GeoConvention 2015
GEOSCIENCE
new horizons
Telus Convention Centre • 4-8 May 2015 • Calgary, AB Canada

Dielectic permittivity at different depths of Rocanville potash mine: Causes of GPR reflection at different depths

Sohely Pervin and Douglas R. Schmitt
Department of Physics, University of Alberta

Summary

Non-destructive GPR or geo-radar has wide application in hydrology, sedimentology, geological structure, glaciers and land mine detection. Moreover, it is a popular technique for imaging the subsurface and is particularly useful in electrically resistive materials such as clean sands, crystalline igneous and metamorphic rock, salt deposits, and ice. But without understanding the physical basis which are controlling factor of GPR operation may result into unsuccessful interpretation of GPR data. Different earth materials have different dielectric permittivities, wave speeds, and attenuation which lead to a reflection of the EM waves at the interfaces between these materials. Finding out the reasons causing reflection on GPR image helps us to interpret GPR data more precisely. One of the most important physical property that controls the propagation speed of EM wave is dielectric permittivity. The main objective of this work is to find out the dielectric permittivities at different depths of Rocanville potash mine and the possible reasons behind the GPR reflection at those depths. Eight samples were prepared from different depths potash core and their dielectric permittivities were measured.

Introduction

Dielectric permittivity (ε) is a very important parameter widely used in various realms of sciences including geophysics, condensed matter physics, biology, forestry, agriculture, engineering and hydrology (Topp, Davis et al. 1980). In terms of geophysical study, earth and its structure are usually imaged at radio frequencies (~10 MHz to 1.5 GHz) at which the dielectric permittivity of pure water is nearly 80 and air is 1 (Weast 1984). Both invasive (time domain reflectometry, TDR and cross borehole radar) and non-invasive (ground penetrating radar, GPR) electromagnetic techniques are used to estimate rock properties such as water content and porosity which are two important parameter for underground mining (Sen, Scala et al. 1981, Sakaki, Sugihara et al. 1998). Further, one common fact to all these techniques is that the propagation speed of electromagnetic (EM) radiation in materials is governed by the dielectric permittivity. Therefore the knowledge of dielectric permittivity is crucial to the accurate interpretation of ground penetrating radar (GPR) images.

GPR has been widely used in salt and potash formations (Holser, Unterber.Rr et al. 1972, Thierbac.R 1974, Unterberger 1978, Annan, Davis et al. 1988, Kulenkampff and Yaramanci 1993, Gorham, Saltzberg et al. 2002, Chiba, Watanabe et al. 2006, Igel, Kurz et al. 2006) to provide detailed structural information that helps the development of underground workings for mining, hazardous waste storage, and scientific studies. Moreover, GPR is employed in a nearly real time basis to assist the steering of large mining machines. Indeed, excavator operators in potash mines direct their machines by monitoring their position within the ore zone on the basis of known reflections.

In the Saskatchewan potash mines, high quality ore zones are often bounded by thin ‘shale’ layers that are principally contaminated with anhydrite and calcite. It is quite important to avoid these ‘shale’ rich zones that are undesirable from the standpoints of both ore quality and mine working stability.

Ground penetrating radars (GPR) attached to mining machines are often used to track these shale layers so that they can be avoided. As such, in order to best interpret the underground observations it is important to understand the reflections seen; but to do this fully requires appropriate knowledge of the physical properties of the constituent evaporate minerals especially dielectric permittivity.

Theory

Dielectric permittivity is a most important parameter and in GPR frequencies it describes the polarisation of induced or oriented electric dipoles within a dielectric material. In general, the relative dielectric permittivity ε^* is complex and given by

$\varepsilon^* = \varepsilon' - i\varepsilon''$ -------------------(1)

where ε' and ε'' are the real and the imaginary components, respectively. The real part ε', often referred to as the dielectric constant despite its frequency dispersion, describes the ability of the material to store energy by polarisation as a result of applying electromagnetic radiation. The imaginary part ε'' describes the energy loss resulting from dielectric hysteresis.

Method

Cold compression technique was used to prepare solid sample from different depths core. In this technique, a small piece from each core was first grinded in a mortar-pastel and then dried up in a woven for one hour so that there would be no possibility of presence of moisture. After drying up the powder was then poured into flexible plastic tubing and sealed on both sides with aluminum end caps and the end caps were then tightened properly using tight clamps so that oil could not get inside when samples are placed in the pressure vessel. The sealed tube was then left heated at about 60^{o}C for 2 to 3 hours. This heating was found to improve particle adhesion, without this step the final compressed sample becomes broken discs instead of one solid sample. After that it was vacuumed for 1 hour to remove air inside the tube otherwise this air would break the sample off. The sample was then slowly pressurized to the desired peak pressure (~ 2500 bar) and left for at least 14 to 16 hours in the pressure vessel. The sample was then slowly depressurized so that it produces a more solid sample upon completion than rapid depressurization. The samples obtained were one inch in diameter and of a few cm thick.

