Absorption Measurements with Radio Waves in Salt Mines, its Possibilities and Limitations

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ABSTRACT

Results of about ten years of research in the field of absorption measurements with radio waves in salt mines for safety purposes are presented in a summarized form. The frequency band used is 3-30 MHz. Transmitting and receiving antennas are placed in galleries or dry or wet boreholes with a minimum diameter of 28 mm.

The main targets were brine inclusions and anhydrites. A further objective was to demarcate large areas of carbon dioxide impregnated salt in the Werra district. Interesting side results concerned the wireless communication through salt rocks.

INTRODUCTION

Safety problems involving brine inclusions in salt mines date back as far as salt mining itself. Recognizing and delimiting brine occurrences in planned working areas in time will increase the safety and economy of salt mining. Electromagnetic methods in the radio frequency range offer good possibilities to solve such problems due to the special electric properties of salt rocks. In the following the possibilities and limitations of absorption measurements with radio waves in salt mines are discussed.

RADIO WAVE ABSORPTION

The principle of the radio wave absorption method is shown in Figure 1. The area of interest, a zone of brine inclusions, a fissured anhydrite or other problem areas, must be penetrated with the direct electromagnetic wave from the transmitting to the receiving antenna. Minima of the measured field strength will be caused by zones with higher absorption, but diffracted and reflected energy is possible too, which may mask the absorption zones. This method was first used in the sixties in salt mines by Winter[1] and later by Winter and coworkers[2,3].

In 1967 we began investigations in this field in the Forschungsgemeinschaft Explorationsgeophysik e.V., a research association concerned with the development of geophysical methods for ore and salt prospection and mining. Members of this research association are German mining and prospecting companies and the Federal and State Geological Surveys of the F.R. of Germany. The work is being supported by the Fed. Ministry of Economics, Bonn, via AIF (Arbeitsgemeinschaft Industrieller Forschungsgemeinschaften), Köln. At that time the folllowing results were known from the work of other groups (summarized in Fig. 2):

1. It is possible to penetrate up to 1,000 meters of Zechstein salt rock with 10 watts transmitter output. The frequency band used was 2-12 MHz.
2. The work was carried out with long wire antennas positioned in workings and galleries.
3. It is possible to delimitate brine inclusions and give their boundaries as a "radio shadow".
4. There are (according to Winter) certain frequencies with minimal absorption coefficients i.e. there will be frequency "windows" where there is the possibility of covering greater distances than with the neighboring frequencies.

Since that time there has been intensive work in our research group to build antennas for absorption measurements in all types of salt mines in the Federal Republic of Germany.

The results summarized from Nickel[4,5,6] (right hand side of Figure 2) are the following:

1. With only one watt energy radiated from the transmitter it is possible to penetrate up to 6,000 meters of Zechstein 1. The field strength measured at this distance is still above the noise level by a factor of 5–10; frequency band: 3–10 MHz. In the younger Zechstein series which have layers of the Main Anhydrite and Red Salt Clay, it is possible to penetrate up to 3,000 m with the same transmitter output assuming that the maximum thicknesses of

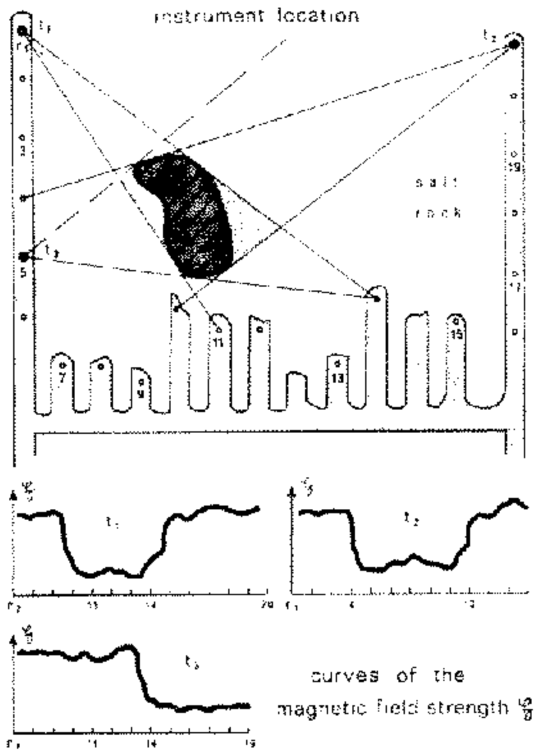

Figure 1. Principle of HF-absorption measurements in salt mines.

the Main Anhydrite and the Red Salt Clay to be penetrated are 150 m or 30 m, respectively.

