PSSeismic Geomechanics of Mud Volcanoes*

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Abstract

Hydrocarbon occurrences in many Cenozoic deltas is characterized by rapid accumulation of great thicknesses of unconsolidated sediments leading to overpressures, which in turn may be associated with mud volcanism. Mud volcanoes provide important windows into the subsurface structure, stratigraphy, and fluid plumbing system as they bring sediment-fluid mixtures to the sediment-water interface where they can be readily sampled. However, mud volcanoes and their related fluid flow phenomena also pose significant level of hazards, with particular reference to field development. These include deformation and fracturing of surrounding sediments, perturbation of local stresses causing shallow earthquakes, presence of methane gas and, other anomalous fluids and overpressures in and around mud volcano systems.

This study utilizes 2D seismic velocity data to examine mud volcano systems offshore Azerbaijan in order to characterize the mud volcano systems and to construct geomechanical models for the surrounding strata which are the focus for oil and gas developments. Although mud volcanoes and their habitats in these areas have been extensively studied and documented with particular respect to tectono-stratigraphical evolution, geochemical characterization and to a lesser extent from a geomechanical perspective, there are many open questions regarding their spatial and temporal evolution and mechanics of formation, which causes significant risk to development drilling. This study addresses these open questions and risks by integrating a detailed research into the geomechanical significance of mud volcanoes and associated geologic features through 2D seismic dataset.

Construction of 2D geomechanical models of mud volcanoes and their habitats are carried out by employing seismically derived properties. Furthermore quantitative model was validated through published data wherever available, to maintain an internally consistent model, with a view to optimize development drilling performance in areas affected by mud volcanism. The presentation will showcase how the findings help to reinforce the observation that a considerable body of geomechanical information can be recovered even from very limited seismic datasets, and that this can be useful both for defining targets for more comprehensive geomechanical studies and for providing guidance on drilling strategies.

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1. INTRODUCTION

Mud volcanoes are considered a significant hazard for field development, with particular reference to well planning and siting of the seabed facilities. To date substantial amount of multi-scale near-surface geological studies have been performed for risk mitigation in seabed facilities linked with mud volcano activity and associated shallow gas, slope failure and pockmarks. Nevertheless, the extent to which drilling in such zones has to be avoided because of mud volcano related risks remains unclear. The principal challenge posed by the complicated geology in and around mud volcanoes concerns the prediction of local pore pressures which has significant implications for development drilling (e.g. borehole blowouts and instability).