Examples

Eight samples were made at different depths of Rocanville potash mine using cold compress technique. This means that we have first crushed the core samples into powder and then compress it to produce a solid homogenous sample. Crushing the samples into powder means that there is no possibility of the presence of brine and the free water is removed. From Fig. (1) we can see that the real part of dielectric permittivity at (1216.65-1217.27) meter and (1223.67-1224.30) meter depths are decreasing with increasing frequency and for the rest of the depth samples it is independent on frequency. As well the imaginary part of permittivity is also high for (1216.65-1217.27) meter and (1223.67-1224.30) meter which indicates the presence of minerals having higher conductivity. This result indicates the presence of clay or shaly dense dolomite at these depths. The presence of clay at these causing reflection on GPR image.

Fig. (2) shows the velocity of GPR at different frequencies. The difference between the low frequency GPR ($<$ 50 MHz) and the high frequency GPR ($>$ 200 MHz) becomes significant when the clay content increase and therefore conducting a GPR at two frequencies may be used as indicator of clay content.

Conclusions

Dielectric permittivity measurements were done on eight cold compressed samples which were made from eight different depths core of Rocanville potash mine. The dielectric permittivities at (1216.65-1217.27) meter and (1223.67-1224.30) meter depth shows the presence of significant amount of clay. The presence of clay at these depths are responsible for the GPR reflection. Moreover, the velocity at these different depths shows conducting GPR at the low frequency (< 50 MHz) and the high frequency (> 200 MHz) may be used as indicator of clay content.

Acknowledgements

This work is funded by research grants from the Potash Corporation of Saskatchewan.

References

Topp, G. C., J. L. Davis and A. P. Annan (1980). "Electromagnetic Determination of Soil-Water Content - Measurements in Coaxial Transmission-Lines." Water Resources Research **16**(3): 574-582.

Weast, R. C. (1984). Handbook of physics and chemistry. Boca Ratoon FL, CRC Press.

Sen, P. N., C. Scala and M. H. Cohen (1981). "A Self-Similar Model for Sedimentary-Rocks with Application to the Dielectric-Constant of Fused Glass-Beads." Geophysics **46**(5): 781-795.

Sakaki, T., K. Sugihara, T. Adachi, K. Nishida and W. R. Lin (1998). "Application of time domain reflectometry to determination of volumetric water content in rock." Water Resources Research **34**(10): 2623-2631.

Holser, W. T., Unterber.Rr, R. J. S. Brown, Fredriks.Oa and F. A. Roberts (1972). "Radar Logging of a Salt Dome." Geophysics **37**(5): 889-&.

Thierbac.R (1974). "Electromagnetic Reflections in Salt Deposits." Journal of Geophysics-Zeitschrift Fur Geophysik **40**(5): 633-637.

Unterberger, R. R. (1978). "Radar Propagation in Rock Salt." Geophysical Prospecting **26**(2): 312-328.

Annan, A. P., J. L. Davis and D. Gendzwill (1988). "Radar Sounding in Potash Mines, Saskatchewan, Canada." Geophysics **53**(12): 1556-1564.

Kulenkampff, J. M. and U. Yaramanci (1993). "Frequency-Dependent Complex Resistivity of Rock-Salt Samples and Related Petrophysical Parameters." Geophysical Prospecting **41**(8): 995-1008.

Gorham, P., D. Saltzberg, A. Odian, D. Williams, D. Besson, G. Frichter and S. Tantawi (2002). "Measurements of the suitability of large rock salt formations for radio detection of high-energy neutrinos." Nuclear Instruments & Methods in Physics Research Section a-Accelerators Spectrometers Detectors and Associated Equipment **490**(3): 476-491.

Chiba, M., Y. Watanabe, O. Yasuda, T. Kamijo, Y. Chikashige, T. Kon, A. Amano, Y. Takeoka, Y. Shimizu, S. Mori and S. Ninomiya (2006). "Measurement of attenuation length for radio wave in natural rock salt samples concerning ultra high energy neutrino detection." International Journal of Modern Physics A **21**: 25-29.

Igel, J., G. Kurz and R. Schulz (2006). "Detecting brine zones in salt deposits with the ground penetrating radar (GPR) for safety assessments of underground waste disposals." Near Surface Geophysics **4**(4): 265-274.

