PS 4D Resistivity and UAV Acquisition and Monitoring of the Piparo Mud Volcano, Trinidad, West Indies*

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Abstract

The Piparo Mud Volcano is located within the quiet agricultural village of Piparo, approximately 20 km northeast of the southern city of San Fernando and within the south easterly verging Naparima Fold and Thrust Belt. The mud volcano is located along the southwest to northeast trending Naparima Thrust which has folded the Late Oligocene Nariva turbidite sandstones, with very steep to overturned geometries on the forelimb. The Piparo Mud Volcano erupted on February 22, 1997, spewing mud hundreds of feet into the air, with the mud flow covering an area of approximately 2.5 square kilometres. The eruption buried the main road and several houses, displacing 31 families. Based on the volcano's historical eruptions, it appears to have a cyclicity of 25-30 years. As such, the Piparo mud volcano is anticipated to erupt in the near future, putting households in vicinity at great risk.

Currently, there are no scientific bodies or established methodologies employed within Trinidad for mapping and monitoring mud volcanoes, despite their ever present threat to the general public. This study has tried and tested a cost effective methodology for monitoring the Piparo Mud Volcano utilizing geophysical resistivity surveys and Unmanned Aerial Vehicles (UAV). This methodology can be easily refitted and deployed for the monitoring of at least twenty-seven named mud volcanoes across the island. A dense grid of fourteen resistivity lines each measuring 165 m and 12 m apart with a 3 m electrode spacing was acquired in a northwest to southeast orientation across the mud volcano on July 17, 2018. The electrodes were laid out using a Wenner array configuration. Processing of this dense dataset yielded a pseudo 3D Inversion Earth Resistivity Model of the Piparo Mud Volcano, a first for Trinidad and Tobago. A complimentary UAV survey was conducted, acquiring a dense overlap of images, generating a high resolution orthomosaic and digital terrain model. The dense resistivity survey was repeated six months later in January 2019 employing the same acquisition design and parameters to yield a pseudo 4D Inversion Earth Resistivity Model. Structural changes between the surveys have been mapped and illuminate the possibility of tracking and monitoring pressure build up within the Piparo Mud Volcano over time.

4D Resistivity & UAV Acquisition & Monitoring of the Piparo Mud Volcano, TRINIDAD, W.I.

Introduction

The Piparo Mud Volcano is a located within the quiet agricultural village of Piparo, within the south easterly verging Naparima Fold and Thrust Belt (Fig.2). Based on the volcano's historical eruptions, it appears to have a cyclicity of 25-30 years. As such the Piparo mud volcano is anticipated to erupt in the near future, putting households in vicinity at great risk. Currently, there are no scientific bodies or established methodologies employed within Trinidad for mapping and monitoring mud volcanoes despite their ever present threat to the general public. This study has tried and tested a cost effective methodology for monitoring the Piparo Mud Volcano utilizing geophysical resistivity surveys and Unmanned Aerial Vehicles (UAV).

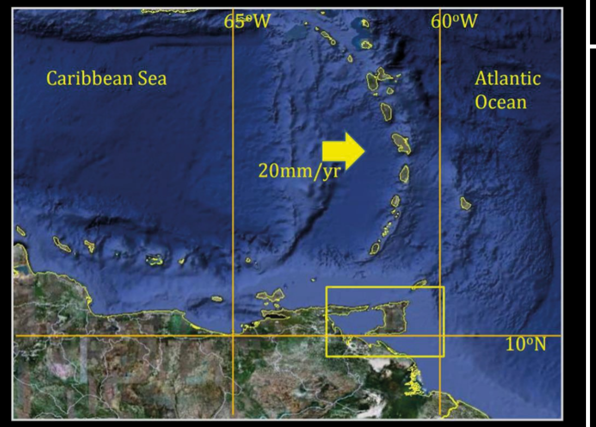

Fig.1: Relative Motion of Caribbean Plate (Weber,2001) Google, 2009

Local Structure

The Piparo Mud Volcano is located approximately 20km north east of the southern city of San Fernando and within the south easterly verging Naparima Fold and Thrust Belt. The Mud Volcano lies along the South West to North East trending Naparima Thrust, (Fig 2), which has folded the Late Oligocene Nariva turbidite sandstones, with very steep to overturned geometries on the forelimb (Fig.3).

