range 10-200 °C
- Metal seal and pressure housing can withstand 450 bar/450 °C
- 6 hours maximum downhole recording time at 450 °C

The measurements with the DESCRAMBLE tool in Lumiera 1 has good correlation with the measurements done with the Kuster K-10 in the same well

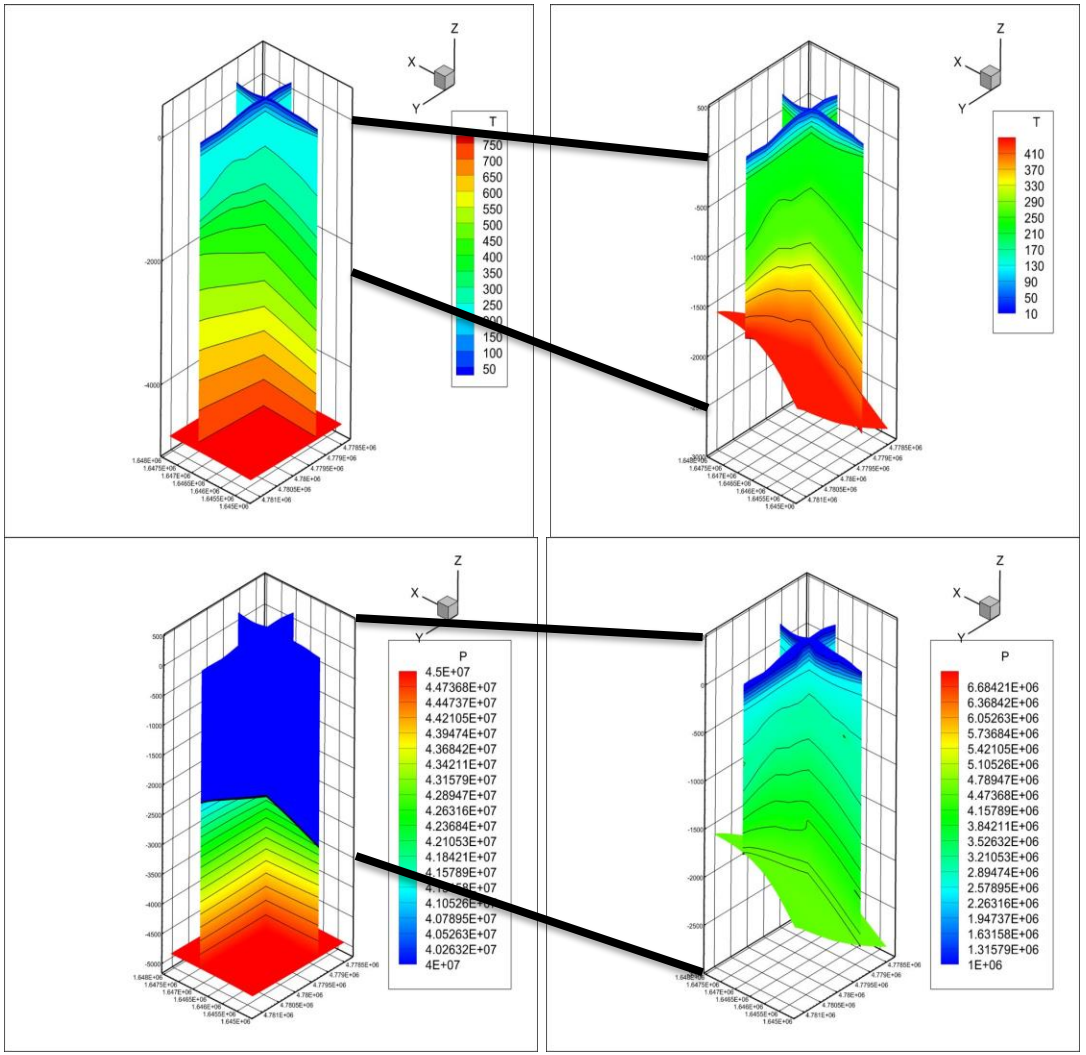


Task 5.2 Simulations of the surrounding of the Venelle 2 well during drilling
Task 5.4 Simulation with TOUGH2

