Geological model of Lobodice undergroun d gas storage facility based on 3D seismic interpretation

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Abstract: The Lobodice underground gas storage (UGS) is developed in a natural aquifer reservoir located in the Central Moravian part of the Carpathian Foredeep in the Czech Republic. In order to learn more about the UGS geological structure a 3D seismic survey was performed in 2009. The reservoir is rather shallow, 400–500 m below the surface. This article describes the process workflow from the 3D seismic field data acquisition to the creation of the geological model. The outcomes of this workflow define the geometry of the UGS reservoir, its tectonics and the sealing features of the structure. Better geological knowledge of the reservoir will reduce the risks involved in the localization of new wells for increasing UGS withdrawal rates.

Key words: underground gas storage, 3D seismic acquisition and processing, 3D seismic interpretation

1. Introduction

The Lobodice Underground Gas Storage facility is located in the middle of the Moravian Carpathian Foredeep between the towns of Tovaov and Poerov (Fig. 1). The exploration of the elevation structure started in 1942 and then continued in the fifties when several wells were drilled. The construction of the aquifer gas storage in the Lower Badenian clastics began in the nineteen sixties. The 50$^{\text{th}}$ anniversary of the start of the operation came in May 2015. So far 62 wells have been drilled in the area of the UGS and some of them are operated as UGS wells. The purpose of the Lobodice

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UGS used to be storage of town gas as surplus from coke production in the Ostrava region. The conversion to natural gas storage started in 1991, and was successfully completed. With the development of geophysical methods in the nineteen seventies refraction and reflection 2D seismic surveys were carried out together with gravity surveys and checkshot measurement. Well logging was performed as new wells were drilled. Gravity surveys helped to determine the extent of the crystalline basement of the elevation on top of which the UGS site is being developed. 2D seismic profiles shot in 1974 and 1990 (*Cahelová et al., 1990; Dvořáková et al., 1998; Dvořáková et al., 2001* and *Haladaj, 2008*) together with new well data provided more detailed knowledge about the geological structure but failed to identify detailed tectonic setting and faults which could answer some unresolved issues with the reservoir. The UGS operator therefore decided to perform a 3D seismic survey in 2009, which covered the whole of the Lobodice elevation structure. The goal was to identify the detailed tectonics, the top and the base of the Lower Badenian clastic horizon. The second goal was to determine the extent and thickness of the Lower Badenian clastics together with the weathered surface of the crystalline units which form the UGS site.

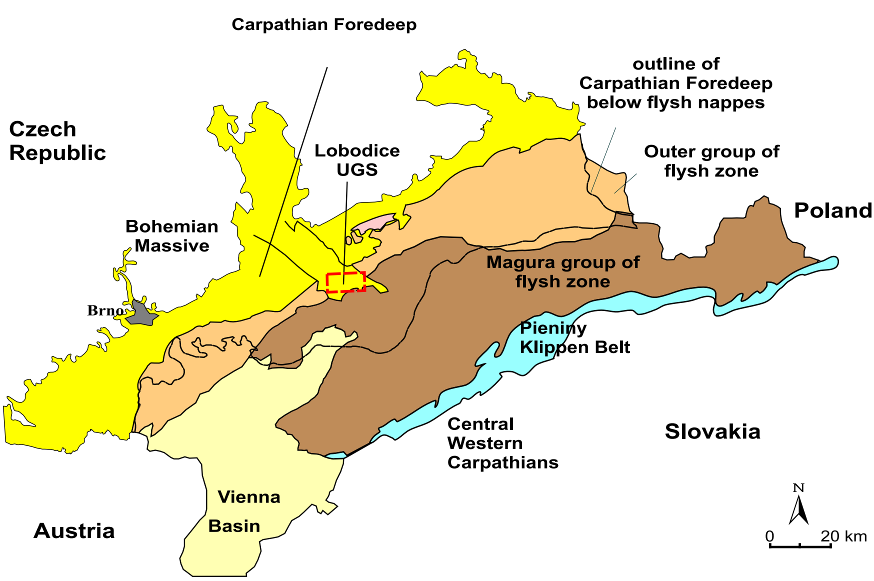

Fig. 1. Location of survey area.