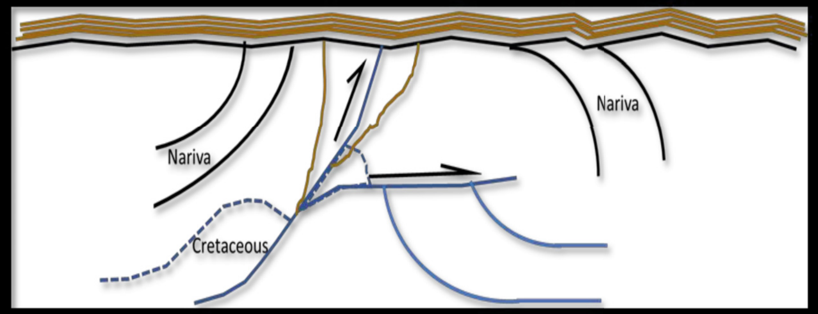

Fig.3: Structural Framework of the Piparo Mud Volcano

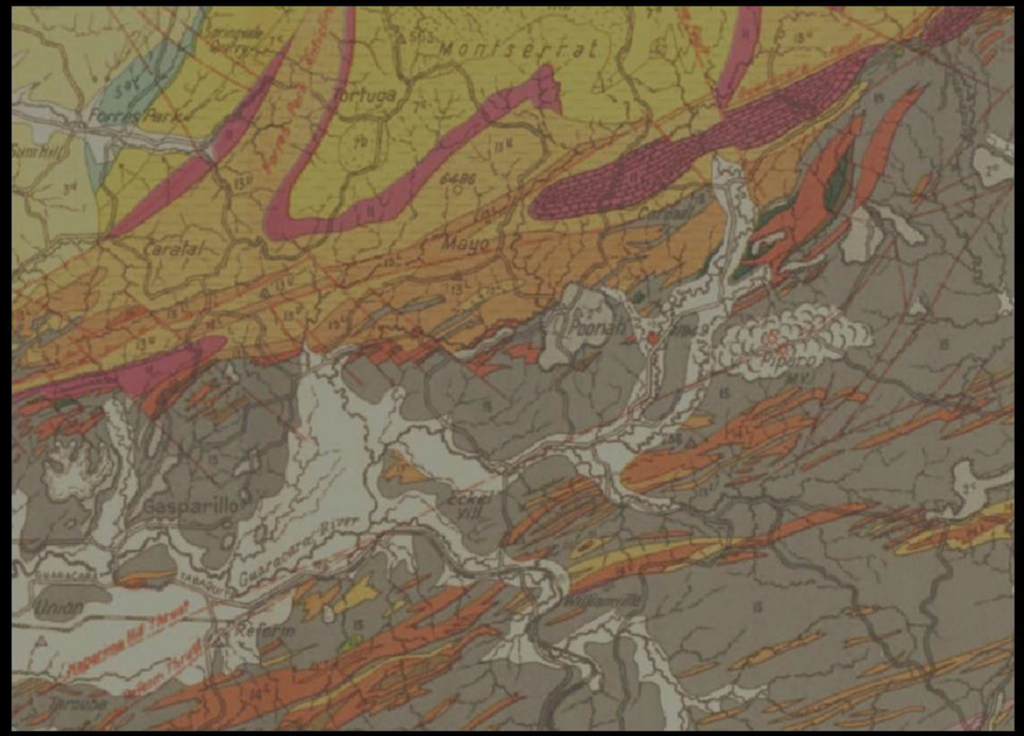
Fig.2: location of the Piparo Mud Volcano in the Central Range Fold and Thrust Belt

