Introduction

As the demand for minerals are increasing, old mining areas are being revisited with the hope of further extracting resources. Some of these areas have been abandoned more than a century ago and as a result the exact location and the extent of the old mined out regions are unknown. Accurate knowledge of the mined out areas are important in order to plan infrastructure and future development. In other circurmstances, mine operators are intersted to detect remnant areas amongst older workings that have been hydrofilled so that these remnant areas can be mined. Seismic imaging methods have the potential to delineate these mined out areas from intact rock, but have traditionally been too expensive to be used routinetly. In this paper, we attempt to use a new passive method (called ambient noise surface wave tomography) to image old workings of an old Australian gold mine. Since the method does not require the use of a costly active source, it can be implemented at a fraction of the cost of a conventional active survey. The goal of the project was to see if the ambient seismic noise method could be used to identify old mine workings, mineral deposits, faults or shears and determine the thickness of the slag-heap.

Method

Cross-correlating ambient seismic noise can be used to construct the seismic Green's function between sensors pairs, effectively turning one of the sensors into a virtual source (Shapiro and Campillo, 2004; Sabra et al., 2005b; Campillo, 2006; Stehly et al., 2008). Over the past decade, Green's functions, constructed by cross-correlating ambient seismic noise, have been predominantly used to image the upper crustal structure of the earth (Sabra et al., 2005a; Shapiro et al., 2005).

This method has also been used to image smaller areas with dense arrays. For example Lin et al [2013] and Nakata et al [2015] imaged the crust below Long Beach, California with high resolution to well below 1 km. This method shows great promise for inexpensive small-scale surveys, and thus was proposed for this project.

Experimental setup

During the September 2016, 100 seismic sensor nodes were installed above an old mine and seismogram data was recorded for 2 days. The nodes were positioned partly above the old mine workings, partly above the slag-heap and partly above in situ ground. The nodes were buried 5 - 10 cm below the ground to shield them from the wind. The location of the nodes relative to the suspected location of the old mine workings are shown in Figure 1. The locations of the old mine workings were estimated from hand drawings. Mining stopped at this location around 100 years ago.

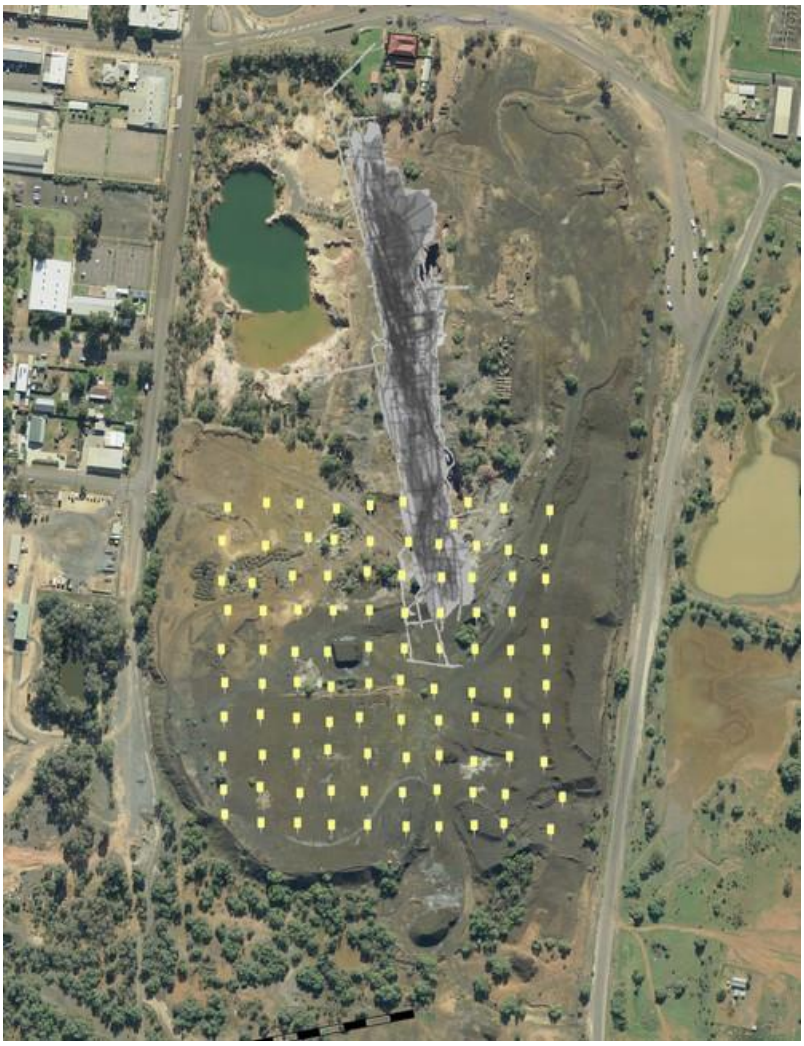

Figure 1: Locations of the seismic sensors relative to the suspected locations of the old workings.

