A laboratory approach for seismic data interpretation: the borehole Humilly-2 (France)

EGU General Assembly, Vienna | 8–13 April 2018

Université de Genève — ETH zürich

Mahmoud Hefny (1), Alba Zappone (1, 2, 3), Claudio Madonna (1), Andrea Moscariello (4), and Jean-Pierre Burg (1)

(1) Department of Earth Sciences, ETH Zürich, (2) Swiss Seismological Service, ETH Zürich, (3) Institute of Process Engineering, ETH Zurich, (4) Department of Earth Sciences, University of Geneva

A. Introduction

- Reservoirs-characterization of geothermal systems, integrating multiscale seismic data, is key towards predicting reservoir-performances. In a joint project by the Canton of Geneva and SIG (Services Industriels de Geneve), a geothermal exploration program GEothermie 2020 integrate the subsurface geological and geophysical data and evaluate the potential of geothermal energy production in the Geneva basin.

- This area is located in the westernmost part of Swiss Molasse Basin, where the "case history" for the ongoing study consists of five main aquifer/aquitard pairs of the Swiss Molasse basin. These pairs have been indicated in literature as potential reservoirs for deep CO_2 sequestration.

- One of our main goals is to quantify the effect of porosity, mineral composition and micro-textural characteristics, such as banding and layering of minerals in sedimentary rocks, on their seismic properties. The final aim is to offer a key to interpret the seismic reflectivity zones identified in the seismic survey (Gorin et al., 1993) and to identify a calibration key for borehole logging data where no coring was performed.

- The stratigraphy of Savoy-Geneva pilot area consists of a 3000-5000 m thick sequence of Mesozoic and Cenozoic sedimentary rocks overlying the Variscan crystalline rocks and dipping gently (1-3°) to the Southeast toward the frontal depression of the Pre-Alps (*see the seismic transect profile in: E. Discussion panel*).

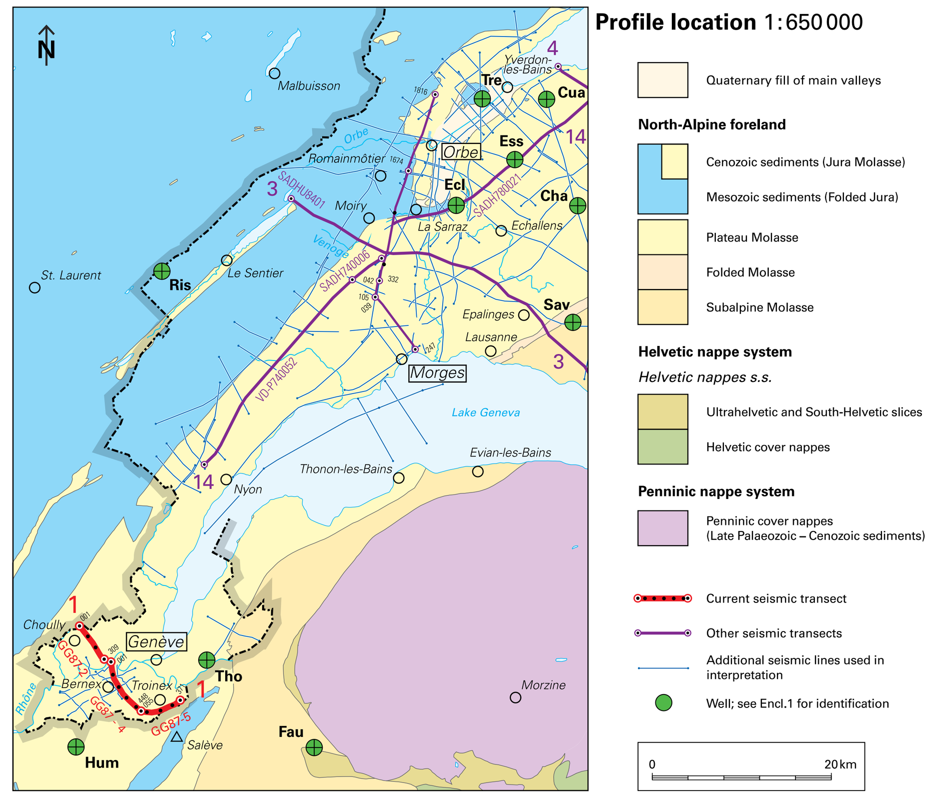


Fig A.1: Location Map after SwissTop 2005.