Stratigraphy

From what is known of the Piparo Mud Volcano, the Nariva Formation is expected to be present within the majority of the subsurface (Fig 4). It is described as a dark grey to brown, non-calcareous claystone with common sub-rounded quartz grains, as well as thin to thick sandstone units, which were interpreted as being Oligocene Deepwater clays and turbidites deposited within the middle to outer neritic zone, as well as the deposition of prodeltaic sediments. Near the site of the Mud Volcano, an outcrop found showing the presence of 'glossy' coals found was interpreted as being Anthracite, the highest quality form of coal. To support the formation of Anthracite, a large accumulation of organic matter and sediments must be present. To accommodate this, it suggests that the Nariva sandstones may have possibly been shallower than the Neritic zone to supply the large amounts of organic matter and sediments needed, which may suggest that in terms of the formation of the Greater Trinidad Area, the outcrop shown may possibly lie along the continental shelf, while the Mud Volcano may have been more offshore on the shelf edge.

Methodology

- PHASE 1: Resistivity Survey
-A resistivity survey was carried in the Area of Interest.
-The Wenner array was used.
-A maximum of 165m was measured off.
-The electrodes were positioned every 3m and hammered into the subsurface.
-The trailing cable was laid down and connected to the resistivity imaging software (Fig.5).
-The survey was run for 75 minutes.
-The process was repeated to acquire a total of 14 lines over the Area of Interest (Fig.6).
-An identical survey was carried out the following year.

- PHASE 2: UAV Survey
The drone was flown over the Area of Interest, taking pictures at various positions and elevations (Fig.7-8).

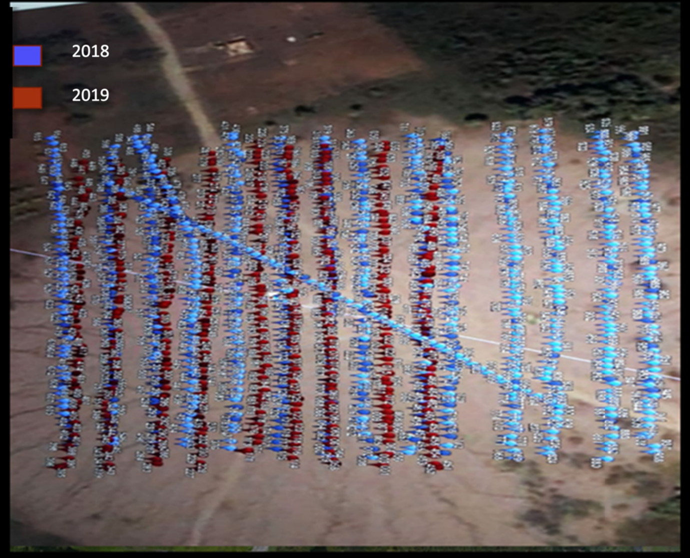

Fig.6: Orientation of Resistivity Lines acquired during the survey


Fig.5: Setup for the Resistivity Survey

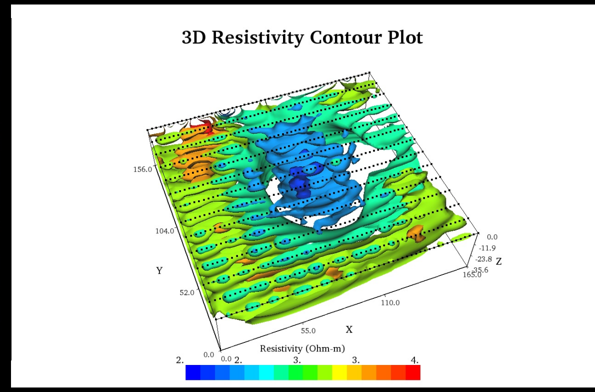

Fig.9: 3D Model of the Subsurface of the Mud Volcano

Data Processing

The resistivity data was processed using EarthImager 3D to render inverted 3D models of the surface of the mud volcano and the sandstone (Fig.9). The pictures obtained from each UAV survey were compiled to generate a full 3D model of the surface of the volcano (Fig.10).


