VSP Survey in the Thonex Geothermal Well – New Characterization of Potential Carbonatic Geothermal Reservoirs*

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Abstract

In the framework of the Geothermie 2020 program being developed in the Geneva Canton and the FP7 IMAGE project, a VSP survey was carried out down to a depth of 1500 m in order to reconstruct a detailed velocity model of the region and characterize the carbonatic reservoir for future potential exploitation for heat storage and production.

One Near Offset (NO), a walk-above (WAB) and 4 additional offsets (VSP1-4) were collected to constrain the fracture condition and their anisotropic distribution.

Overall quality of data is good, with evidence of good direct arrivals and reflections, in particular below 700-800 m in depth.

The presence of a strong high velocity resonant system makes it impossible to pick reliable first breaks on the vertical section of VSPs 1, 2, 3 and on the Near offset VSP. On VSP 4, although the first breaks are of better quality, the upgoing wavefield is also contaminated by the said resonant system.

A Kirchhoff migration algorithm was applied and Full waveform inversion (FWI) was tested on VSP4. A detailed starting model based on the interval velocities was beneficial for the successful application of FWI. Final elastic-parameter models were obtained that resolve small-scale velocity structures and result in seismograms that very closely match the actual field data.

Interpretations show that the Molasse strata appear well visible on the VSP profile, as well as the top of the Mesozoic because of its high contrast of acoustic impedance. On the other hand, the Cretaceous and Upper Malm limestones are very transparent on the VSP. This could be explained by the fact that the acoustic impedance contrasts within these limestone units are much lower than those generated by the sandstone alternations of the Molasse or that generated by the Molasse-limestone contact. Additionally, the Cretaceous shows a variety of acoustic impedance, which can be interpreted as response to the well-known variability in lithology (i.e. limestone and marls alternations) and facies within this interval. In particular the high acoustic impedance at 1450 m has been calibrated with logs and core indicating that the strong seismic response is caused by the occurrence of a complex open and closed fracture system subsequently affected by infill (sedimentary dykes?) and dissolution (karst?) processes, which can represent favorable conditions for potential development of heat storage and production projects.

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Website Cited

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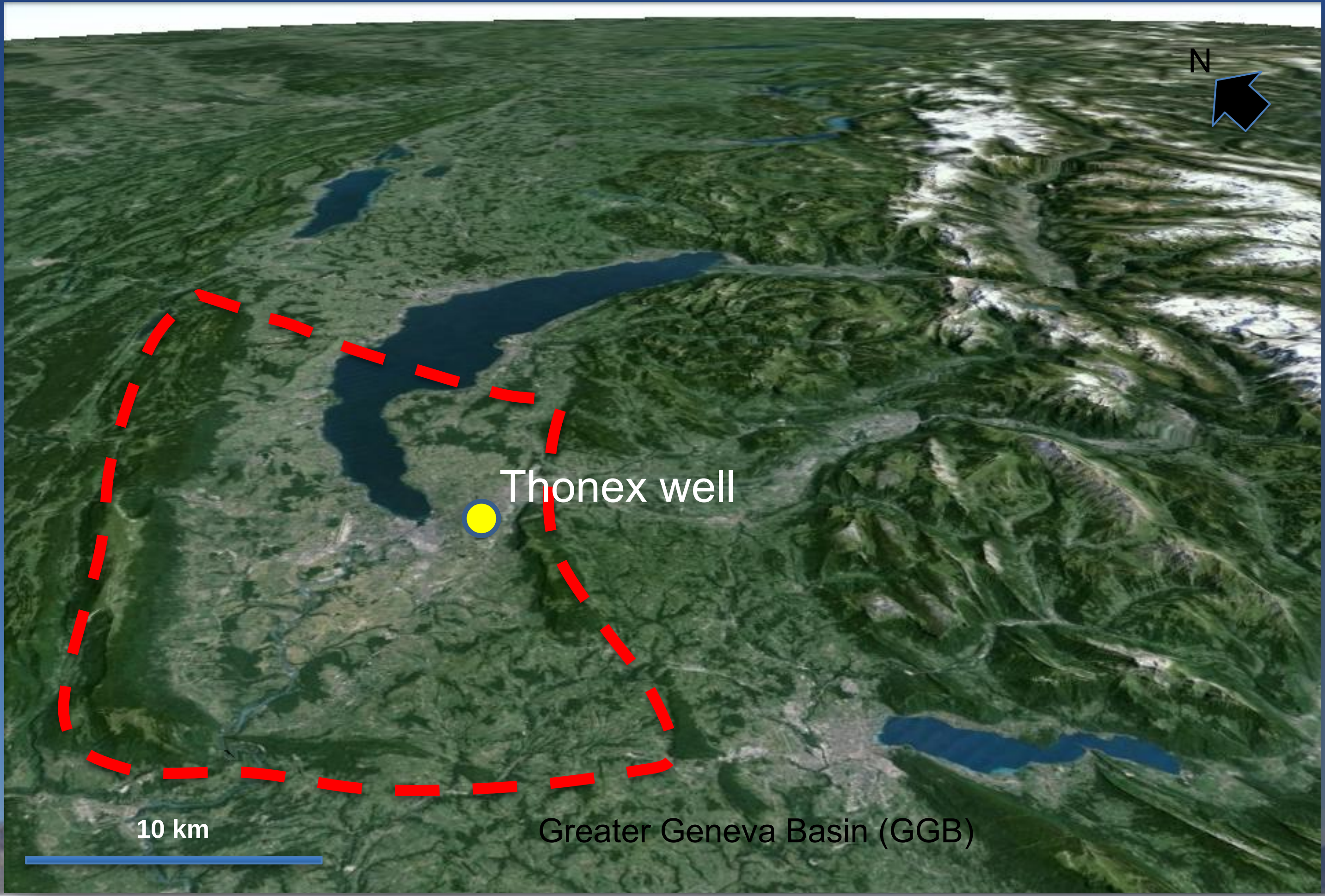
Outline

- Preamble / Introduction
- Geological setting
- Survey Design
- Survey Acquisition
- Survey Processing
- Interpretations
- Conclusions