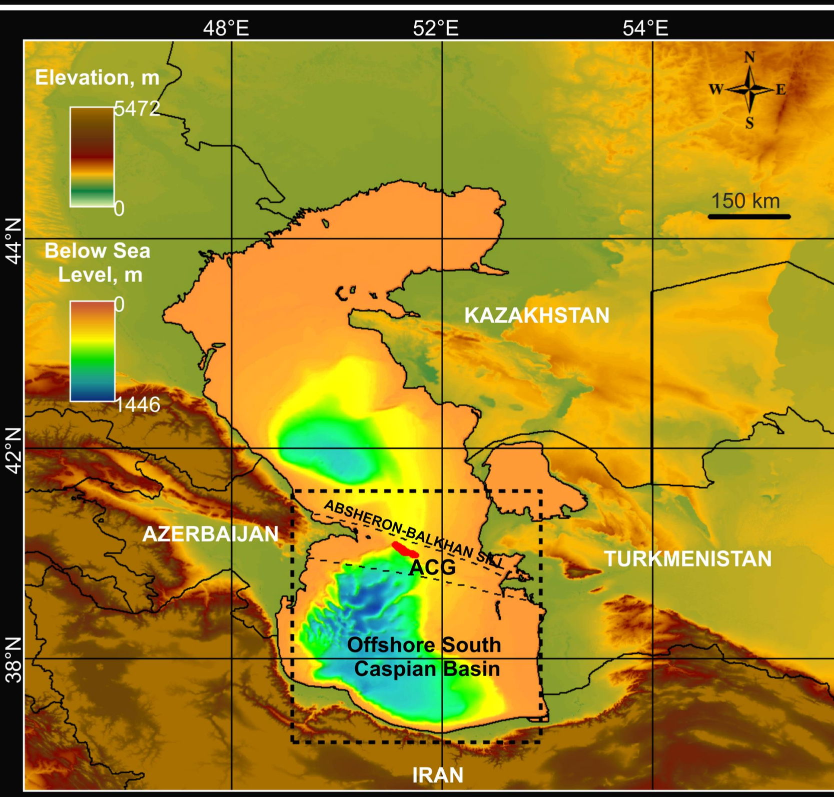


Figure 1: Map of the study area showing the location of the Azeri-Chirag-Guneshly (ACG) & Kurdashi-Araz-Deniz structures (KAD) in the South Caspian Basin

2. THIS STUDY

The study area is within the South Caspian Basin (SCB), a neo-tectonic Tertiary basin (Fig. 1). The principal objective of the study is to understand the extent of using P-wave velocity in geomechanical characterization of fluid flow structures. Particular attention is on assessing the implications of mud volcanoes on development drilling, and establishing the limitations of this approach. This study is comprised of the feasibility study and a 2D modelling. The former serves to identify whether the realistic values of mechanical properties and stresses can be obtained using public-domain data, while the latter aims to establish a workflow to understand the significance of mud volcanoes as geo-hazards for drilling.

3. DATASET

FEASIBILITY STUDY

Feasibility calculations of the mechanical properties and stresses around the mud volcano in Kurdashi-Araz-Deniz (KAD) structure (Fig. 2) was constructed using generalized Vp and Vs vs. depth curves for marine sediments (Fig. 3) coupled with compaction curve from the northwest SCB (Fig. 4).

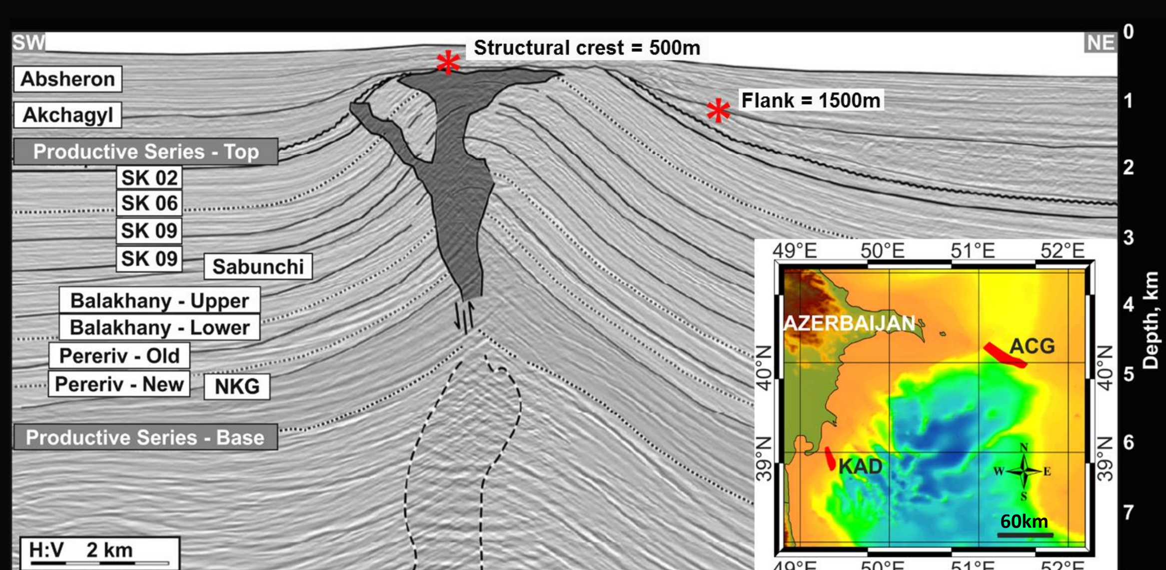


Figure 2: Vertical seismic section of an investigated mud volcano from the KAD structure (modified from Soto et al. 2011)

