[PS]UAV Application to Mud Volcano Monitoring: A Devil's Woodyard Case Study*

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Abstract

Mud volcanoes can be described as vertical vents at the earth's surface where pressurized mud, liquid, water and even gaseous hydrocarbons are released. These vents tend to occur along fault traces, and tend to encourage the growth of conical structures, with associated mud pools. Over decades, pressures naturally build up at depth within these mud volcanoes, possibly due to changes in the natural density and by extension, viscosity of the mud. Coupled with this pressure build up, regional tectonic events such as earthquakes and seasonal changes in the water table can potentially lead to eruptions. Whilst not as devastating as the lava-associated volcanoes, the destruction that they cause to the local community and environment can be quite considerable. One such example is the eruption of the Devil's Woodyard mud volcano on the 13th of February 2018, located on the island of Trinidad. Post-ground observations showed that the mud flow diameter was approximately 350 ft, with local imbrication of 1-1.5 feet of topsoil and vegetation on the eastern side of the mud flow. Qualitatively, there appears to be some cyclicity to this mud volcano erupting, with a previous eruption occurring in 1995. This compares well with the nearby Piparo mud volcano which previously erupted in 1997 destroying homes and covering an area of 11 acres under a thick pile of mud, indicating that there could potentially be a major eruption here within the next 2-5 years. Currently, no agency monitors mud volcanoes in Trinidad. This has led to very little being understood about these natural features due to the absence of frequent or real-time data at these sites throughout the country. However, the use of UAV technology which is relatively inexpensive can provide tremendous insight into performing more quantitative analysis of these eruptions. Immediately post the Devil's Woodyard eruption which lies in an area where there are laterally extensive south easterly verging Middle Miocene reverse faults with a proliferation of NNE-SSW and NW-SE trending tear faults, several drone surveys were carried out over the area. High resolution images together with its metadata allowed for the generation of high resolution orthomosaics, digital elevation models and high-density point clouds datasets. Results from time-lapse survey UAV data acquired over a week period post eruption showed the mud flow at the periphery migrating slowly north eastward with recommencement of 'bubbling', re-pressurization and a height increase of approximately 5 feet across the central vent. This study has shown that the integration of UAV technology together with existing geological and geophysical subsurface data, can provide a 4D monitoring solution of these mud volcanoes. If done consistently and effectively across all major mud volcano sites, it can potentially aid in better forecasting, hazard awareness and emergency response preparedness than what currently exists.

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Mud volcanoes can be described as near vertical vents at the earth's surface where pressurized mud, liquid, water and even gaseous hydrocarbons are released. These vents tend to occur along faults, and tend to encourage the growth of conical structures, with associated mud pools. Over decades, pressures naturally build up at depth within these mud volcanoes, possibly due to changes in the natural density and by extension, viscosity of the mud. Coupled with this pressure build up, regional tectonic events such as earthquakes and seasonal changes in the water table can potentially lead to eruptions.

Whilst not as devastating as the lava-associated volcanoes, the destruction that mud volcanoes cause to the local community and environment can be quite considerable. One such example is the eruption of the Devil's Woodyard mud volcano on the 13th February 2018, located on the island of Trinidad. Post-ground observations showed that the mud flow diameter was approximately 350 ft, with local imbrication of 1-1.5 feet of topsoil and vegetation on the eastern side of the mud flow. Qualitatively, there appears to be some cyclicity to this mud volcano erupting, with a previous eruption occurring in 1995. This compares well with the nearby Piparo mud volcano which previously erupted in 1997 destroying homes and covering an area of 11 acres under a thick pile of mud, indicating that there could potentially be a major eruption here within the next 2-5 years.