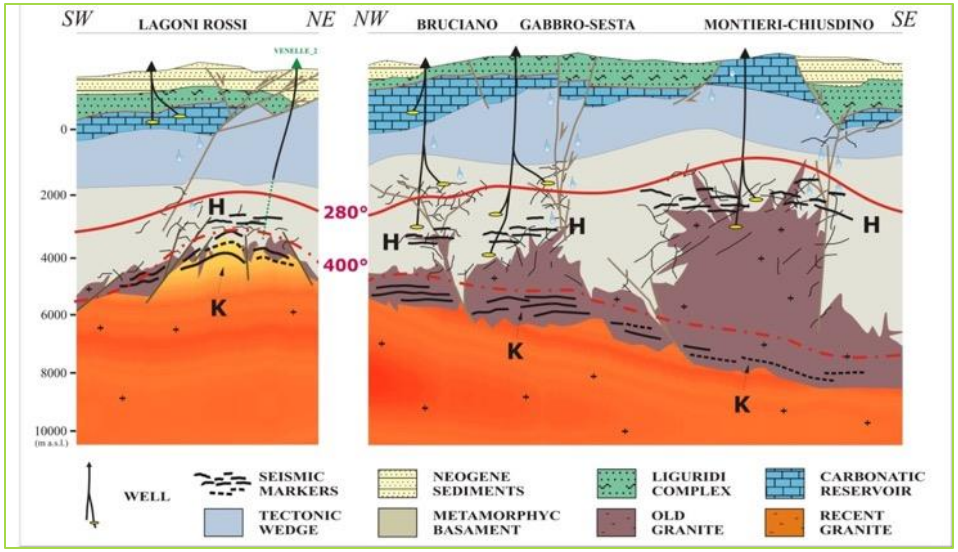
Supercritical version of TOUGH2: D5.3 Updated version of TOUGH2

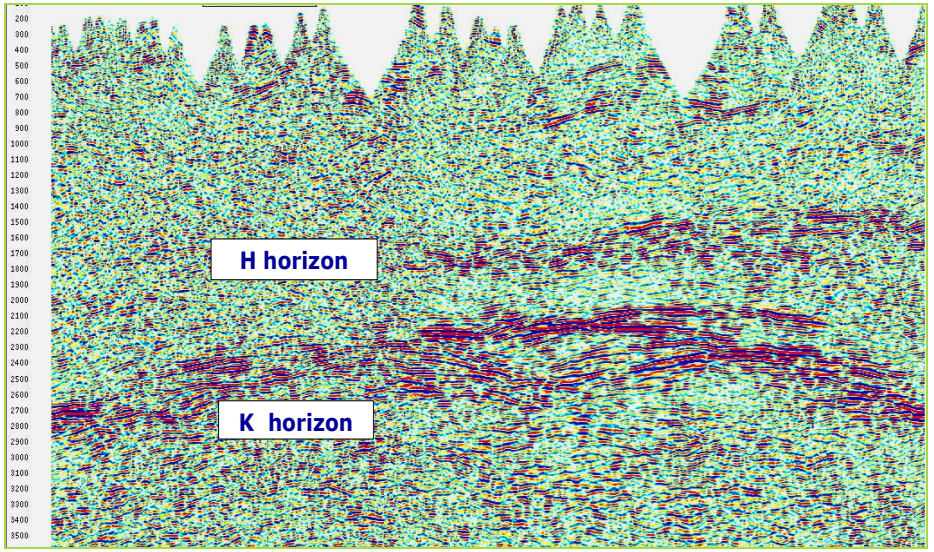
Temperature distribution:
Left: from surface to -5000 m
Right: from surface to K-Horizon

Pressure distribution:
Left from surface to -5000 m
Right: from surface to K-Horizon



K Horizon represents a seismic marker which may be associated with overpressured fluids at supercritical conditions