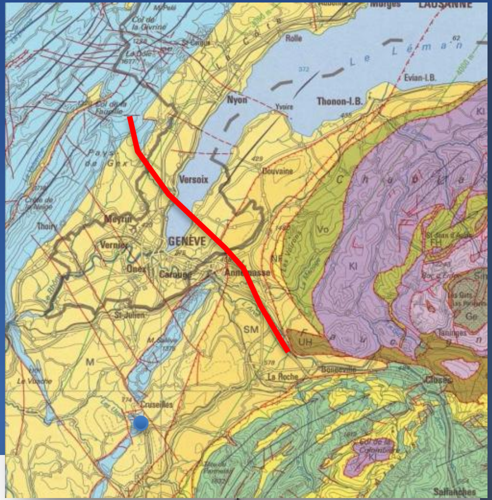
Geneva Basin in Western Switzerland

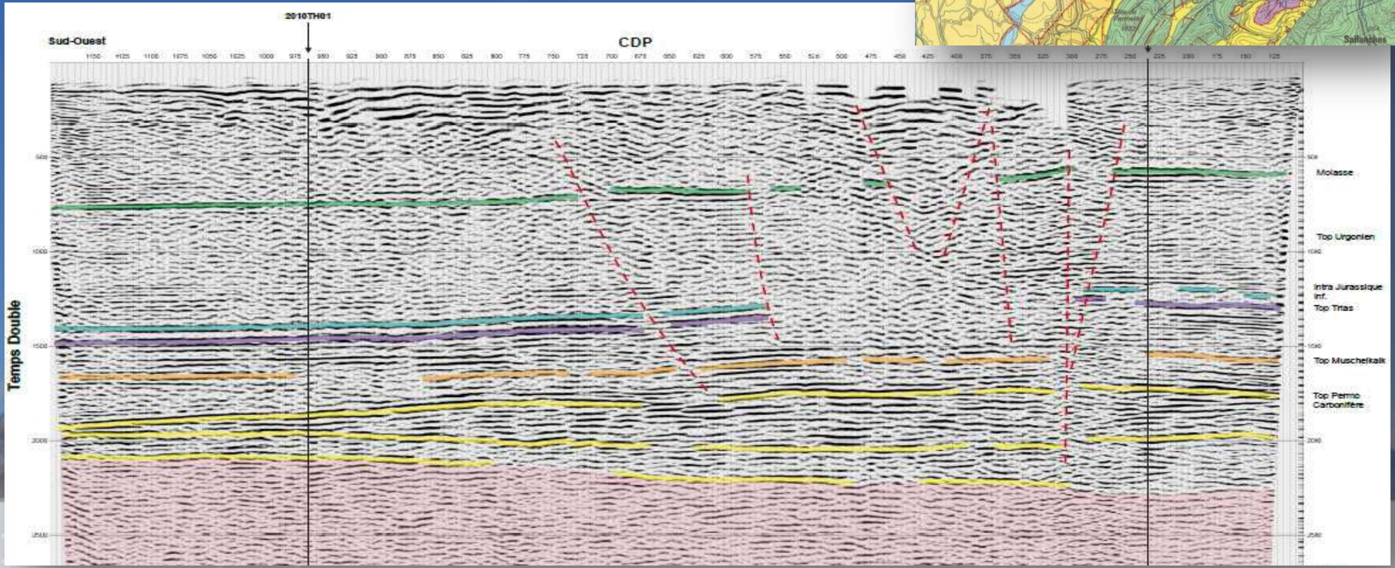


GB Geothermal Exploration: a glance into the past

Early 1990's the Canton of Geneva acquired several seismic lines and then drilled an exploratory geothermal well Thônex-1 (1993).

TD: 2690 m bdf; Upper Jurassic (Malm).
Reservoir T°C= 75±10 - Gradient 28.5 °C/km
Long transit time (10-15k years)
Basin: extensive low-K reservoir, likely not connected with deep geothermal fluxes connected to large faults.



