NERC Centre for Doctoral Training in Oil & Gas - Ph.D. Scholarship

High-resolution imaging of structures beneath active mud volcanoes: reconstructing fluids emission and assessing future hazards

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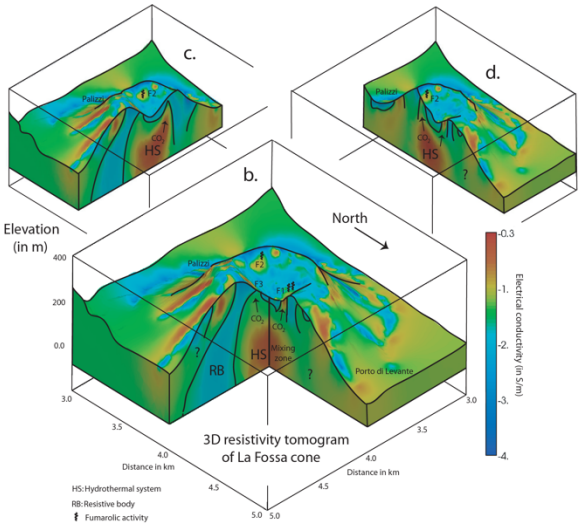
Project outline

Mud volcanoes are impressive geological features generated by eruption of argillaceous material, water and gas rising from deep sedimentary layers. The study of onshore mud volcanoes contributed with fundamental information to understand deep fluids migration mechanisms, also giving insights on the different origin of connate waters and hydrocarbons, and on their relations with associated petroleum systems (e.g. Oppo et al., 2013, 2014; Oppo and Capozzi, 2016).

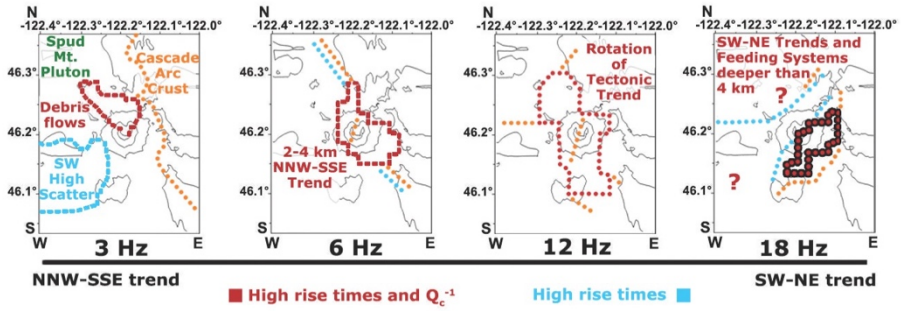
A clear understanding of processes related with mud volcanoes is fundamental to entirely evaluate their impact on petroleum exploration and exploitation, specifically as potential hazards. There have been large efforts to understand mud volcanoes internal structure by observing outcrop analogues and, more importantly, by using subsurface datasets that consent to characterize their deep features across the overburden. Geophysical techniques until now applied to the study of mud volcanoes provided 1) relatively shallow (less than 60m), high-resolution imagines of the subsurface and 2) deep seismic sections, which are missing of necessary resolution to accurately represent the mud volcano internal structures. Both these techniques are inadequate to clearly visualize the first hundreds of meters below the surface. On the basis of previous works on igneous and sedimentary volcanoes (Revil, 2002; Revil et al., 2010; De Siena et al., 2014, 2016), this project will address the problem of improving joint applications of Electrical Resistivity Tomography and seismological techniques to obtain high-resolution images of structures at intermediate depths beneath the Nirano Mud Volcanoes Field (NMVF), Italy. In medium-sized mud volcanoes, as NMVF, the most important structures governing medium-short term fluids emission activity are likely located within the first hundred meters below the surface.

We propose to perform a 3D geoelectrical survey to measure self-potential, DC resistivity and induced polarization using a ca. 900m-long-cable array. This setup allows to reach a maximum investigation depth of ca. 180m, which is more than triple respect to previous similar investigations at NMVF that touched ca. 50m (e.g. Lupi et al., 2016). Various surveys in different periods will provide data for time-lapse resistive tomography, in order to observe subtle changes in fluids temperature and gas saturation inside the volcano reservoirs and conduits. A new 4D inversion technique, which uses a regularizer operating over time (Karaoulis et al., 2011), allows filtering uncorrelated noise in data over time. This workflow enhances the resistivity contrasts between fluid conduits and host sediments, highlighting subtle changes in gas saturation inside the volcano reservoirs and conduits, and allowing a better imaging of preferential flow paths in subsurface. The joint acquisition and processing of data from active and passive seismic surveys will expand the investigation depth of time-lapse resistive tomography down to 500m. Chaotic seismic phases and intensities provide the deepest insight into the problem of imaging fluid propagation and highly heterogeneous structures. The seismic dataset will be analysed to (1)



3D resistivity tomogram on Vulcano Island, Aeolian archipelago, Italy (Revil et al., 2010)

reconstruct noise directionality, symptomatic of volcano dynamics at different depths, and (2) to exploit seismic noise and coda for imaging deep volcanic structures via absorption/scattering tomography and interferometry. This project represents an ideal "break-test" for these techniques given the challenging environment.



Sketch of features mapped underneath Mt. St. Helens volcano (USA) thanks to absorption seismology, and imaged in different frequency bands (De Siena et al., 2016)

In the final stage of the project, 4D joint inversion of seismic and resistivity datasets (Karaoulis et al., 2012; Rittgers et al, 2016), will provide the best coupled imaging resolution and depth penetration so far available in mud volcanic settings. Since first year, the student will collect geophysical and geological data at NMVF, and will start to acquire competences in processing ERT and seismological data. During the following years, he will progressively gain expertise in 4D processing for both datasets, working at UK and France partner Institutions. At the end of the PhD, the student will also gain the ability to integrate geophysical and geological data during interpretation, a competence increasingly required by academia and industry. The proposed project comprises techniques ideally suited for gas and fluids detection in shallow subsurface of challenging environments, with feasible application also to environment-focused studies.

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