B. Geological Constraints

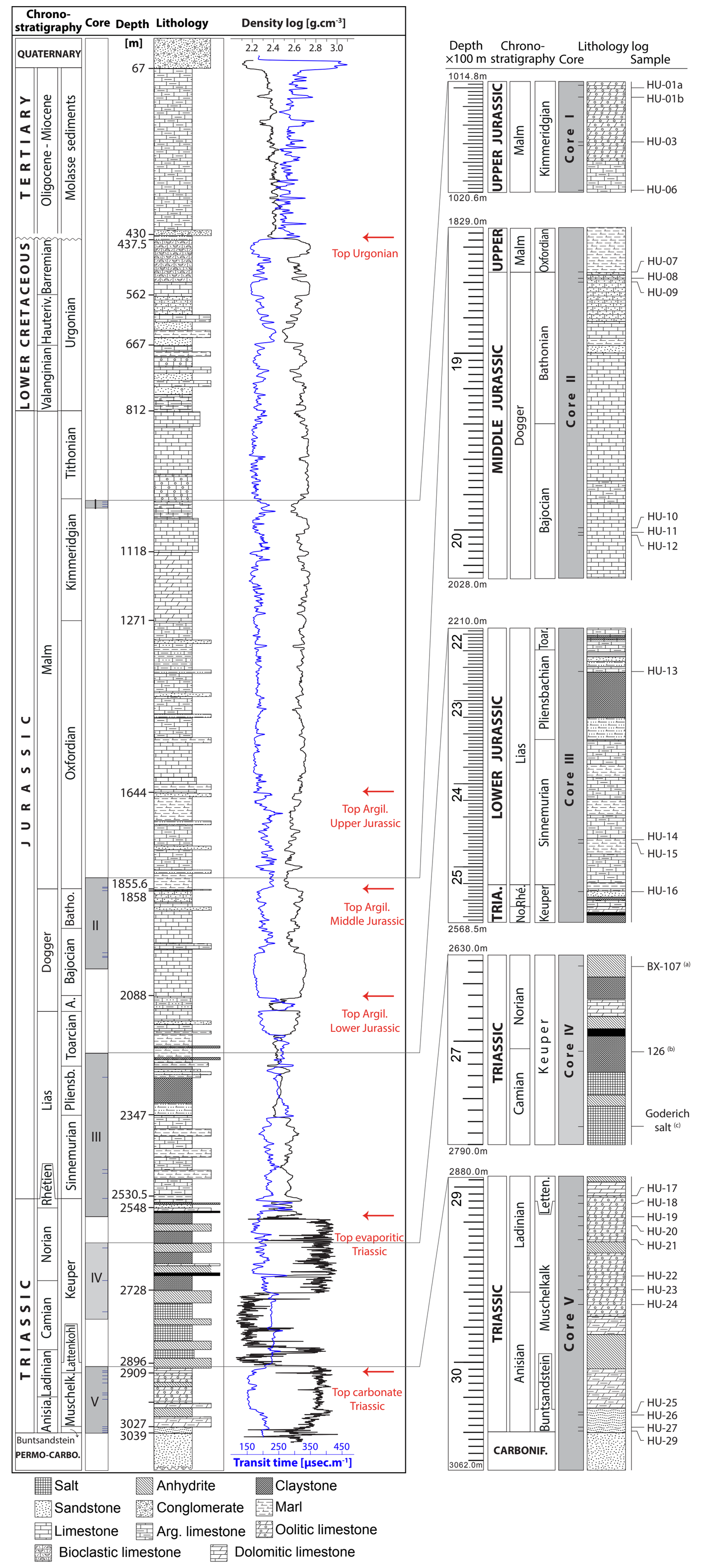


Fig B.1: Stratigraphic succession of Humilly-2 borehole, show the six majors seismic reflectors (red). For the location "Hum", refer to Fig A.1

