Comments on “Realistic Expectations of GPR Performance in Mineral Exploration” by J. Francke

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Introduction

A recent publication (J. Francke, “Realistic Expectations of GPR Performance in Mineral Exploration”, Proceedings of Exploration 17: Sixth Decennial International Conference on Mineral Exploration ed. V. Tschirhart and M.D. Thomas, 2017, p. 817-820) purports to demonstrate that statements made by competitors (selected by the author from published papers, marketing materials, and even a newspaper article from 20 years ago) are inconsistent with the laws of physics that govern the behaviour of electromagnetic waves. In this context the author provides explanations of some elementary properties of subsurface radar.

However in doing so, the article makes several rather fundamental mistakes in the technical analysis presented. As ADROK is one of the companies that is criticized, we feel compelled to point out those mistakes here. We will leave it up to the readers to decide for themselves if these errors affect the conclusions.

Technical comments

Power and penetration

On p.118, section “Increasing Penetration”, second paragraph the author states that “power of the transmitter must be increased exponentially to increase penetration” which, if interpreted to mean that the relation between power and penetration depth is exponential, is correct. The next sentence then claims that “In theory, an increase of 32 times is required to double penetration”, which is not even approximately correct, because the relation is exponential, not linear.

The energy in a subsurface EM wave (the radar pulse) decreases due to material losses (correctly reviewed in the paper elsewhere) at a constant rate through the material, leading to an exponential relation between energy and distance traveled. This loss can be characterized by the so-called “skin-depth”, d_s, which is the distance the wave has to travel to attenuate it by a factor $1/e \approx 0.37$. Penetration is then the largest distance (D_{max}) at which the radar pulse is still detectable. Consequently, if the power is increased by a multiplicative factor $e = 2.7$, it will penetrate a distance d_s deeper. For reflection mode scanning, the wave has to travel down and up again, so the increase in penetration depth is $d_s/2$ for a power boost of 2.7. So a power increase by a factor 32 will result in an increased penetration of $d_s \log(32)/2 \approx 1.7 d_s$. This does not depend on D_{max} and certainly does not double it, as the author claims.

Wavelength and reflection

On p.819, second sentence, the author states:

"One paper claims that the ADR instrument, which emits EM fields at these frequencies, could detect gold-bearing veins on the scale of decimetres in thickness to depths exceeding 800 m (Richards et al., 2015). With conventional radar, a layer is generally considered to be resolvable if its thickness is on the order of the incident EM wavelength."

This is not correct. Consider for example the textbook example of computing the orthogonal reflection coefficient of a plane electromagnetic wave incident on a thin rectangular conductive plate. To a very good approximation, if the plate is thicker than about one "skin-depth", the wave will be completely reflected. This does not depend at all on the wavelength, except indirectly (as the skin-depth depends somewhat on the wavelength). If the conductivity of the plate is high, the skin-depth is small, and a thin conductor will reflect irrespective of the incident wavelength. For the detection of highly conductive sulfide layers (candidates for bearing gold) in resistive granite, the skin-depth is of the order of a *cm* and these layers **will** reflect waves with wavelength of the order of tens of meters,

Possibly the author is confusing reflectivity with spatial resolution. It is true that distinct layers, though generating detectable reflections, cannot be well separated unless they are about a wavelength or more apart, as the reflected pulses tend to merge.

Average and peak power

On p.819 the author argues that the depth of penetration is governed by average power, rather than by peak power and produces the following (correct assuming a rectangular pulse) formula for average power

$$P_{avg} = PulseWidth * PRF * PeakPower \tag{1}$$

where everything is in SI units and PRF is the pulse repetition frequency.

A simple thought experiment suffices to show this cannot possibly be correct. If we perform $100,000$ scans with $PRF = 1000Hz$ it will take $100s$ to complete, whereas if we did the same with $PRF = 10,000Hz$ it would take $10s$, but the data acquired is obviously the same. Penetration is determined by the power in the pulse, and not dependent on the PRF.

Perhaps the author assumed a fixed acquisition time limit of the scan, in which case a higher PRF would allow a larger stack (the set of repeated measurements is usually called the "stack"). In that case, additional denoising through increased stacking indeed results in higher penetration for higher PRF, but this is due to noise reduction. If we assume the P_{avg} is supposed to represents the ratio of power to noise (i.e., the signal to noise ratio), even though the dimension don't add up, the "effective power" would indeed increase with the PRF but by a factor $\sqrt{PRF}$, not linearly, because the noise reduction through averaging is proportional to the square root of the number data items averaged under quite general assumptions.