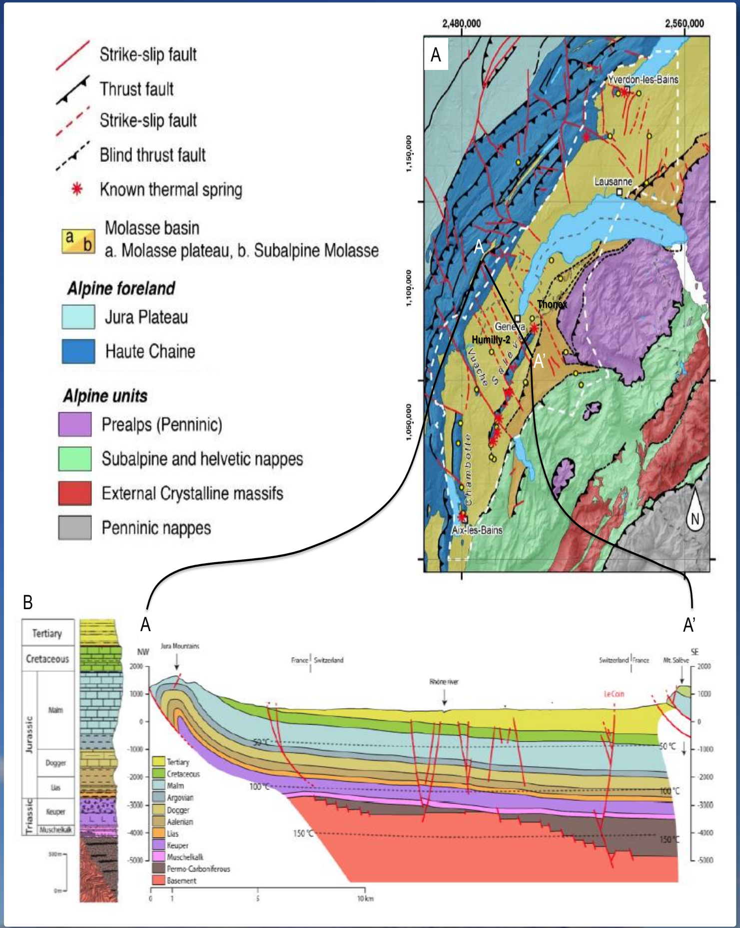


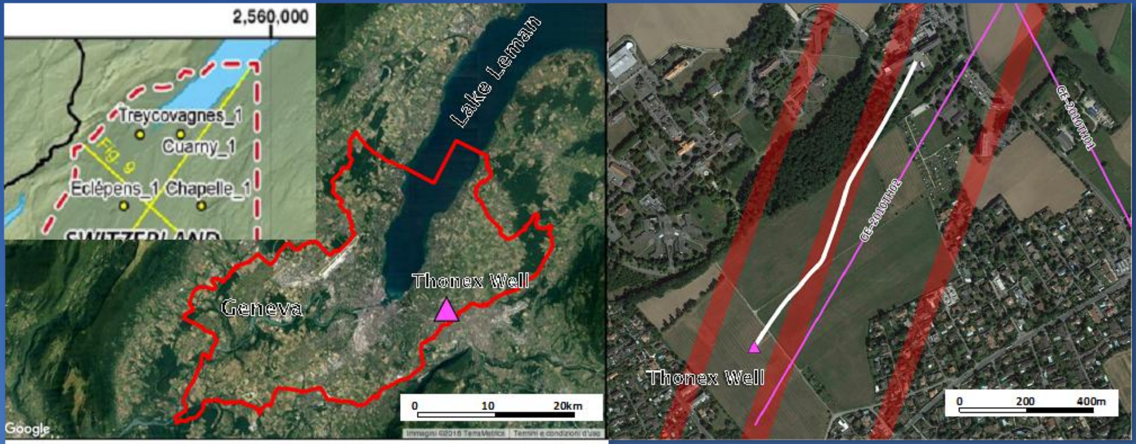
Introduction

- A vertical seismic profiling (VSP) survey was carried out in 2016 at the directional Thonex geothermal well,
- This study has been carried out in the framework of the IMAGE FP7 project allowing the collaboration among University of Geneva, Services Industriels de Genève (SIG), BRGM, INOGS, and ETHZ.

- The main goals of this study were:
  - Test the VSP method to **improve the imaging of potential geothermal reservoirs** in the Geneva subsurface;
  - Gather more detailed **constraints on the depth and geometry of geological horizons** in the study area;
  - Focus on the **karstified transitions** between the Tertiary Molasse sediments and the Mesozoic sequence, and on the **reef complex** at the contact between Cretaceous and Jurassic lithologies;
  - Evaluate the **effect of faults** on rock properties (reflectivity);
  - **Acquire an accurate velocity model** to calibrate better the current interpretations of the large 2D reflection seismic dataset available in the Geneva region.

Geological Setting

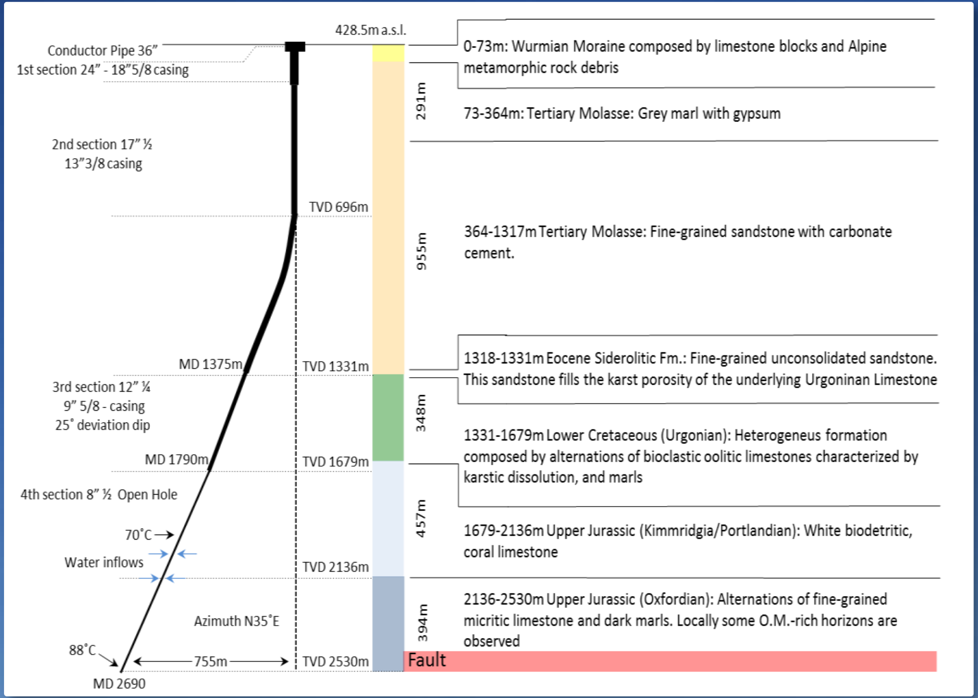




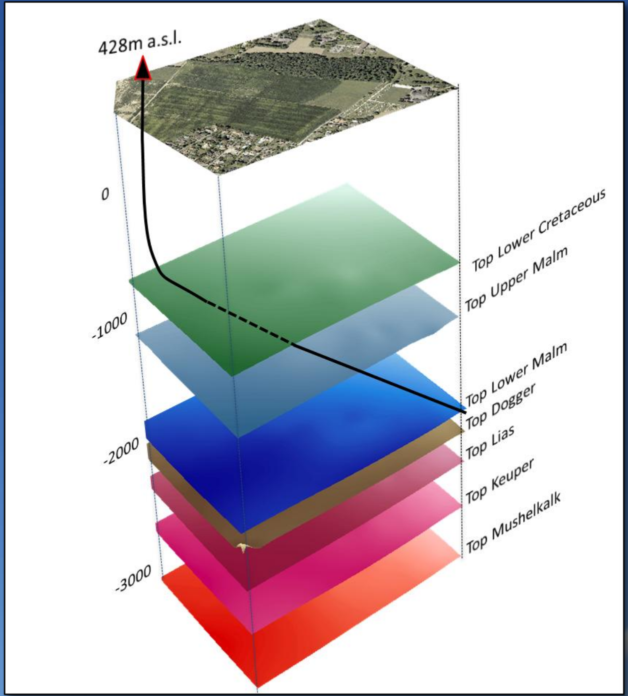
Location of the Thonex well site reporting the trace of the deviated well and the main geological structures interpreted on the 1980s-1990s 2D seismic lines (mod. from final report Etat de Geneve, 1994) and most recent 2010 2D seismic lines