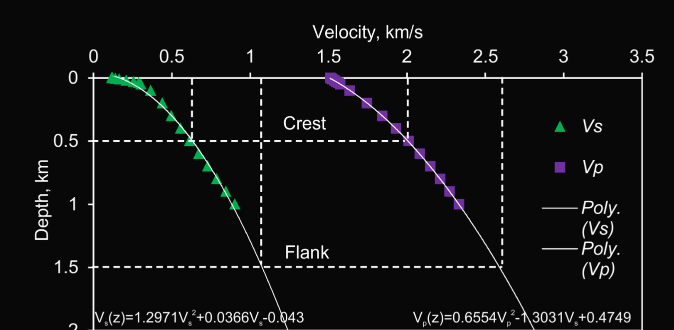


Figure 3: Generalized P- and S-wave velocity curves in marine sediments (modified from Hamilton 1979)

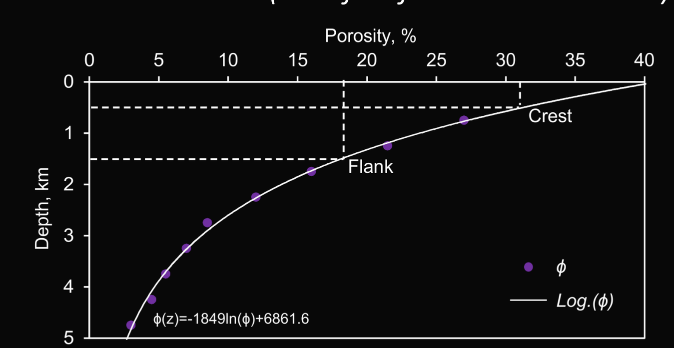


Figure 4: Shale compaction curve in NW SCB (modified from Bredehoeft et al. 1988)

2D MODEL

The mechanical properties and stresses on a 2D vertical section across an ACG mud volcano were modelled by digitizing the P-wave velocities presented on a Full Waveform Inversion (FWI) image published by Selwood et al. (2013). The seismic line was 10 km long by 5 km deep, in an unknown orientation across one of the mud volcanoes in the Azeri part of the ACG field. Contemporary stress regime was assessed by employing the bathymetry data available on a public domain (Fig. 6). In addition, a vertical pseudo-well (RM-1) located on the structural crest was incorporated into the 2D model to assess the modelled parameters in 1D along the well trajectory.

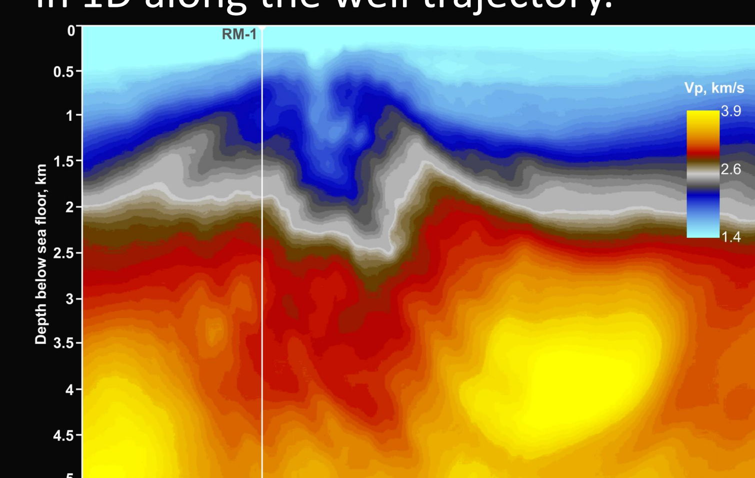


Figure 5: P-wave velocity data generated from the FWI image published by Selwood et al. (2013).