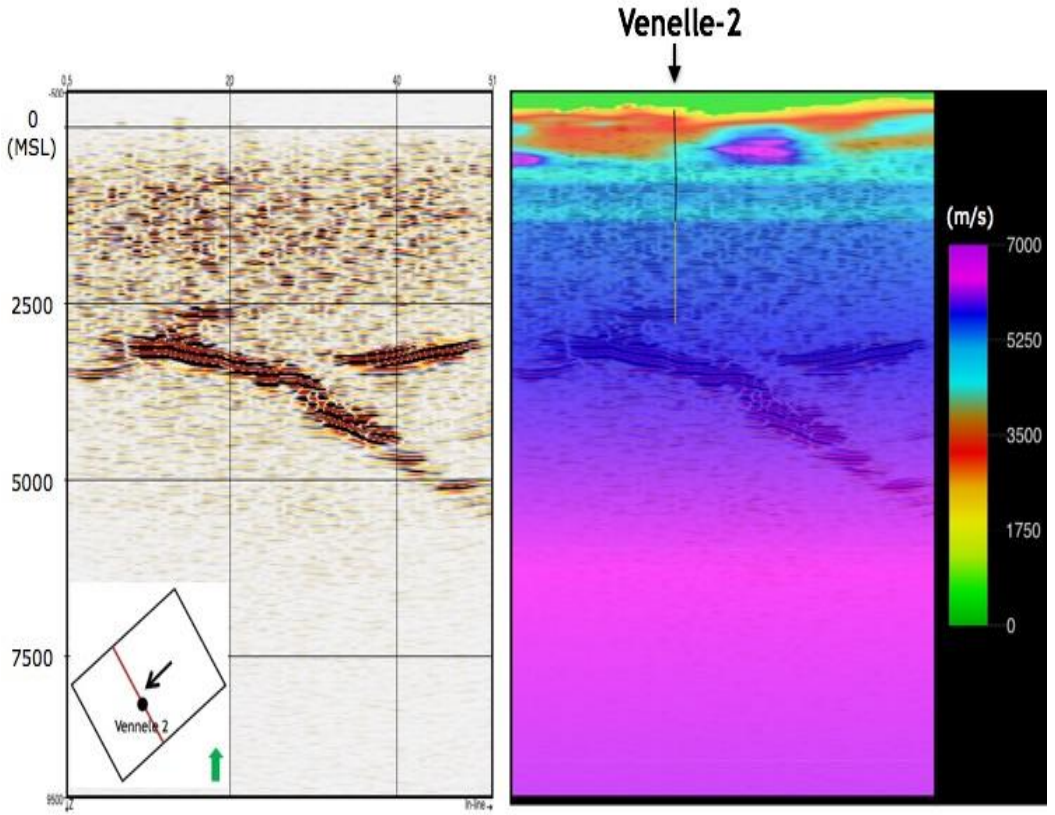




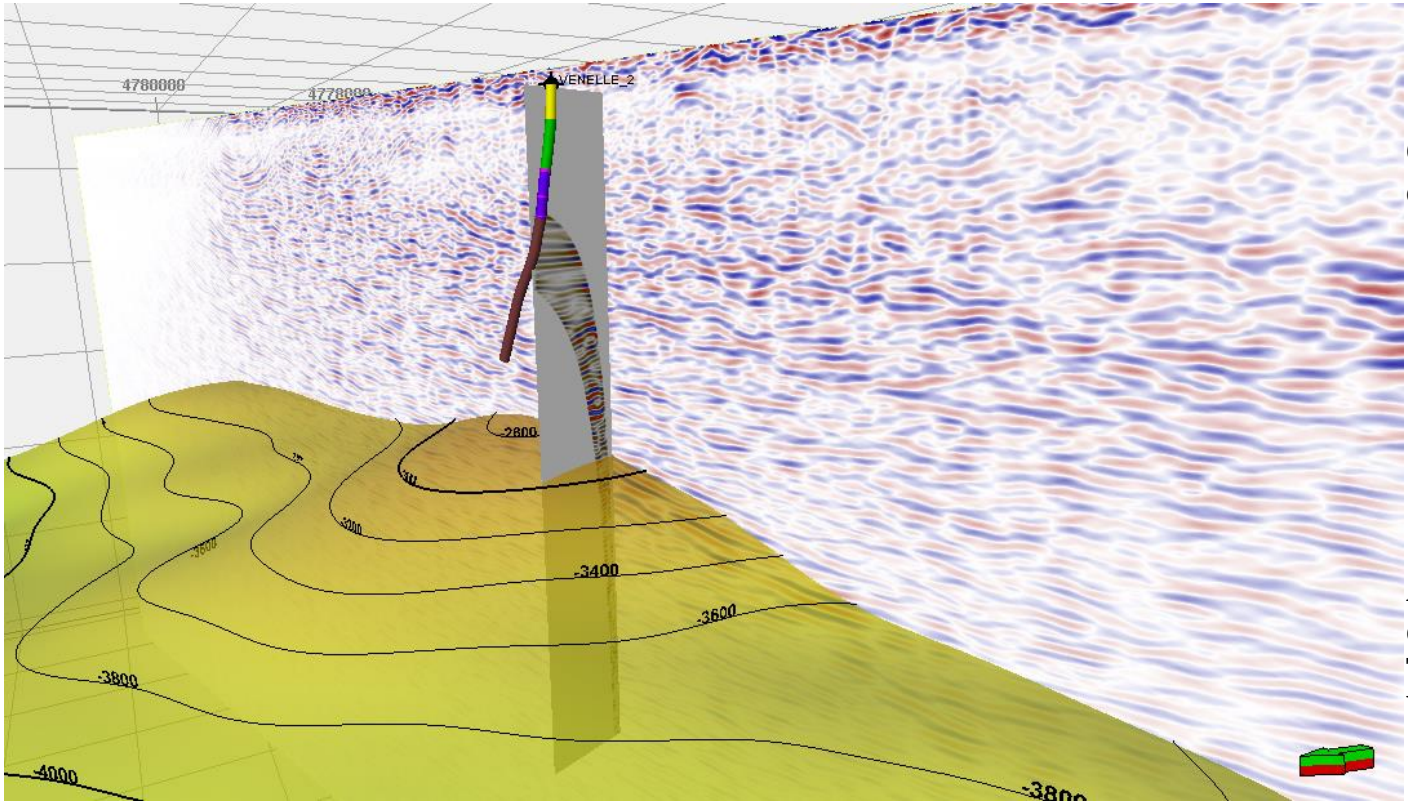
Drilling the K horizon will open possibilities of exploiting deep supercritical fluids that could be hosted in the recent granites, with a new development phase for the Larderello field.