A. Location of the Western Alps Molasse Basin (white dotted line) superposed on the regional geological map (mod. from Chelle-Michou et al., 2017). B. Cross section cutting though the Geneva area (mod. from Clerc et al., 2015)

Geological Setting

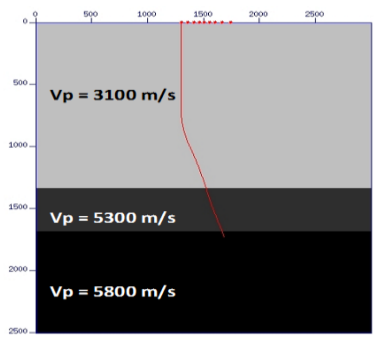


Simplified stratigraphy, geometry and design of the Thonex well (mod. from Jenny et al, 1995)

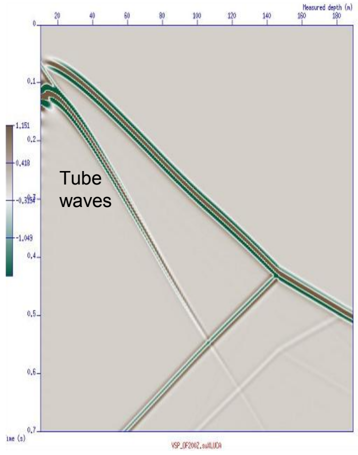


3D geological layers-surfaces of the Thonex area extracted from the GeoMol 3D model (http://www.geomol.eu/home/index_html)

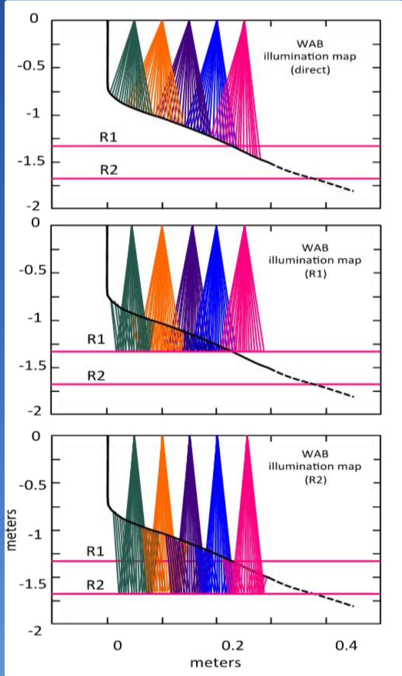
Survey Design



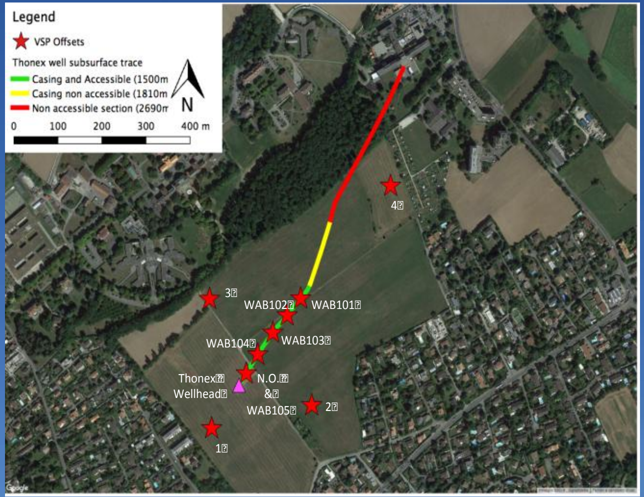
Thonex well provisional P-velocity model, 2D section in the well deviation direction extracted from the 3D model



Example of VSP synthetic signal obtained with the source at 200 m from wellhead.
The variation in the direct signal and the reflection from Upper Mesozoic and Lower Cretaceous interface can be observed

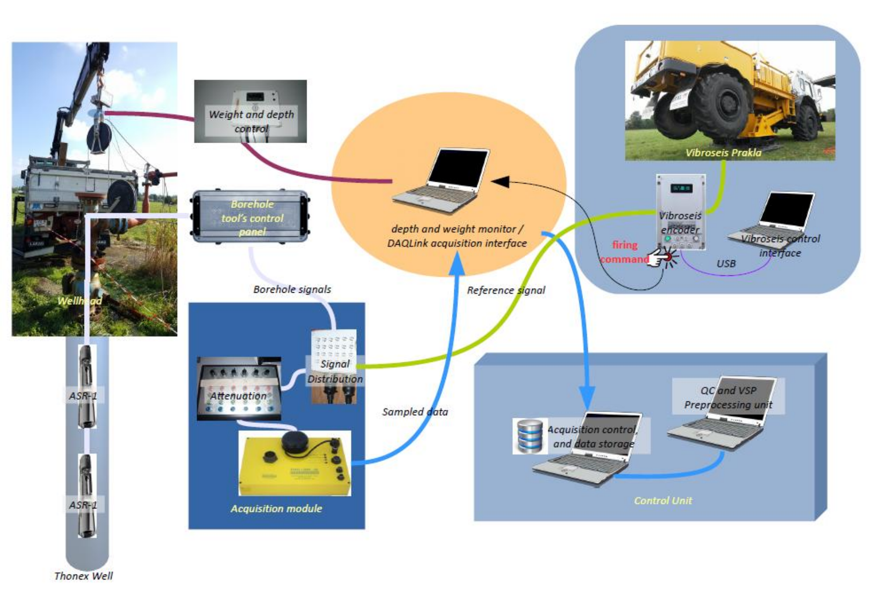


Example synthetic ray tracing design for the Walk-Above / subsurface illumination