- High-resolution mineralogical maps and automated quantitative mineralogical compositions identification are assessed using a combination of back-scattered electron values, energy-dispersive X-ray spectra, and X-ray count rates (QEMSCAN); at University of Geneva.

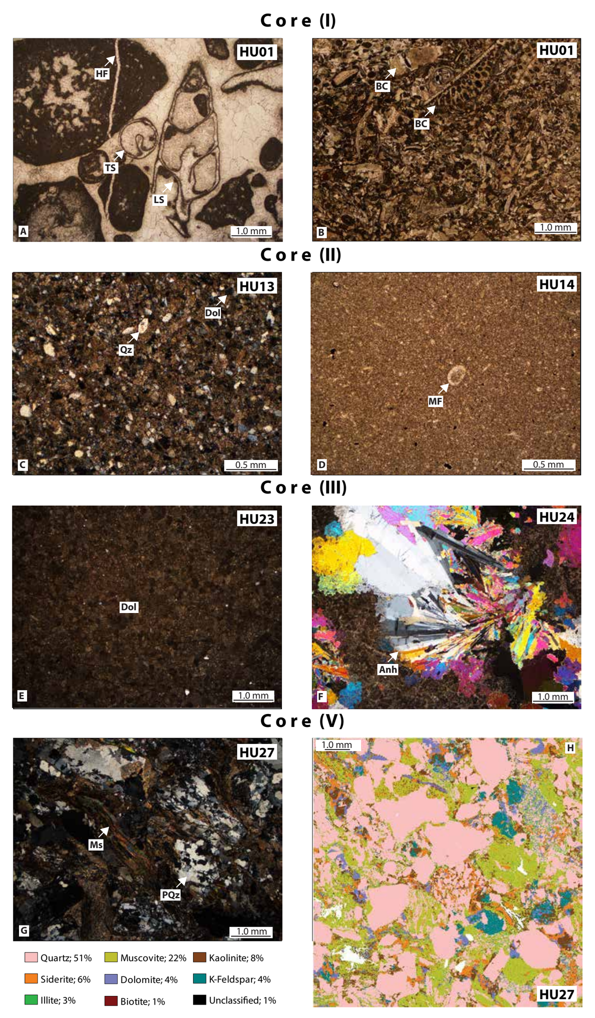


Plate B.1: Optical photomicrograph of representative samples. Longitudinal (LS) and transversal (TS) cross-sections of a high-spired gastropod. Fractures (HF) were healed by a sparite cement. Quartz (Qz). Dolomite (Dol). A few of shell fragment (benthonic forams) which are preserved as a mold (MF). fibrous anhydrite (Anh). The kaolinization (Kln) of K-feldspar (Kfs) is occurring to form the clay cement for pore-filling and grains coating firm on Quartz (Qz) grains.

C. Methods

- We bored three mutually orthogonal plugs: one in the vertical Z direction, parallel to the drilling axis, and two in the horizontal plane at 90° between each other, in the so-called X and Y directions. The experiments were performed under hydrostatic pressure.

- P- and S- wave velocities were measured using pulse transmission technique (Birch 1961) at 1 MHz resonance frequency.