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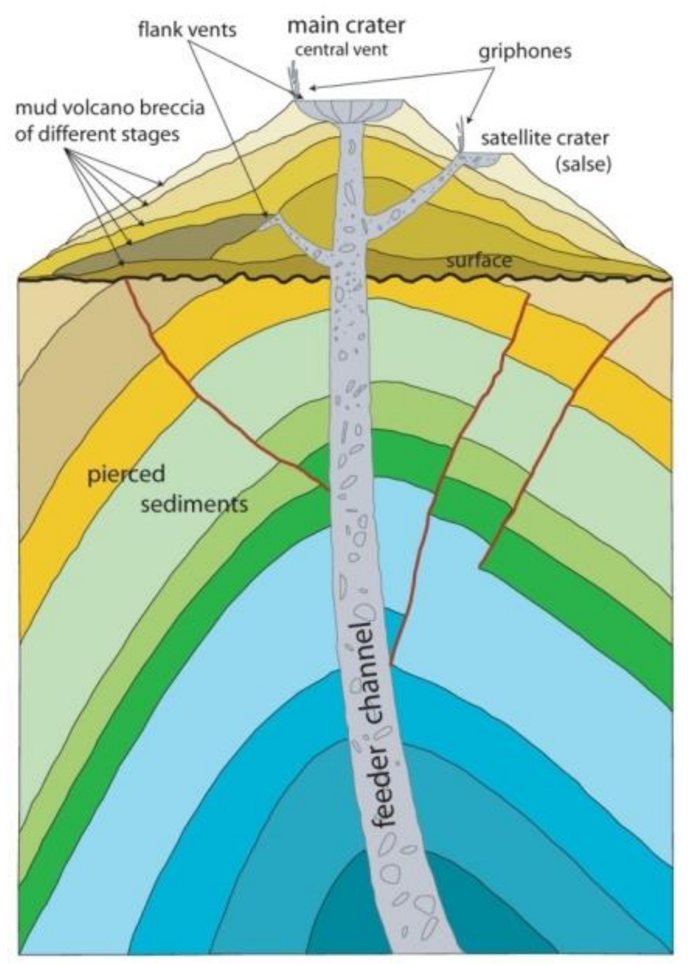
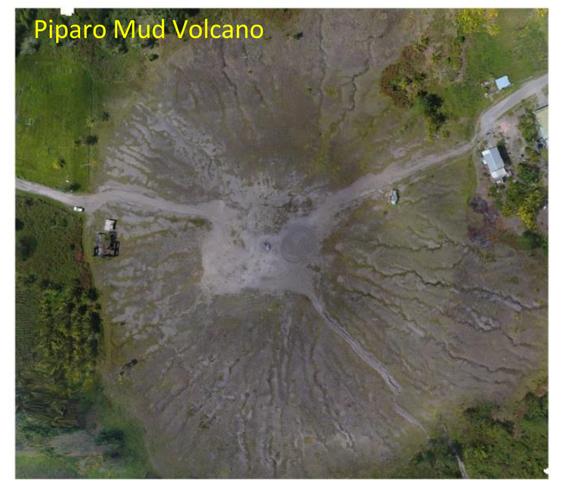