Advanced seismic imaging to identify the drilling target

- **"best" possible 3D velocity model for as accurately as possible determination of depth (and lateral location) of K-Horizon**
- **"best" possible "focused" 3D seismic image of K-Horizon**



Advanced seismic imaging to identify the drilling target

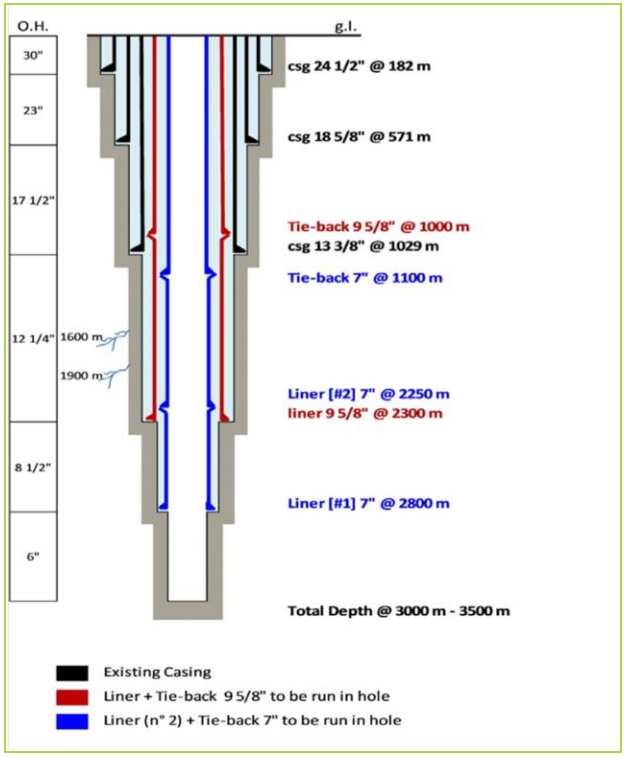


Correlation between the available data in depth:

- Offset-VSP data
- In-depth converted surface
- 3D seismic data reprocessed in-depth (TUBAF)

All the data indicate a K horizon depth of about 3150 – 3200 m TVD in correspondence of the Venelle_2 well

Well profile and casing string



EXISTING CASING (VENELLE 2)

Diametro	Grado acciaio	Peso nom.	Spessore	Drift		Connessione
				API	Special	
24 1/2"	J55	133 #	12.71 mm	23.125"	-	Tenaris ER
18 5/8"	J55	96.5 #	12.32 mm	-	17.500"	Tenaris ER
13 3/8"	L80 (*)	68 #	12.19 mm	12.259"	-	Tenaris ER

(*) = 0 - 100 m Steel Grade L80 13%Cr

CASING (planned)

