Systematic radar and borehole radar investigation in the salt mine of Borth (Germany)

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After some experimental work in the mid 80's, radar and borehole radar investigation techniques have been used systematically in the Solvay salt mine (Germany) since 1988 in order to optimize mine planning. Due to the excellent dielectric properties of the salt in the Borth mine, very accurate results are obtained at ranges up to 100 meters or even more. Radar techniques may be used in several ways : low frequency survey with surface antennas to map the structure above or below existing galleries, high frequency survey with surface antennas to detect cracks in the roof or floor of galleries, low frequency survey in horizontal boreholes to map the deposit ahead of galleries. Several examples of borehole radar results are presented and interpretated.

1. INTRODUCTION

The Borth salt mine is located along the left bank of the Rhine, North of Düsseldorf. The total thickness of the evaporitic deposit is approximately 150 m, but the mining activity, at a depth of about 800 m, is restricted to a 20-30 m thick layer of very pure halite overlying anhydrite. The layers are mostly horizontal, with some distinct uplifts of the anhydrite resulting in local anticline structures. Such structures must be taken into account to optimize the planning of operations. Since the late 80's, these structures have been localized using systematic radar surveys, first in galleries and later in long horizontal boreholes ahead of mining operations.

2. PRINCIPLE OF RADAR METHODS

Radar exploration techniques are based on the propagation and reflection of electromagnetic waves in the subsurface. In the early 70's, the applicability of radar exploration in rocksalt has been demonstrated in the USA by Unterberger , 1974 [1] and in Germany by Thierbach, 1974 [2]. Various instruments have been developped in the late 70's and early 80's, giving satisfactory results for measurements in galleries, using surface antennas.

Borehole antennas were also developped, but the losses in the long cables connecting the antennas to the control unit resulted in a significant degradation of the signal. This problem was overcome in the late 80's by the Swedish Ramac Borehole Radar originally developped for use in granitic rocks, in connection with nuclear repositories. The system uses fiber optics cables which do not produce any loss in signal quality.

An abundant litterature about radar techniques is available in geophysical journals and proceedings.

Daniels, 1996 [3] gives a comprehensive overview of the theory and practice of subsurface radar. A very brief summary is given hereafter, in the specific case of borehole radar in a vertical hole.

Two dipole antennas are placed in the borehole, with a fixed spacing of 1 to 2 m. Frequencies from 20 to 200 Mhz are used according to the application : a low frequency gives better penetration, a high frequency gives better resolution. The antennas are moved along the borehole stepwise or continuously. The transmitter sends an impulse which propagates in the rockmass around the borehole. Discontinuities like contacts between layers produce reflections which are detected by the receiver.

Dry rocksalt is a very favourable medium for radar wave propagation because the attenuation is negligible due to the very high electrical resistivity.

The results are displayed as radar sections after suitable processing. These sections must then be interpreted so as to produce interpreted sections showing the geological section around the borehole.

3. SURVEYS IN GALLERIES

Normal Ground Penetrating Radar (GPR) systems with 80 to 250 MHz surface antennas may be used to map the deposit below and above the galleries. These surveys were mainly useful in the past, when borehole radar (see below) was not used systematically ahead of mining operations. Typical results are described in Halleux et al., 1992 [4].

Since a few years, high frequency antennas (500 to 1000 MHz) are also used in order to detect cracks at the roof or at the floor of the galleries. These cracks are due to stress relieve and they delimitate slabs which may become unstable. The early detection of such cracks is useful to adapt the roof bolting program and it contributes significantly to the safety. The repetition of the measurements show the evolution of the cracks with time.

4. BOREHOLE RADAR SURVEY

Using a modern borehole radar system in horizontal boreholes drilled from the end of existing galleries has provided a very efficient way of mapping all the relevant geological sturctures up to 600 meters ahead of mining operations.