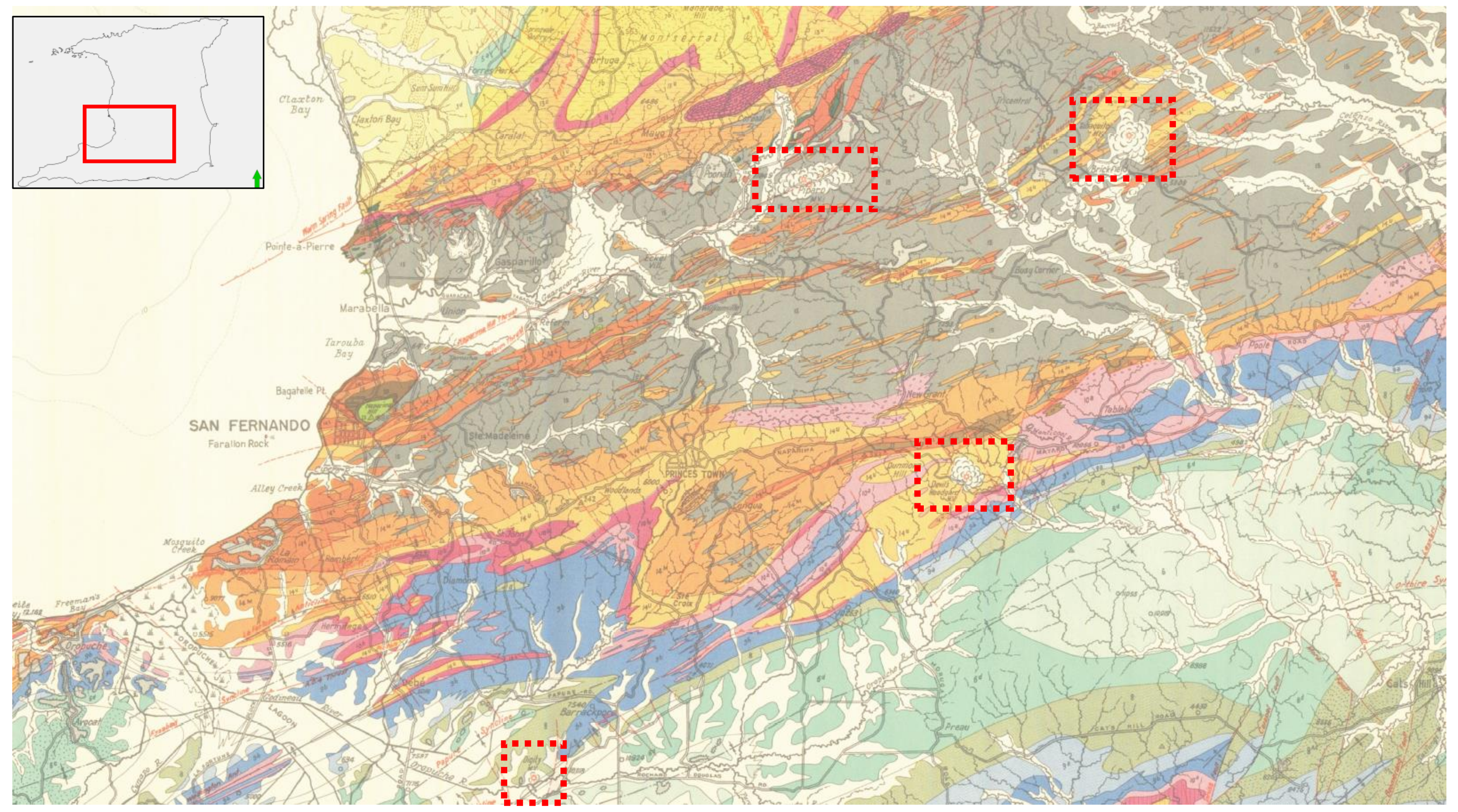
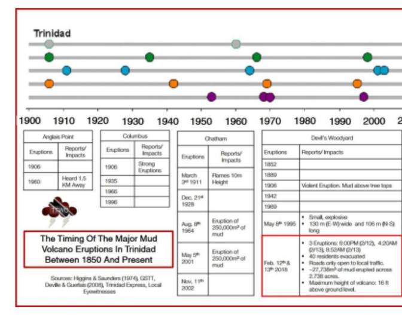
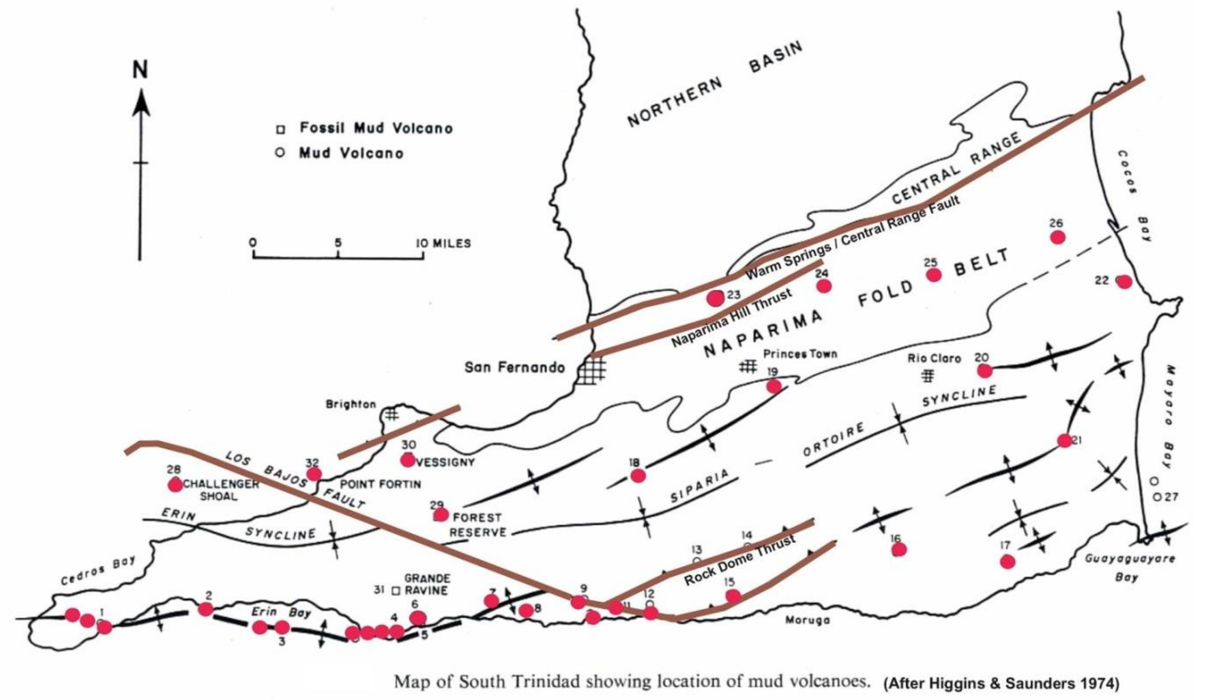




