Planning for shallow high-resolution seismic surveys

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Shallow high resolution seismic surveys are routinely used in near surface for mineral exploration and in environmental surveys to detect small structures and lithology for pollution detection purposes.

Electromagnetic systems and the frequency domain electromagnetic (FDEM) systems in particular, utilise more than one frequency to obtain information from the subsurface at different depths (e.g. Apex Max-Min system). These frequency domain electromagnetic systems utilise an entity called the skin depth [1,2]. The definition of the skin depth is the effective depth of penetration of an electromagnetic plane wave up to the point where it is attenuated to 1/e of its original amplitude. The electromagnetic skin depth is given by Eqn. 1.

$$\delta = \sqrt{\frac{2\sigma}{\mu\omega}} \qquad (1)$$

where

σ = resistivity

μ = permeability

$\omega = 2\pi f$ = angular frequency.

The skin depth is largely controlled by the frequency used. As a rule, lower frequencies, allow for deeper depths of investigation. The conductivity also plays an important role. Lower conductivities (higher resistivities) result in deeper depths of investigation. High conductivities have a shielding effect on the electromagnetic waves.

This approach is also employed by using certain seismic or sound waves [3]. They used the frequency dependency of the surface waves to determine the depth of shallow voids. The penetration of the surface seismic waves of P-waves and S-waves, the so-called Rayleigh and Love waves definitely have these properties [4, 5].

All seismic waves undergo attenuation. The loss of amplitude is exponential of a seismic wave through an imperfect medium [6]. This means that the ratio in which the amplitude decays is a constant, which is called the logarithmic decrement *(δ)*. The specific logarithmic decrement is called the Q-factor. Together with the velocity *(v)* and the frequency *(f)* one can calculate an attenuation constant *(α)* for each situation.

Shallow high resolution seismic surveys are routinely used in near surface for mineral exploration and in environmental surveys to detect small structures and lithology for pollution detection purposes. In this paper a very simple spreadsheet is introduced to aid in the planning and design of shallow high resolution seismic surveys, when all of the important parameters are taken into account.

Attenuation of seismic waves

Seismic waves undergo attenuation, even when the waves have very small amplitudes. This happens because the subsurface medium is not perfectly elastic and because the earth is strong but not critically damped [7, 8]. The deviations from Hooke's law are usually small and the approximations of the elastic wave theory are sufficient [6, 7].

Friction arising from the sliding of grains or crystals against each other is widely acknowledged as the most probable mechanism of energy loss, and the term "solid friction" is frequently used [6].

The symbol *Q* is used to indicate the rock quality for seismic wave propagation, analogue to the electrical circuit situation. For the "solid friction" model the attenuation coefficient *(α)* is dependant on the following properties of the seismic wave:

- Frequency *(f)*
- Velocity *(v)*
- Quality factor *(Q)* and
- Logarithmic decrement *(δ)*, where $\delta = \pi/Q$

The attenuation constant can thus be expressed as the following [6]:

$$\alpha = \frac{\Pi f}{Qv} \qquad (2)$$

The attenuation is exponential. To calculate the distance that the wave must travel in a specific environment before it is reduced to a certain amplitude is given by Waters [6]:

$$e^{-\alpha x} = A_R \qquad (3)$$

Where

α = attenuation constant

x = distance travelled by the wave

A_R = Resultant amplitude

These relationships in Eqn. 2 and 3 were used to develop a simple spreadsheet to aid the scientist with seismic survey design.

Spreadsheet description

During any reflection seismic survey some survey planning has to be done to ensure the success of the survey. Usually the size and the depth of the target have the most influence on the planning. This will determine the frequencies to be used. The attenuation also depends on the Q-factor of the different lithologies of the subsurface.

Q-factor information of rocks is very incomplete. As a rule of thumb, the Q-factor for rock is usually estimated as being 1% to 3% of the velocity [1]. Our experience is that it could be as low as 0,5% to 0,25% if the weathered layer with the unconsolidated material is investigated.

During the data acquisitioning process of any normal seismic survey, there is an offset between the source and the receiver (Fig. 1). The maximum allowed angle is 45°; otherwise more surface waves will be generated with little penetration, which is energy insufficient. This angle at 45° is the maximum ray path that should be used for a survey. Depending on the physical properties of the subsurface and the acquisition parameters such as the frequency, velocity and the Q-factor, a maximum target depth can be estimated using the spreadsheet. The aim of all processing is to obtain a zero offset or stack section (Fig. 2). The spreadsheet allows for this option.