The figure 1a shows an example of borehole radar section in a 500 meter long horizontal borehole. From 0 to 140 meters, the hole is dry. From 140 meters to the end, the hole deviates slightly downwards and is filled with brine, which results in a strong attenuation of the signals. However, after suitable processing, the results can be interpretated even in the brine filled part. A large number of events are visible on the section. The most important ones are :

- reflections on clay layers ;
- reflection on the salt basis ;
- artefacts due to point reflectors (diffraction hyperbolae) ;
- artefacts on the brine-air and brine-salt interfaces in the borehole.

The interpretation of the section takes into account the geological structure of the deposit and the theory of borehole radar operation in order to eliminate artefacts, to identify typical reflectors and to position them around the borehole. The interpretated section is shown on figure 1b where an anhydrite uplift is visible around 280-300 meters.

The figures 2a and 2b illustrate similar results in another borehole.

The interpretated sections are used to plan future mining operations : the galleries can be driven at exactly the required distance above the salt-anhydrite contact, resulting in both more efficiency and more safety. All operations carried out since the beginning of the systematic borehole campaigns have confirmed the accuracy of the predicted positions of the major reflectors.

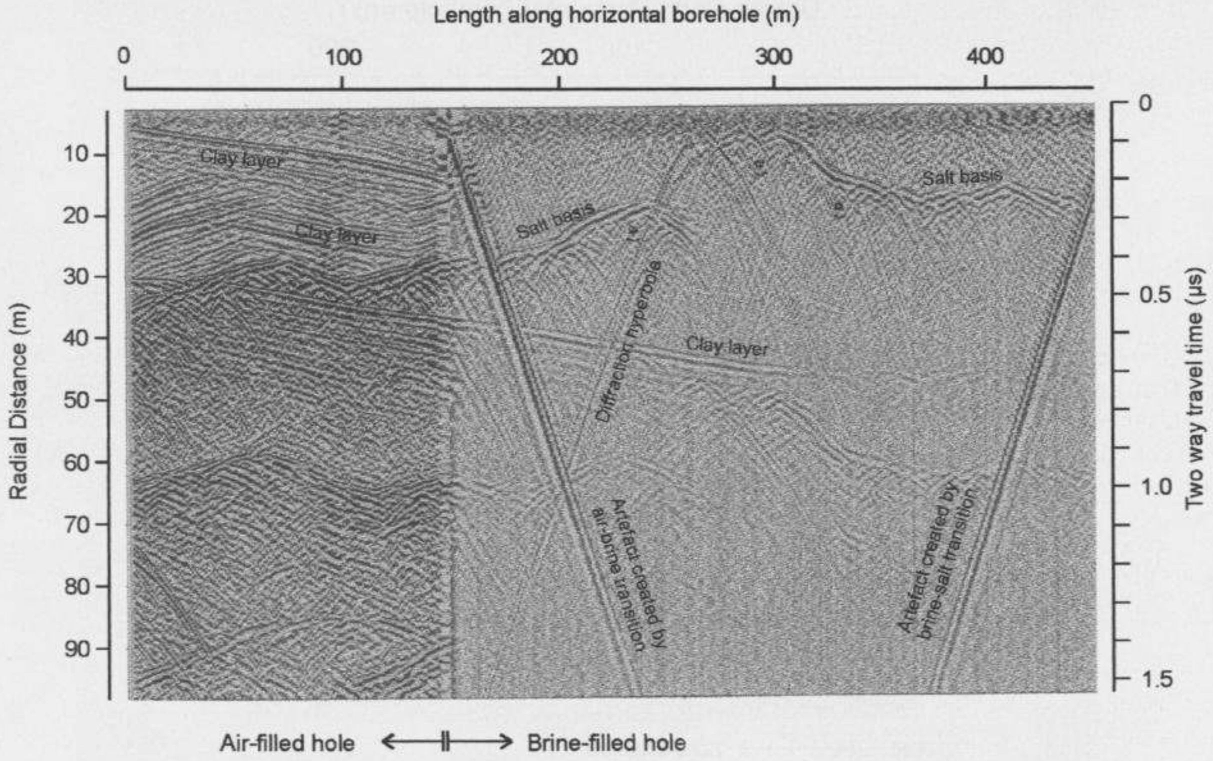

Figure 1a : Borehole Radar Section

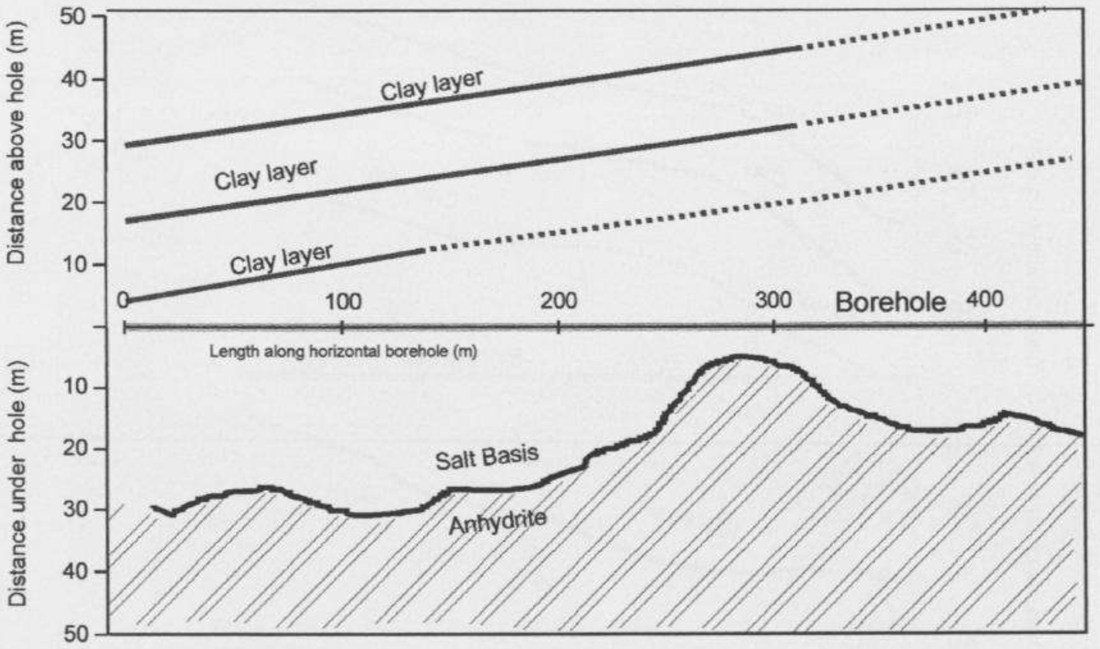

Figure 1b : Interpretated Section

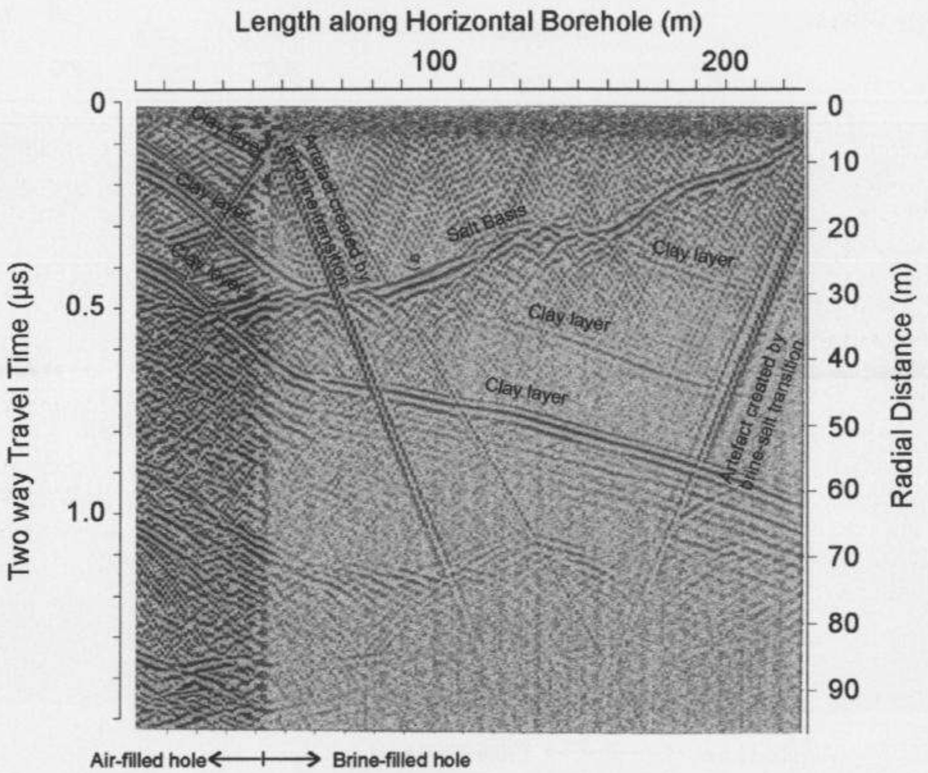

Figure 2a : Borehole Radar Section

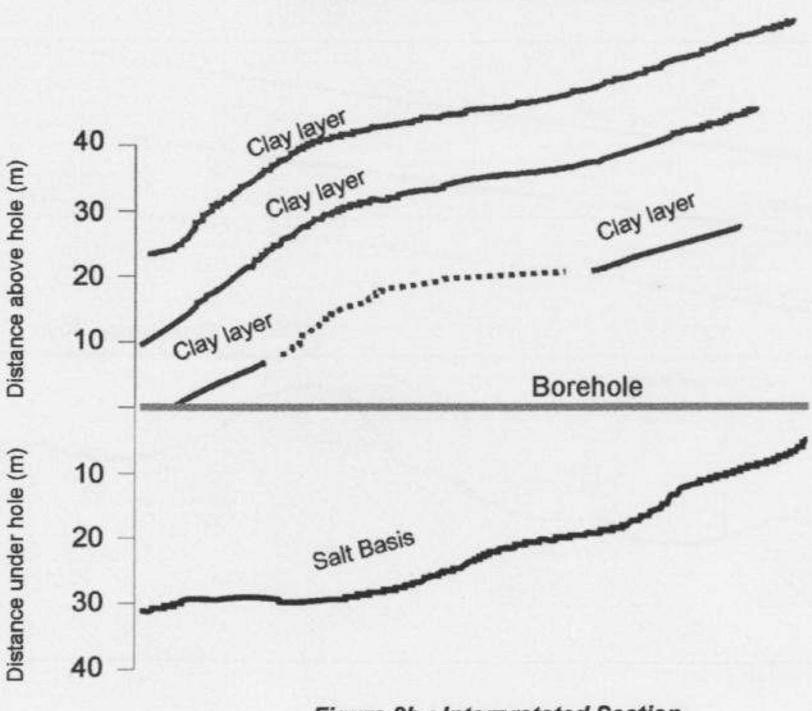

Figure 2b : Interpretated Section

5. CONCLUSION

Radar techniques have become the main exploration tool in the Borth salt mine since the late 80's. The situation in Borth is favourable because the salt is very dry an very pure, resulting in a negligible attenuation of the radar waves. Radar surveys are used in galleries mainly to detect slab formation at the roof. For exploration purpose, borehole radar surveys in long horizontal boreholes ahead of galleries show all relevant geological structures well in advance of mining operations.

Since the beginning of the systematic radar surveys, there has always been a close cooperation between the geophysicists and the engineers in charge of mining operations. In this way, the integration of the interpretated radar results in long term planning has been realized in an optimal way.

References

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