Map showing the accessible depth of the well and the location of the shot points

Survey Acquisition



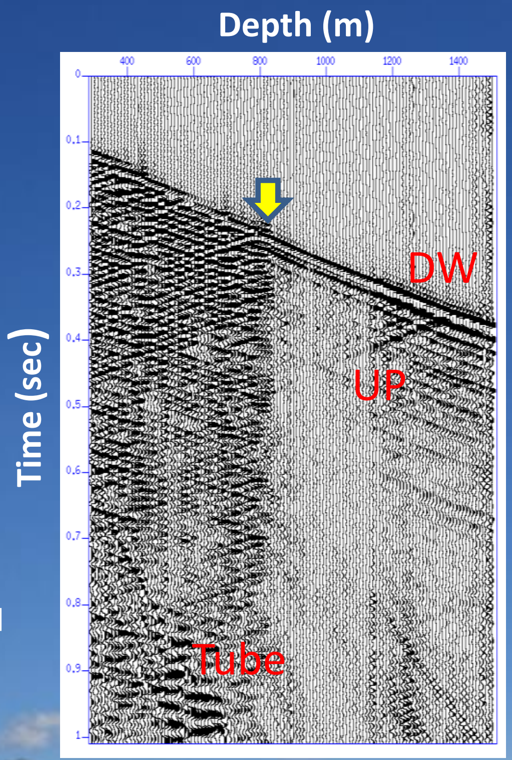
- The wireline VSP systems used a chain of two Avalon ASR gimbal 3-C geophone tools, 15 Hz natural frequency.
- The Vibroseis source parameters selected were 14 s upsweep in the frequency range 8 – 120 Hz, with 0.3 s taper, total recording time 20 s.

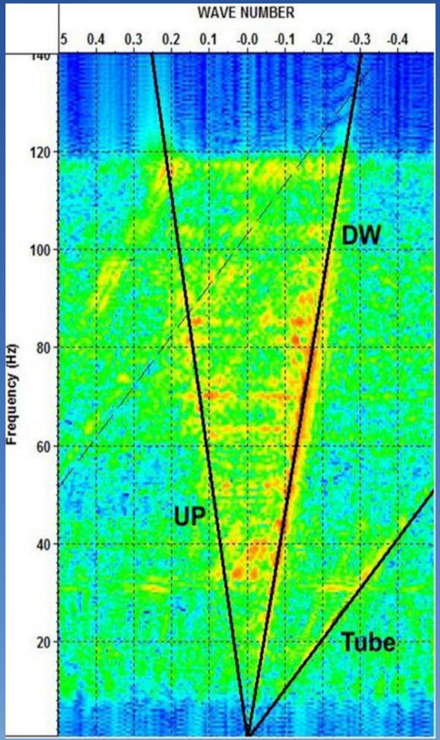
Survey Processing

Quality of the acquired data was good below 700-800 m depth from ground level, showing strong direct arrivals and reflections,

Above this depth, along the vertical section of the borehole, we observed effects probably due to the condition of the casing or to problems in the cement bonding.

Tube waves have been recorded in the lower part of the records in al VSPs





Analysis of wavefields in the time-depth and frequency-wavenumber F-K domains, with downgoing waves, upgoing waves and tube waves, which are aliased.