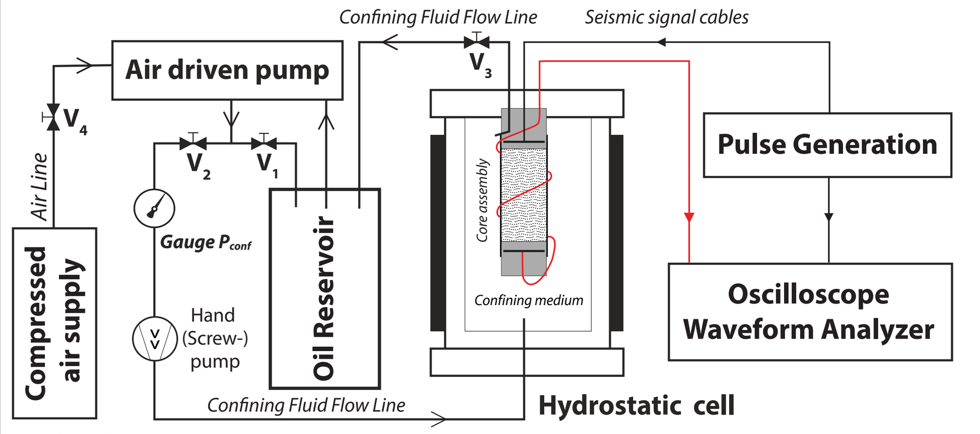


Fig C.2: Schematic set-up of seismic apparatus used to measure the ultrasonic velocities.

Experimental conditions:

- Confining pressure: 260 MPa
- Temperature: 25 °C
- Pore pressure: 0 MPa (dry conditions)

$$V_{p,s} = \frac{L}{t_{obs} - t_{sys}} \pm \delta V_{p,s}$$

$V_{p,s}$: seismic velocities,
L : plug's length,
t_{obs} : total travel time,
t_{sys} : time delay,
$\delta V_{p,s}$: uncertainty propagation.

D. Results

Seismic Hysteresis

- The seismic hysteresis is due to the closure of microcracks at the high-confining pressure that do not reopen during depressurization.

- Intrinsic velocity at room pressure, calculated from the experiment curves by linear regression above 150 MPa (V0), ranges from 4.34 to 6.79 km/s and 2.71 to 3.79 km/s, respectively.

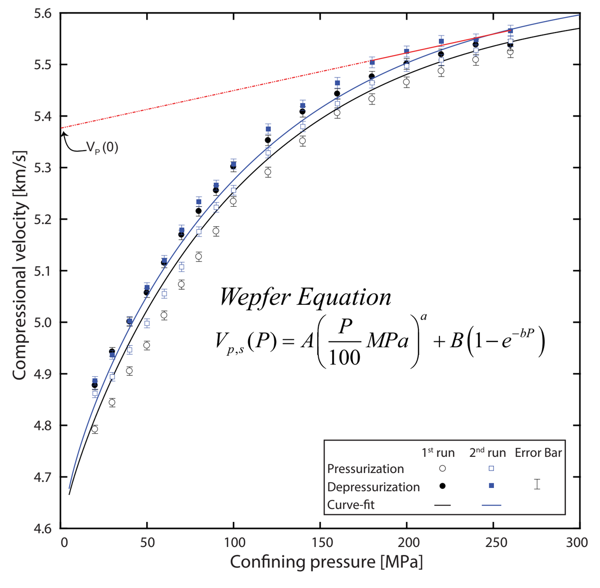
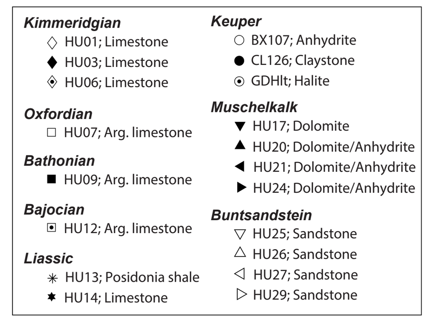


Fig D.1: Example of velocity measurements under two successive cycle of pressurization-depressurization. Sample HU25X; depth 3028.3 m.