Fig.7: Aerial View of the Piparo Mud Volcano


Fig.8: Aerial View of the Piparo Mud Volcano

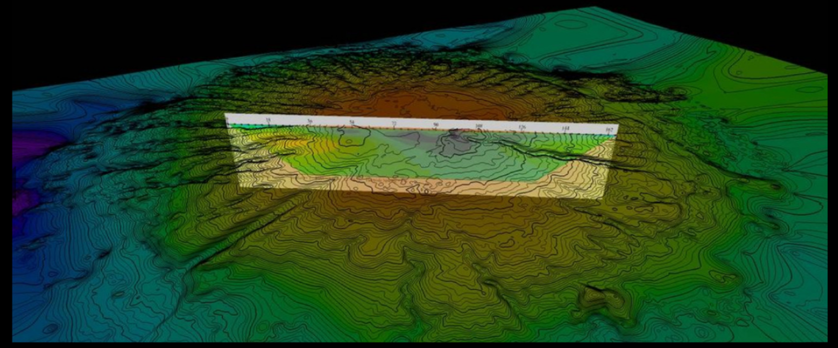
Fig.10: 3D Model of the Surface of the Mud Volcano

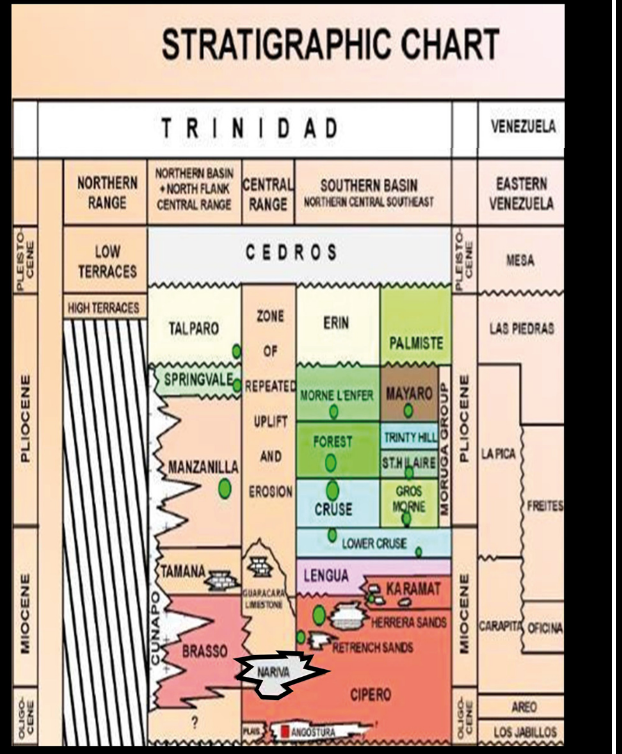

Fig.4: Partial Stratigraphic chart of Trinidad

EXECUTIVE SUMMARY

The pseudo 4D Inversion Earth Resistivity Models were successfully generated for the Resistivity surveys conducted in 2018 and in 2019. From the distinct in changes observed in both the surface and subsurface, it was concluded that the main vent of the Mud Volcano has become constricted and was shifted towards the East South East. From the comparison of the topographical maps, it was determined that between the 2018 UAV survey and the 2019 UAV survey, the main vent of the Mud Volcano had dropped by an average of 0.2 m, while the flanks of the Mud Volcano experienced a rise in height by an average of 0.7 m. This change observed over this period of time indicates that the methodology used is applicable in mapping and monitoring structural changes of the Mud Volcano, as it clearly showed evidence of uplift and deposition.

