

## The use of CAD programs for the three-dimensional analysis of geological and geophysical data on the complex fold structures in salt diapirs

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Owing to the complicated folding in salt domes, it has only been possible up to now to represent the structures in two-dimensional maps and sections. This made it rather difficult to integrate different kinds of data (e.g., underground mapping along drifts, borehole logs, and geophysical data) into a model of the salt dome structures.

With a high-performance CAD system, the data from various parts of the salt dome can be represented in three dimensions and evaluated. Three-dimensional radar data (GPR) is used to correlate point data. The links determined in this way are used to construct a three-dimensional representation of the structural surfaces. The GPR data can have relatively large gaps, important is that the relationships between the reflectors are recognizable. Complicated relationships can be visualized, including overturned strata. With a high-performance CAD system, a section across any part of the salt dome can be generated automatically. This makes it possible to predict the situation beyond the working face. Exploration boreholes can be better targeted to more precisely determine the position of a specific horizon, or if the point data density is high enough, the drift can be continued.

For special problems in specific parts of the salt dome, the surfaces and volumes of selected geological units with complicated structures can be constructed. This has been possible in the past only for simple cases.

The application of a CAD program for the above purpose will be illustrated using the "Gorleben Bank" key horizon, which is in the highly folded service area of the Gorleben salt dome. Underground mapping data, borehole logs and GPR data will be used in this example.

### 1. Introduction

The Gorleben salt dome in Germany is investigated for the storage of all types of radioactive waste [1, 5]. The underground investigation will provide information about the dome's geological structure. The results contribute to the assessment of effectiveness of the geological barriers, the planning of potential repository areas and the constructive design of drifts and boreholes depending on the geological situation. Finally, the combination of all geological results will form the entire geological model of the salt dome.

Up to now all obtained data of the geological exploration (geological mapping, geophysical

investigations, etc.) were interpreted separately in different steps and projected on a two-dimensional working map. The result was a two-dimensional solution for a three-dimensional problem. For each interpretation of new data or for any combination of a set of data in order to reply to special planning requests all the time consuming working steps have to be repeated.

The aim was the development of a three-dimensional model of the geological units based on a CAD-system, in which exploration data of different working teams are integrated. The CAD-system should allow a faster and more efficient working face exploration in repository fields in concordance with the ongoing mining activities.

## 2. Method

In order to get the three-dimensional geological model all exploration data from the mine surveying section, based on the mine plan, were used as a combined input in a CAD-system. The exploration data were classified in primary data (geological mapping in drifts and core drilling examination) and secondary data (geophysics, in this case GPR-Measurements, and geochemistry).

The processing of data is done in a non-scale mode in order to combine different sources of data based on special scales (e.g. geological mapping with scales of 1 : 100 and 1 : 1000) to obtain one single model. Thereby no losses of data appear in detail.

The different working steps should be explained in the following. First, and the

most important prerequisite is the alignment of all data to one identical coordinate system. The world-wide used Gauss-Krüger system is taken. The Gauss-Krüger system facilitates the combination of regional and nationwide obtained data or models.

The next step of the work is the interconnection of all geological primary data. Thereby results a first overview about the trend of geological structures. The spatial orientated GPR-data will be integrated in this first preliminary geological model. This allows relative precisely the connection of geological information from more remote drift sections. It is very important to know the stratigraphic reference profile and the reflecting layers and their special reflectivity for the connection and modelling. The "Gorleben Bank", a widely occurring small seam of anhydrite, is an excellent key horizon

