SEISMIC SURVEYS FOR IMAGING THE REGOLITH

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1. INTRODUCTION

Seismic reflection and refraction imaging are geophysical methods widely used for investigating the structure of the Earth's crust. They are used, particularly, in sedimentary basins for finding geological structures where oil and gas might be accumulated. Both reflection and refraction imaging are techniques that can be scaled to the structure of interest, and are therefore useful for imaging the regolith.

Seismic energy generated as shock waves at the surface of the Earth travel outwards in all directions through the layers below the surface (Figure 1).

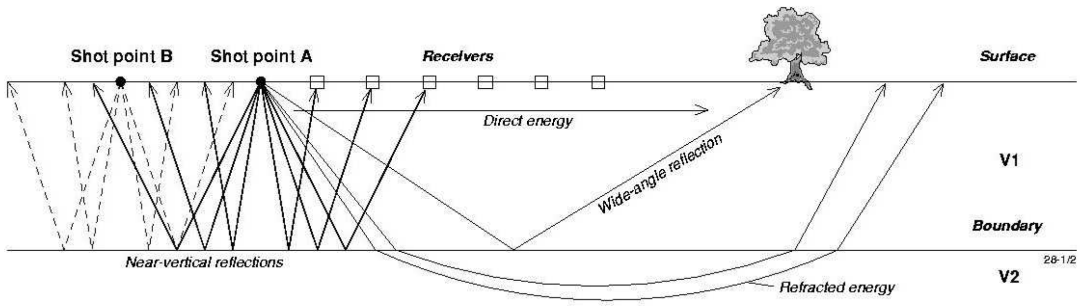

Figure 1. The seismic energy travels along several paths at and below the surface.

Any energy returning to the surface is detected as minute ground vibrations by geophones, which are similar to sensitive microphones. The geophones are connected by lightweight cables or by radio to a recording system. The time between the generation of the shock waves at the surface and their arrival at the geophones is measured and used to create images of the subsurface.

The principles of seismic reflection and refraction are shown in Figure 1. Figure 2 is a seismogram showing both reflected and refracted energy. Each "wiggle" trace shows the energy recorded at a geophone. The energy source, or shotpoint[1], was mid-way along the line of geophones.

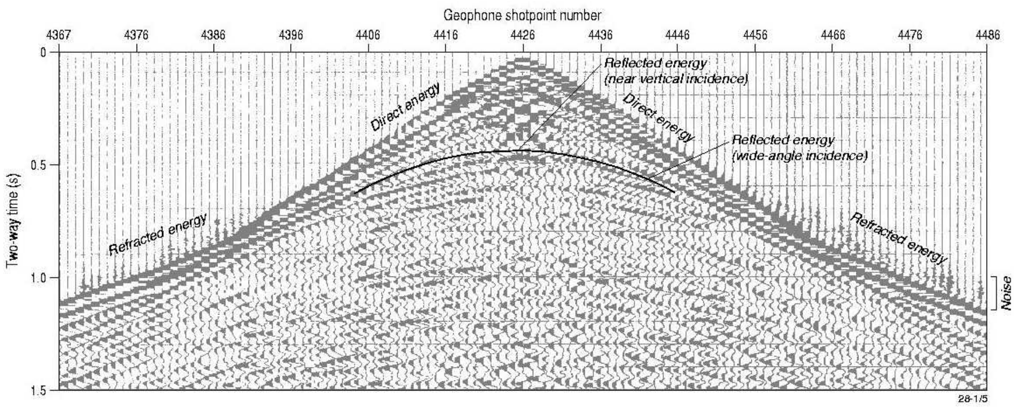

Figure 2. A seismogram showing both reflected and refracted energy.

[1] The term "shotpoint" is traditionally used for the point where seismic energy is generated. Early seismic surveys used explosive sources, hence the name. In recent times, mechanical sources such as ground vibrators and weight drops have been used.