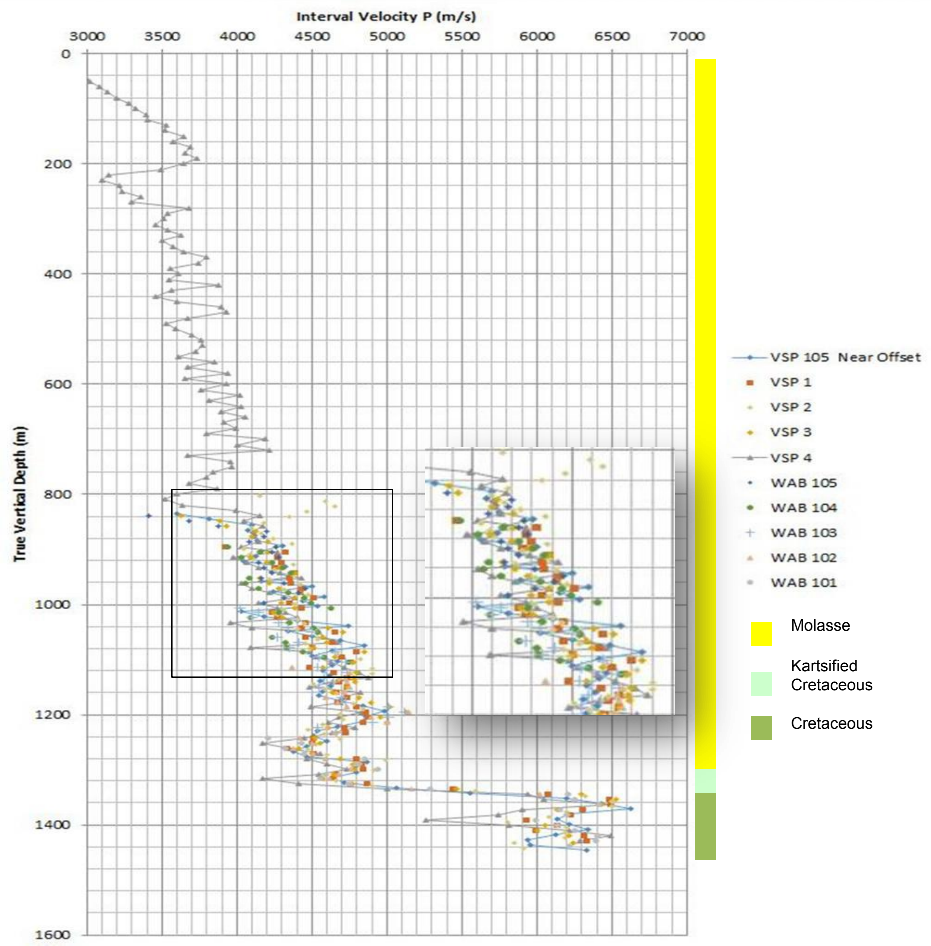
Survey Processing

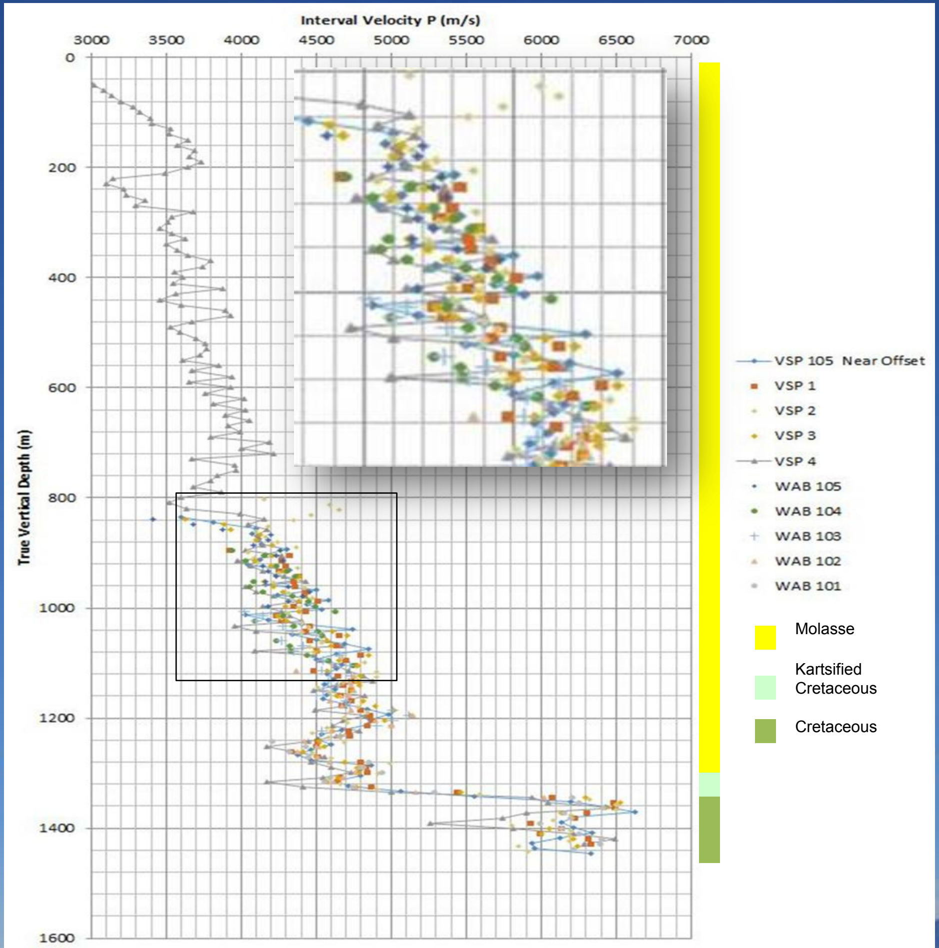
Velocity model for each offset VSP was obtained by data processing on the Z component and referenced to Ground Level.

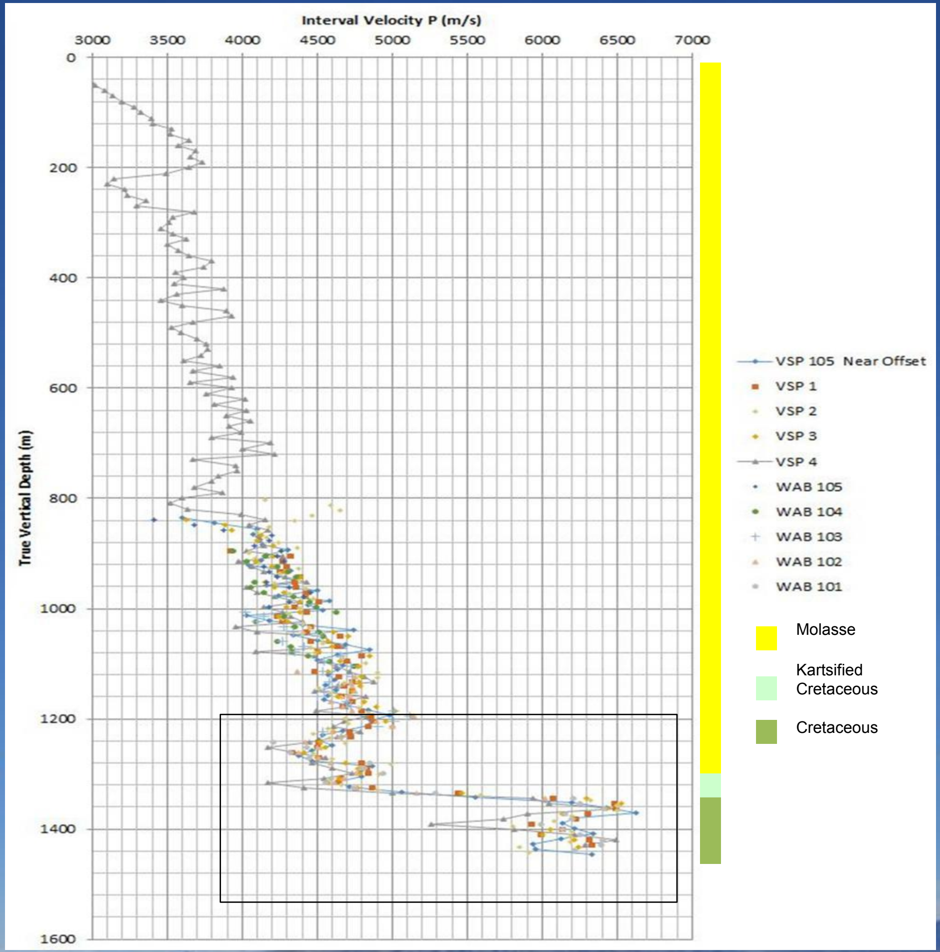
The main processing steps were: Editing, sort and trace header adjustment; Geometry check and source receiver offset calculation with the deviated well path; Signal frequency analysis, and Band Pass filtering 8- 12-110-120 Hz (Ormsby filter).

