Application for NSGG Postgraduate Fieldwork Fund 2021/2022

Name in Full: [redacted]
Affiliation/University: [redacted]
PhD title: Imaging Earth's Interior with Seismic Gradiometry, Interferometry and Machine Learning
Period of study (start date, proposed end date): [redacted]
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Broader Research Context & Field Survey Motivation:

The part of the Earth's shallow subsurface where life and atmosphere interact with the subsurface directly, the so-called critical zone, is of particular research interest as it provides most resources for modern life and is heavily impacted by climate change. To date, dynamic geological processes in this critical zone are not well understood. The proposed project aims to further develop seismic gradiometry, an emerging non-invasive imaging method, that constructs detailed 3D images of the shallow subsurface in near real-time. It allows us to directly recover key physical parameters that are related to dynamic subsurface processes. This novel insight can be leveraged in various environmental geophysics applications such as geothermal prospect exploration, natural hazard monitoring, aquifer monitoring, rockpore capacity assessment for CO2 storage etc. **Our focus lies on the development of gradiometry as a new and efficient method for geothermal heat mapping.** In particular, the proposed field survey is targeting the characterization of abandoned, flooded coal mine sites as they are of increasing interest for mine water heating schemes throughout Scotland ([1], [2]).

Seismic wavefield gradiometry allows us to estimate phase velocity maps over a dense receiver grid through discretely calculating the temporal and spatial gradients of a measured seismic wavefield at the surface [3]. The method relies on only 15 min of ambient seismic noise recordings to produce a useable dataset [4]. From these phase velocity maps, 3D images of the subsurface can be produced via surface-wave inversion in a matter of seconds by training a neural network with synthetic datasets [4]. **This work flow has shown promise as a rapid seismic acquisition scheme in the field and thus motivates further testing and validation in a well-defined geological setting.**

To date, gradiometry uses a simplified wave equation approximation as its basis: this impacts the accuracy of the velocity information and key parameters such as density and attenuation cannot be estimated. I am working on tapping the full potential of the gradiometry methodology by using more sophisticated wave equations that represent the subsurface more accurately. This theoretical extension would aid seismic interpretation substantially as density and attenuation provide independent information about subsurface heterogeneity. **These new gradiometry implementations have been tested synthetically but remain to be demonstrated in the field**.

The proposed field work is laid out to (1) validate the seismic gradiometry work flow in an area with pre-existing well mapped geological information, (2) test new theoretical advancements based on more sophisticated wave equations with field observations, and (3) develop the methodology for geothermal heat mapping.
To meet these goals, the survey is planned such as to investigate the following aspects: the vertical resolution of the imaged lithology and detectability of the water table, as well as the trade-off between recorded frequency content, lateral resolution and receiver spacing. This field survey would output a representative key data set that could help to further understand and develop seismic gradiometry into a fast seismic acquisition, monitoring and interpretation tool.

Field Survey Setting & Description:

A total of 98 hydrocarbon exploration and appraisal wells were drilled within the Midland Valley of Scotland between 1919 and 2008 [5]. Depending on drilled depth, data quality and information density, borehole data can yield invaluable geological control information to validate our gradiometry methodology together with maps of surface deposits from geological field investigations (Fig. 1).

A preliminary field location is chosen near Roslin, Midlothian as it offers several readily available, high quality borehole data sets and exhibits a well-constrained varying surface geology (Fig. 1, Site 1) along with a nearby abandoned coal mine (Fig. 1, Site 2). This site lies in close proximity to Edinburgh and is easily accessible by car. The proposed field work planning is in line with COVID-19 health and safety guidelines, and would be able to go ahead under current, or even stricter, regulations.

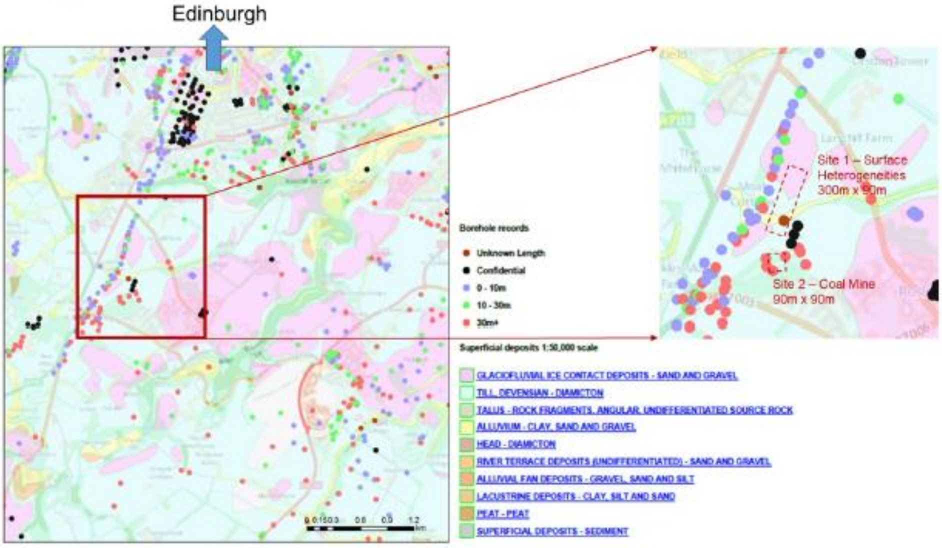

Fig. 1 – Proposed field survey location near Roslin, Midlothian.

Map gives information on borehole location and geology of surface deposits. [6]

In terms of field equipment, 4 geodes and 96 single-component receivers are available at the [redacted] as well as 17 three-component sensors.

In order to efficiently map the areas of interest, the sensors will be deployed in a roll-along fashion. A rectangular grid formation of 9x10 single-component receivers will be placed above the larger field site 1 for a recording period of 15 min (best trade-off length as defined by [4]), and subsequently displaced until the whole area of interest (~300x50 m^2) is covered. Similarly, this will be done over field site 2 (~90x90 m^2) with a 4x4 receiver grid of the 3-component sensors with a central receiver station as control point. Exact coordinates of receiver stations need to be known for spatial gradient calculations and are recorded by an inherent GPS system. Two separate data sets will be recorded: for a setup with 5m and 10m receiver spacing respectively to investigate the impact onto feature detectability and data quality. The choice of receiver spacing might need adjustment after a first evaluation of the available ambient noise frequencies. An active shot survey with a controlled frequency source should be conducted in order to cross-check the velocity results obtained from ambient seismic noise only.

Itemized budget (in £):

~£469 To cover pay for 2 field assistants at Demonstrator/Ue05 rate (£14.66/h) for 2 days

~£250 Vehicle hire to transport the equipment

~£60 Fuel for the vehicle

Minimum support needed (in £): ~£779

Details of other funding sources available to the project:

The 'Research Training Support Grant' of the [redacted] will provide support on equipment and other incidental costs.