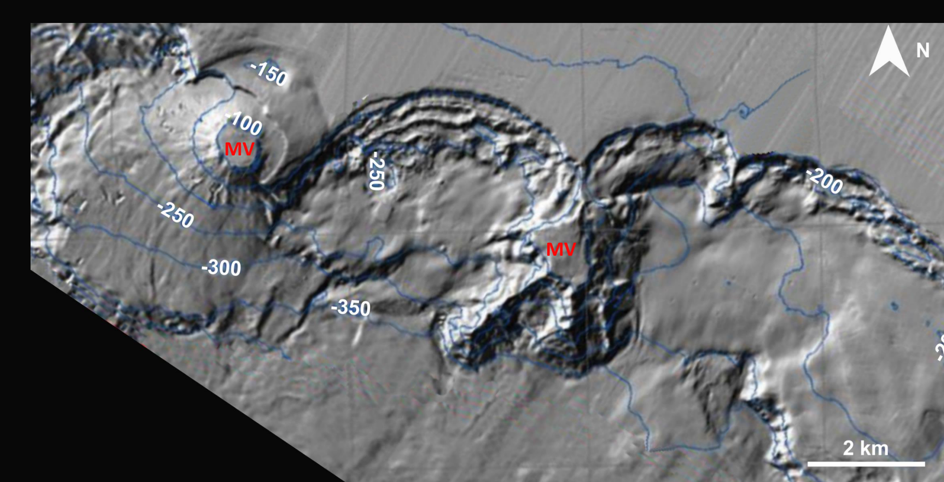


Figure 6: Publicly available bathymetry map showing the mud volcanoes from the Azeri field (modified after Hill et al. (2015))

4. RESULTS

P- & S-wave velocities from the feasibility study reveal good consistency with 2D model; hence elastic properties of both models are in agreement (Fig 7).

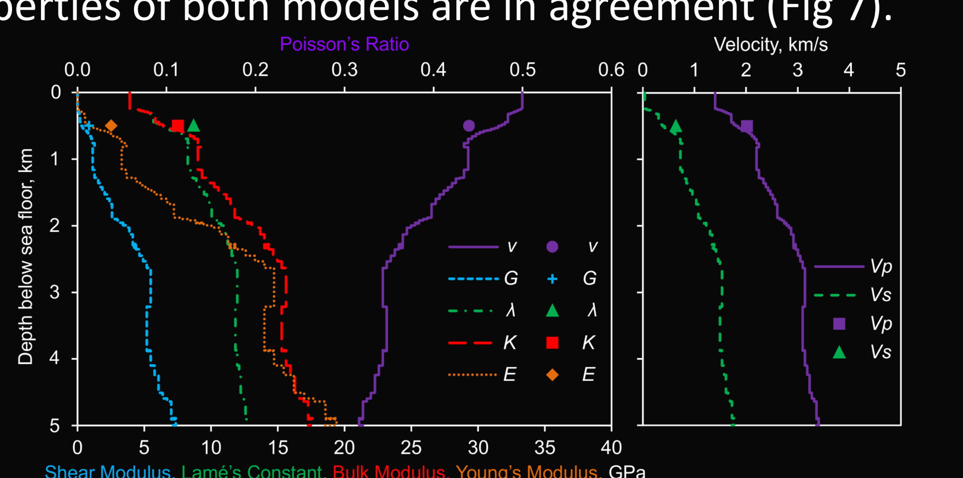


Figure 7: Elastic rock properties and velocities along the RM-1. Markers indicate the magnitudes of physical properties from feasibility calculations