This preprocessing was followed by:

- FB picking.
- Velocity analysis on VSP data from near and offset VSPs
- Wavefield separation
- FK filter design and application for upgoing wavefield enhancement.
- Design of deconvolution operator from downgoing wavefield
- Deconvolution using the designed operator
- Wave shaping deconvolution.
- Spherical divergence recovering
- Upgoing reflections conversion to Two Way Time (TWT)
- Corridor mute and corridor stack to obtain reflectivity sections
- Kirchoff Migration. Time and depth-migration outputs.
- Component rotation to investigate lateral-offset data.




Interval Velocity P (m/s)
3000
3500
4000
4500
5000
5500
6000
6500
7000
True Vertical Depth (m)
0
200
400
600
800
1000
1200
1400
1600
VSP 105 Near Offset
VSP 1
VSP 2
VSP 3
VSP 4
WAB 105
WAB 104
WAB 103
WAB 102
WAB 101
Molasse
Kartsified Cretaceous
Cretaceous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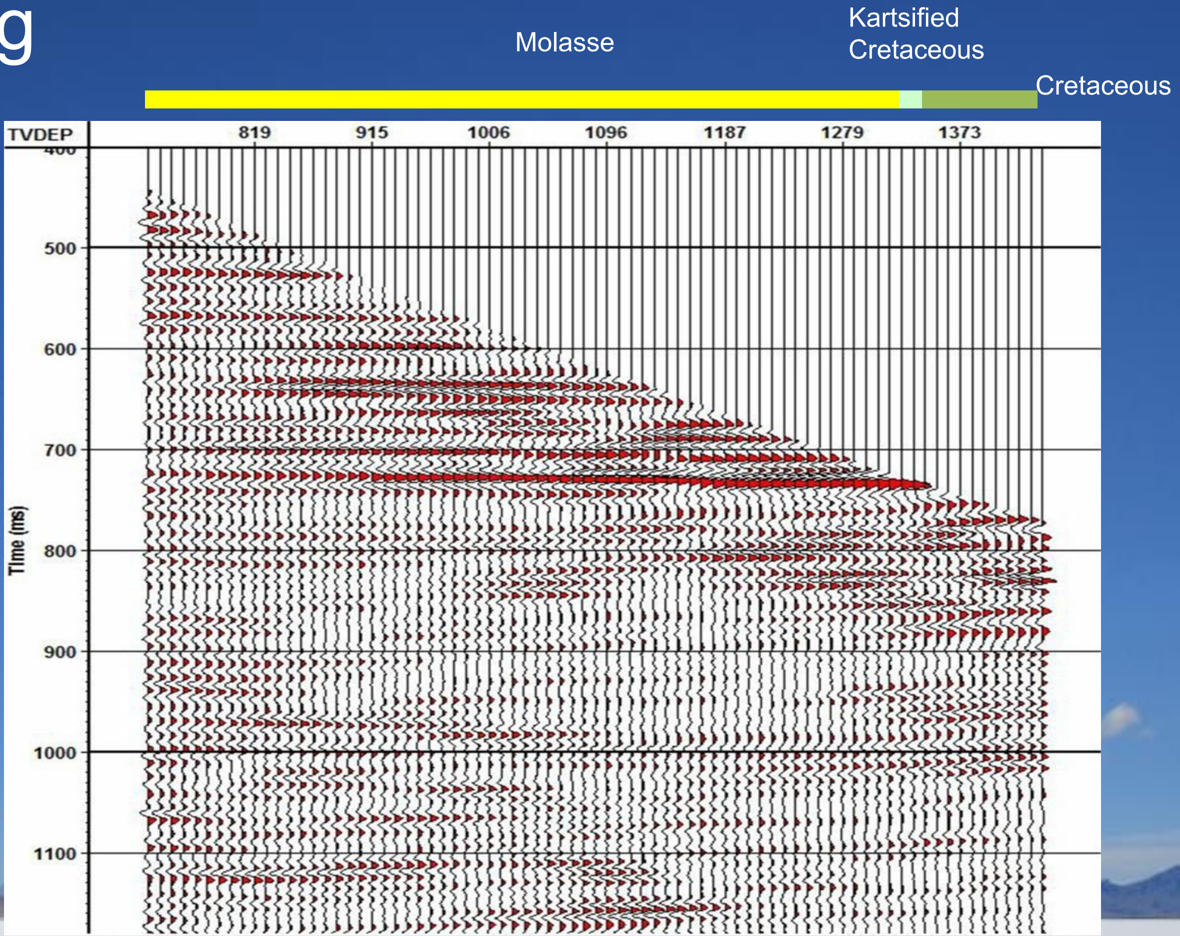
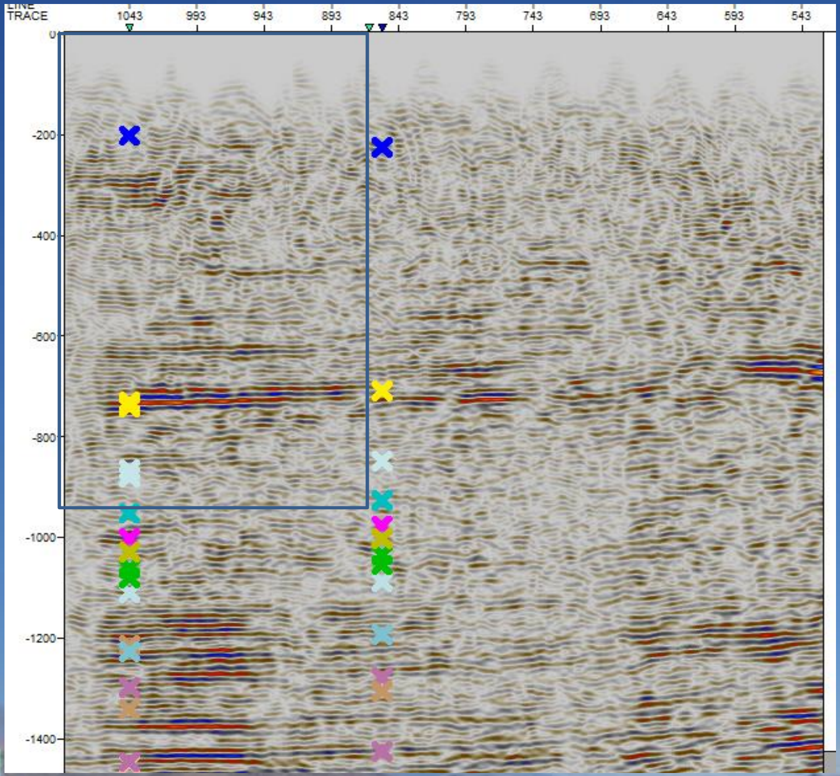
VSP 2
VSP 3
VSP 4
WAB 105
WAB 104
WAB 103
WAB 102
WAB 101
Molasse
Kartsified Cretaceous
Cretaceous

