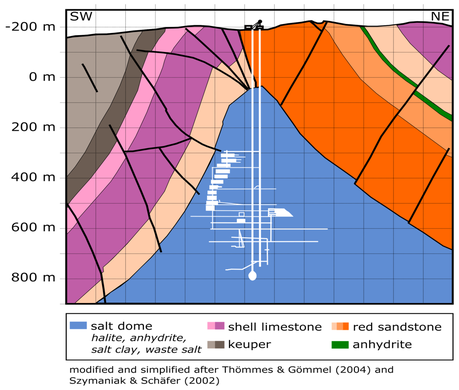
Advancing Seismic Imaging:
Fresnel Volume Migration in Anisotropic and Anelastic Media

Niklas Kühne[1], Felix Hlousek[1], Stefan Buske[1], Hui Ding[2] and Maximilian Scholze[2]

[1]TU Bergakademie Freiberg, [2]Bundesgesellschaft für Endlagerung

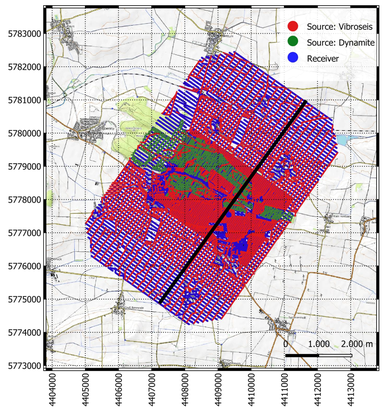
PROJECT „DOSIS“



modified and simplified after Thömmes & Gömmel (2004) and Szymaniak & Schäfer (2002)

The "**DOSIS**" project was launched with the objective of developing an optimized, combined and high-resolution approach to address key geophysical and geological questions regarding site investigations of potential repositories in Germany. As part of the project, **Fresnel volume migration** is being expanded so that **anisotropy** and **anelastic attenuation** can be taken into account for a detailed characterization of the complex geology in the "**Asse**" area.

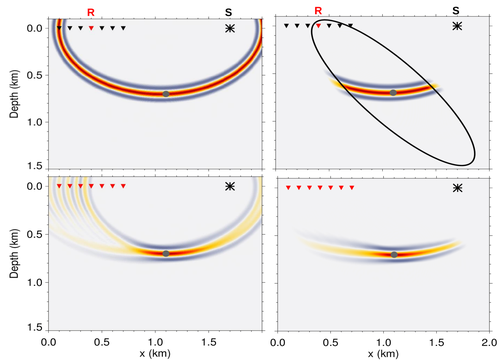
ASSE 3D SEISMIC SURVEY 2020



During the winter months of 2019/2020, the Bundesgesellschaft für Endlagerung (BGE) conducted a **3D seismic survey** in the vicinity of the “Asse II” salt mine. The acquisition layout of the 3D seismic data set is illustrated in the figure on the left. A total of 36.137 source positions (Vibroseis and dynamite) and 44.677 receiver positions were utilized. The **2D test line** investigated in our study is indicated by a black line and comprises **744 source** and **101 receiver locations**.

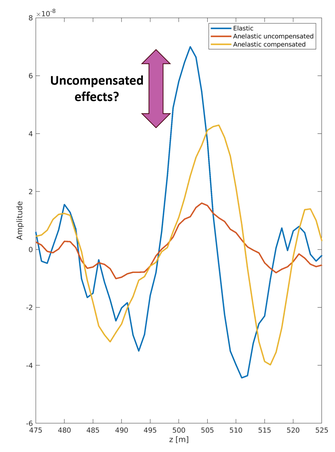
FRESNEL VOLUME MIGRATION

Fresnel volume migration (**FVM**) is based on the classical Kirchhoff prestack depth migration (KPSDM) method. In contrast to KPSDM, the migration operator in FVM is **restricted** to the physically relevant part around the actual reflection point with the aid of **Fresnel volumes**. This approach enables **focused imaging**, even of steep and complex structures such as the flanks of salt bodies or faults in the subsurface, as present in our investigation area of the "Asse" salt mine.



Comparison of KPSDM (left) and FVM (right) (Hlousek et al., 2015).