Although the spreadsheet can be adapted and customised, it currently allows for different options. These include:

- The maximum two-way ray path distance at 45°.
- The two-way ray path distance at zero offset.
- The one-way ray path distance at zero offset

Amplification and attenuation in electronics, acoustics, seismic instrumentation and other fields are often described by means of a logarithmic rather than linear scale, because the range of values of interest is very large. The notion of decibels was first used in comparing signals of sound, and in this case the desired comparison is between intensities of sound. Thus if two signals have intensities I_1 and I_2 respectively then the intensities are compared using the formula 10 log (I_1/I_2). Now the intensity of a sinusoidal signal having fixed amplitude and frequency is proportional to the square of its amplitude.

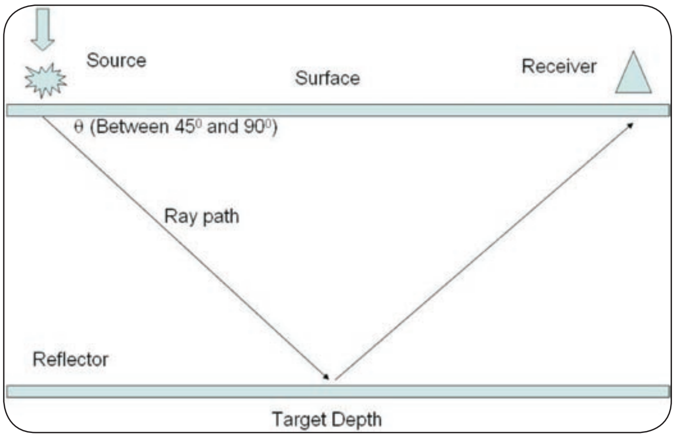

Fig. 1: Schematic diagram of the seismic data acquisitioning process.

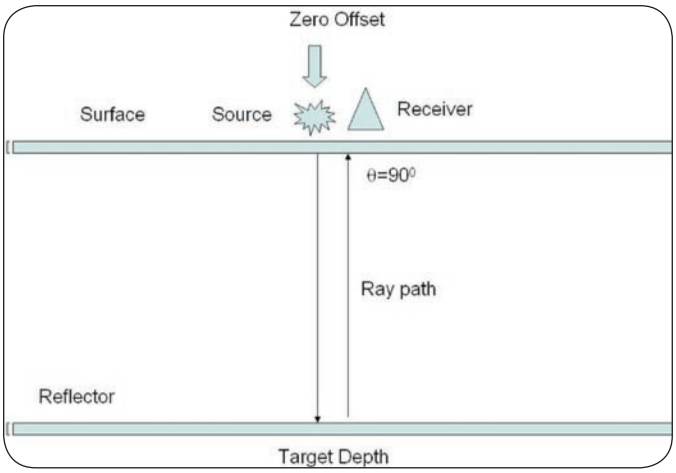

Fig. 2: Schematic of the zero offset principal.

Let A_1 and A_2 be the amplitudes of two sinusoidal signals and I_1 and I_2 their intensities.

Then $I1 \propto A_1^2$ and $I_2 \propto A_2^2$ implies $I1 = kA_1^2$ and $I_2 = kA_2^2$ for some constant k. (Revise proportion.)

Then 10 log (I_1/I_2)

= 10 log $(kA_1^2/(kA_2^2))$

= 10 log (A_1^2/A_2^2)

= 10 log $(A_1/A_2)^2$,

= 10 [2log (A_1/A_2)],
(from log $a^b = b$ log a)

= 20 log (A_1/A_2).

In this way the expression 20 log (A_1/A_2) has come into use where amplitudes of voltage or current are under consideration.

This spreadsheet thus allows the user to calculate the loss of amplitude in decibels (dB). This is important because it gives an indication of the amplification properties a seismograph must have to record the data within acceptable noise levels (Fig. 3). It is often referred to as the gain.

