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High-resolution 3D CRS imaging for seismic assessment and monitoring of subsurface CO_2 storage sites

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CO2CRS project within the R & D Program Geotechnologies.

Seismic measurements - a key control tool for CO_2 subsurface storage

The long-term storage of CO_2 in the subsurface is one of the key technologies for reducing the emission of green-house gases into the atmosphere. For the economic and social acceptance of underground CO_2 storage, it is essential to identify appropriate storage formations in the subsurface, and to predict their long-term safety with a high reliability. A thorough monitoring must be implemented during the actual storage process, and beyond. In order to detect possible hazards and breakouts, the monitoring has to continue for a long time after filling the available storage volume, and removing the injection infrastructure.

Due to the long monitoring period, expensive monitoring methods are not feasible. The most effective monitoring strategies must be selected from a variety of methods that comprise

1. local measurements in the subsurface,
2. local measurement at the surface,
3. remote subsurface measurements from the surface.

Local measurements are not sufficient, since they obviously cover only parts of the storage site. Moreover, local measurements in the subsurface are confined to the lifetime of instruments that were buried during the development and operation of the storage site.

Remote surveying from the surface, on the contrary, may cover the whole underground at the storage site, with straightforward deployment and exchange of instruments. Among these methods, 3D reflection seismic surveying has proven to be highly effective in obtaining a structural image of a full subsurface volume, and in investigating the properties of potential storage formations. Modern 4D (or time lapse) seismic measurements have been established as methods to explore and monitor the development of reservoir and gas storage sites in the subsurface.

High-resolution CRS imaging of 3D reflection seismic data

Seismic measurements offer an excellent cost-benefit relation for a detailed resolution of large subsurface structures and processes. This resolution is available in the final subsurface images after extensive seismic data processing. Processing costs, however, are small in comparison to acquisition costs. Hence, any significant improvement of the subsurface resolution by new processing techniques can be readily adopted in a monitoring scheme, and may even be used to cut the overall costs by reducing the acquisition efforts.

Such new processing techniques are provided by the 3D Common-Reflection-Surface (CRS) stack methodology that is developed within the R & D Program “Geotechnologies” in Germany. The developments focus on imaging, i.e., on the reconstruction of subsurface structures by localizing the seismic energy scattered by these structures, and by collecting this energy into a structural image. Because of its quite general subsurface assumptions, the CRS method may localize the contributions to a certain structure in very large portions of the seismic data, thus achieving a very clear image of that structure.

As a consequence, the CRS images provide both, an excellent signal-to-noise ratio, and a high resolution, which are often superior to Prestack Depth Migration (PreSDM) results. PreSDM is a powerful imaging method that can handle almost any kind of seismic wavefield without approximation, but it requires a very good knowledge of the subsurface velocity model. On the contrary the CRS method, although it imposes some approximations on the wavefield, provides excellent imaging results with much less model information or even without such information in model-independent applications.

The 3D CRS methodology that is developed in the CO2CRS project consists of three work packages (WP), which deliver a high-quality image of the storage reservoir:

WP 1: 3D CRS imaging for improved time processing
In the first step, the 3D imaging method and software delivers a time domain image with excellent resolution and signal-to-noise ratio. Additionally, it provides densely sampled volumes of CRS stacking attributes which provide access to an abundance of local wavefield information, like wave front curvatures, incidence angle, slowness, geometrical spreading, projected Fresnel zone, etc.

WP 2: 3D CRS tomography software for reliable velocity depth models
The 3D CRS attribute information is input to the second step. A 3D CRS tomography method and software inverts these attributes with respect to a reliable velocity-depth model. This velocity-depth model allows to perform Poststack Depth Migration on the CRS stack which transfers the excellent resolution and signal-to-noise ratio from the time to the depth domain.

WP 3: 3D Fresnel volume migration using CRS slownesses
The slowness information contained in the 3D CRS attributes of the first step, and the velocity-depth model from 3D CRS tomography of the second step are input to the third step. This allows to determine local Fresnel volumes for an extended 3D Kirchhoff PreSDM method and software. Migration noise is reduced, and signal-to-noise ratio of the depth section is increased by restricting PreSDM to the physically relevant portions of the data.

The development and test stages of the methods are followed by a final evaluation on possible gas/CO_2 reservoirs and the information increase with respect to conventional methods.