In Papp, É. (Editor), 2002, *Geophysical and Remote Sensing Methods for Regolith Exploration*, CRCLEME Open File Report 144, pp 95-99

The propagation of energy from a shotpoint is best described in terms of the distance of the geophones from the shotpoint. The first energy recorded by geophones close to the shotpoint will be energy travelling directly through the near surface rocks. It will be followed by reflections from boundaries directly underneath the shotpoint. These energy phases have a distinctive appearance in seismograms (Figure 2). On the left hand side of Figure 1, which has two layers, energy from shotpoints A and B is shown reflected back to the surface at near vertical incidence to the boundary between two layers. This is the energy used for reflection profiling.

Other energy from shotpoint A (Figure 1) is shown reflected back to the surface at wider angles of incidence. Refracted energy, which has passed through the boundary into the deeper layer, propagates to greater distances before returning back to the surface at the right hand end of the diagram. Wide angle reflected and refracted energy are used in refraction profiling. These energy phases are shown in Figure 2. Note that the direct energy is the first phase recorded for most of the geophones both to the right and left of the shotpoint, but at greater distances the refracted energy is recorded first. Although it has a longer travel path than the direct energy because it has to reach and penetrate the deeper boundary before it travels sub-horizontally, it travels faster in the deeper layer, and eventually overtakes the shallower direct energy. In the seismogram, wide angle reflections join the near vertical reflections to the refracted energy.

2. REFLECTION PROFILING

Seismic reflection surveys are used where the primary information required is the geometry of interfaces in the regolith and the underlying basement.

For seismic surveys that study the regolith, the seismic energy can be produced by a variety of means. Mechanical sources are preferred because of their low environmental impact. These include vibrator trucks, which vibrate a heavy mass on the surface of the ground (Figure 3), hammers used to thump the ground, and accelerated weight drop tools which use hydraulic rams or heavy springs to accelerate weights downwards onto the ground. Explosive sources can also be used. They include explosive charges down drill holes and shotguns that fire vertically at the ground.

Figure 3. The truck on the right has a large pad mounted at the back. It is lowered to the ground, and the weight of the truck used to hold the pad firmly on the ground. Hydraulic rams are then used to send vibrations through the pad. Because the pad cannot move up and down, the vibrations are transmitted into the ground. The instruments used to record the reflected energy are in the back of the vehicle on the left.

In reflection surveys of the regolith, up to 48 geophones[2] might be arrayed at 1–2 m intervals either side of the shotpoint. Once the energy is recorded, the shotpoint is moved further along the line and the process repeated. This is done in such a way that at least some of the energy from one blast is reflected off the same part of boundaries at depth as the energy from the blasts either side. In a typical survey using, say, 96 geophones, each point in the subsurface would be sampled 12, 24 or 48 times. This is called multi-fold recording using the Common Mid Point Method, and is done to allow higher fidelity images of the subsurface to be created in the data processing centre after the field survey. Very few seismic surveys produce a final image of the subsurface in the field in real time. Most require extensive post-field processing using specialist software.

In seismic reflection surveys, the structure of subsurface geological formations is mapped by the variation in the time taken for the reflected shock waves to return to the surface. The information is usually displayed as continuous reflection-time cross-sections, which are really pictures of the geological structure at depth. Figure 4 gives an example (Courtesy of Christopher Leslie, CRC LEME). It shows the geometry of transported material and a basement high to the right. The time for the seismic energy to travel to the reflectors and back (two-way time) is shown as a linear scale on the left. Two-way time can be converted to depths using estimates of seismic velocities generated during the data processing stage. Depths are shown on the right. Note that a linear two-way time scale does not convert to a linear depth scale.