2. Borehole antennas with a minimum diameter of 20 millimeters are used. They are of the symmetrical coaxial dipole type, i.e. the coaxial cable to the midst of the antenna leads through the pipe of the antenna counterweight. All types of boreholes normally drilled in salt mines can be utilized for our purposes, even counter flush bore holes filled with brine. During the measurements in such boreholes, the brine is expelled from between the antenna and the borehole wall by compressed air.
3. It is possible a) to find and delimitate brine inclusions ahead of mining, b) to investigate the Main Anhydrite and to recognize minor changes in its parameters, c) the presence or absence of Red Salt Clay or Main Anhydrite can be distinguished by measurements with several frequencies between 3 and 30 MHz.
4. There are no absorption minima in the frequency band used. All the effects which have been interpreted as frequency windows must be due to antenna effects. This result could be derived from systematic measurements of the standing wave ratio of both transmitting and receiving antennas. We are able to shift the so-called "windows" to points we prefer by varying the antenna configuration.
5. We use multi-channel borehole antennas that enable us to measure with up to 10 frequencies between 3 and 30 MHz without changing the mechanical length of the antenna. We save time by this method during measurements in long boreholes. Even for the highest frequency used, the length of the antenna is shorter than the half rock wave length, so the antenna still has a radiation characteristic curve similar to the Hertz dipole.

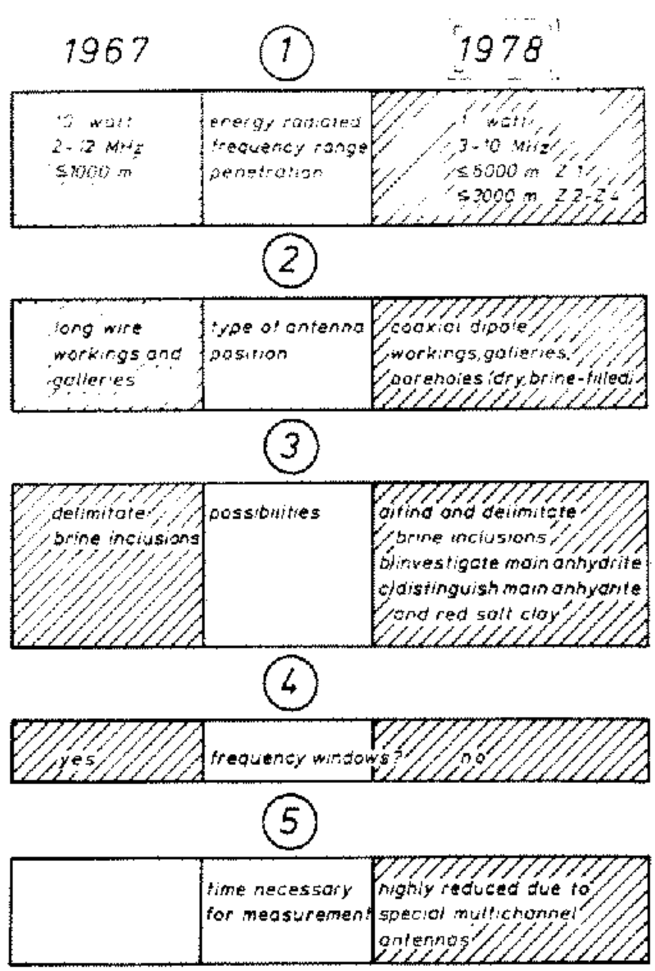

Figure 2. Knowledge of the possibilities and limitations of e.m. absorption measurements in salt mines and its development, 1967–1978.

GENERAL RESULTS

In the following some examples of our work should underline these general results.

Figure 3 presents the results of an investigation in a potash mine in the North Hesse-mining district.[4] A brine inclusion was hit during mining. During our measurements the safety pillars around the brine inclusions were penetrated with radio waves. Thanks to the high sensitivity of the used laboratory field strength unit, specially dust- and shock-protected for the environmental conditions of salt mining, data could also be collected concerning the wet salt rock surrounding the brine nucleus. The differences in the readings for wet salt rock, as opposed to dry were still almost a

