PACIFIC

Passive seismic techniques for environmentally friendly and cost efficient mineral exploration

D1.4 – Development of a physical parameter model for seismic wave simulations

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Description
A realistic physical properties model for seismic wave simulations.

Dissemination Level		
PU	Public	X
CO	Confidential, only for members of the consortium (including the Commission Services)	

Table of content

Table of figures

Executive Summary

Seismic sources such as dynamite, air guns and vibroseis generate good P-wave energy for reflection seismic studies. However, they can have negative environmental impacts and are expensive, both of which have motivated the development of passive seismic methods. Passive methods have been successful for surface wave recovery but extracting body waves has been a challenge. The purpose of this task and deliverable (D1.4) is to develop physical parameter models that characterise the geo-structure and seismic reflectivity of the Marathon site. The aim is to then use synthetic seismic signals generated in these models to develop and test the best processing procedures for body wave recovery and body wave imagery. The information obtained through numerical simulations will be applied during the processing of field seismic data from the Marathon site. In this report, we introduce some schematic models and show initial seismic simulation results. Models will be updated as new physical parameter data become available through 2019.

1 Introduction

The primary aim of this deliverable is to gain a better understanding of the constraints on body wave recovery, using passive seismic data obtained at the Marathon site. The approach is to build representative physical parameter models of the site and to use numerical simulations of the seismic wavefield in those models. Numerical seismic forward modelling is of great importance for seismic exploration as it allows us to determine the expected wavefield for a given physical model. While the basic concept is clear, there are many different methods available for the implementation of the forward modelling method. These include, among others: the finite difference method, finite element method, pseudo spectral method and the boundary element method. The finite difference method has a long history and is used extensively for the modelling of seismic wave propagation (e.g. Aki and Larner, 1970, Virieux, 1986). It is a powerful well established technique and is the approach taken in this work.

Velocity and density are two important input parameters for forward modelling. We constructed several synthetic velocity-density models using available structural and physical parameters estimates for the Marathon site. For the **first model** we added the physical parameters to a geological cross section that extends from the Marathon intrusion into adjacent country rocks. The **second model** was created by adding a thin low velocity 'weathered' layer to the first model. The reason for adding the shallow low velocity layer is to better understand the effects of very shallow structure on body wave recovery from passive seismic data. The **third model** is along the strike of the main geological structures and includes interpolated data from lithology logs.

2 Simulating a synthetic seismic signal

Since passive signals are dominated mostly by surface waves, to simulate them we need to derive and solve the elastic wave equation. Here we use a full wavefield staggered finite difference method to simulate synthetic seismic signals. For more details about the use of the staggered grid finite difference method for solving the elasto-dynamic equations, see Virieux (1986).

2.1 Essential Physical Parameters needed for seismic simulations

To solve elasto-dynamic equations using finite differences, it is essential to have a velocity model, a density model and source wavelet properties.

A velocity model representing the geological situation is needed in order to conduct forward modelling. Since there exists a provisional laboratory-derived rock velocities database for the Marathon site we can use the lithology logs from distributed boreholes in combination with this velocity information to derive a laterally smooth velocity model. We derive models in both the geological strike direction (fig 7) and perpendicular to strike (fig2a).

2.1.1 First model: a synthetic petrophysical model, perpendicular to strike

Our synthetic models are based on a published report and a paper on the Marathon site (EcoMertix Inc 2012; Good et al 2015). Fig 1 shows the location of the "4400 north" cross-section that cuts the Two Duck Lake intrusion (from Good et al., 2015). The models presented in fig 2 are schematic but capture the main structural components perpendicular to strike, seen at the site. The petrophysical information is approximated using laboratory rock velocity data. The velocity model (fig 2) includes the four main rock types and is 1000m long and 500m deep. The model velocities will likely be updated in February 2019 after we receive additional velocity information following the analysis of cores from the Marathon site.