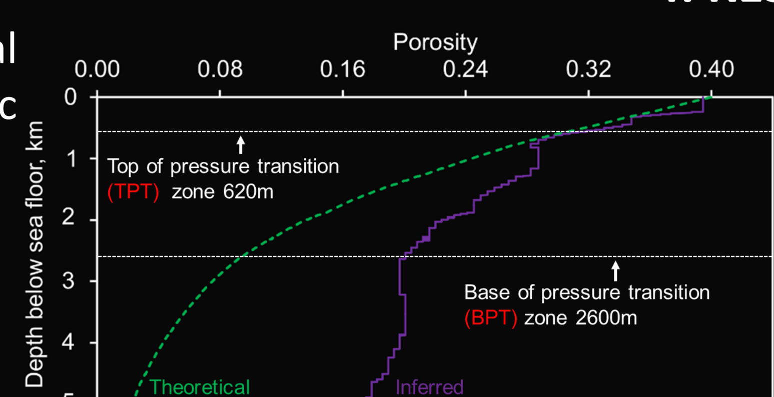


Figure 8: Detecting onset of overpressure in RM-1 by comparing the porosity & theoretical porosity trends

Magnitudes of porosity and theoretical porosity were computed to enable detecting the potential onset of overpressure (Fig 8).

The objective of computing elastic rock properties is constructing profiles of in-situ stresses, which allows estimating pore fluid and fracture pressures (Fig. 9 & 10).

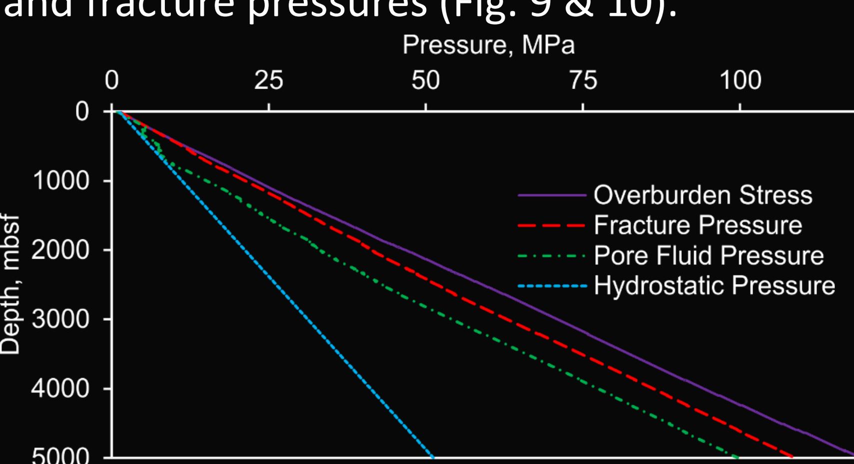


Figure 9: Profiles of stress and pressures along the RM-1 well

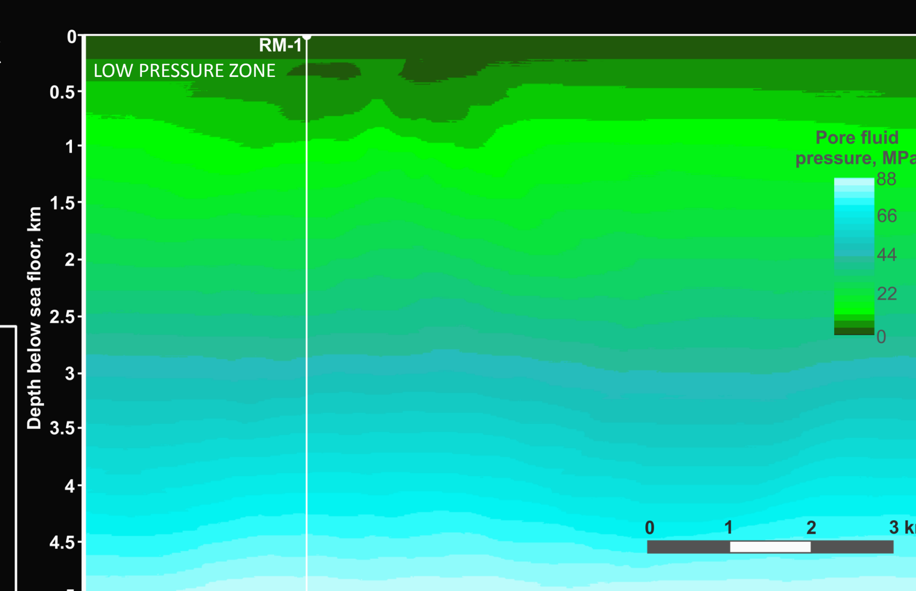


Figure 10: Vertical cross-section across the ACG showing the variation in pore fluid pressure. This highlights the relatively small pore fluid pressures in the shallow unconsolidated sediments