2. General geological overview

The Lobodice structure is located in the middle Moravian part of the Carpathian foredeep and it was formed on the top of an elevation by Brunovistulicum crystalline rocks, such as phyllites, schists and granitoids. The crystalline units are heavily faulted and on the surface often weathered. During the Lower Badenian marine transgressive sedimentation of basal clastics took place predominantly in the tectonically predisposed valleys (Fig. 2). These rocks are mostly gravels and sandstones. During and after this sedimentation fault activity formed the shape of horst structures. Afterwards Lower Badenian clays of significant thickness were deposited in the whole area. Pliocene and Quaternary fluvial sediments terminated the sedimentation cycle in the studied area. The shape of the Lobodice elevation is determined by faults of different age disturbing the crystalline units to synsedimentary faults active during the sedimentation of Lower Badenian clays.

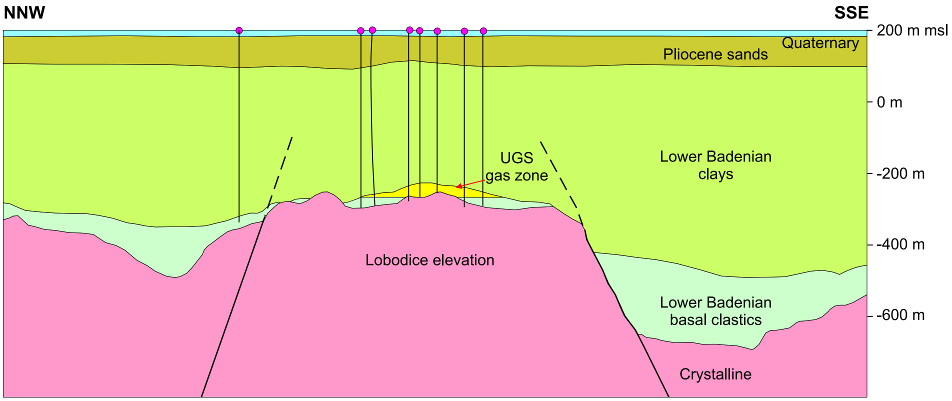

Fig. 2. Geological section in depth across the Lobodice elevation with UGS horizon. Yellow area is the gas-saturated zone of the reservoir.

3. Methods

3.1. 3D seismic acquisition

Field acquisition works were performed by DMT-Geosurvey, Ltd. from Oct–Dec 2009 using the staff and equipment of DMT Germany GmbH.

The nominal fold of the seismic was 32 × in the coverage area of 23 km^2 and the bin size was 15 × 15 m due to relatively shallow target 400–500 m below the surface (*Wright et al., 2009*). The seismic sources used were Vibroseises Mertz 12/P602 with peak force 133 kN in the land with unlimited access, a boat-mounted two air guns GSSI Sodera Dual GI gun in size of 6.88 cm^2 on the water of gravel lakes, while the third source consisted of 200 g Semtex 1A explosives in 4 m deep holes for areas with limited access for vibroseis and in the Zástudánčí conservation area. For vibrator source were used 3 vibrators, doing 4 sweeps per vibro point, with sweep length 12 seconds. Sweep was logarithmic, +3 dB/octave with frequency range 14–120 Hz. Geophones were 2 × 6 serial connected to Sensor JF-20-DX boxes with natural frequency 10 Hz. Hydrophones used in gravel lakes and in the rivers were Geospace MP25–250 with natural frequency 10 Hz. Seismic data were recorded using ARAM24/GEO-X system (*Seitz, 2009*). Different seismic sources were applied due to the vicinity of the military airfield, active underwater gravel quarries, the existence of the Morava and Malá Bečva River with conservation areas along their banks, two villages, a forested area and the existing infrastructure of the UGS in order to minimize gaps in the field data. The 3D seismic survey was successful and the quality of the data was good.