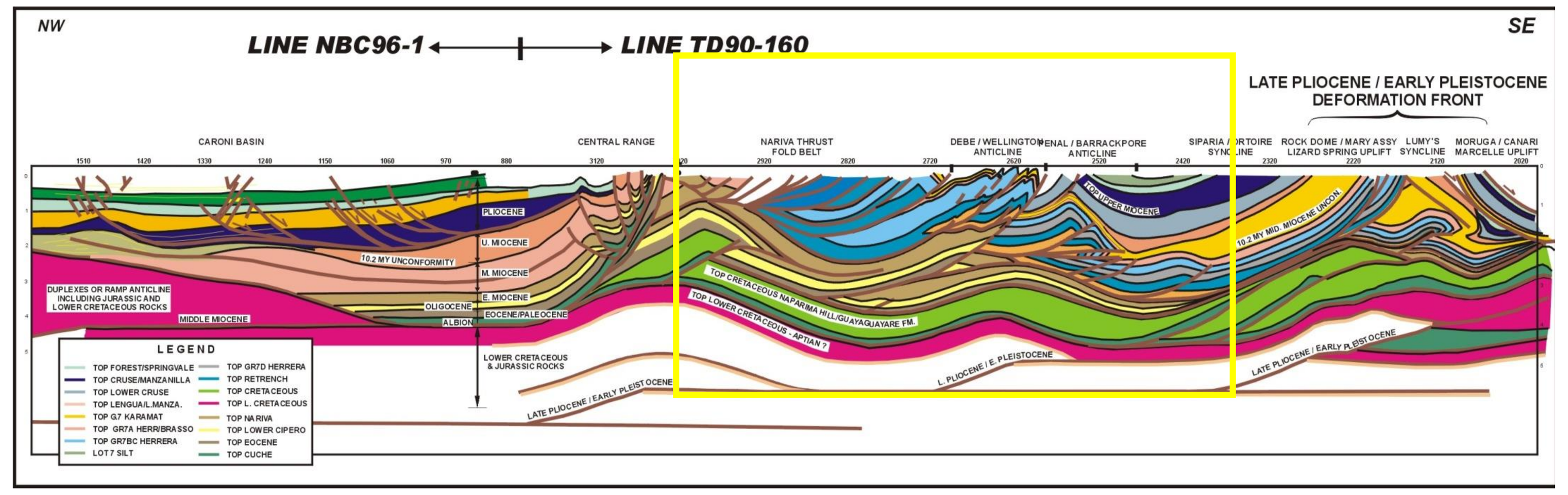
Key Mud Volcanoes within the Nariva Fold & Thrust Belt