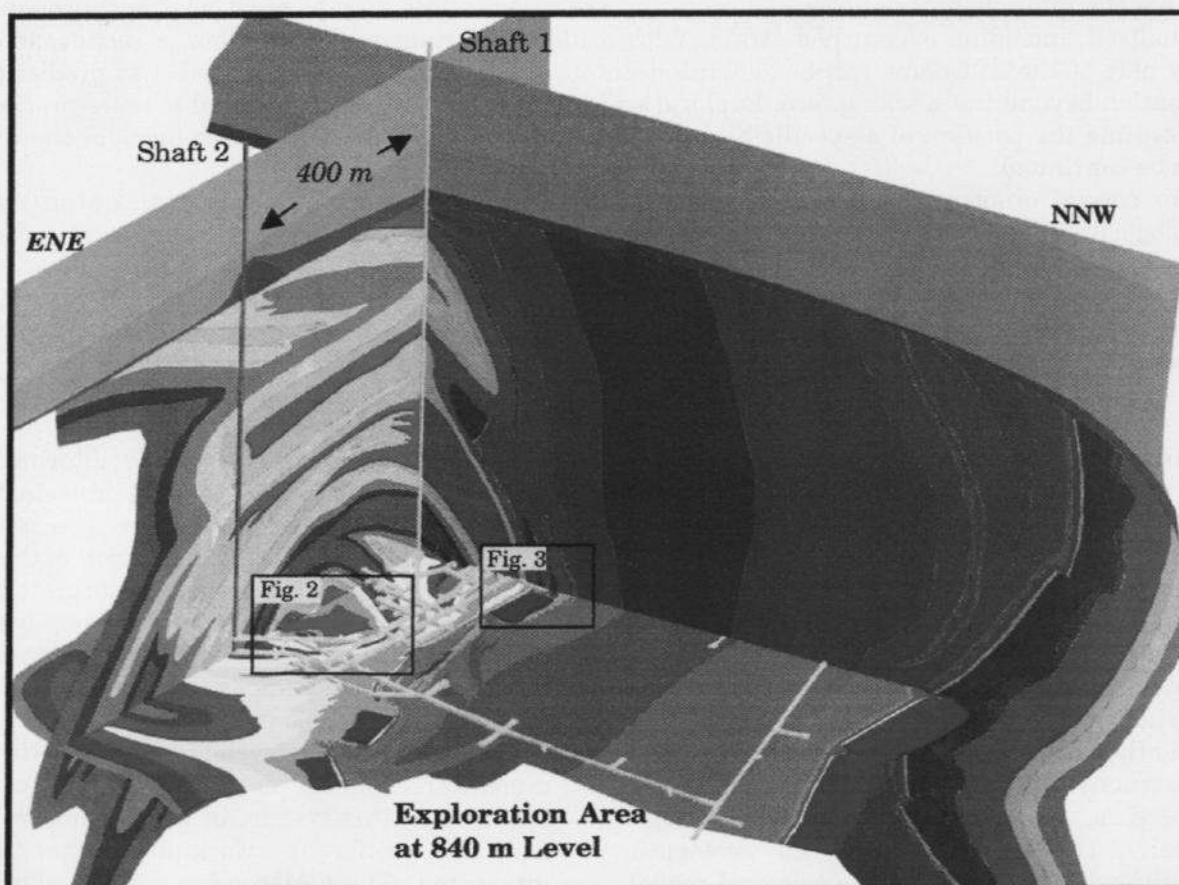


Figure 1: 2,5 D-geological-Model of Exploration Area at Gorleben site [3]

for the GPR due to its high reflectance.

Subordinate reflectors are the potash layer "Kaliflöz-Staßfurt", some beds of the "Anhydrit-Mittelsalz", the "Hauptanhydrit", a thick anhydrite bed, and the unit of "Grauer Salzton", a clay bed. The determination of these reflectors is obtained by a comparison of the known geological exposures in drifts and boreholes with the spatial position of the reflectors. Now it is possible to construct the whole stratigraphic sequence aided with the stratas identified by the reflectors and the geological reference profile.

This procedure approaches a continuous analysis and improvement of the model when new data are available. The work is optimised in such a way, that the geological mapping and model improvement is done immediate after the construction of a drift. This gives a quick analysis of internal structure of the

mining area and it allows the opportunity to guide further mining activities nearly just in time.

If the amount of primary data is high (e.g. service area of the Gorleben repository), gained from drift and shaft mapping [2] and data of GPR measurements (detection made also in the drifts, shafts and boreholes), a secured projection in front of working face for distances greater than 500 m is possible, even in case of the extremely folded inside of a salt dome.

### 2.1. Example

In order to demonstrate the efficiency of the method the internal updoming of older rock salt of the "Staßfurt-Folge" is used. The updoming is accompanied by intensively isoclinal folds. They consist of rock salt of the