3.2. Processing the 3D seismic data

The 3D seismic data were processed by Geophysik GGD GmbH Leipzig in 1Q 2010. The data were checked, filtered, static and dynamically corrected as described in the processing flow scheme (Fig. 3). The outputs were seismic data in Pre-Stack time migration and Pre-Stack time migration versions converted to SEG-Y to be imported into the interpretation SW (*Karp et al., 2010*).

3.3. Checkshot data

The only available checkshot from the survey area was the checkshot from the Vlkoš-1 well. This depth/time conversion was used for well top conversion during the interpretation of the seismic data and also for depth

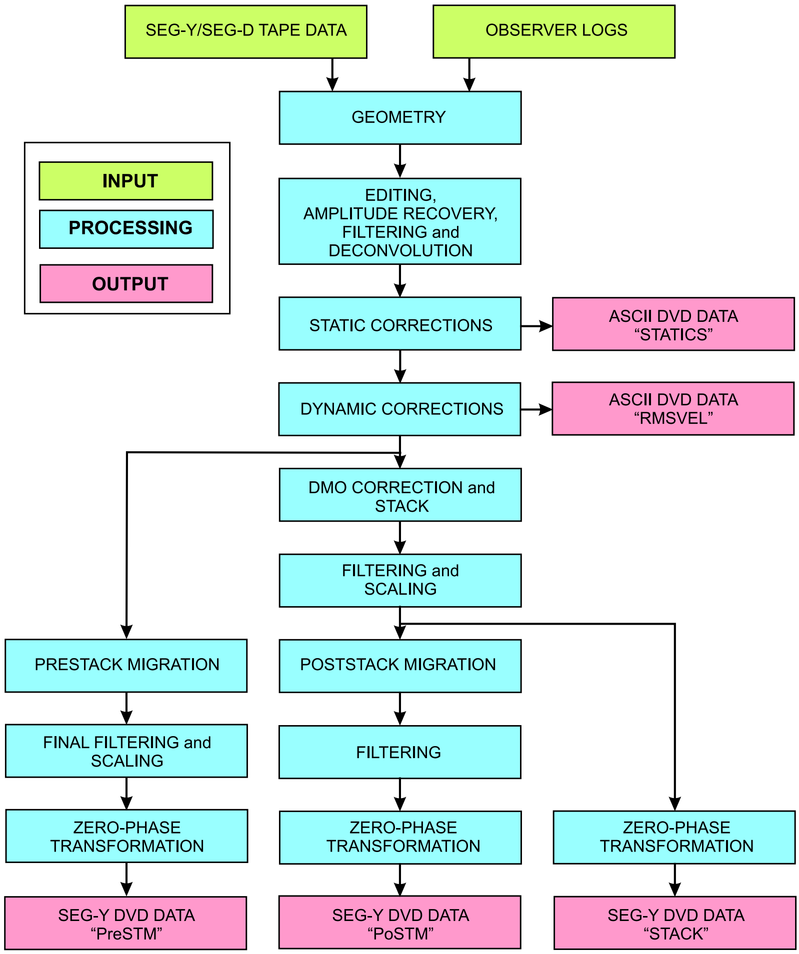

Fig. 3. 3D Seismic data processing workflow (according to *Karp et al., 2010*).

conversion of time interpretation into the depth domain. The checkshot data are published in *Filová (1974)*.

3.4. Well data

The first step prior to interpretation is loading the input data – well coordinates, total depth, well path deviation survey and well log data. The well tops were defined based on interpretation of the well logs and evaluation of the well cores was taken from the final reports summarized in *Dvořáková et al. (2001)*. Well tops were loaded into the project and checked in the well correlation sections with imported well logs. Some well tops were corrected during horizon and fault interpretation. Some intervals are affected by faults resulting in reduced thickness; some wells did not penetrate the whole thickness mainly in the canyon area.

3.5. Interpretation and geological model creation

Petrel 2009 software was used to interpret the seismic data and to create the geological model. The SW contains modules for seismic interpretation, fault and structural modelling and depth conversion. The interpretation was carried out internally within the RWE Gas Storage s.r.o. (*Čížek et al., 2013*) and it was done in the 2D interpretation window on individual crosslines and inlines but also in 3D visualization especially for better space orientation in fault interpretation. Major faults were interpreted in the first phase and consequently also the small ones. The top surface of the crystalline complex is indicated by strong reflection that is simple to identify and could be tracked across the whole 3D seismic cube. The time converted well tops were displayed to guide the interpreter during horizon interpretation.