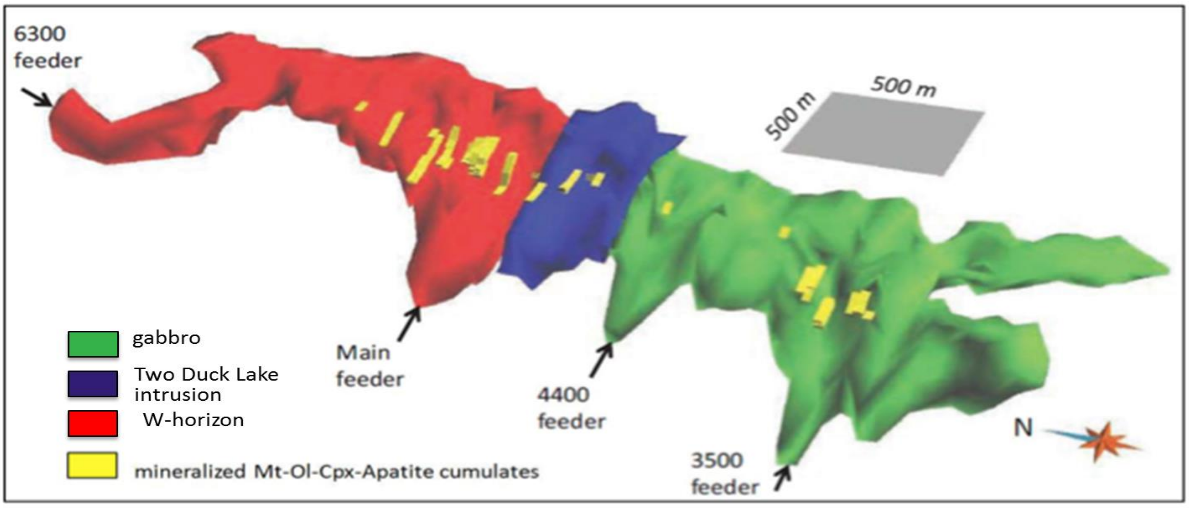
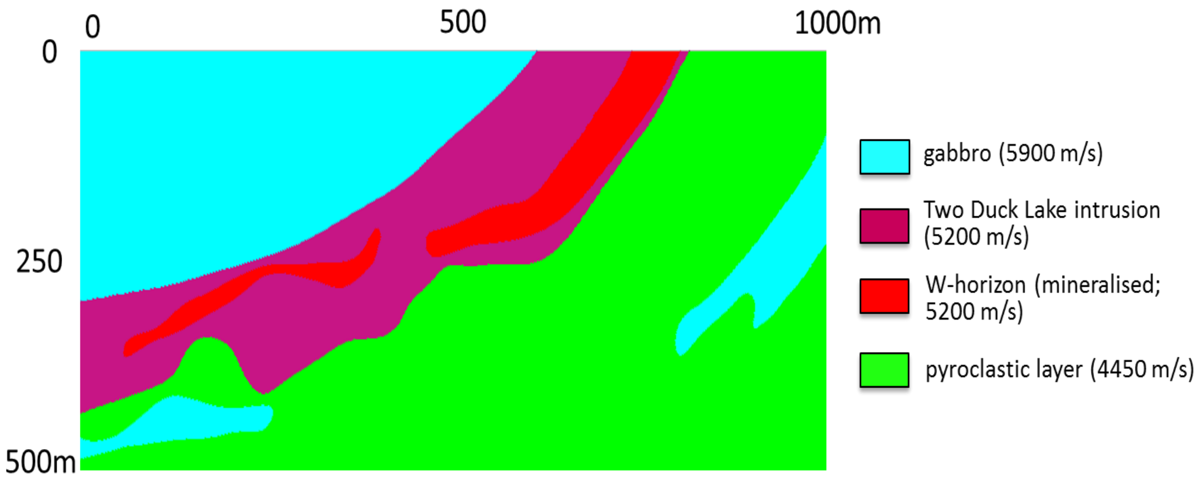


Figure 1: 3D isometric view of the Two Duck Lake intrusion (Good et al., 2015). Figure 2 is a cross section through the feeder 4400.