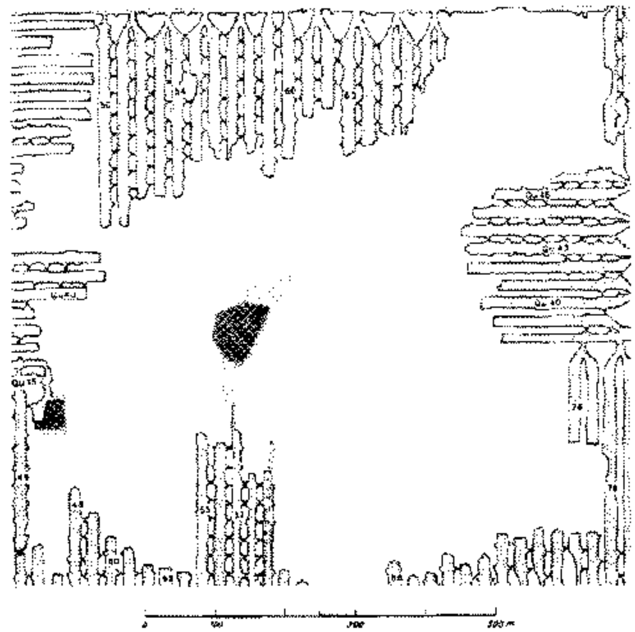

Figure 3. Results of an absorption investigation with radio waves on a brine occurrence in a salt mine of the Werra-Fulda district.

power of ten above the data spread, because of inherent instrument factors. Several frequencies were used for making the influence of diffracted energy on the data visible. For the first time it could be demonstrated (Fig. 4) that energy had been reflected from the top and/or the base of the flatlying salt rock.[4] This fact, which was confirmed in other mines with flatlying beds of salt rock, provided an explanation for contradictions in the measured data, obtained at different distances.

The great majority of potash mines in the Federal Republic of Germany are located in diapirs, where it is necessary not only to demarcate brine inclusions in one plane, but in their three-dimensional extent. The close relationship between brines and the Main Anhydrite in diapirs requires the penetration of the anhydrite (Fig. 5). With the transmitting and the receiving antenna in boreholes these demands are met. With borehole antennas of only 28 mm diameter it is possible to measure in dry boreholes of more than 200 meters length in any direction with a pulley-block only. Sometimes, boreholes crossing the Main Anhydrite yield some brine. In a case where about three liters per minute were flowing out of the borehole, a plastic pipe covering the antenna for insulation purposes allowed reproducible data.

A radio shadow was observed in a portion of the steep flank of the anhydrite. This could have been caused either by brine-filled fissures inside the anhydrite, or by a nearly doubled thickness of the anhydrite. A borehole was drilled to check the location. It encountered more than 50 m (instead of 30 m) of anhydrite and, in addition, there was some brine in fissures in this part of the anhydrite. The area of the anomalous thickness of the main anhydrite was con-

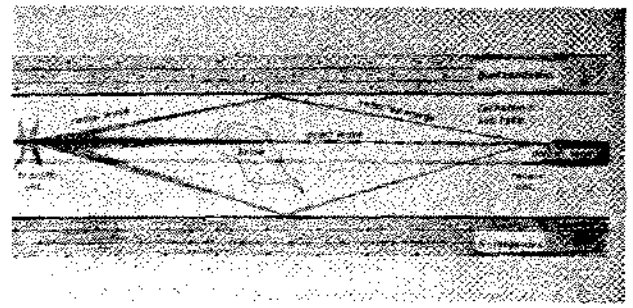

Figure 4. Reflected e.m. energy interfering with direct waves in flat-lying salt deposits, Zechstein 1 salt.

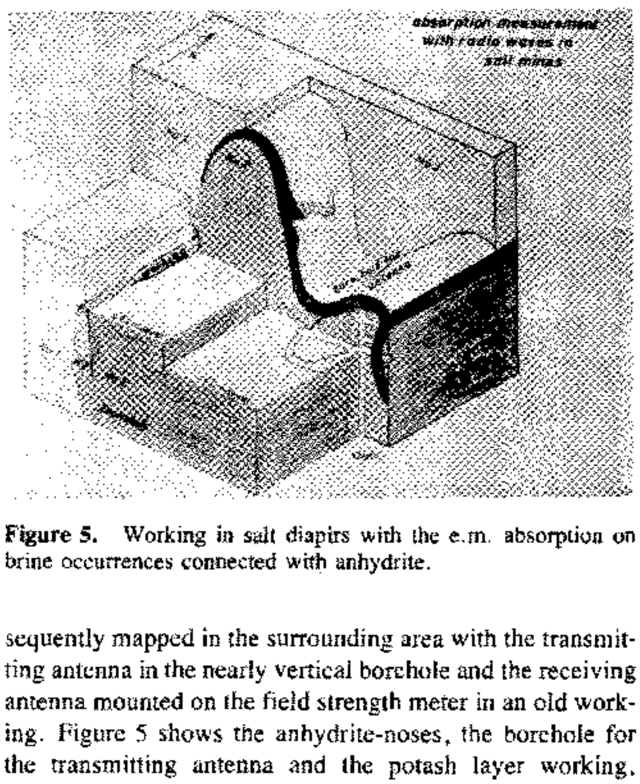

Figure 5. Working in salt diapirs with the e.m. absorption on brine occurrences connected with anhydrite.

sequently mapped in the surrounding area with the transmitting antenna in the nearly vertical borehole and the receiving antenna mounted on the field strength meter in an old working. Figure 5 shows the anhydrite-noses, the borehole for the transmitting antenna and the potash layer working, where the receiver was moved.