4. Results and discussion

4.1. Fault interpretation

We can state in general terms that the Lobodice elevation comprises a spindle-shaped horst oriented NE-SW and it is bordered in the north and south by deep canyons mainly filled with Lower Badenian clastic sediments. The top of the structure is often rugged. Several types of faults were identified during the interpretation (Figs 4 and 5):

1. Regional faults which are significantly long, corrupting both the Crystalline and Miocene rocks. The eastern fault serves to seal the UGS structure. This fault was active during the Lower Badenian but its activity disappeared in the overburden strata.

2. Smaller faults and fracture systems are visible in the crystalline units on the rim of the Lobodice elevation. They are abundant and also disturb the basal Badenian clastics. They form the rugged morphology of the crystalline units, with particular elevations and depressions on the top of the Lobodice elevation.

3. Synsedimentary faults are situated in the Lower Badenian clays on the rim of the Lobodice elevation. These syngenetic faults resulted from the movements on some older re-activated faults. These faults are very important for sealing the Lobodice structure.

4. Deep canyons are also probably tectonically predisposed along the steep slopes, but unfortunately this is not clearly visible on seismic profiles within crystalline units. The horst structure located in the NW part of the area indicates a tectonic origin and is expected to continue into the northern canyon (Figs 4, 5 and 6).

5. The resulting fault model incorporated all of the above tectonic features for further operation with surfaces.

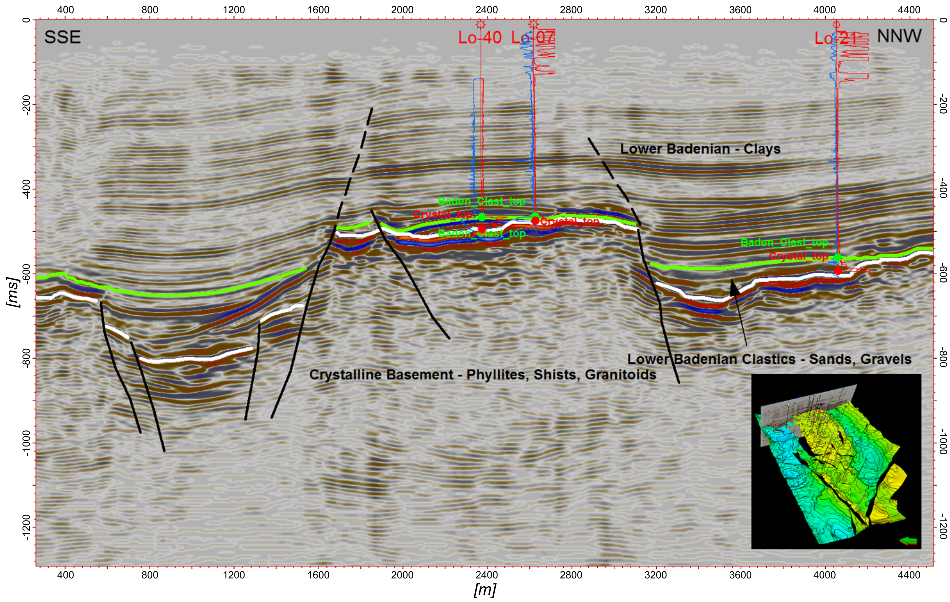

Fig. 4. PreSTM 3D seismic-cross section I408 (Lobodice elevation, surrounding canyons and Lo-40, Lo-7 and Lo-21 wells).