Whilst the model in fig2a captures the main geological features, we introduced a variant of that model in fig2b, for seismological purposes. Both models (figs 2a and 2b) are identical except for the addition of a low-velocity 'weathered' layer (LVL) in fig 2b. As both passive seismic sources and receivers are directly at the surface in the real case scenario at Marathon, there is the potential for the development of guided waves if low velocity shallow structures are encountered. Hence, we include them in the simulations to assess their possible effect on our ability to recover body waves from passive field data at the site.

a)



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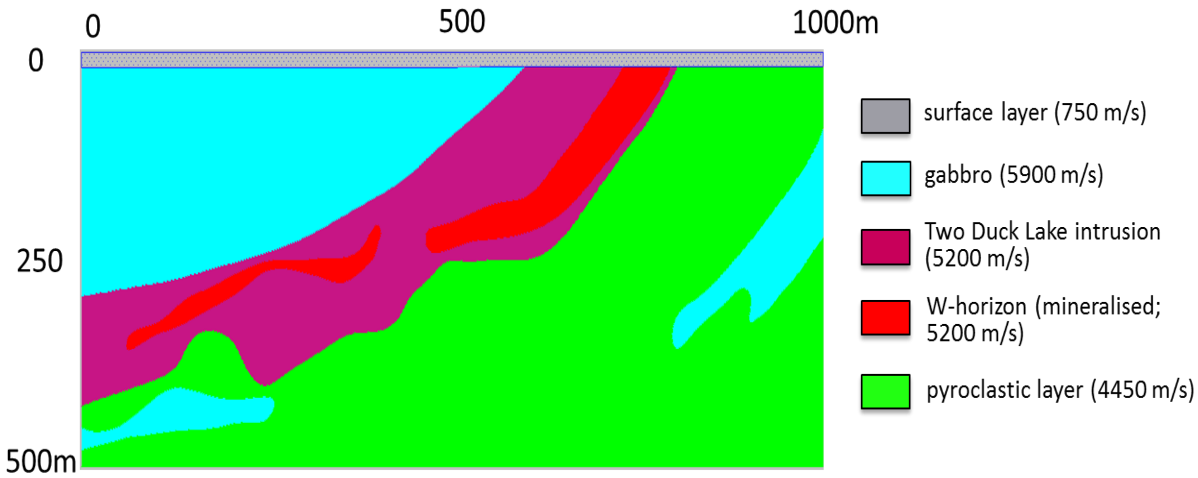

Figure 2: a) Synthetic model without a weathered layer at the surface; b) Synthetic model with a weathered layer. Both models are identical except for the weathered layer at the top of the model. In general, our models include four rock types: Gabbro – blue (Vp=5900(m/s), Two Duck intrusion – purple (Vp=5200(m/s), mineralized zones – red (Vp=6000(m/s) and pyroclastic layer – green (Vp=4550(m/s). Weathered layer - dotted grey in Fig 2b (Vp=750(m/s)).

2.1.2 Second model: Propagation of elastic waves through the synthetic perpendicular to strike models

As a first step, we show examples of active seismic wave propagation through the down-dip models (Figs 2a and 2b) - although ultimately, we will simulate passive seismic signals in these models. Active shot records due to elastic wave propagation through the models have been created with the source located in the middle of the profile (Figs. 3 & 4) to determine the seismic characteristics of the medium. The source is a Ricker wavelet with a 10Hz central frequency. Clear body wave reflections can be seen in fig 3 associated with the lithological boundaries in fig 2a. This is encouraging as it means that there is sufficient contrast in acoustic impedance at the geological boundaries in the model to be seen seismically. Adding a thin low velocity surface layer (LVL) to the model (Fig 2b) causes wave reverberation and strong ground-roll (surface waves). This combination of reverberations and ground-roll masks deeper body wave reflections of interest. This demonstrates that a knowledge of near surface velocity structure may be important. We may seek to determine very near surface velocity structure from field measurements at Marathon through 'hammer' seismic experiments.