Tomographic results

Figure 2 shows all the tomographic maps assigned to a related depth. Even though a complete depth inversion is not performed here, we estimated the depths for the tomographic results at 1/3 of the associated wavelength. The high velocities (>1 km/s) are likely related to the bedrock. The low velocities on the North East could be a marker for the old mine workings and the low velocities on the south west are very likely related to the slag heap.

The meshes show that the tomographic images are able to delineate the slag-heap and old working successfully. The results indicate that the slag-heap is deeper on the South Western side of the survey area (up to 25 m) compared to the South Eastern area. As expected, the tomographic maps also show an increase in seismic velocity with depth. However, in the Northern side of the survey area there is a strong low velocity anomaly in the vicinity of the expected old workings below 25 meters beneath the surface. The low velocity anomalies are present (but not as distinct) at shallower depths, indicating that some subsidence could have occurred.

We can create isosurfaces of the low velocity areas to try aid in interpreting the velocity anomalies. The isosurfaces for one low velocity zone are shown in Figure 4.

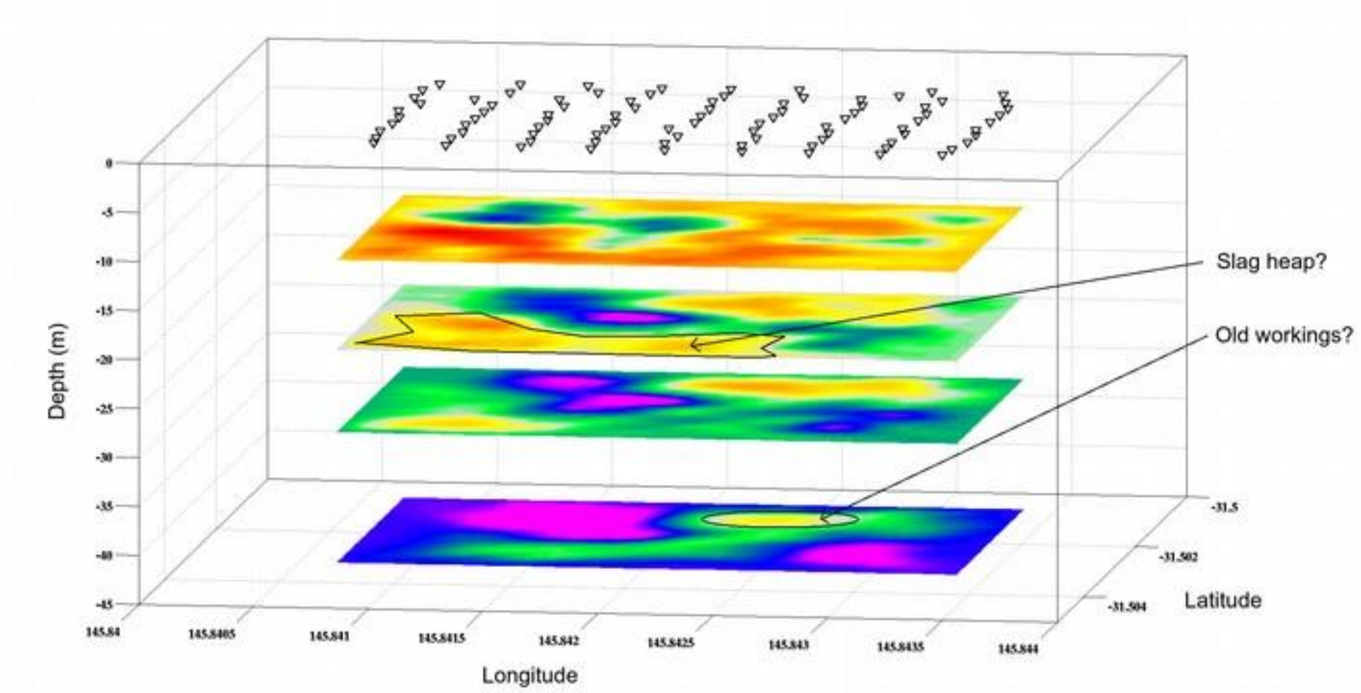

Figure 3: Tomographic maps represented in 3D. The vertical axis is depth in meters.