At this point few words should be added about the field strength meter used. It is a selective microvolt meter with a sensitivity of 0,1 μV. Mounted in a special dust and shock protection case we have used it for more than 2,000 hours without any breakdown. Figure 6 shows this instrument with a magnetic dipole antenna. The same instrument is used for the electric dipole borehole antenna.

After one week of measurements the amount of brine flowing out of the transmitter borehole increased and soon reached 20 liters/min. The antenna was still working with a good standing wave ratio. But it was found by comparison with results at identical positions that nearly 80% of the energy was absorbed inside the borehole. This was the reason to search for a way to build antennas that work in brine-filled boreholes without any loss of energy between the antenna and borehole wall. During the time of measurement the brine has to be replaced in this part of the borehole by a medium with electrical constants similar to air or salt rock. It was found that this problem could be solved by covering the total length of the antenna with a highly elastic rubber hose. The brine is expelled between antenna and the borehole wall by inflating the hose with compressed air. The pressure in the brine filling in front of and behind the antenna can be equalized along a thin plastic pipe by-pass[6].

Shown in Figure 7 is the plastic pipe which brings the antenna to the borehole position wanted. Inside the pipe the coaxial cable runs from the instrument to the antenna and the compressed air from a special head of the plastic pipe to the rubber hose. Between the hands of the man (Fig. 7) is the pressure seat to hold and tighten the ends of the rubber. Along the rubber hose, covering the antenna, one can see the thin pressure equalizing plastic pipe. The coaxial cable passes the head pressure-tight.

During the intensive studies of the behavior of borehole antennas in salt rock we obtained some very interesting side results. The optimum frequency band for wireless communication through Zechstein salt rock is such that with frequencies between 4 and 5 megacycles and only 1 watt transmitter output we could cover distances of 3,000 m or more in nearly all potash mines in the Federal Republic of Germany[7]. In a typical situation in a potash mine in a diapir, the wave has to pass through the Main Anhydrite and the Red Salt Clay on its way to the receiver more than once, yet the field strength is still high enough for communication.

Figure 6. Field strength meter with magnetic dipole antenna as used in our investigations.

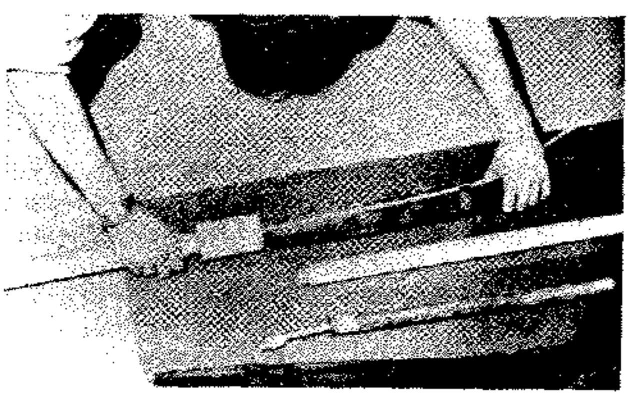

Figure 7. Specially developed equipment to work in boreholes filled with brine.

There is another effect that first caused difficulties, but subsequently was utilized for further developments. If the borehole passes through rock salt and anhydrite one notices a change in the standing wave ratio. This effect is caused because the wave velocity of anhydrite is lower than that of rock salt due to its electrical constants. We developed special antennas which react even more sensitively to a change of the wave velocity in the rock drilled. With these antennas it is also possible to recognize areas of different wave velocities present in the neighborhood of the borehole, but not hit by the hole itself.[8]

Measurements with such an antenna in a borehole drilled through carbon-dioxide impregnated salt in the Werra district yielded very interesting results. There were remarkable low values for the standing wave ratio in the area of the impregnation. In a special program we developed antennas that still retain this effect, but are nearly uneffected by changes of the mineral composition along the borehole. The results of such measurements in the area of a large impregnation have been proven to be correct by mining the area.

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