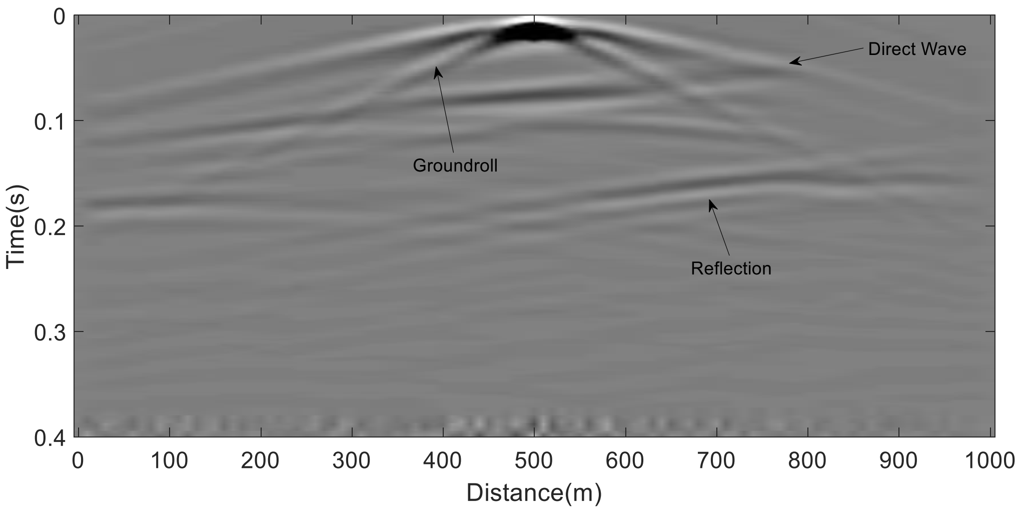

Figure 3 : Shot record due to elastic wave propagation through the model in Fig 2a. Clear body wave reflections can be seen

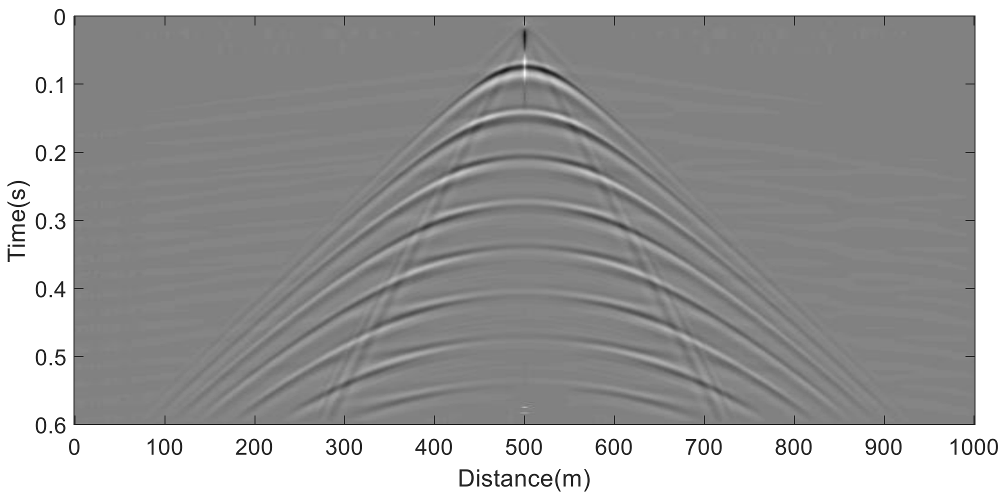

Figure 4: Shot record due to elastic wave propagation through the model in Fig 2b. Reverberations and surface waves mask deeper body waves of interest.

2.1.3 Third model: a synthetic model created from the interpolation of 11 drilled core lithology logs along strike

To build the **third model** along strike we use information from the longitudinal section $A-A^{'}$ (Fig 5) which cuts the main zone of the Marathon deposit. The section includes lithological information from 11 boreholes that run along strike (Fig 6). The velocity model (Fig 7) is constructed from interpolated lithology logs from the boreholes married to laboratory wave velocities calculated in rock samples from a single borehole.