Porosity-Velocity relationship

- The seismic velocities were calculated at 40 MPa using Wepfer's parameters and plotted against porosity.
- The V_p and V_s are dependent not only on the porosity as it is evident within the large scatter data for the velocity-porosity relationship, but also on the constituent minerals.



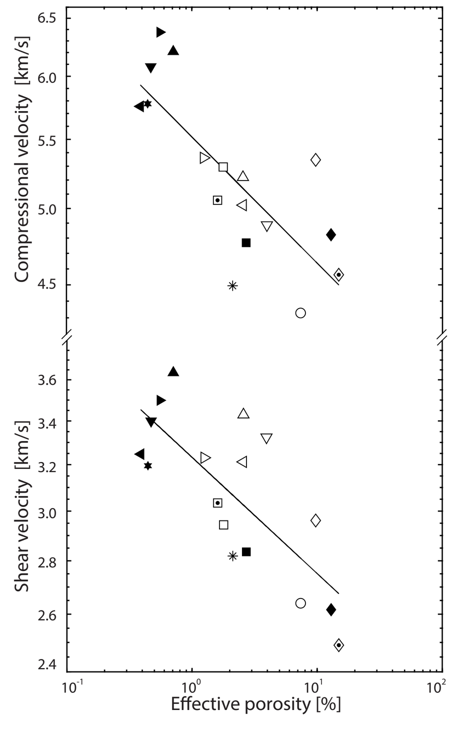


Fig D.3: Effect of porosity on velocity at 40 MPa.

Seismic Reflectivity

- The larger the contrast in seismic impedance, the larger the amount of incident energy that is reflected (and the smaller the amount that is transmitted).
- Assuming reflection coefficient >0.05 will cause a reflector in the upper crust, we interpret the source for seismic reflectors.