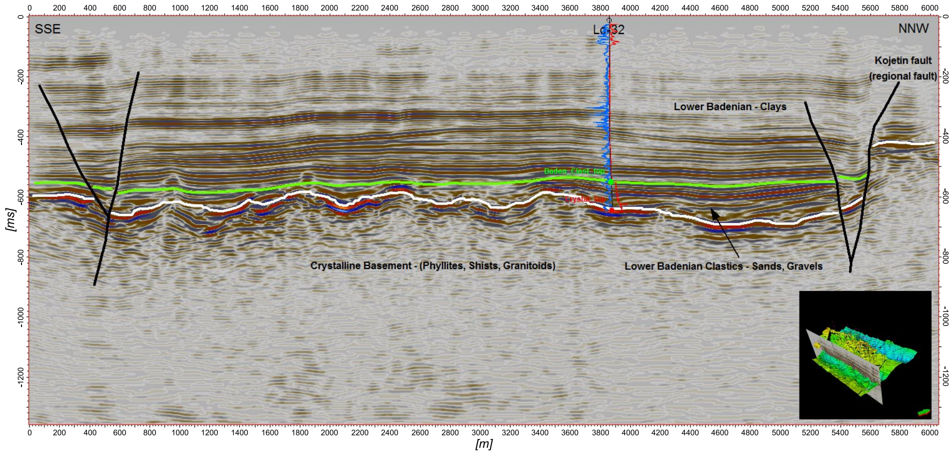

Fig. 5. PreSTM 3D seismic-cross section X082 (canyon area and Lo-32 well).

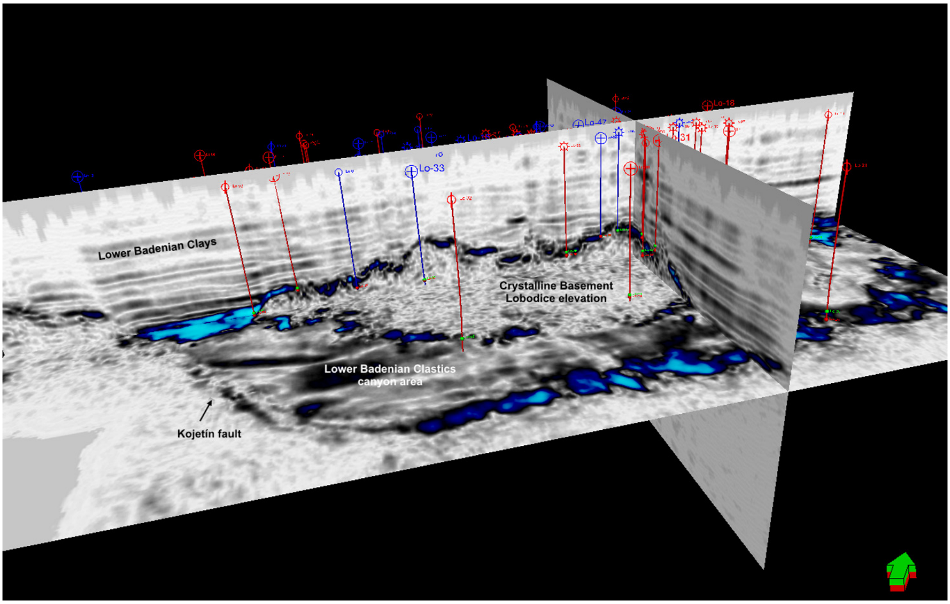

Fig. 6. 3D view of Lobodice elevation, canyon area and Kojetin fault on seismic attribute (variance) cube.

4.2. Horizon interpretation

The main horizon of interest was the storage horizon of the Lower Badenian clastics. The Lower Badenian clastics mainly consist of sands, gravels and breccia laying transgressively on the eroded surface of crystalline units. The thickness of the Lower Badenian clastics at the Lobodice elevation varies from 0 to 115 m based on well data. Such large differences are caused by the sedimentation environment, debris cones, channel and valley fills and its possible consequent partial erosion, mostly on the top of the elevation. The thickness of the Lower Badenian clastics increases outside the Lobodice elevation and in the deep canyons it could reach more than 115 m as in the case of the Lo-32 well or even more as for example the Lo-12 well. This well is situated in the middle part of the northern canyon and did not reach the base of the Lower Badenian clastics even after penetrating 175 m. The Lo-12 well. In the eroded areas is the top of the Lobodice elevation not interpreted as a continuous body but it is connected with the top of the crystalline units. The base of the storage horizon is formed by Brunovistulicum crystalline rocks and was the second horizon to be interpreted. The top Lower Badenian clastics are overlain by Badenian clays with interbedded sands and silts that are not so thick. The average thickness is 350 m. Together with the aforementioned faults this forms the caprock for the UGS horizon. There are deposits of Pliocene sands and Quaternary fluvial sediments (gravels and sands) of the Morava and Malá Bečva rivers which are a few tens of metres thick (Fig. 2).