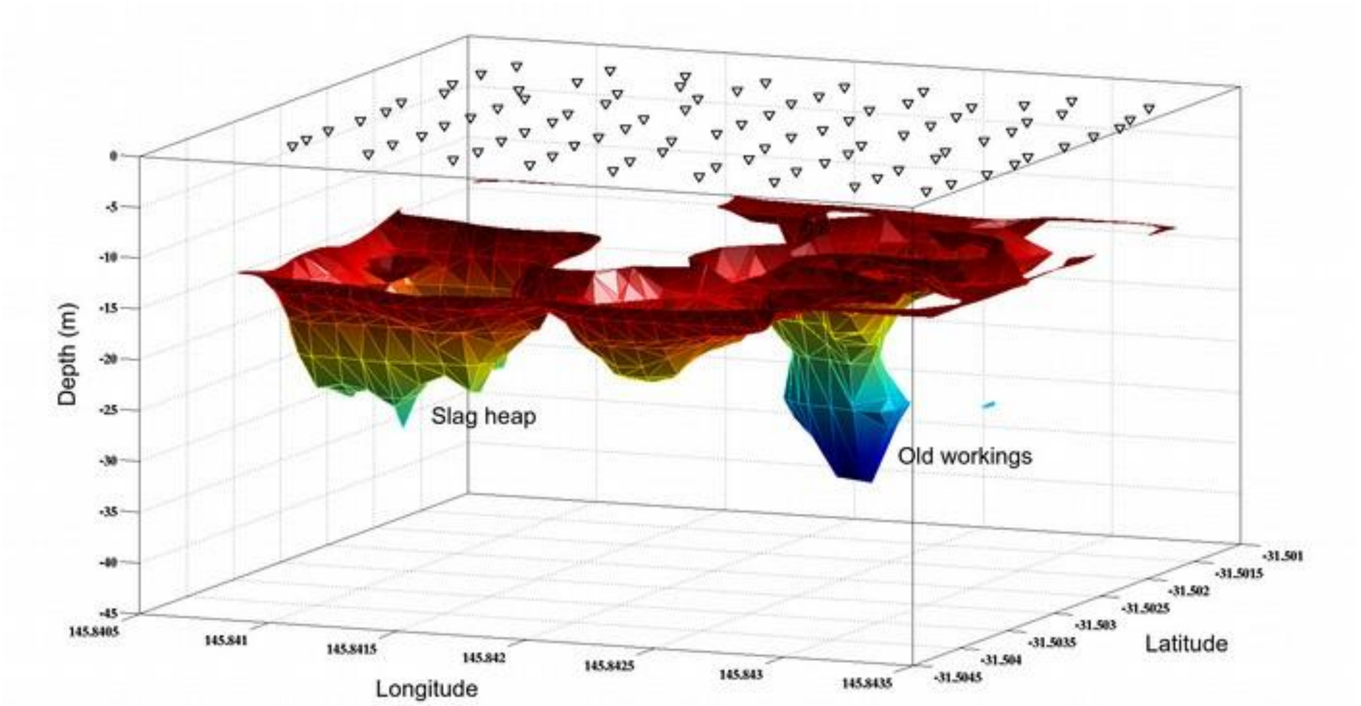

Figure 4: Isosurfaces of low velocity anomalies. The anomaly in the South West is interpreted as being the slag heap, while the deeper anomaly in the North is interpreted as the old workings.

Conclusions

The results from the project are encouraging and suggest that the method is well suited towards imaging old mine workings and mined out areas. The tomographic images appear to clearly delineate the slag heap and old workings, while some other intriguing velocity anomalies can be seen.

Even though the outcomes of this trial project are positive, the total amount of data recorded (recording duration) was not enough for all the correlation functions to converge. This prevented us from conducting a full 3D shear wave velocity depth inversion. In retrospect, it seems that about one week of data would have been needed to perform the full 3D inversion.

A large survey is currently being planned which will illuminate the subsurface to much greater depths and greater resolution, which could aid in the identification of faults and shear – which we did not have the opportunity to investigate in the pilot project.

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