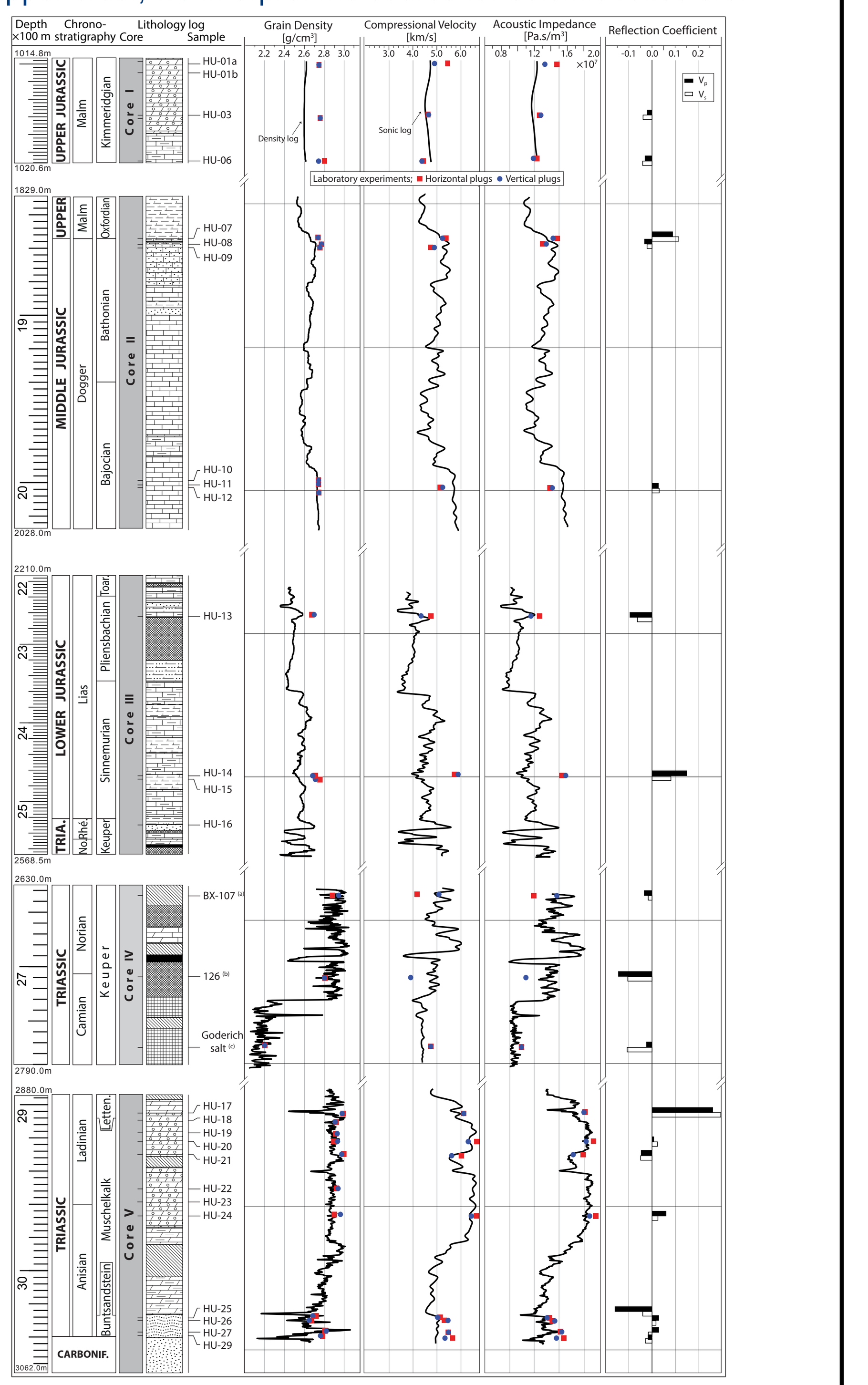


Fig D.5: Integration between laboratory measurment and well-loggings.

Seismic Anisotropy

- Seismic Anisotropies are very low (< 6%).

$$AV_{p,s} = \frac{V_{p,s}^{max} - V_{p,s}^{min}}{V_{p,s}^{mean}} \times 100$$

- The dynamic seismic anisotropy, as a function of the confining pressure, shows strong variations controlled by a complex interaction between the effects of the closure of oriented microcracks, lattice-preferred orientation (LPO) and confining pressure.

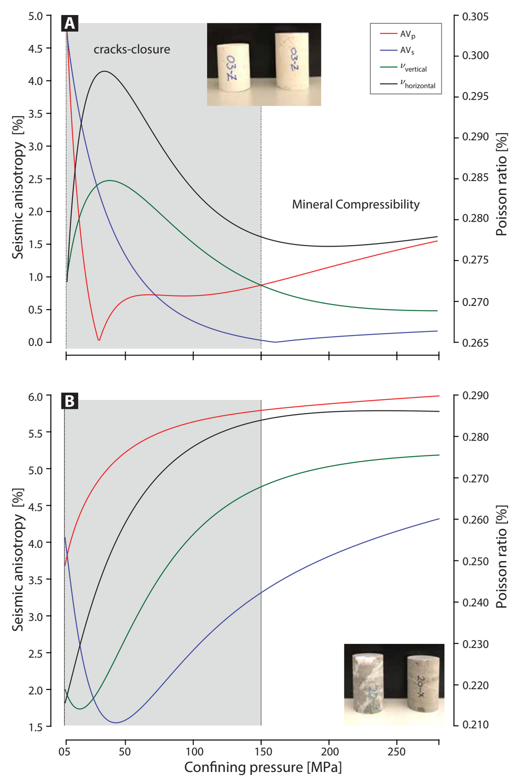


Fig D.2: Two examples (A: sample HU03, B: sample HU20) of dynamic seismic anisotropy and Poisson ratio corresponding to confining pressure.