5. DISCUSSION

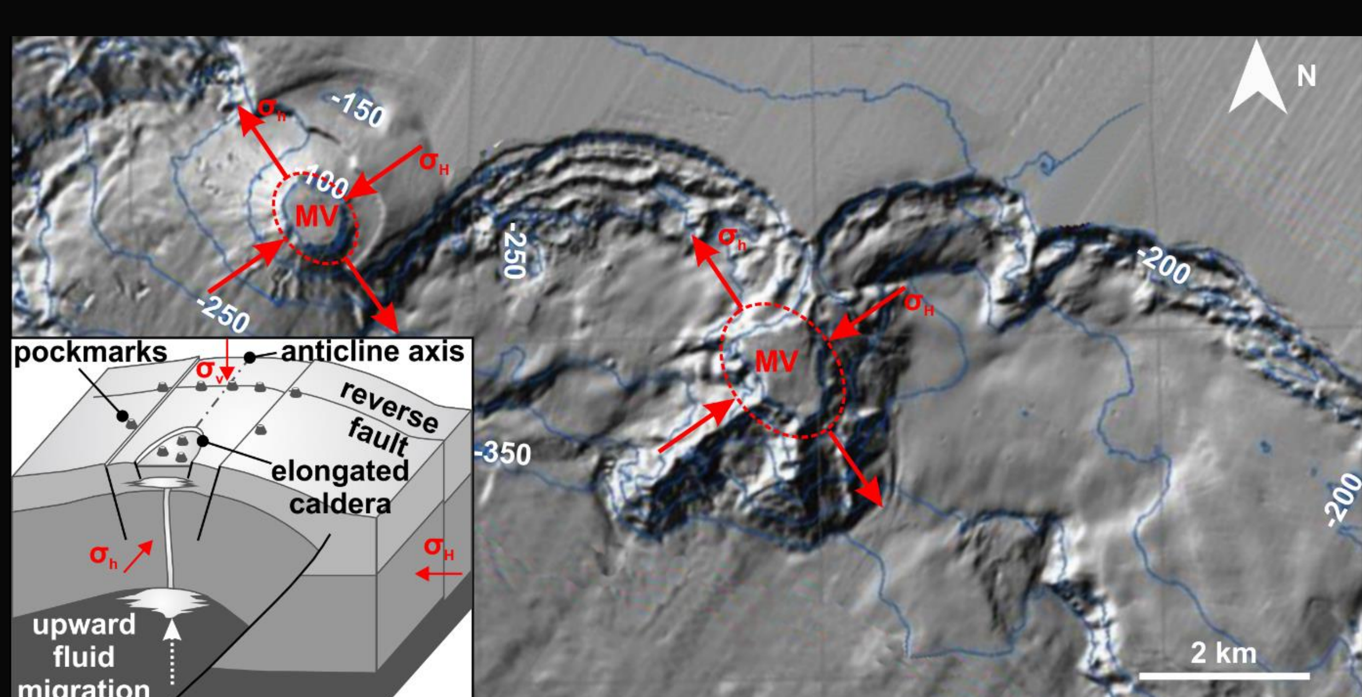


Figure 11: Elliptical mud volcano calderas on the ACG bathymetry map

Both mud volcano (MV) calderas are elliptical on the bathymetry map (Fig. 11), where the long caldera axis (σ_h) elongates NW-SE and parallels the orientation of Apsheron-Balkhan uplift zone, which is the northern structural bound of the SCB, while the short axis (σ_H) is trending NE-SW and aligns with the direction of compressive regional stress, which is the direction of South Caspian basement subduction beneath Absheron-Balkhan uplift. This observation is also consistent with borehole breakouts (Fig. 12) from World Stress Map database (Heidbach et al. 2008).