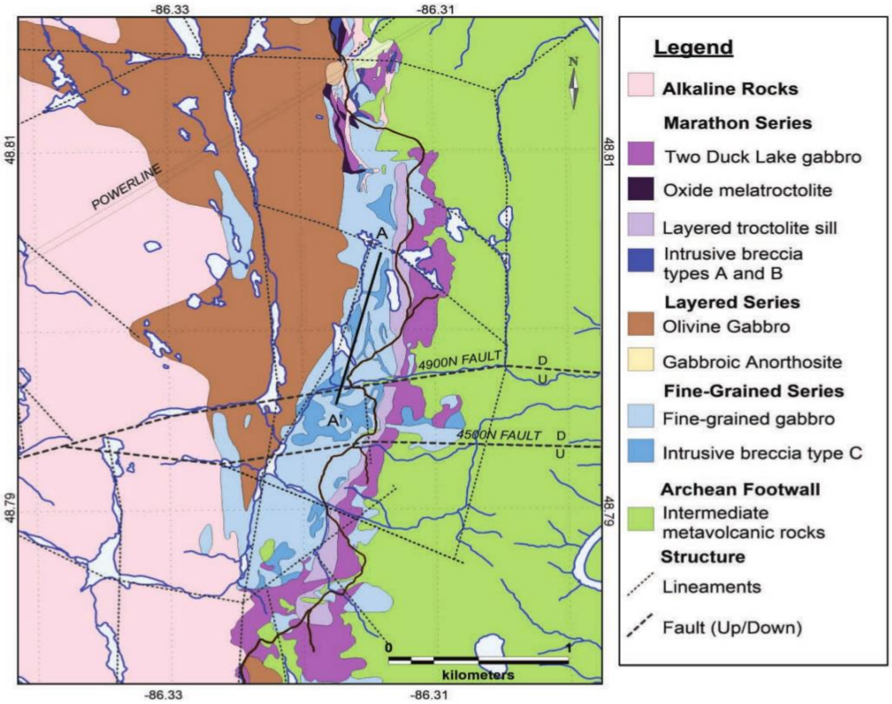

Figure 5: The longitudinal section that cuts the main zone of the Marathon deposit (from Good et al., 2015)

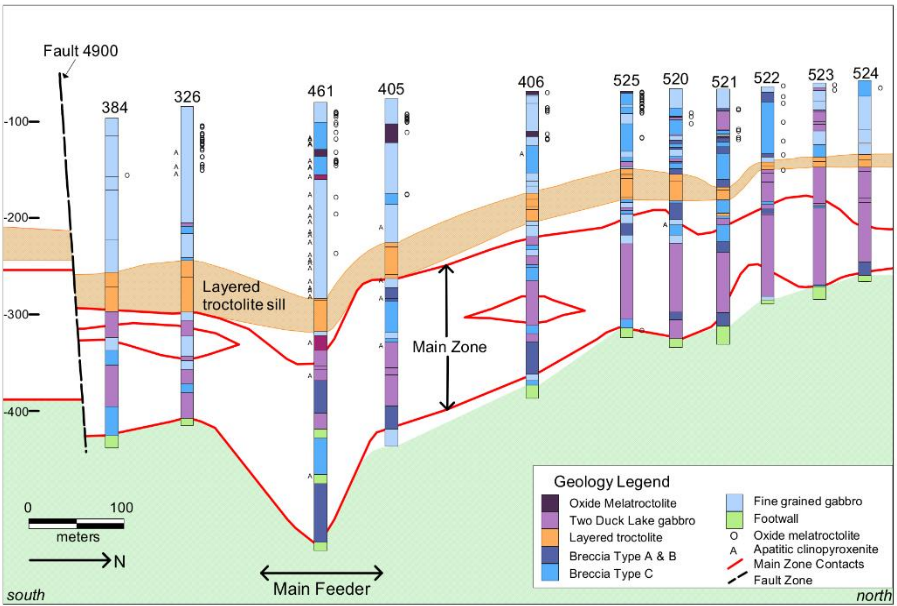

Figure 6: Cross section through the longitudinal section that includes 11 boreholes (from Good et al., 2015)