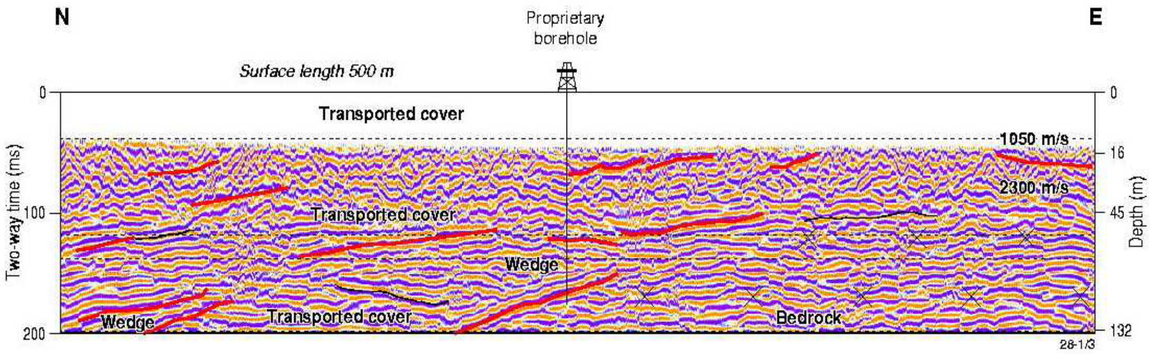

Figure 4. An example of continuous reflection-time cross section, picturing geological structure at depth (Courtesy of Christopher Leslie, CRCLEME).

The most used information in sections like this is the structural information. The amplitude, frequency, phase, and other characteristics of the reflected waves can also provide information on the likely physical characteristics of the boundaries. For example, stronger reflections come from boundaries where the seismic impedance contrast[3] is high compared to boundaries where the impedance contrast is low. Reflections from a boundary where the impedance increases from the upper layer to the lower layer will have the same phase as the energy source, whereas those from boundaries where the deeper layer has a lower impedance will have the opposite phase to the energy source.

[2] The optimum number of geophones depends on the problem to be solved. However, the number of channels and how far they are arrayed each side of the shotpoint can also be limited by the depths of the surfaces to be imaged. Practical limitations of field deployments can limit the number of channels for regolith work to around 48. The type of recording system can also limit the number of channels. Instruments that send analog signals from the geophones to the recording system are limited by the practical number of wires that can be built into the cables; they usually have 24, 48 or 96 channels although larger numbers are possible. Systems that use digital telemetry between the geophones and the recording system can effectively have unlimited numbers of channels.

[3] Seismic impedance is the product of the density of a rock and the velocity at which seismic waves travel in the rock. Impedance contrast is the contrast in the seismic impedances of the rocks on either side of a boundary.

3. REFRACTION SURVEYS

Seismic refraction surveys are used when variations in the composition of the regolith or the underlying basement are the targets, and not the detailed geometry of interfaces. This is because seismic refraction profiling provides a robust image of the variation in the velocity at which seismic waves travel through rocks. Seismic velocity is often an indicator of composition. However, refraction surveys usually provide a less detailed geometrical image than reflection profiling.

The primary data used for refraction interpretation are the direct and refracted phases and often the wide angle reflections. The data are generated using field practices similar to reflection profiling, with the exception that the length of the array of geophones is typically at least 5 times the depth to the target layer. Figure 2 illustrates how non-intuitive these data can be when viewed for the purpose of generating subsurface models. Typically the data have to be forward or inverse modelled. Figure 5 shows one form of output from an inversion (Courtesy of GA). The lower part shows the thickness of regolith along a 120 km profile from the Broken Hill Block into the Murray Basin. It has considerable vertical exaggeration. It was derived from 30,000 traces similar to those in Figure 2 (Figure 2 is from the right hand end of the profile shown on Figure 5).