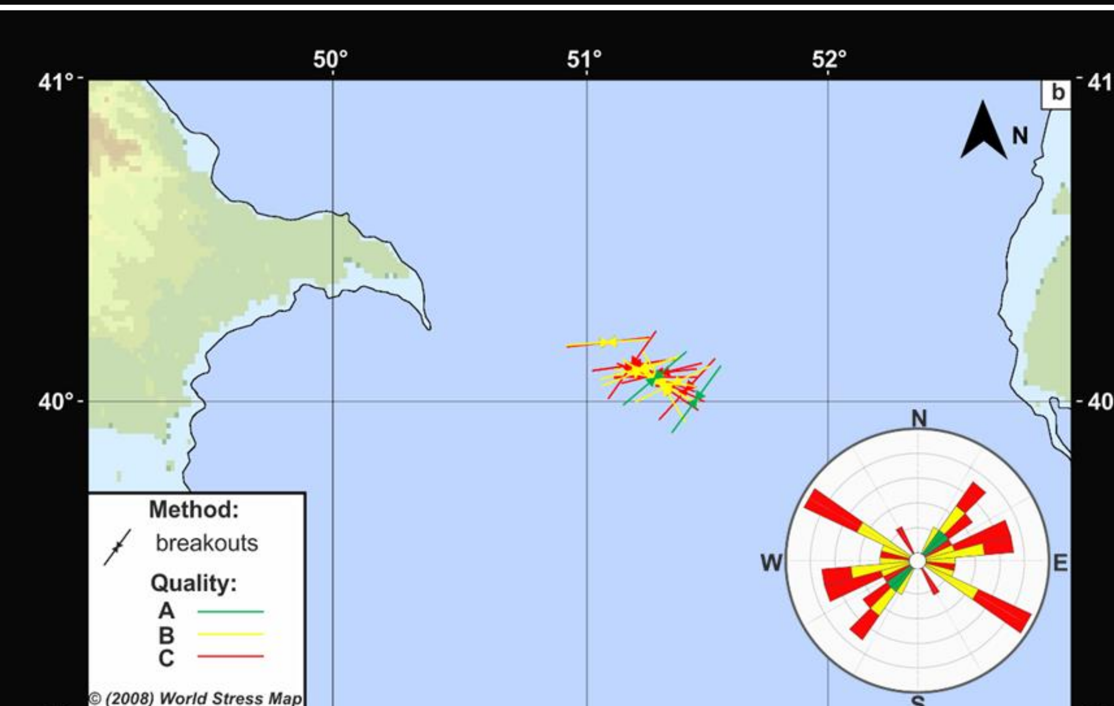
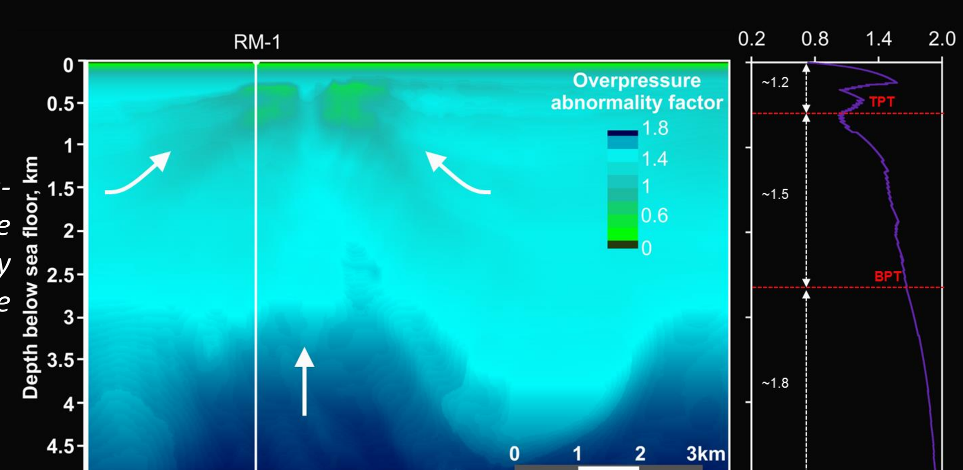