Survey Processing

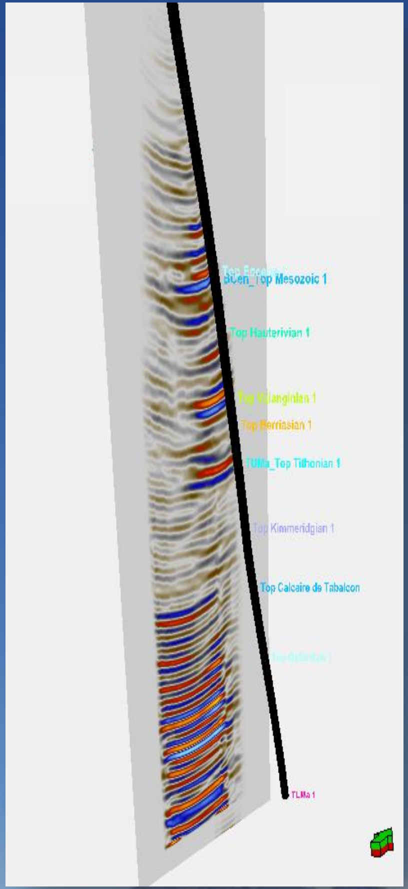
VSP at Near Offset, TWT upgoing deconvolved reflections, where the depth of the reflectors encountered by the well is clearly interpretable on the horizontal scale (true vertical depth) according to the stratigraphic interpretation, together with predictions below the total depth.



Interpretations



Location of the VSP study area over the vintage Thonex-2 seismic line. The blue box area covered by the VSP and the coloured crosses indicate the picked horizons

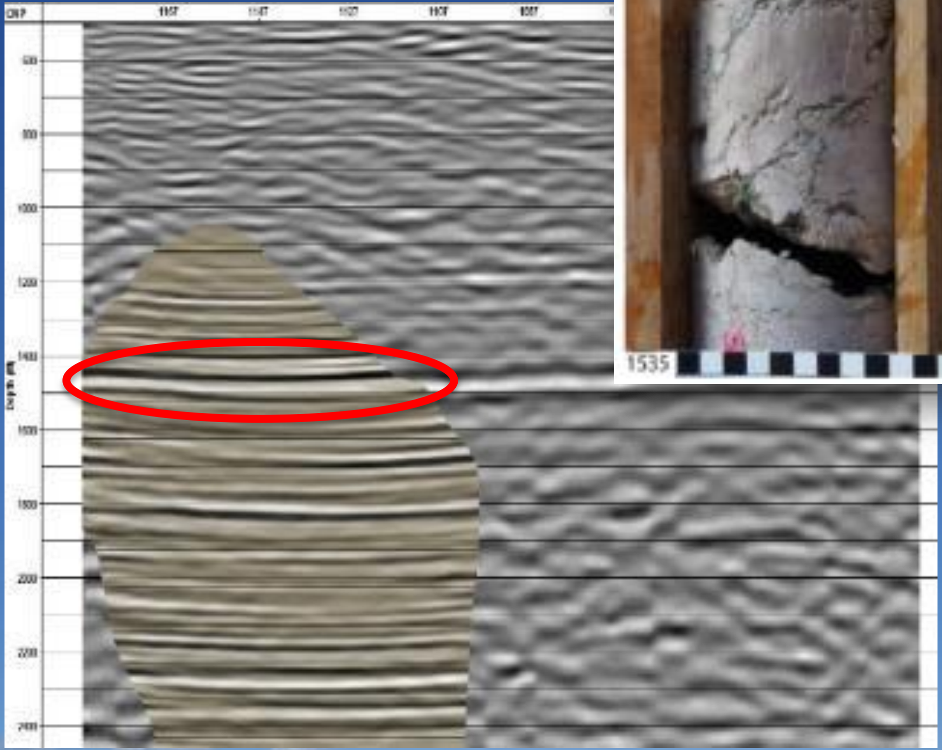


Superposition of the well trace over the WAB VSP reflection section, showing the reflection zone illuminated even below the deviated well

Interpretations

Superposition of the depth-migration WAB VSP result over the Thonex2 seismic line and corresponding fractured and karstified cores found in the formation corresponding to the interpreted zone (red circle). The VSP improves the resolution and guides the interpretation of details, net always evident in the surface section

Some reflection in the Upper Jurassic can be visible



Conclusions

- The VSP survey carried out in the Thonex well provided some encouraging results for the characterization of the Mesozoic formations in the Geneva Basin which represents the main geothermal targets for heat production and storage
- The upper part of the well is affected by a noisy signal most probably due to the bad coupling between the casing and the rock
- The transition between the Tertiary Molasse sediments and the Mesozoic limestone is very well highlighted with particular focus on the karstified top Cretaceous
- Walk-Above provides a better definition of the local reflection compared to the available 2D seismic lines
- Reflections in the Upper Jurassic can be visible as well on the Walk-Above but further processing is needed to constrain better the lateral extent and the correlation with the lithological vertical variations
- Given the positive results, VSP will used on future wells as an uncertainty risk reduction tool for imaging near well bore subsurface (doublets)