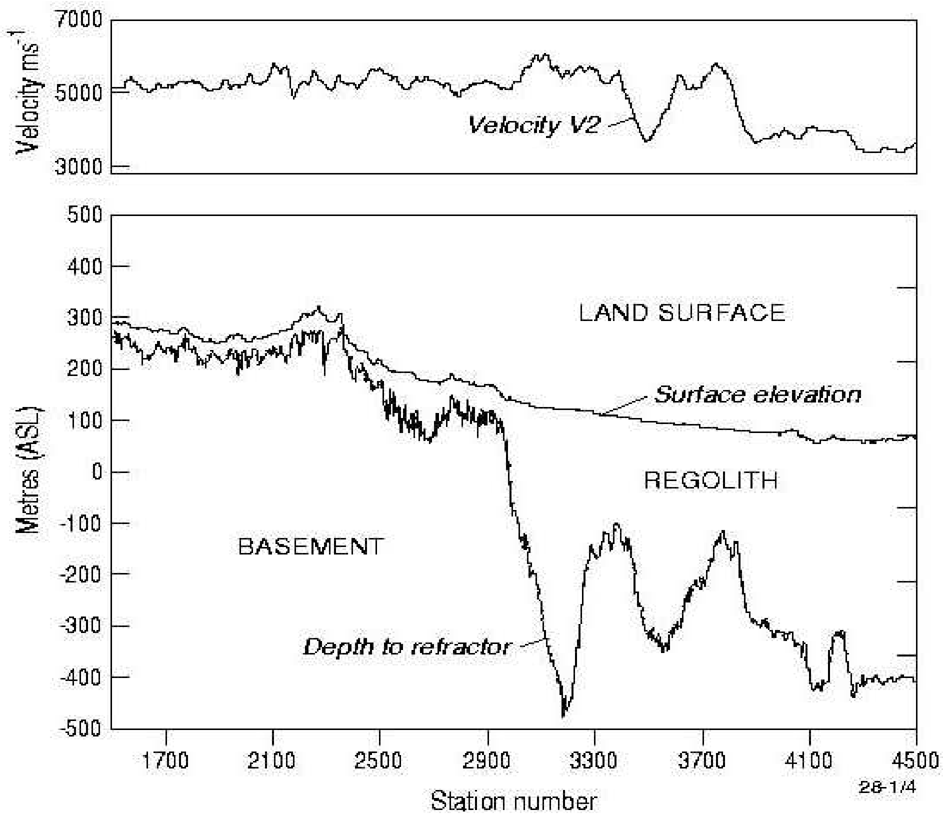

Figure 5. Results of a seismic inversion (Courtesy of GA). The lower part shows the thickness of regolith along a 120 km profile from the Broken Hill Block into the Murray Basin. The section has a considerable vertical exaggeration.

The style of presentation depends on the purpose for which the study was undertaken. In this example, the top of the basement is highlighted. The lower part of the figure shows the regolith thickening because of the transported material of the Murray Basin, to the right of Station 2900. The graph at the top shows the velocity at which seismic energy travels in basement. It shows velocities near 5000 ms^{-1}

on the left, typical of Proterozoic metamorphic rocks in the region. East of about station 2900, the velocities are higher, and are probably basement consisting of rocks of the Delamerian Orogenic Belt. A sharp drop in velocities between stations 3300 and 3700 corresponds to a small ?Mesozoic basin underlying the Murray Basin, and the steady drop to the right of station 3900 correlates with the Palaeozoic Darling Basin.

Just as this example was used to extract information on the nature of the basement, seismic refraction profiling could be used at higher resolution to determine variations in the seismic velocities within the regolith, and thereby map indirectly variations in regolith density.

4. OPPORTUNITIES AND LIMITATIONS

Seismic techniques are extremely flexible, and in their reflection or refraction forms can usually be adapted to image most kinds of features in and below the regolith. The cross section in Figure 4 is an example; palaeochannels would be another.

Seismic techniques are limited in their resolution by the wavelengths of seismic signals that are generated at the surface, passed through the regolith and returned to the surface. This is usually determined by the regolith, because although seismic sources are available to generate most frequencies, the regolith can severely attenuate high frequency signals, which have the greatest resolving power. It is not possible to calculate a nomogram that demonstrates the resolution of seismic techniques for a particular region without specific details of the depths of the surface to be imaged and the velocities at which seismic waves travel in the region. Any field survey should therefore undertake a range of tests at the beginning to ascertain the seismic frequencies generated, the frequencies recorded by the geophones, and therefore whether the survey will provide suitable resolution.

5. COSTS

The cost of seismic imaging varies considerably, depending on the nature and size of the target, the amount of resolution required, and the logistics of working in the area concerned. Data processing costs should also be considered. A seismic survey crew can have as few as 3-4 people or as many as 30. People who wish to use seismic imaging techniques should clearly define their target in geological terms, and then seek professional guidance from a qualified geophysicist.

6. MORE INFORMATION

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