Impedence Contrast

- The highest acoustic impedance was found within the Muschelkalk rock where the dolomite is the major constituent. The lowest acoustic impedance was found in the halite layer of Keuper.

- Within the contact between two lithotype, the difference in acoustic impedance over the sum of acoustic impedance will give arise the Reflection Coefficient (R_c).

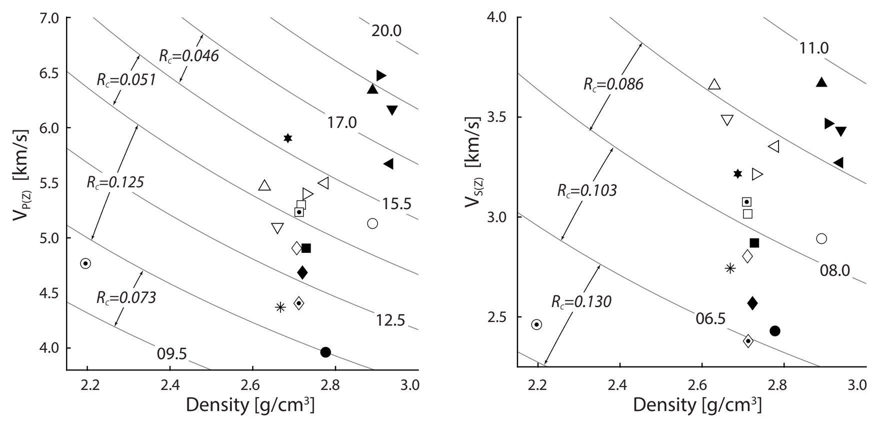


Fig D.4: Grain density vs seismic velocities with isoline of constant impedence

E. Discussion

- The influence of mineral content on Vp/Vs ratio is summarized in Figure E.1, where shear vs compressional waves of our samples are plotted together with the single crystal values for single crystals of quartz, calcite, and dolomite, i.e. the main components of our rocks.

- The measurements along the Z-direction were used to simulate the normal incidence of seismic waves encountering the sub-horizontal layering during a near-vertical incidence reflection survey. Figure D.5 shows that the strongest reflecting interfaces were found within the evaporitic facies of the Keuper (Lettenkohle) between the overlying Liassic carbonates and downward Muschelkalk unit (R_c= 0.27) and between the Dogger and the Kimmeridgian carbonates (R_c= 0.09). Reflective interfaces could be between Keuper and Sinemurian carbonates.

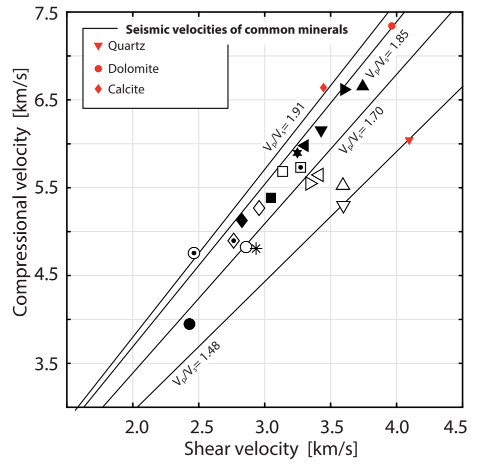


Fig E.1: Effect of minerals on V_p/V_s Ratio.