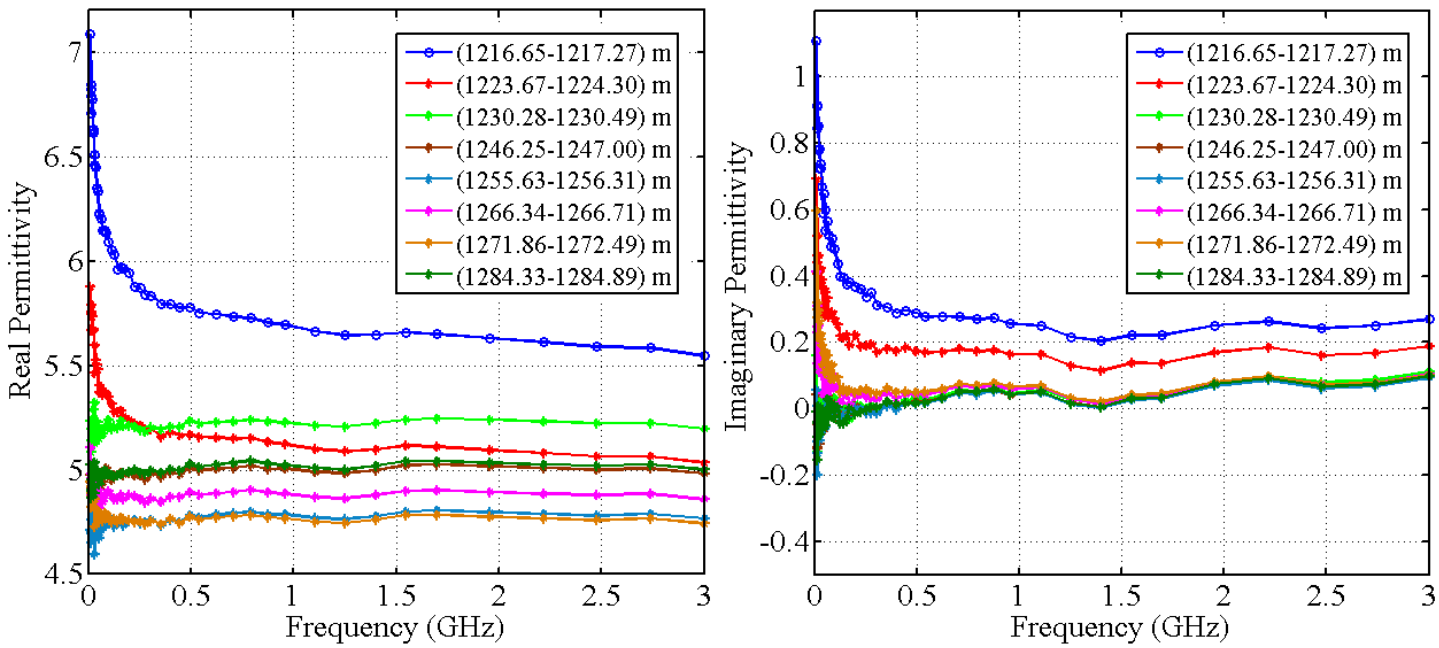

Figure 1: The real and imaginary permittivity of samples taken from GPR reflection zone. The samples names stand for the depth it was taken from.

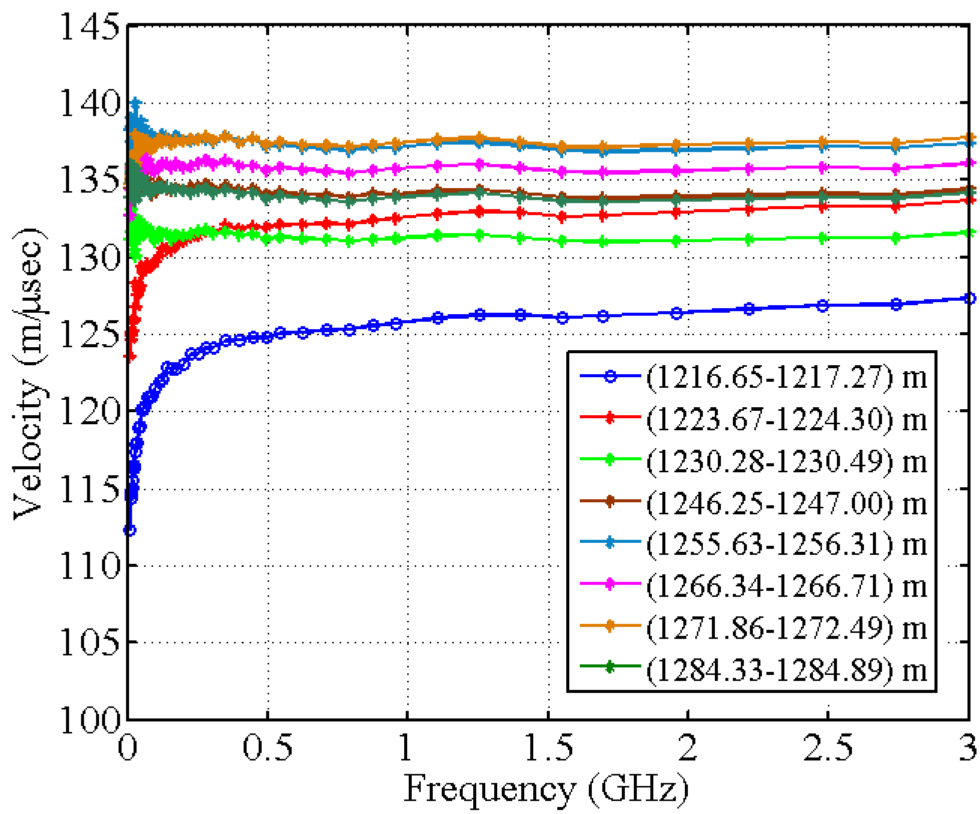

Figure 2: The velocity of samples taken from GPR reflection zone. The name of the samples stand for the depth it was taken from. At high clay content the velocity becomes a function of frequency.