ATTENUATION



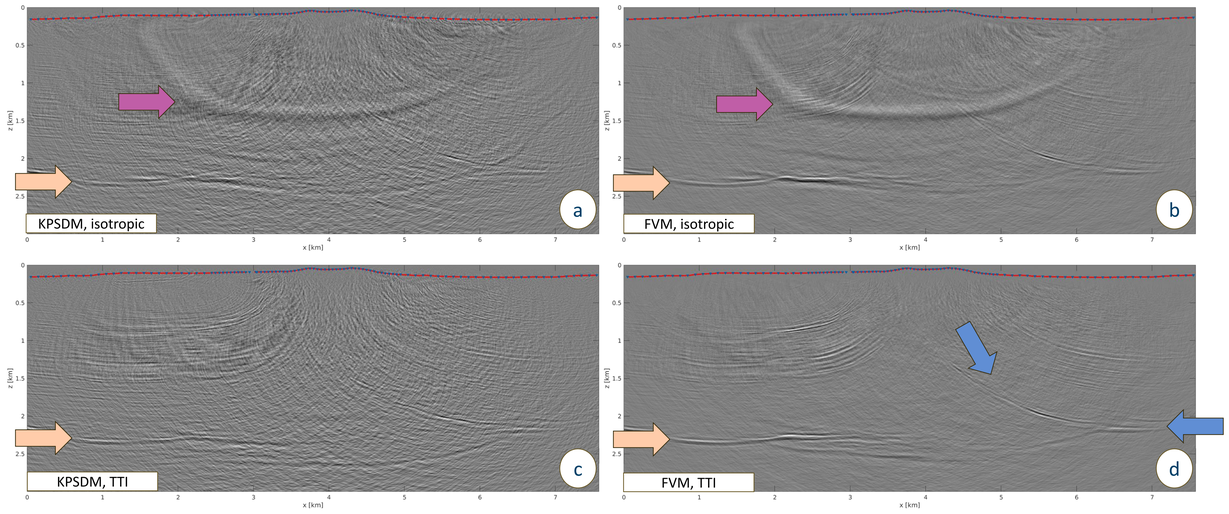
Q compensation test for a synthetic data set.

Seismic waves travelling through the subsurface encounter **anelastic attenuation**, resulting in amplitude decay and phase distortion of the wavelet. The **seismic quality factor Q** quantifies the anelastic attenuation of the media under examination. To account for this, we integrated compensation of attenuation by incorporating an **anti-dissipation filter** into the migration operator. In synthetic tests, we attempted to replicate the elastic wavefield by compensating the anelastic propagated waves. Our objective is to accurately image the **true reflectivity** of the subsurface.

Anti-dissipation filter in frequency domain (Xie et al., 2010):

$$W_Q(\boldsymbol{r},\boldsymbol{r}',\omega) = \exp\left[i\omega\left(-\frac{i}{2}T^* - \frac{1}{\pi}T^*\ln\left(\frac{\omega}{\omega_0}\right)\right)\right]$$

SEISMIC IMAGING RESULTS FOR 2D TEST LINE

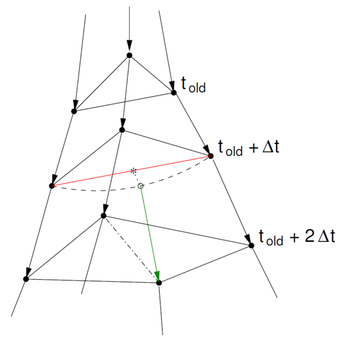


Comparison of KPSDM (a+c, left) and FVM (b+d, right) for isotropic (a+b) and TTI traveltimes (c+d).

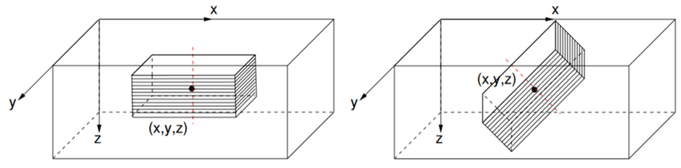
The seismic imaging results were obtained by application of KPSDM and FVM to the 2D test line extracted from the Asse 3D seismic data set. FVM effectively **reduces** a substantial portion of **migration noise**. Furthermore, the consideration of anisotropy helps to **eliminate artifacts** and accurately **positions reflectors** within the subsurface.

ANISOTROPY

The 3D **Wavefront Construction** (**WFC**) approach is a ray-based **traveltime calculation** tool. It operates by propagating rays through a three-dimensional medium by solving the kinematic ray-tracing equations at regular time intervals (Δt). At each time step, a new triangulated wavefront is generated based on the positions of ray endpoints. If neighboring ray endpoints are too distant, new rays are interpolated. The program is able to compute travel times for **anisotropic media** (VTI, TTI) (Schulze, 2014).



Principle of ray propagation and interpolation of new rays in the WFC approach (Schulze, 2014).



VTI media (left) and TTI media (right) (Schulze, 2014).

Acknowledgment

The DOSIS project received funding by BGE, the federal company for radioactive waste disposal. We express our gratitude to our project partners from BGE and KIT (Karlsruhe Institute of Technology) for their valuable contributions and constructive discussions on the results.

Contact: Niklas Kühne (niklas.kuehne@geophysik.tu-freiberg.de)

References

- Schulze, S., (2014). Laufzeitberechnung in anisotropen Medien mittels Wellenfrontenkonstruktion. Masterarbeit, TU Bergakademie Freiberg.
- Hloušek, F., Hellwig, O., and Buske, S. (2015). Improved structural characterization of the Earth’s Crust at the German Continental Deep Drilling Site (KTB) using advanced seismic imaging techniques, J. Geophys. Res.-Sol. Ea., 120, 6943–6959.
- Xie, Y., Xin, K., Sun, J., Notfors, C., Biswal, A.K. & Balasubramaniam, MK. (2010). 3D prestack depth migration with compensation for frequency dependent absorption and dispersion. ASEG Extended Abstracts, 2010:1, 1-4.