Map of South Trinidad showing location of mud volcanoes. (After Higgins & Saunders 1974)



Eruption Timeline & Data Acquisition

Tuesday 13th February 2018

3:00am Villagers heard loud noises coming the mud volcano area. A video taken (in very poor lighting) showed fresh cracks in the playing field at Devil's Woodyard. The residents were asked to comment on any change in elevation in the playing field and area near the vents.

4:20am The mud volcano erupts

8:30am Second phase of eruptions. Videos go viral on social media. Environmental Management Authority (EMA), Police and Fire Fighters onsite. Area cordoned off and EMA begins gas testing.

7:00pm EMA informs geological groups that the gases were tested and deemed safe for field assessment.

Wednesday 13th February 2018

10:30am Initial assessment - examination of fractures, mud flow, rocks entrained, and 1st Drone survey. Mud flow extremely wet.

Tuesday 20th February 2018

2:00pm Visited site with Prof Grant Wach and his students from Dalhousie University. Conducted 2nd Drone survey. Mud flow mostly dry allowing closer examination of extruded material.

Monday 26th February 2018

12:00 noon Visited site with University of the West Indies Petroleum Geoscience PGSC 3013 class to examine fractures/faults. Conducted 3rd Drone survey.

Devil's Woodyard Mud Volcano 14-02-2018

Post-Eruption Observations
From the air

Post-Eruption Observations - *On the ground*

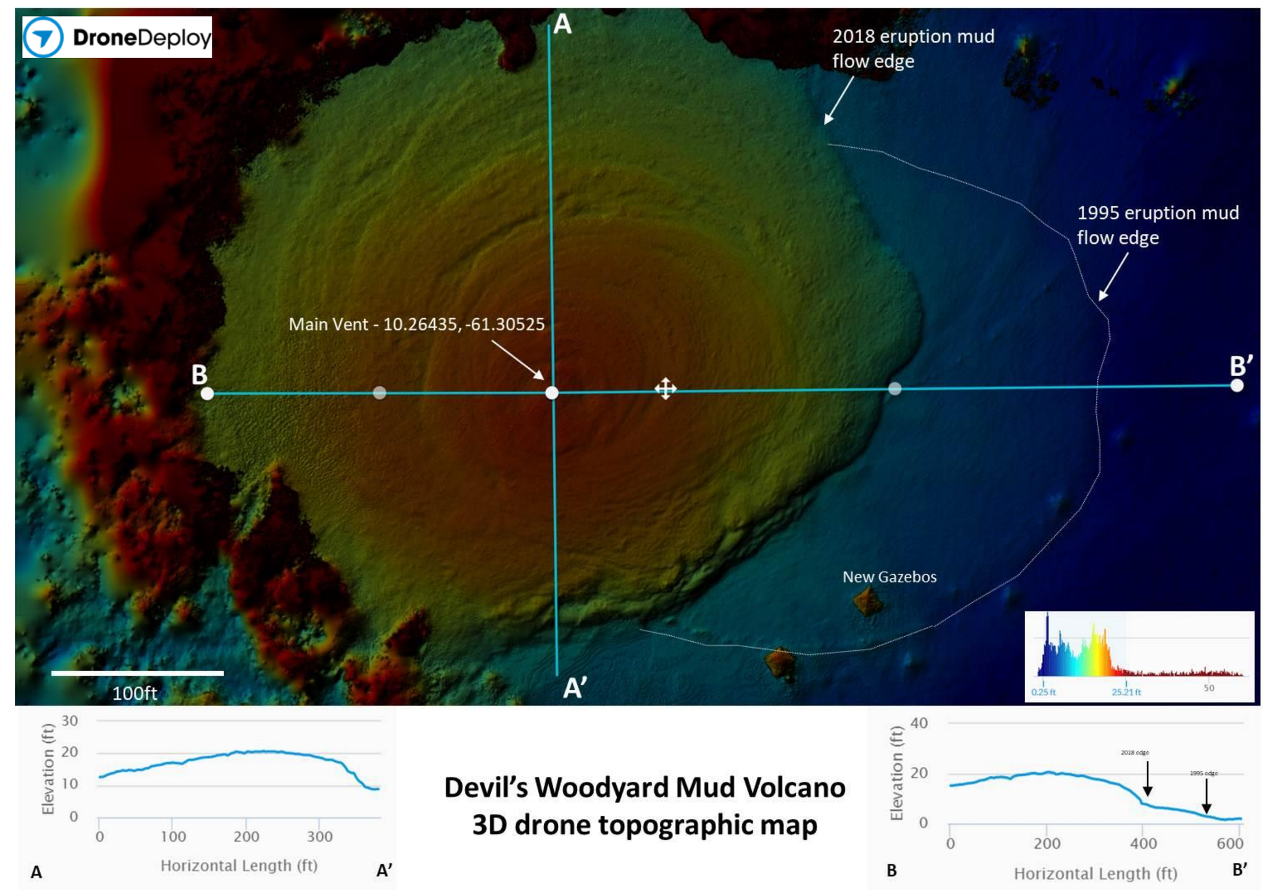
Curtis Archie (2018)

Observations gathered by PGSC 3013 field exercise (Feb 26th, 2018)

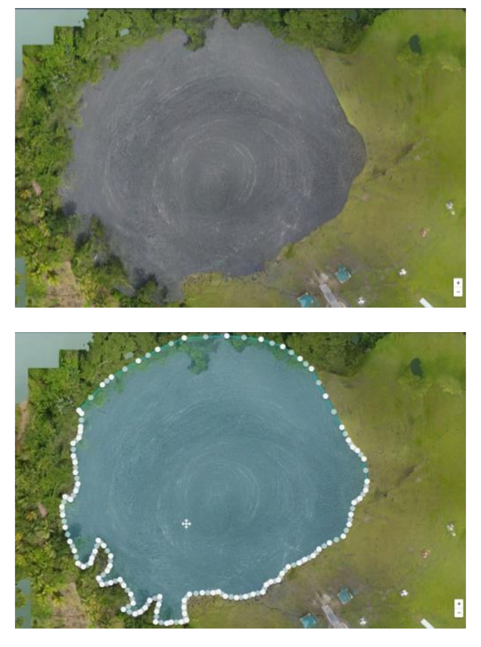
- Mud flow diameter of approx 350ft
- NE-SW trending fractures/faults with predominantly dextral motion
- Concrete walkway offset
- Periphery fence broken along path of NE-SW fracture
- Localised imbrication of 1-1.5ft topsoil and vegetation on the eastern side of the mud flow only
- Extruded boulders include: Oil impregnated sandstones with distinct 'salt & pepper' appearance and pyrite.
- Biostratigraphy of the clays suggests that they were derived from the *Middle Miocene Lengua Formation..* despite extensive Cipero outcrops at surface.