Diametro	Peso nom.	Spess.	Drift	Sp. Drift	Grado	Conness.	Profondità		Descrizione	Note
inches	lb/ft	mm	inches	inches	acciaio		da m	a m		
9 5/8"	43.5	11.05	API	-	L80	TSH ER	0	1000	Casing	
9 5/8"	43.5	11.05	API	-	L80	TSH ER	1000	2300	Liner	
7"	32	11.506	-	6	TN125SS	TSH BLUE	0	1100	Casing	OK per t > 80°C
7"	32	11.506	-	6	TN125SS	TSH BLUE	1100	2250	Liner intermedio	OK per t > 80°C
7"	29	10.36	API	-	T95	TSH BLUE	2250	2800	Liner profondo	Full Sour

The casing operations are completed with the 7" at 2600 m; there is the possibility of using an additional 6" liner in the deepest part of the well, in case of need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Rock bits

Rock bits commonly used in our geothermal drilling have three cones rolling on bearings.

The high temperature expected in K horizon can lead to failures because of the fast decay of elastomeric parts (Rubber and Kevlar).

- Stinger bit has been selected as the best option
- No bearings subject to fast decay in high temperature
- Successfully tested on the Well Radicondoli 7 bis

Photo Album: cement

The high temperature Thermalock cement ready for the 7" casing cementing phase - operation completed

Photo Album: mud cooling

The reinforced mud cooling station

Photo Album: mud logging

The data acquisition station for drilling data and mud logging

Advanced well monitoring

Mud Logging system

- Geology master log from cuttings
- Monitoring drilling parameters (ROP, RPM, Torque, Flow in/out, T in/out)
- Collecting and analyze gas from mud: Total gas, CO_2, H_2, H_2S, CH_4 and He through a micro TCD+GC

