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Shallow seismic exploration of the Keuper layers outcropping on the shoulders of the Rhine Graben using P and S waves

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Research motivation

We have performed several seismic P and S waves profiles in Keuper layers outcropping on the shoulders of the Rhine Graben in order to investigate if the lithological and structural heterogeneity that characterize these layers can be detected at depths less than 100 meters. These shale and limestone layers contain anhydrite levels and are offset by faults that constitute potential hazards for shallow geothermal drilling *(Fig. 1)*.

In Staufen in Brisgau, anhydrites present in a Keuper layer *(green in Fig.2)* were put in contact with an aquifer, resulting in swelling of the layer and damages to buildings [Goldscheider and Bechtel, HydrogeologyJournal (2009) 17: 491-493]. We seek to determine if shallow seismic prospecting is able to detect heterogeneities within such layers.

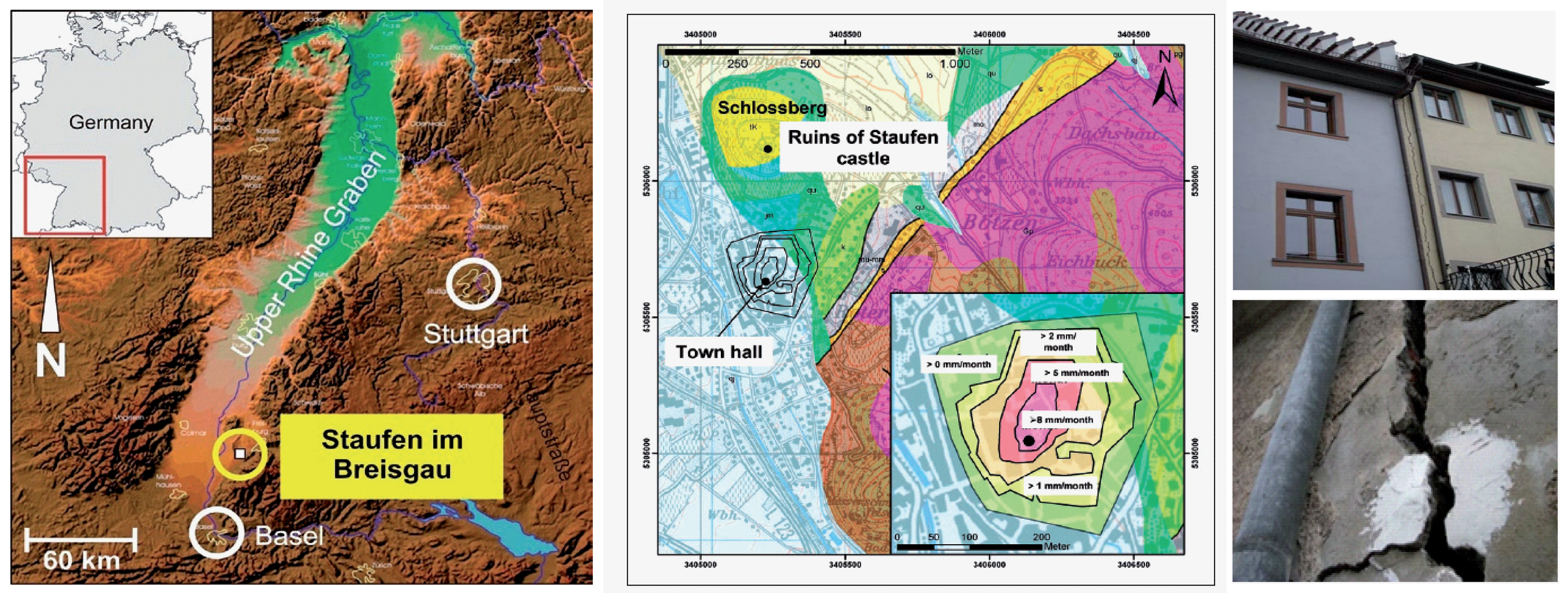


Fig. 1. The location of the small village of Staufen in South Germany and consequences of the geothermal drilling(*)