The interpretations of the top of the Lower Badenian clastics, the top of the crystalline unit and faults were used to create a 3D grid in time domain that was consequently converted to the depth.

4.3. Horizon of interest depth conversion and geological model creation

The inputs for depth conversion are horizons incorporated in the 3D grid in time domain. In the first step the time values from each horizon grid were recalculated using the look-up function (taken from the Vlkoš-1 checkshot data), which resulted in average velocity grids for both horizons. In the second step these velocity grids are used as the second input for depth conversion. Petrel software recalculates both the horizon into the depth domain and corrected to the well tops data according to the given velocity model.

5. Conclusions

The most significant results of this work can be summarized as follows:

- depth structure maps with detailed description of the geometry and morphology of the storage horizon – geological model (Fig. 7);
- interpretation of faults (Figs 4 and 5);
- thickness maps of the storage horizon and of caprock.

The closed contour of the structure confirmed the spill point structure, which corresponds to the mean gas-water contact observed in the monitoring wells (Fig. 7). The side-sealing function of the faults and Badenian clays

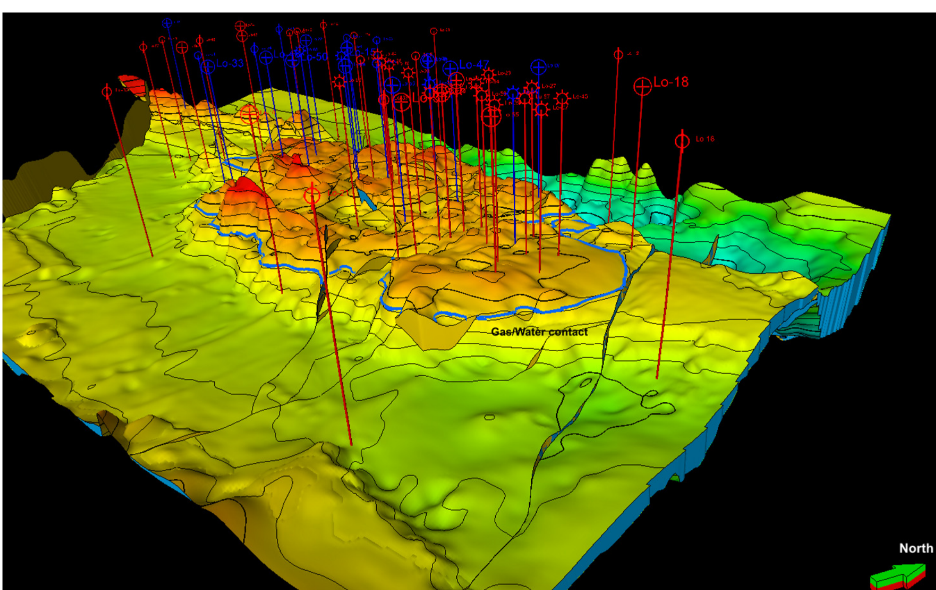

Fig. 7. 3D geological model of the Lobodice UGS with visible wells located in the Lobodice elevation. Red wells penetrate the Lower Badenian clastics. Blue wells reached only the crystalline units (no reservoir). The size of the displayed model is 6×4 km.

opposite to the storage horizon is clearly visible on the depth cross sections (Fig. 4). Such a detailed geological model can be used for the localization of new UGS wells to increase and optimizes UGS withdrawal.

Improved knowledge of geological structure explained some unresolved issues from previous exploration phases especially related to the lateral extent of reservoir rock.

Further works such as petrophysical modelling using core analyses and quantitative well log interpretation and based on this reservoir flow simulation are expected but were out of the scope of the presented study.

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