Figure 12: World Stress Map of the ACG overlain by rose diagram of borehole breakouts

Overpressure variation informs about the fluid flow direction near the mud volcano

Figure 13: Vertical cross-section showing the overpressure abnormality factor. Arrows indicate the fluid flow direction



Stress polygon was implemented to assess the permissible ranges of horizontal stresses (Fig. 14).

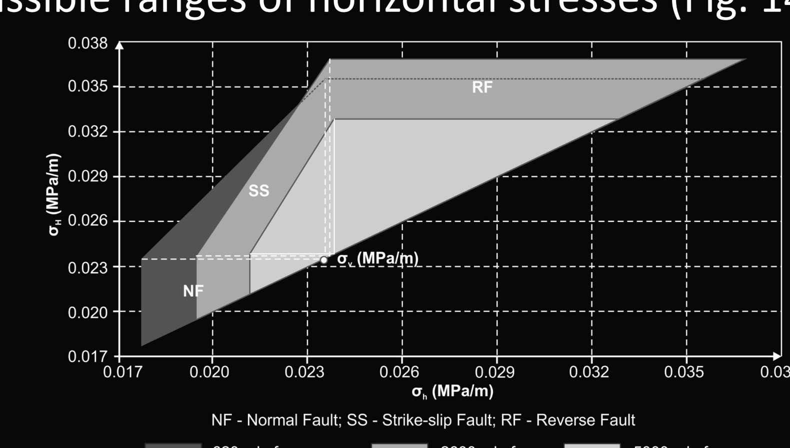
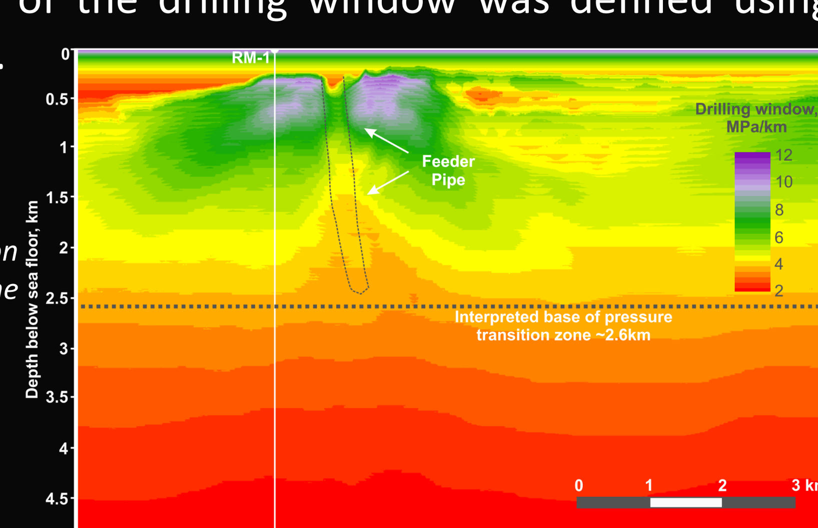


Figure 14: Stress polygons for three depth points

Preliminary estimates of the drilling window was defined using seismic velocities only.

Figure 15: Vertical cross-section across the ACG showing the width of the drilling window



6. CONCLUSIONS

Geomechanical characterization of a mud volcano using P-wave velocity reveals (a) that the values of the properties and stresses calculated have realistic values, (b) spatial variation of pore fluid pressures potentially highlight areas of fluid recharging, and (c) the first-pass indications of the width of the drilling window can be obtained from the P-wave velocity.

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