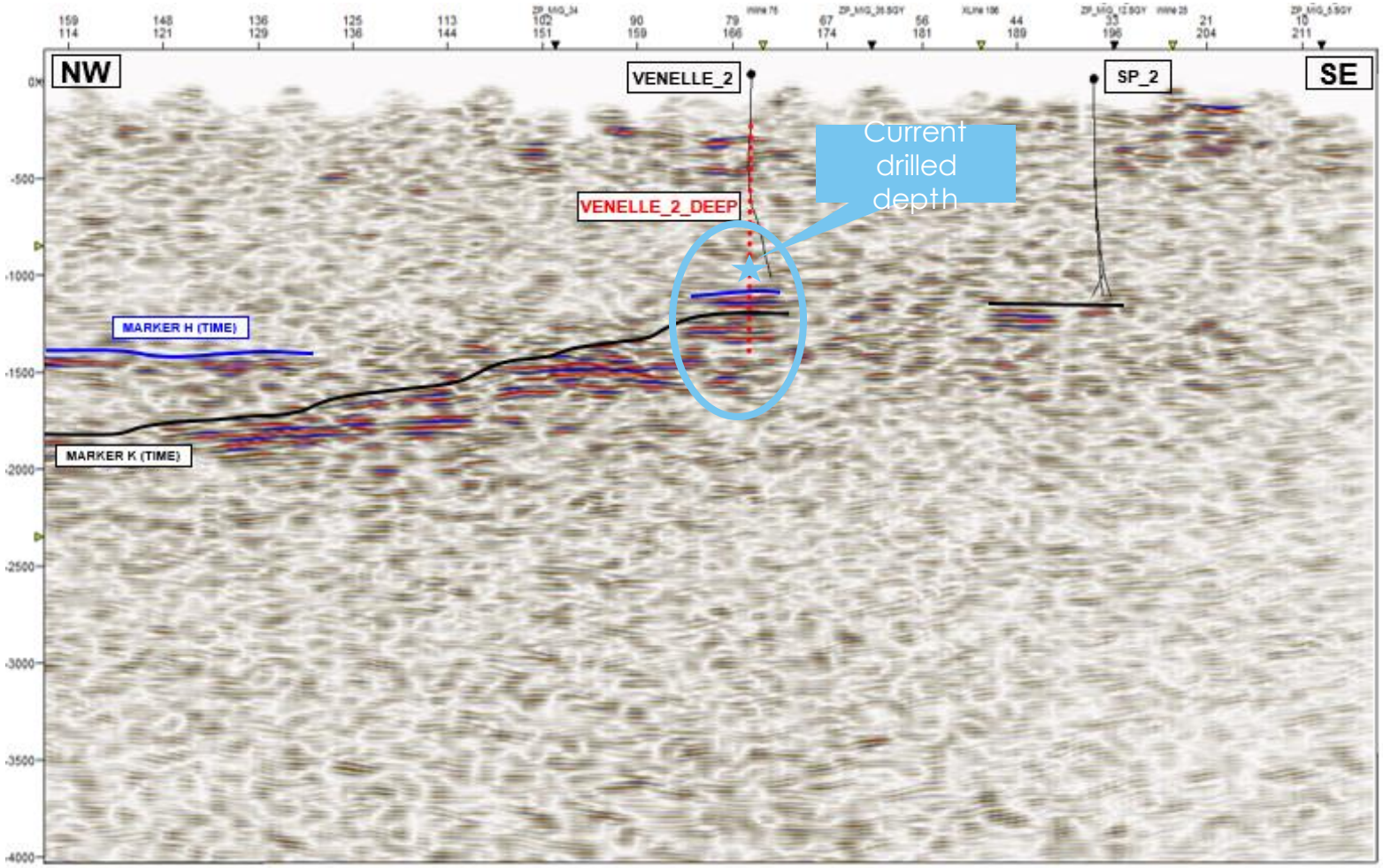
Mud Cooling system

- High temperature expected of the drilling fluid coming out. Cooling system needed to keep the fluid temperature in a range that maintain the rheological properties of the fluid itself and keep the drilling operation safe.

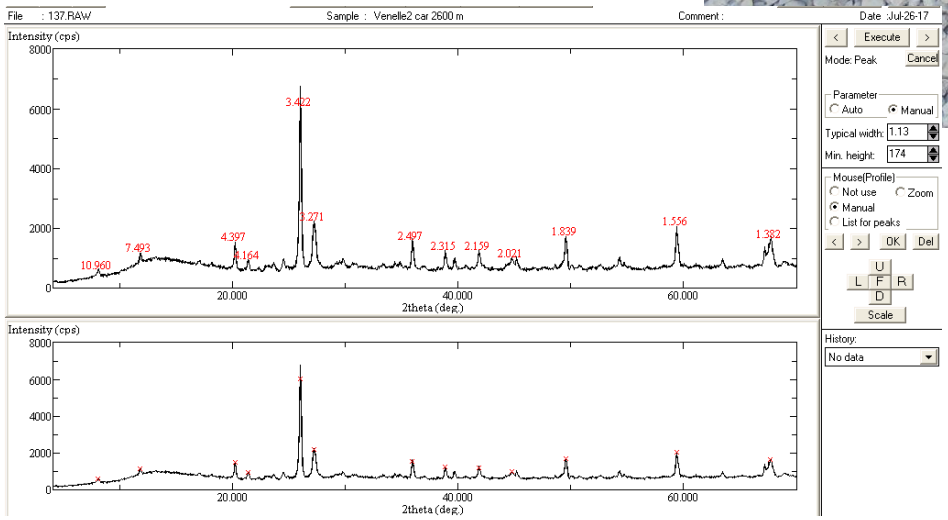
Managed pressure drilling

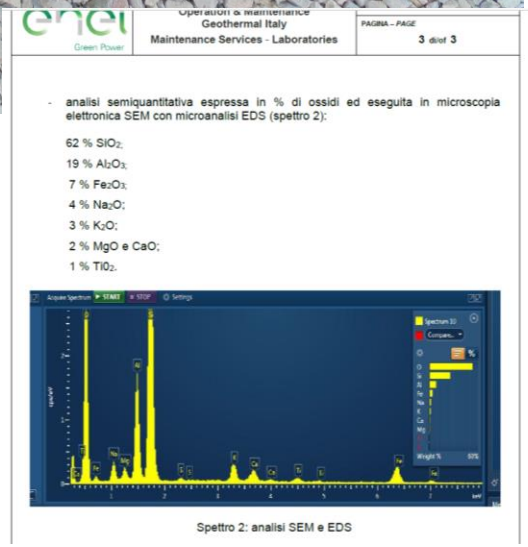
- Mitigation of the risks related to the uncertainty regarding the pore gradient and the fracture gradient
- Real time control of the annular pressure and of the wellbore parameters while drilling
- Closed-loop circulating system

Keep Drilling into the K target!