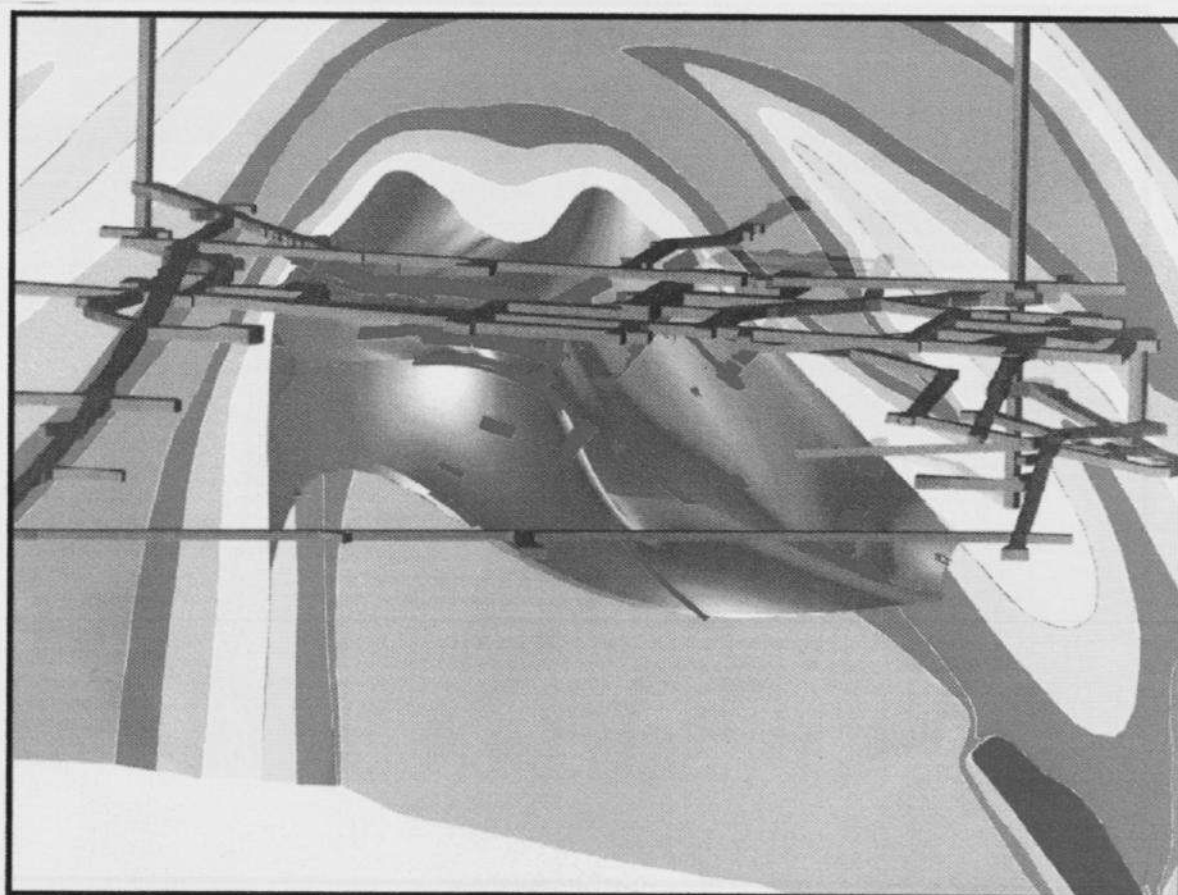


Figure 2: 3 D-Model of the key horizon „Gorleben-Bank“ (green) constructed by GPR-Reflectors (red)

stratigraphic younger "Leine-Folge". The folds amplitudes reaches up to hundreds of meters with widths of a few meters partly (Fig 1) [3].

The actual boundary between the sequences of "Staßfurt-" and "Leine-Folge" is not detectable by the GPR. But the boundary can be constructed by the detour of the easily identifiable "Gorleben Bank" and the stratigraphic reference profile.

The first step to establish the complete model of the strata of "Gorleben-Bank" is the representation of geological base data (mapping, boreholes), which have been analysed with standard procedures like map and profile compilation. This results in a 2,5 dimensional model which serves the base for the incorporation of secondary data (GPR).

The second step consists of the spatial

connection of the 2,5-dimensional geology with the GPR data. From the reflectors assigned to the key horizon of the "Gorleben Bank" several single plains could be constructed. Hence surrenders a coherent plain, which shows the spatial position of the „Gorleben Bank“ (Fig. 2).

The last step is the construction of the spatial trend of the boundary of the sequences of "Staßfurt-" and "Leine-Folge"

The geological mapping (scale 1 : 100) and the investigation of cores were done very detailed. The tolerance of GPR data is only a few percent for the distance determination and only a few degrees of direction determination [4]. This ensues a projection of high reliability in front of the working face.

A verification of the projection might be necessary in several cases. This is important if a reflector has been detected in a sensible