Drone Mapping and Monitoring

- On each drone / UAV survey some 200-230 geo-tagged pictures were acquired using DJI Phantom 4 aircraft.
- Photos were input into two photogrammetry software – Drone Deploy & Agisoft Photoscan
- Point Clouds were generated with an accuracy of 1.7cm to one pixel (~50 million points) – can be exported as x,y,z, r,g,b.
- DEM generated at 3.1cm per pixel, Vertical accuracy ~10cm, contours can be exported as ArcGIS shape files



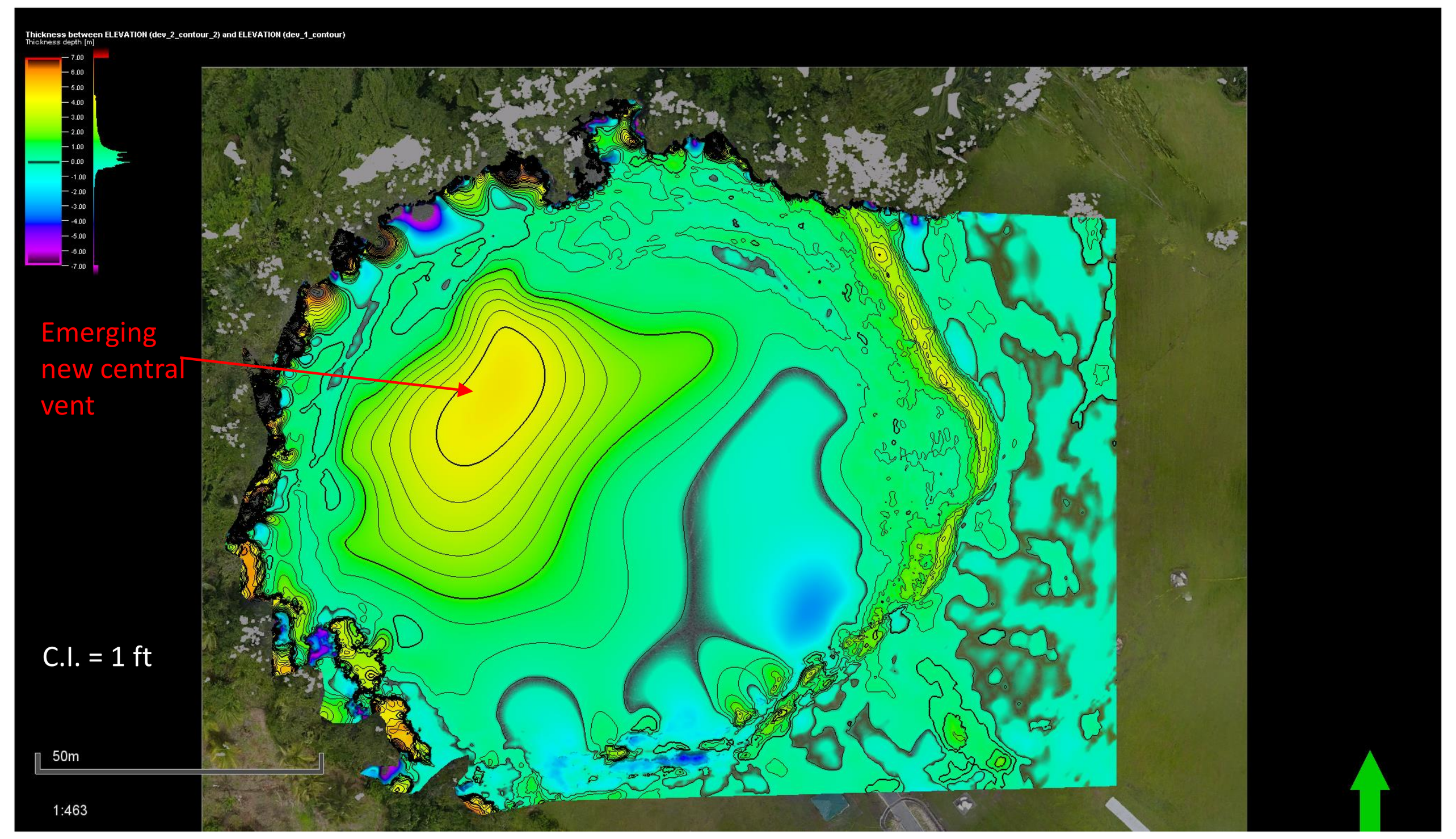
Devil's Woodyard Mud Volcano 3D drone topographic map