Core drilled samples (2600-2601.2 m depth) under investigation.





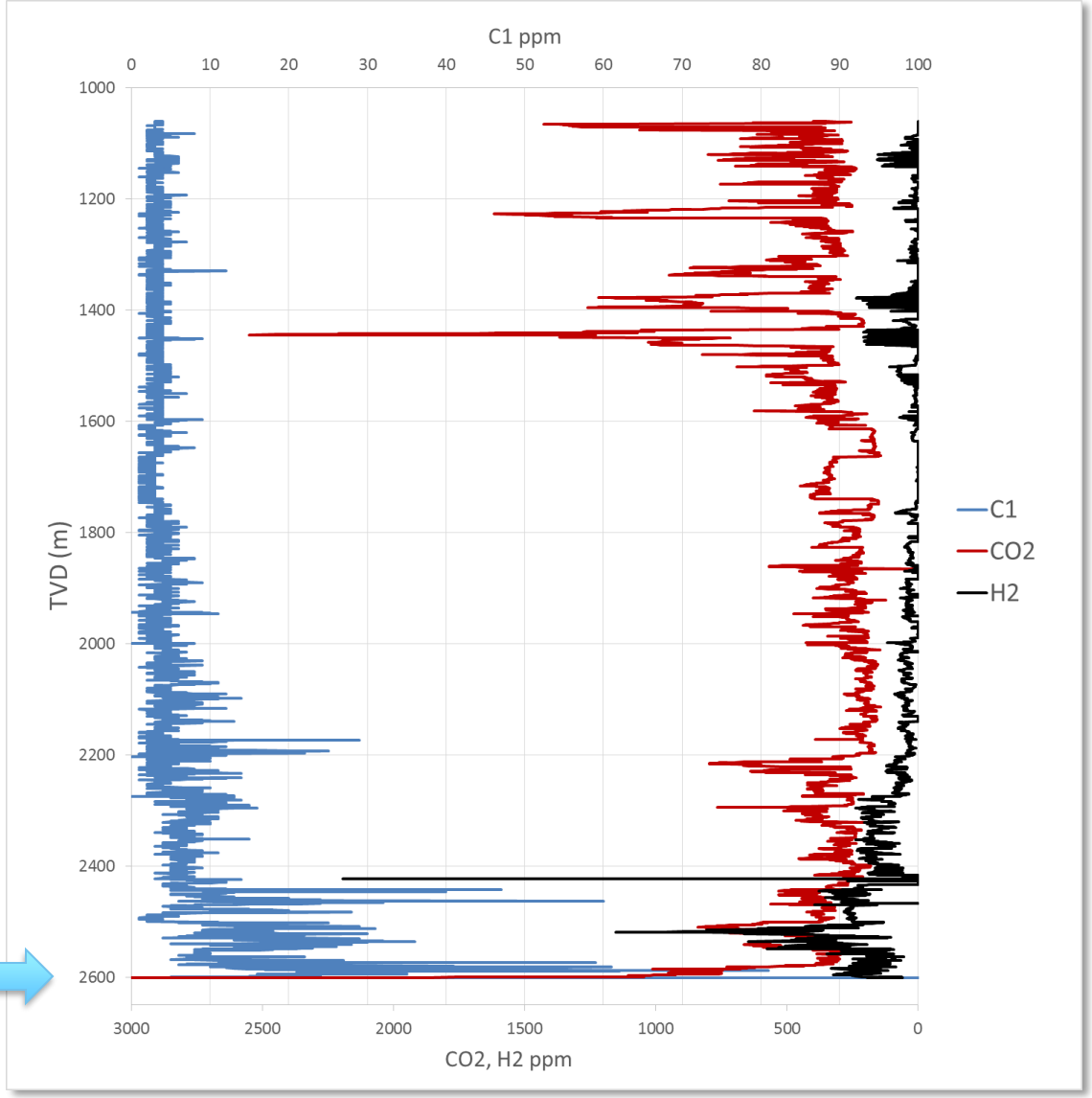
XRD on core drilled sample @ 2600 m

Continous gas monitoring during drilling:

Results updated up to 15/10/2017.

Many gas components are under surveillance, not only the main components (CO2, N2, H2S…) but also noble gases like He, and hydrocarbon from C1 to C6.

Reached a Temperature of 410 °C @ 2600 m



THANK YOU