Spreadsheet operation

Using the spreadsheet is quite easy (see Fig. 3). It calculates penetration depths for five different frequency options (Fig. 4). On the left side is the amplitude ratio and on the right side is the gain in decibels (dB) and the remaining energy of the wave. At the bottom of the table the operator can change the wave velocity (v), the frequency and the Q-factor. It is thus possible to compare penetration depths for the same frequencies using different parameters, or to make comparisons between different frequencies and keeping the other parameters constant.

Five different curves are displayed where the percentage of energy against the penetration depths are displayed. The operator can also calculate the penetration depths by adjusting the wave paths. For a maximum two-way path distance of 45° the factor is 2,38. A zero offset two-way path is calculated with a factor 2 and a one way path distance is calculated at a factor 1.

Discussion

The development of this spreadsheet was done primarily to aid the geophysicist with the design of shallow high resolution seismic reflection surveys where resolution of small faults and structures are important.

	Amplitude ratio	Target depth in m for respective frequencies and Q to which remaining signal levels apply					% Energy remaining	dB
		125	125	50	125	50		
	0,6	14	138	345	632	1580	60	-4,437
	0,5	19	187	468	858	2144	50	-6,0206
	0,4	25	247	618	1134	2834	40	-7,9588
	0,3333	30	297	741	1359	3398	33,33	-9,5433
	0,3	33	325	813	1490	3724	30	-10,458
	0,2	43	434	1086	1991	4978	20	-13,979
Skindepth	0,1	62	622	1554	2849	7122	10	-20
	0,01	124	1243	3108	5698	14 244	1	-40
	0,0001	186	1865	4662	8547	21 366	0,1	-60
	0,0001	249	2486	6216	11 395	28 489	0,01	-80
	0,00001	311	3108	7770	14 244	35 611	0,001	-100
	0,000001	373	3729	9324	17 093	42 733	0,0001	-120
	Wavelength	**24,0**	**24,0**	**60,0**	**44,0**	**110,0**	**m**	
	Period	**8**	**8**	**20**	**8**	**20**	**ms**	
	Frequency	**125**	**125**	**50**	**125**	**50**	**Hz**	
	V	**3000**	**3000**	**3000**	**5500**	**5500**	**m/s**	
	Q-Factor	**10**	**100**	**100**	**250**	**250**		

Fig. 3: Spreadsheet operations to calculate amplitude, energy and gain losses for different parameters.

Attenuation of seismic waves is influenced a lot by the physical properties of rocks, which have a large influence on the wave velocity and the Q-factor. By varying these parameters the effects of the changes are immediately apparent on the graphs.

Simple aid and prediction tools to help the geophysicist in designing surveys are not so easy to find. It is proposed that the simple spreadsheet discussed in this paper can meet this requirement in one aspect of small seismic surveys, by giving the geophysicist the possibility to quickly vary input parameters, which will aid and guide him to better predict survey specifications. This spreadsheet is available free from the authors.

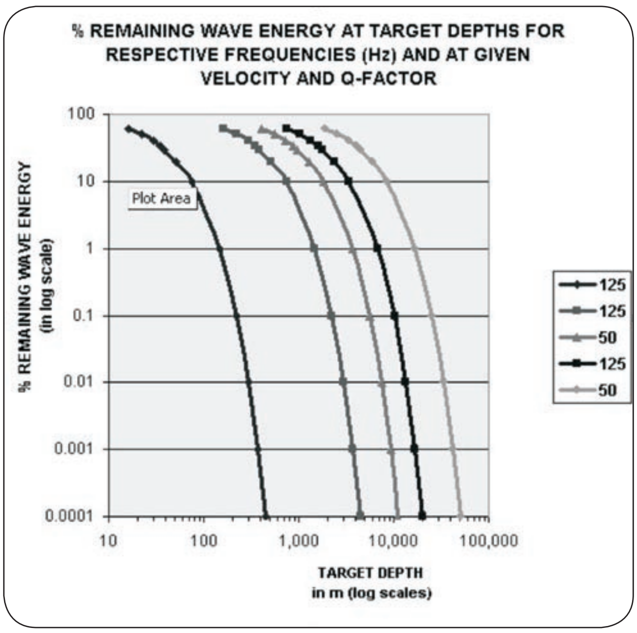

Fig. 4: Penetration depths as calculated by the spreadsheet.

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