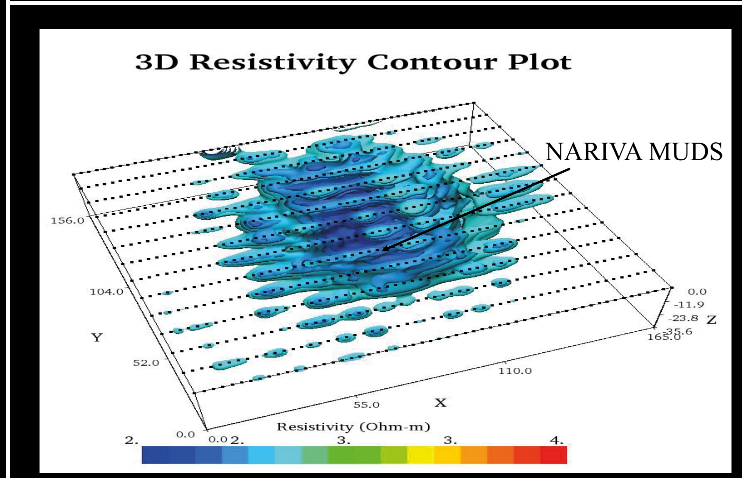

Fig.11: 3D Contour Plot showing Low Resistivity Zones

From the 2018 Resistivity survey, the Nariva Muds have been categorized by lower resistivity readings, from approximately 2.0 to 2.5 Ohm-m. in 2018, it can be seen that the muds are accumulated around and within a particular section of the Area of Interest. This subsurface area can be interpreted as the mud within chamber below the main vent.Comparing these results with that of the 2019 survey, the Nariva muds are seen to lie within a lower resistivity that 2018, being approximately 1.5 to 2.3 Ohm-m. Here, it can be observed that the mud appears to be more dispersed over the area of interest, which can be interpreted as being fresh mud brought up from the subsurface and then possibly redistributed over the surface.

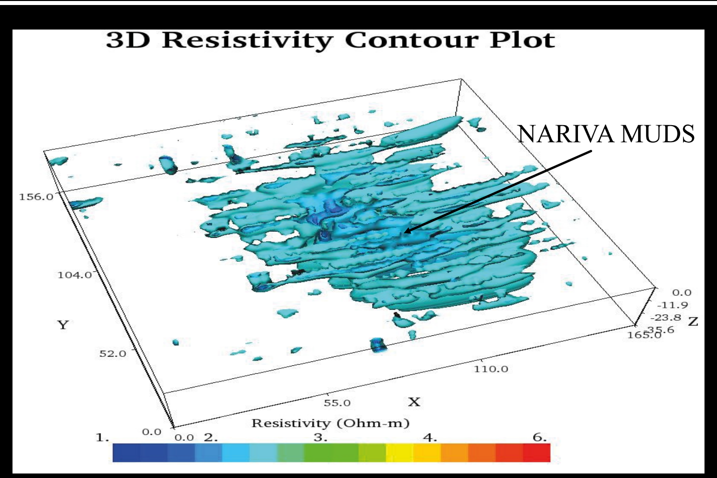

Fig.12: 3D Contour Plot showing Low Resistivity Zones

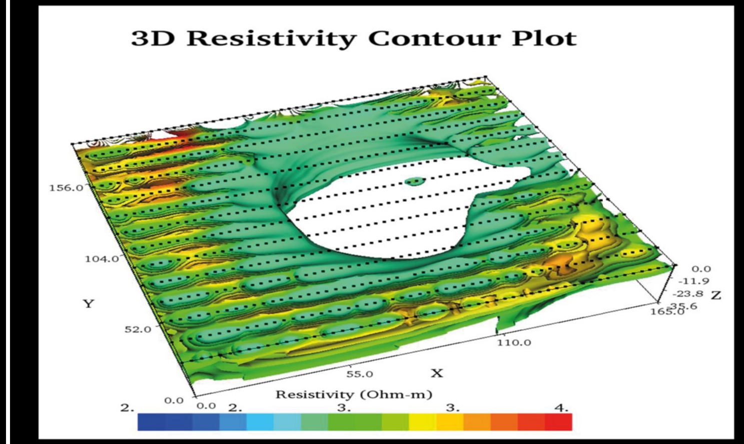

Fig.13: 3D Contour Plot showing Medium to High Resistivity Zones

The Nariva sandstones were seen to occupy a much higher range of resistivity values, from approximately 2.6 to 3.2 Ohm-m, which depict the chamber below the main vent of the Mud Volcano as a conical chamber with a curved channel rising up to the surface. However, the results in 2019 show a much higher resistivity range of 2.6 to 3.7 Ohm-m, with the main vent appearing constricted as it is shifted towards the East-South-East.