Method and study area

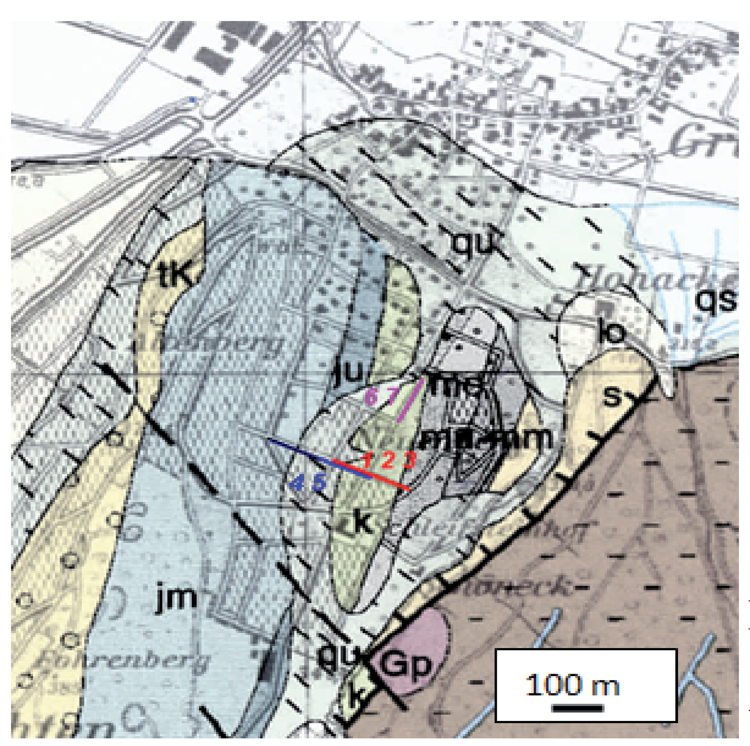
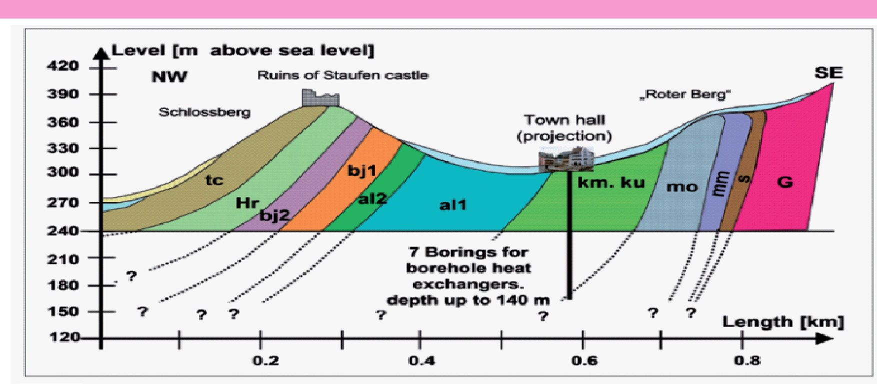


Fig. 2. Geological map of the studied region



Geological cross section NW-SE (modified after Schreiner, A. 1991, cited in: Landesanstalt für Umweltschutz Baden-Württemberg 2005).

7 short profiles have been done in the Keuper layers outcropping in Grünern (Baden-Württemberg), and 3 profiles in similar layers outcropping on the opposite shoulder of the Rhine Graben in Flexbourg (Alsace) where ancient gypsum mining is known.

We are using a seismic hammer with 48 to 72 vertical geophones for the P profiles, an ElViS horizontal vibrator with 48 to 72 horizontal geophones for the S profiles.

We have experimented intervals between geophones and shots between 2 m and 50 cm, in an effort to detect reflections which have proved to be difficult to observe, except on one profile in Flexbourg. First arrivals, clearly observed up to offsets of 150 m for single hammer blows, are mainly used in the analysis of the data.

Fig. 3. ElViS horizontal vibrator, field works

Determination of velocity models

For each profile, we have determined velocities within the first 20 m depths by fitting first arrivals times computed for models having constant velocity layers separated by plane dipping interfaces. The reciprocal time method was used for the 2 layers model (Sheriff, Geldart 1995). For more than 2 layers, the Adachi formula was applied (Adachi 1954, Johnson 1976).

