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.
Introduction
The Piparo Mud Volcano is located within the humid tropical forest of the Caribbean coast of Trinidad and Tobago, an area that has been repeatedly studied for its unique geological features and its significant impact on the local environment. The volcano, which is known for its vivid orange-brown, is one of the most active mud volcanoes in the world. The study area is characterized by a series of mud and gas escape features, including fumaroles, mud ponds, and gas plumes, which are indicative of ongoing volcanic activity.

Local Structure
The Piparo Mud Volcano is located approximately 20 km north-east of the southern city of San Fernando and within the south-west region of the Venezuelan Plateau. It is divided into two main sections: the lower and the upper sections. The lower section is known as the Piparo Mud Volcano, while the upper section is known as the Rapakantu Mud Volcano. The upper section is separated from the lower section by a ridge, which can be seen on the satellite images. The study area is characterized by the presence of active mud volcanoes, which are distributed along the ridge of the upper section.

Methodology
- **Phase 1: Refraction Survey**
  - A refraction survey was conducted in the area of interest.
  - A seismic survey was conducted within the area of interest.
  - A magnetic survey was conducted within the area of interest.
  - An aeromagnetic survey was conducted within the area of interest.

- **Phase 2: Ground Survey**
  - The survey was conducted in the area of interest.
  - The survey was conducted to investigate the presence of mud volcanoes within the area of interest.
  - The survey was conducted to investigate the presence of mud volcanoes within the area of interest.

Data Processing

- **Refraction Data**
  - The refraction data was processed using the software Geot_DETECT to create 3D models of the subsurface and the surface.
  - The models were created using a 3D model of the subsurface and the surface.

- **Magnetic Data**
  - The magnetic data was processed using the software Geot_DETECT to create 3D models of the subsurface and the surface.
  - The models were created using a 3D model of the subsurface and the surface.

- **Aeromagnetic Data**
  - The aeromagnetic data was processed using the software Geot_DETECT to create 3D models of the subsurface and the surface.
  - The models were created using a 3D model of the subsurface and the surface.

- **Ground Data**
  - The ground data was processed using the software Geot_DETECT to create 3D models of the subsurface and the surface.
  - The models were created using a 3D model of the subsurface and the surface.

- **Seismic Data**
  - The seismic data was processed using the software Geot_DETECT to create 3D models of the subsurface and the surface.
  - The models were created using a 3D model of the subsurface and the surface.

Stratigraphy
- From what is known of the Piparo Mud Volcano, the stratigraphy is expected to consist of three main layers:
  - The first layer consists of weathered mud, which is found in the upper part of the stratigraphic column (Fig. 1). This layer is characterized by a relatively uniform composition, which is influenced by the weathering processes that have occurred in the area.
  - The second layer consists of unweathered mud, which is found in the middle part of the stratigraphic column (Fig. 2). This layer is characterized by a more diverse composition, which includes a variety of minerals and organic matter.
  - The third layer consists of weathered and unweathered mud, which is found in the lower part of the stratigraphic column (Fig. 3). This layer is characterized by a complex composition, which includes a variety of minerals and organic matter.

- A more detailed stratigraphic interpretation can be obtained from the 3D models and the satellite images, which provide a more detailed view of the stratigraphic layers.

From the results of the refraction survey, the Mud Volcano has been categorized by lower resistivity readings, from approximately 2.0 to 2.5 ohm-m. In 2018, it can be observed that the Mud Volcano is still active and within a particular section of the stratigraphic layer. This can be seen on the satellite images, which show a bright spot on the surface of the Mud Volcano. The Mud Volcano is also characterized by a higher resistivity reading, which is found in the upper section of the stratigraphic layer. This can be seen on the satellite images, which show a bright spot on the surface of the Mud Volcano.

For the 2018 and 2019 UAV surveys, the bright spot observed in the 3D models is associated with the presence of mud volcanoes. The bright spot is characterized by a higher resistivity reading, which is found in the upper section of the stratigraphic layer. The bright spot is also characterized by a higher reflectivity reading, which is found in the upper section of the stratigraphic layer. These surface changes in the Mud Volcanoe were determined to be due to a drop in height of 0.2 m for the main vent of the Mud Volcanoe, while the flanks of the Mud Volcanoe experienced a rise in height of 0.3 m. This suggests that the Mud Volcano is still active, with the central vent area being uplifted continuously to supply mud volcanoes material to be eroded, with the rate of erosion remaining constant to some extent and thus surpassing the rate of deposition.