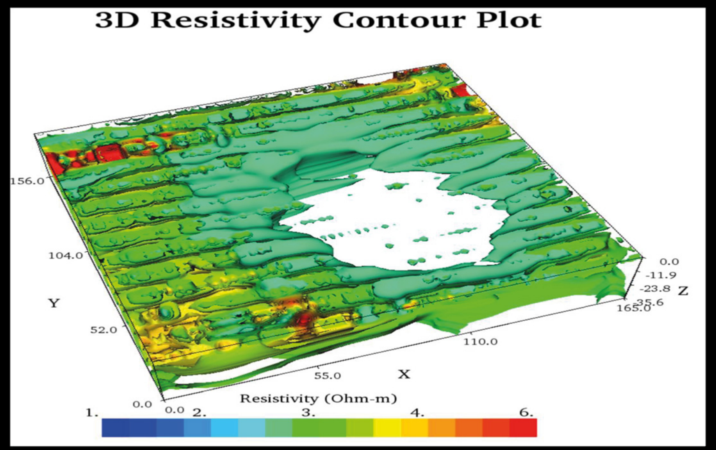

Fig.14: 3D Contour Plot showing Medium to High Resistivity Zones

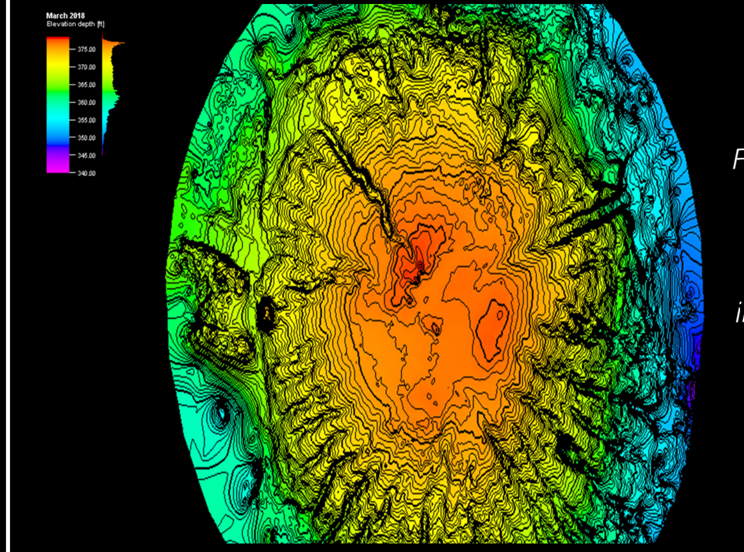
Fig.15: 3D Model of the Surface of the Mud Volcano (2018)

For the 2018 and 2019 UAV surveys, the brighter colours depicted represent a high topography, whereas the darker colours indicate a lower topography. Between the 2018 and 2019 surveys, some areas appear to show brighter colours, while some have darker colours than from the previous survey, indicating that the Mud Volcano experienced both increases and decreases in height across the surface.

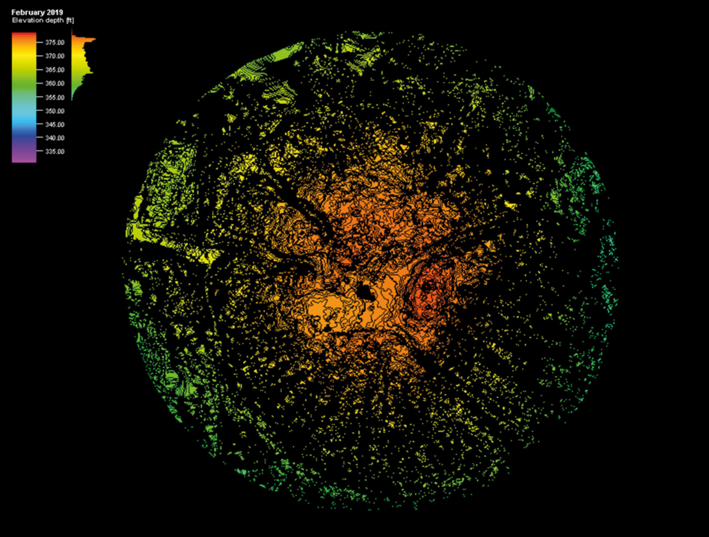
Fig.16: 3D Model of the Surface of the Mud Volcano (2019)