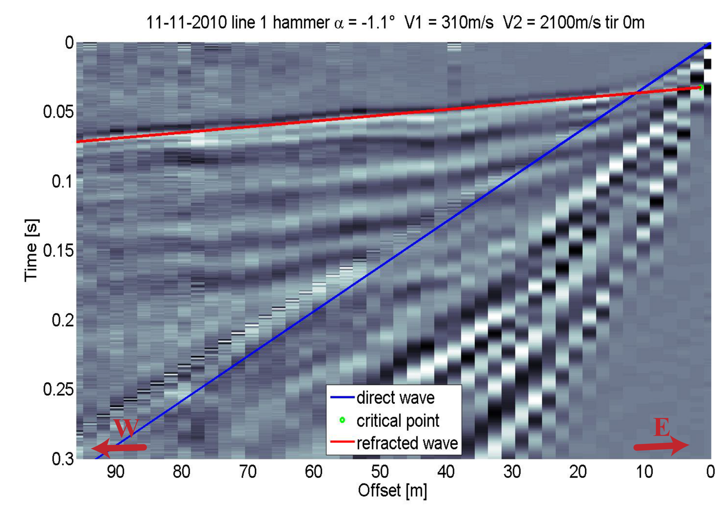


Fig.4. Example of the seismic section

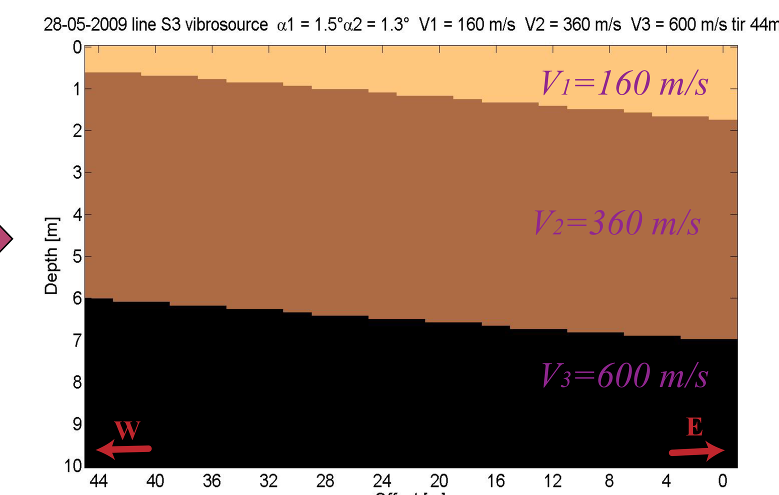


Fig. 5 . Example of the 3 layers model

Layer number	Vp, m/s	Vs, m/s	Thickness (m)
1	from 310 to 500	160	1 to 7
2	800	360	6 to 10
3	2000	600	