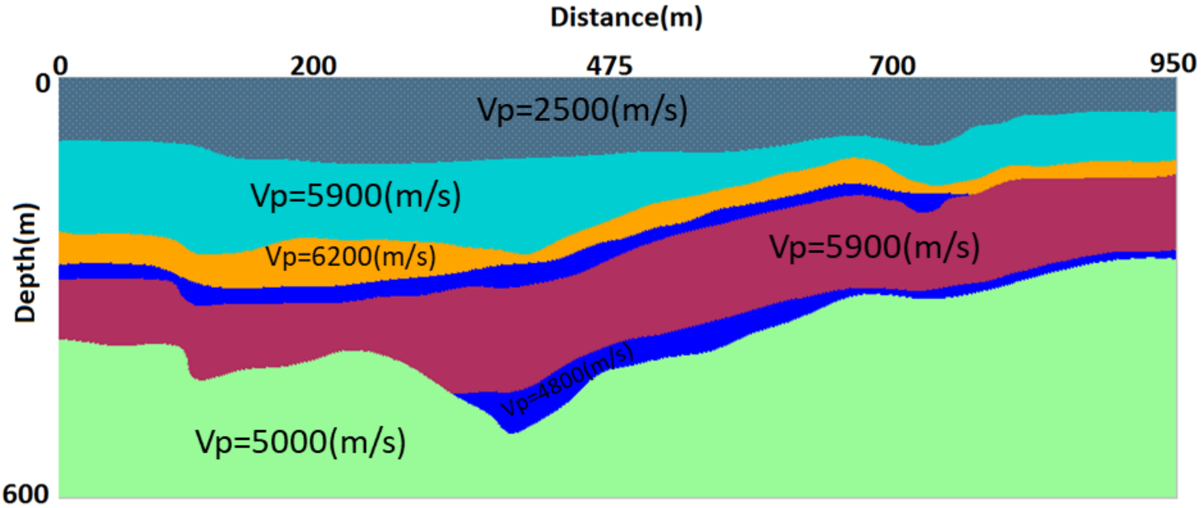

Figure 7: The geological cross section obtained by interpolation of lithology logs at 11 boreholes: Footwall or Pyroclastic layer (green colour) with Vp=5000(m/s), Breccia layer (dark blue colour) with Vp=4800(m/s), Two Duck lake Gabbro (maroon colour) with Vp=5900(m/s), Breccia layer (dark blue colour) with Vp=4800(m/s), Layered Troctolite sill (orange colour) with Vp=6200(m/s), fine grain Gabbro (dark Turquoise colour) with Vp=5900(m/s) and altered shallow layer (grey colour) with Vp=2500(m/s).

Figure 8 shows a shot record due to propagation of elastic waves through the third model (Fig 7). As in Fig 3 we can see that acoustic impedance contrasts are sufficient to show good reflections at lithological interfaces represented at the Marathon site.

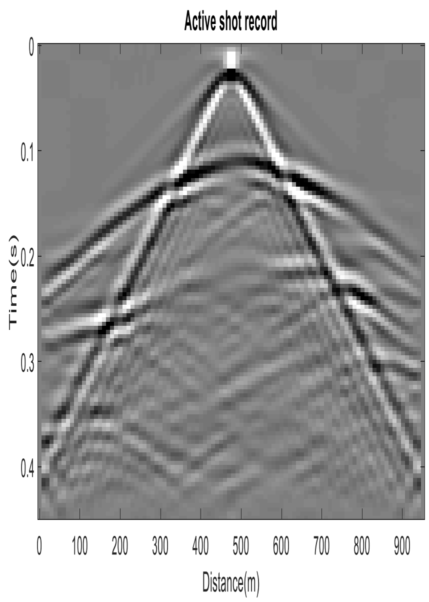

Figure 8: An active shot record due to propagation of elastic waves through the third (along strike) model (Fig 7). The shot is in the lateral centre of the model, at the surface.

3 Conclusion

In PACIFIC we are developing new methodologies for the body wave extraction and imaging by using passive seismic techniques in a mining environment. Numerical simulations of seismic wave propagation play an important role in both the testing of these methodologies and in our understanding of wave propagation at specific sites. This requires a reliable velocity-density model for the site under investigation. For Marathon we build synthetic velocity-density models using previously published information from surface geology mapping and borehole lithology samples. Rock velocities are obtained from preliminary laboratory experiments on rock samples. We show some full seismic wavefield shot records in order to assess the seismic response of those initial models. More laboratory derived petrological information will be incorporated to develop more accurate models, when it becomes available, likely in February 2019.

Seismic shot records from two perpendicular directions show clear reflections from the lithological boundaries in the model. This is a very encouraging finding as it indicates that the lithological boundaries should be seen on seismic sections. Shot records from models (Figs 2a and 2b) show that our ability to recover body waves at depth will be influenced by near surface velocity structure. As passive seismic noise sources are likely to be at the surface at Marathon, this accentuates the need for a good understanding of the near surface velocities at the site.

The aim of this work is to simulate passive seismic signals in realistic velocity-density models in order to test the processing sequences and the performance of body wave extraction methodologies. The initial models developed herein will be used to that end.

4 Bibliography

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