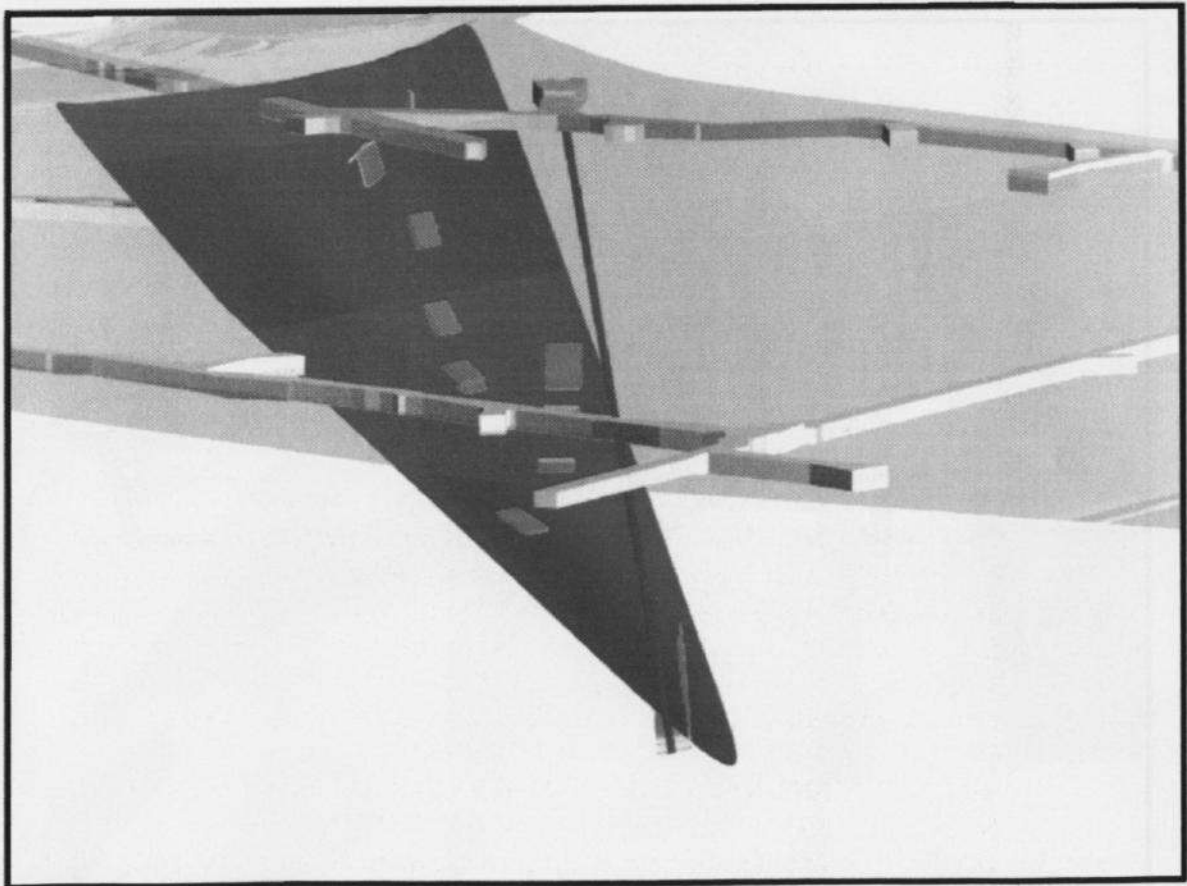


Figure 3: Borehole (blue) target on a GPR-Reflector (red) characterizing the boundary of the sequences of "Staßfurt-" and "Leine-Folge" (green plain)

area and cannot be fitted to the existing model. It is now possible for it to place a borehole from any point in the mine on any point of the constructed plain or measured reflector situated free in space (Fig. 3). The start and end of the bore can easily be read off the CAD-system incl. the direction and length. The end or start of a certain borehole can be moved now easily in the model in order to optimise the orientation. Boundary conditions like as maximum drilling depth, pressure steps or safety pillars can also be considered.

The procedure of construction has to be repeated for several geological units. The result is an assumed geological profile along a borehole or drift. A calculation of a volume of a stratigraphic unit is possible after modelling.

### 3. Conclusion

The three-dimensional modelling of geological structures is an approved method for the Gorleben site. By means of the above mentioned method the spatial trend of rock salt layers can be demonstrated in detail from the top of salt dome down to a depth of 950 m including an area of 0.25 km<sup>2</sup>.

The method allows the combination of results of different investigations and allows the three-dimensional modelling of geological structures. It is not only useful in the case of simple horizontal bedding also in case of the complex fold structures in salt diapirs.

The new high performance CAD systems allow a fast combining and matching of different data in the correct spatial orientation in a three-dimensional geological model. The automatic generation of sections reduces working time extremely. Complex geological settings can be fast recognised and visualized.

Summarising, the method can be used independently from location and rock type. Up to now the method is constructed exclusively for an exploration input at salt deposit resp. at location to be proper for GPR measurements. With adequate interfaces data from research (e.g. seismological) can be incorporated too.

In future, a fully automatic generation of layers will be developed from a data base for a stratigraphic unit. The correlation of reflectors with exposures shall only happen by a simple click.

### 4. References

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