Tab. 1. The parameters of the model

Data from Flexbourg

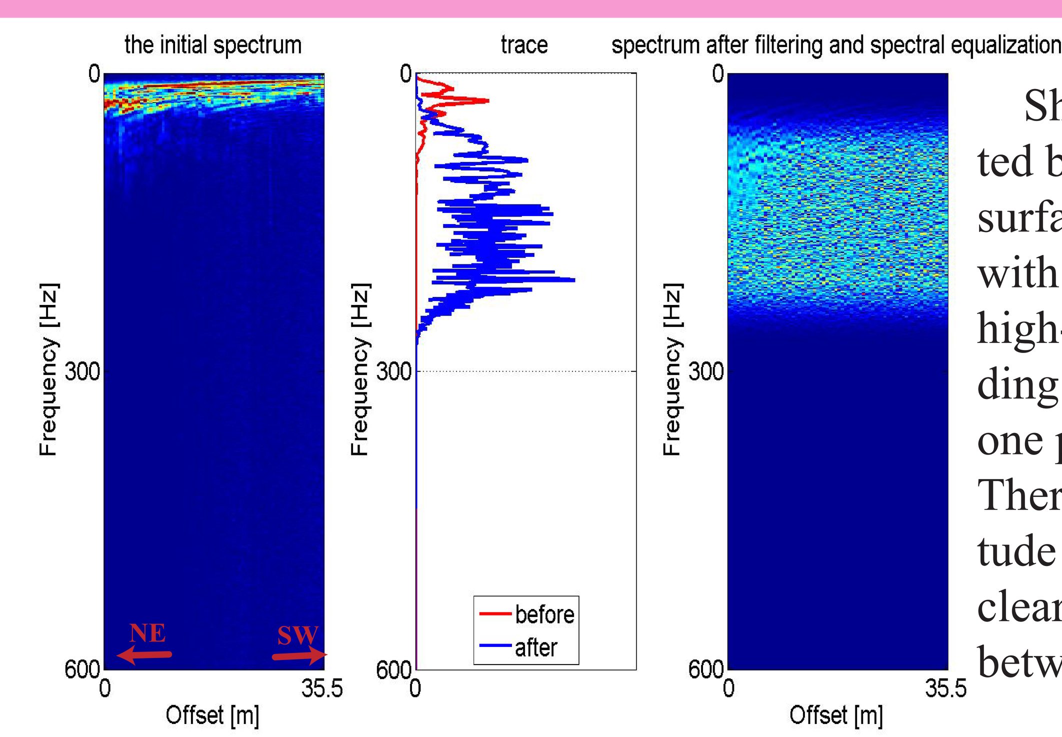


Fig. 6. Spectral balancing 80-200 Hz

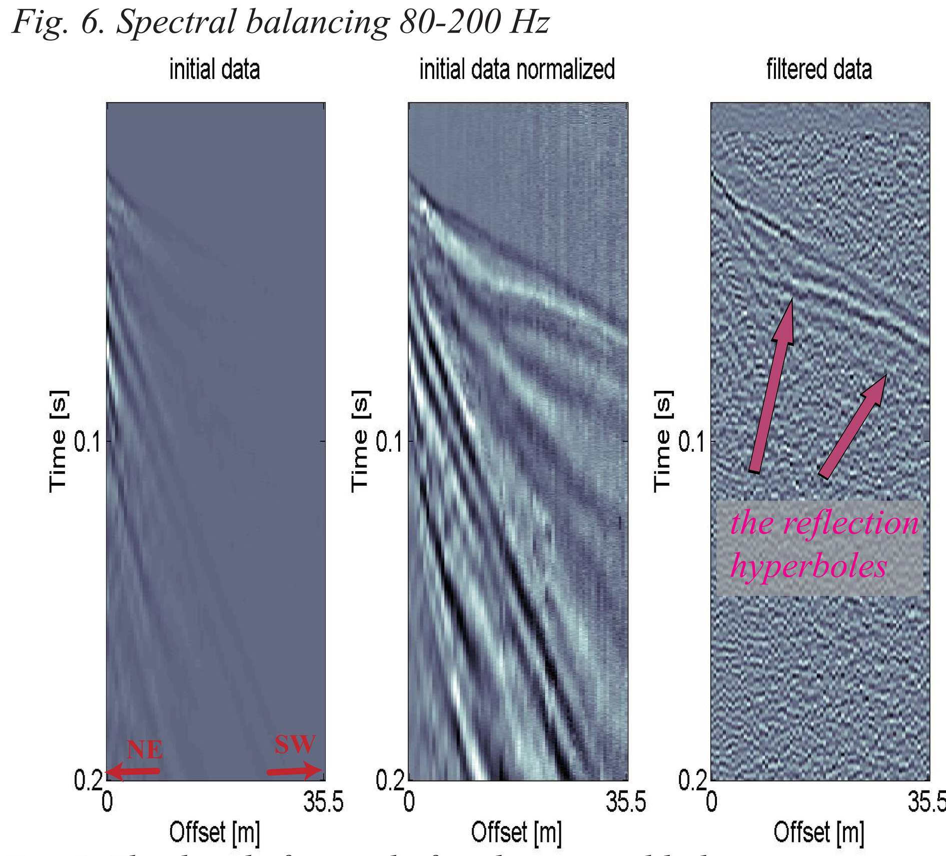


Fig. 7. The data before and after the spectral balancing

Shot records are generally dominated by high amplitude, low frequency surface waves. We have experimented with spectral equalization in different high-frequency bands without succeeding in detecting reflections, except on one profile done in the Flexbourg area. There, a reflection visible on amplitude normalized shot gathers is made clearer by spectral equalization between 80 and 200 Hz.