Area – 2.738 acres
Volume – 27738m^3 or 174,472 bbls mud extruded

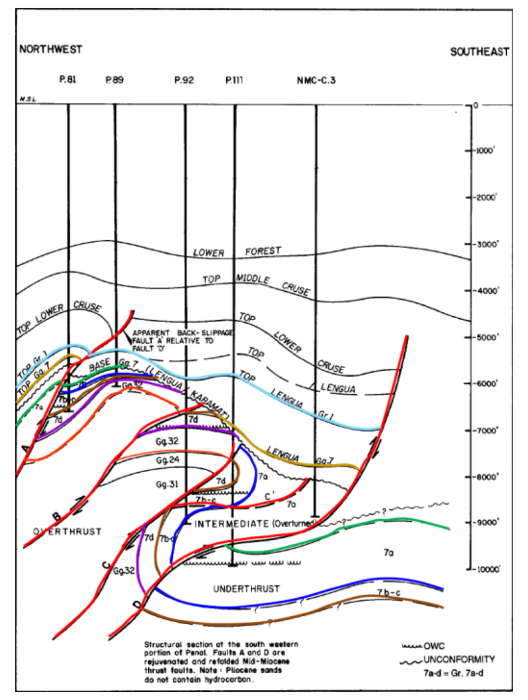
Comparison of 14th Feb and 26th Feb UAV surveys

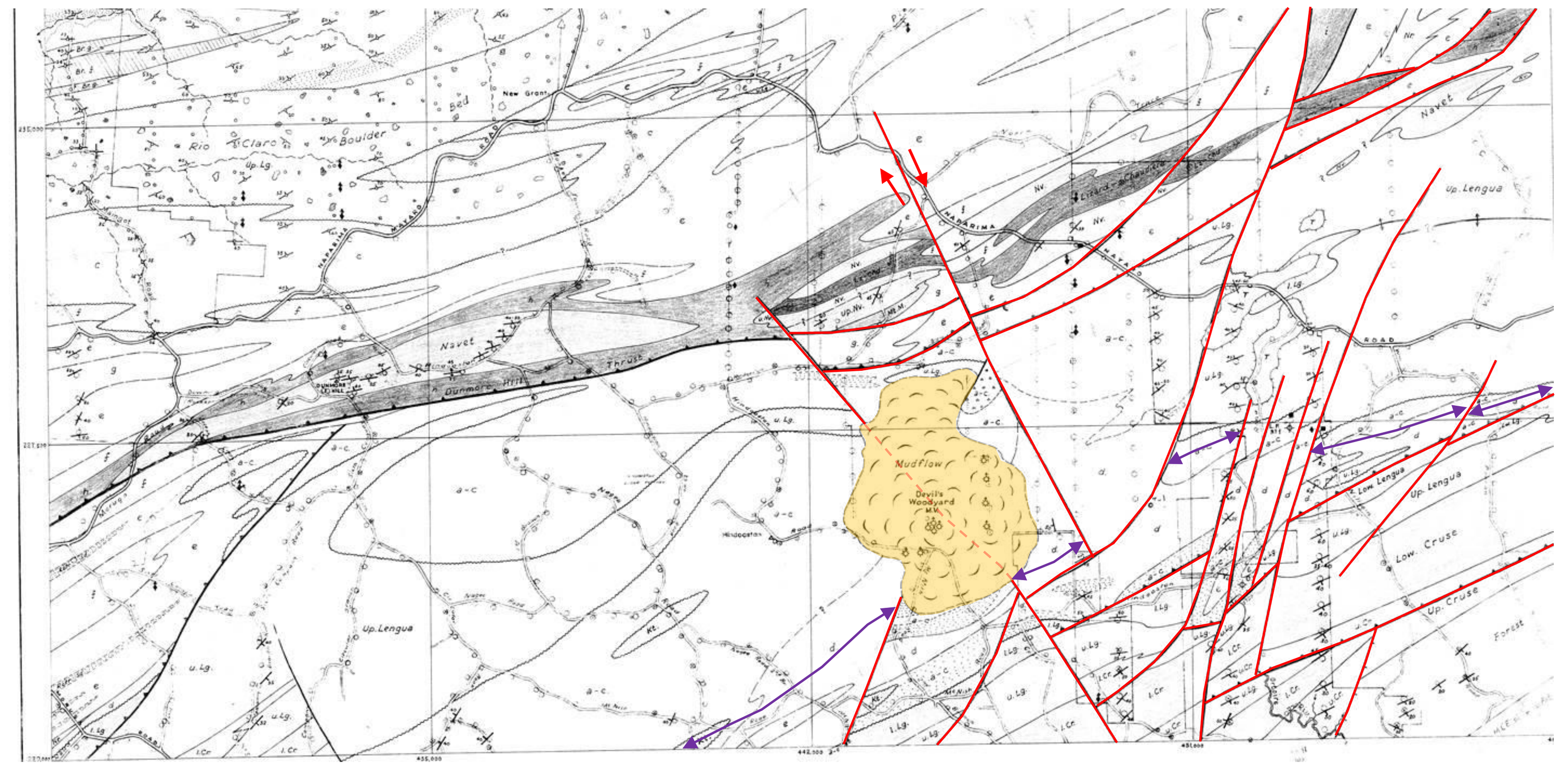
Post-eruption the mud flow at the periphery continues to migrate slowly north eastward. The central vent has restarted 'bubbling', repressurizing and has shown a 5ft overall increase in height since eruption.