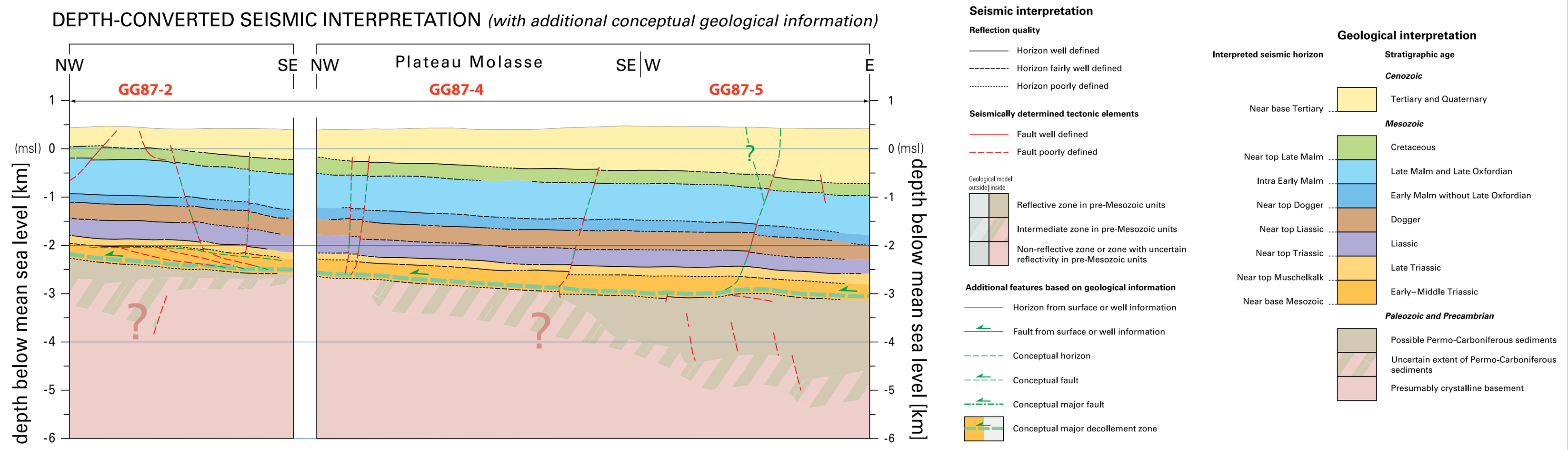


Fig E.2: Interpreted Seismic transact. For the location, refer to Fig A.1.

F. Conclusion

- Laboratory measurements on core samples shows significant variations in the physical rock properties and mineralogical content:
  - Grain densities [kg.m^{-3}]: range from 2165 to 2948
  - Seismic velocities [m.s^{-1}]: ranges 3955 to 6771 ±16 and 2426 to 3975 ±6 for P- and S-waves propagation modes, respectively.
  - Seismic anisotropy (%) seems to be quite low (< 6), except the anhydrite sample (AVp = 20, AVs = 7).

- The variations in seismic characteristics are due to small-scale heterogeneities, mineral composition and micro-textural features.

- The highest values of the seismic velocity and density were measured in Muschelkalk; therefore, those rocks might give raise to good reflectors if in contact with almost all the other lithotypes.

- The reflection coefficients calculated for the stratigraphic sequence in Humilly borehole show possible good reflectors at:
  - The top of Muschelkalk, at the top of Keuper (with the caveat that we used samples from different boreholes or literature due to absence of Keuper samples in Humilly borehole).
  - A good reflector can also be the contact between Buntsandstein and Muschelkalk.

References

Birch, F., 1961. The velocity of compressional waves in rocks to 10 kilobars, Part 2. JGR 66, 2199-2224.

Gorin, G.E., Signer, C., Amberger, G., 1993. Structural configuration of the western Swiss Molasse Basin as defined by reflection seismic data. Eclogae Geologicae Helvetiae 86, 693-716.

SwissTopo 2005. Tektonische Karte der Schweiz. Karte 1:500 000. - Bundesamt für Landestopografie Swisstopo, Wabern

Acknowledgements

We acknowledge the funding from the Structural Geology and Tectonics Group at ETH Zürich and the Swiss Governmental Excellence scholarship to perform the experiments in the Rock Deformation Laboratory at ETH Zurich. Some experimental data were provided by the SAPHYR project, from Swiss Geophysical Commission.

email: mahmoud.hefny@erdw.ethz.ch