These reflections which correspond to vertical two-way times of 0.05 and 0.075 s *(Fig.3)* indicate impedance discontinuities at depths of 30 and 50 m respectively.

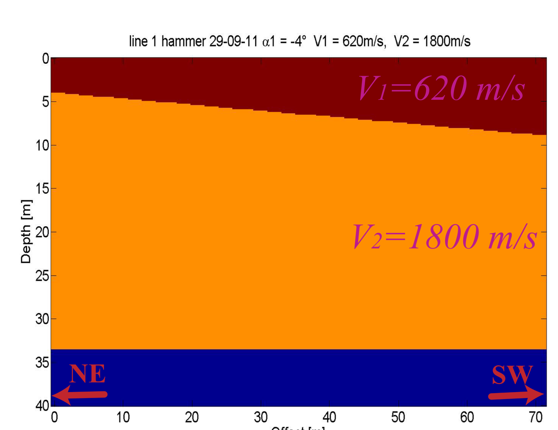


Fig.8. Model obtained from refracted and reflected waves in Flexbourg.

Data from Grünern

The refracted waves on the different profiles show several evidences of lateral heterogeneities. Strong reflections of refracted waves indicate the existence of steep discontinuities that may indicate subvertical faults *(Fig. 9)*. High frequency filtering (80-200 Hz) makes obvious the multiple reflections of the refracted waves between two discontinuities.

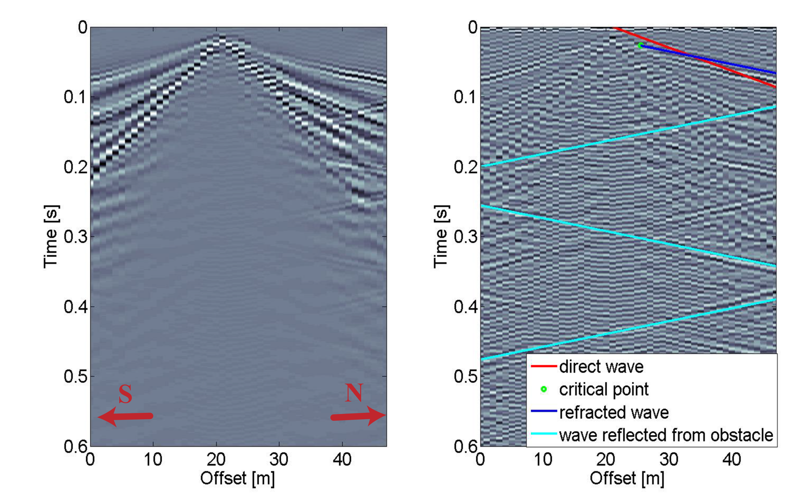


Fig. 9. Field record left-normalized; right-filtered with low-cut filter (80-200 Hz) with superposed calculated time of seismic waves