These surface changes in the Mud Volcano were determined to be a drop in height of 0.2m for the main vent of the Mud Volcano, while the flanks of the Mud Volcano experienced a rise in height of 0.7m. This suggests that the that the central vent area is being uplifted continuously to supply mud volcano material to be eroded, with the rate of erosion remaining consistent to some extent and then surpassing the rate of deposition.

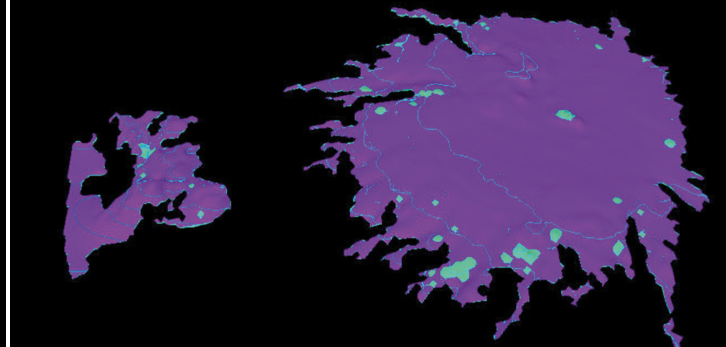
Fig.17: 3D Model showing the area of the Mud Volcano that dropped

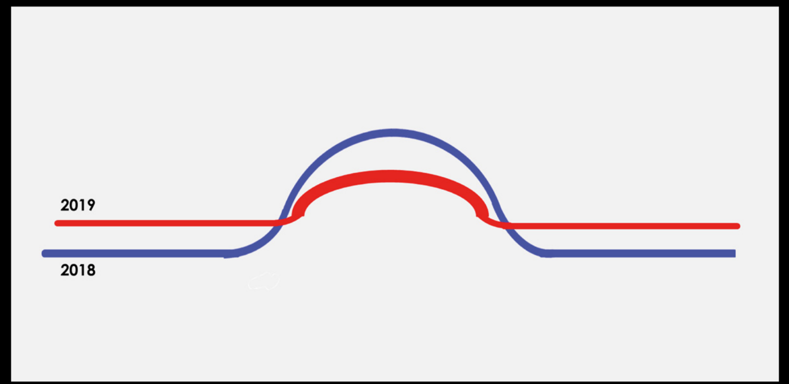

Fig.19: Model representing the change in height of the Mud Volcano from 2018 to 2019

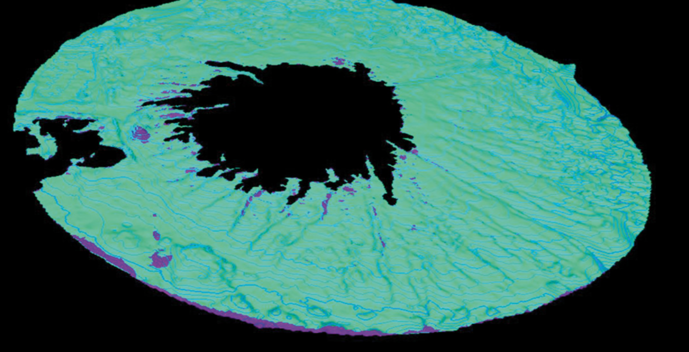
Fig.18: 3D Model showing the area of the Mud Volcano that rose