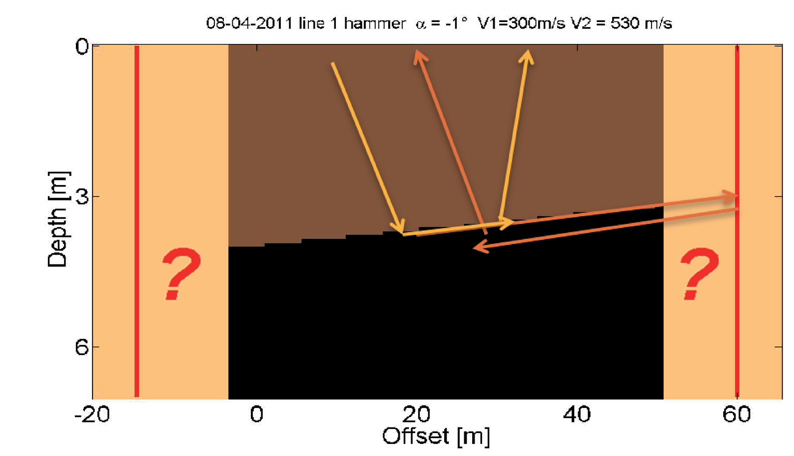


Fig.10. Mechanism of the formation of the reflections of the refracted waves

While we have modelled the first arrivals with simple plane interfaces, short wavelength changes in apparent velocities are often observed *(Fig. 11)*. These indicate the existence of short wavelength topography on the interfaces. The undulations sometimes coincide with the origin of reflected refractions *(Fig. 11 left)*. This indicates a sudden change in depth at the interface.

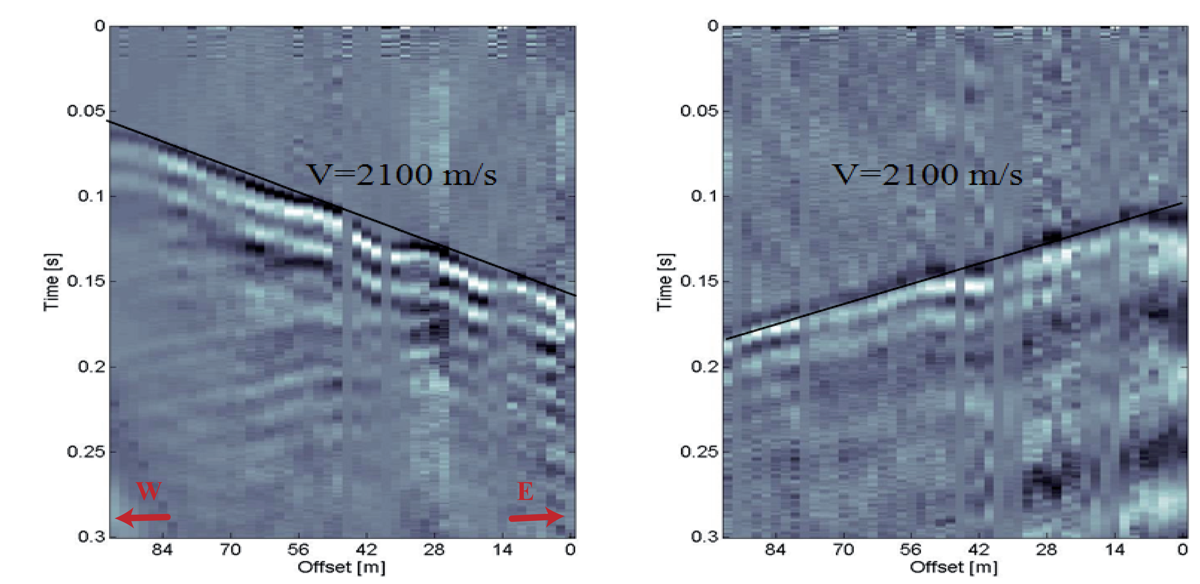


Fig. 11. Undulations in the seismic registration

Conclusions

Shallow seismic profiling allows gathering information on the heterogeneity of the near surface in the consolidated Triassic sediments outcropping on the shoulders of the Rhine Graben in the normal faulted zone of transition between the graben and the mountain.

A dense acquisition is necessary to detect the short wavelength changes indicating the presence of sudden lateral changes.

Even in areas where reflections are not observed, the refracted waves provide strong evidence of lateral variations in the Grünern area, in addition to vertical increase in velocity in the first 20 m depth interval.

When reflections are observed, we are able to detect deeper discontinuities, down to 50 m in the Flexbourg area.

(*) Landesamt für Geologie, Rohstoffe und Bergbau (LGRB), 2010, Geologische Untersuchungen von Baugrundhebungen im Bereich des Erdwärmesondenfeldes beim Rathaus in der historischen Altstadt von Staufen i. Br., Baden-Württemberg Regierungspräsidium Freiburg, 304