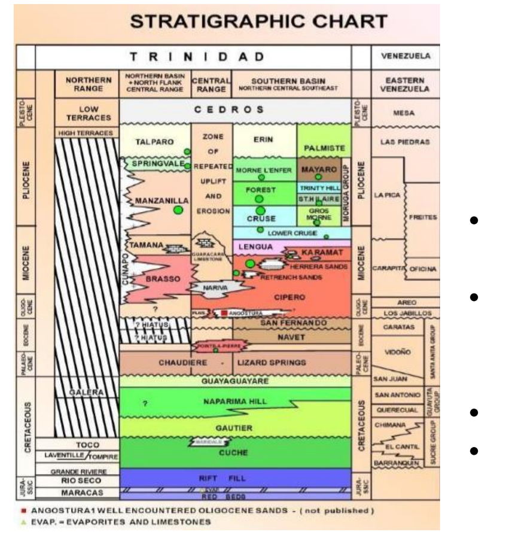


Geological & Geophysical Review of the Devil's Woodyard Area

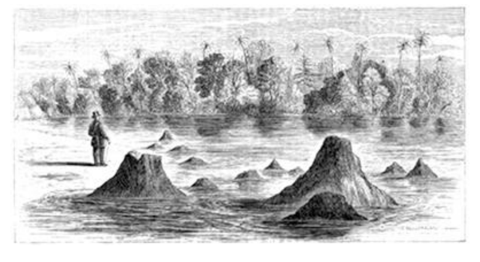
Kugler & Rohr, 1958 1:10000 G5 Geological Map





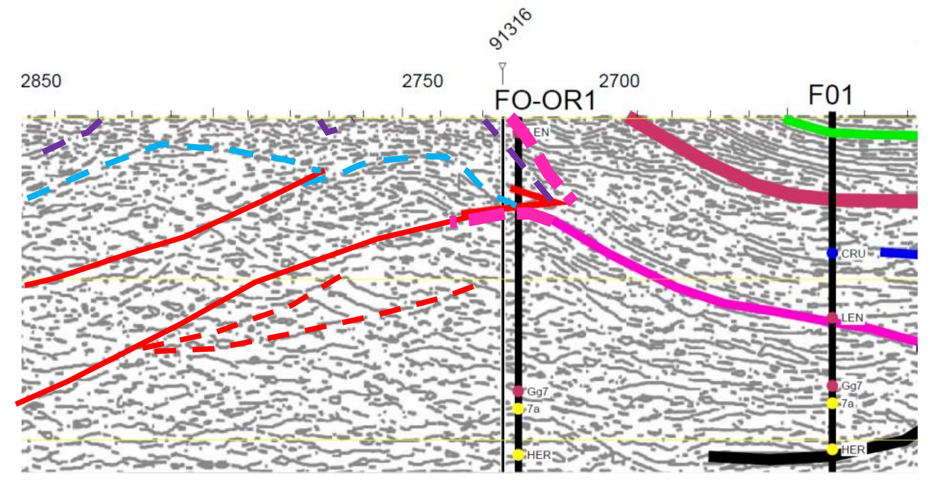


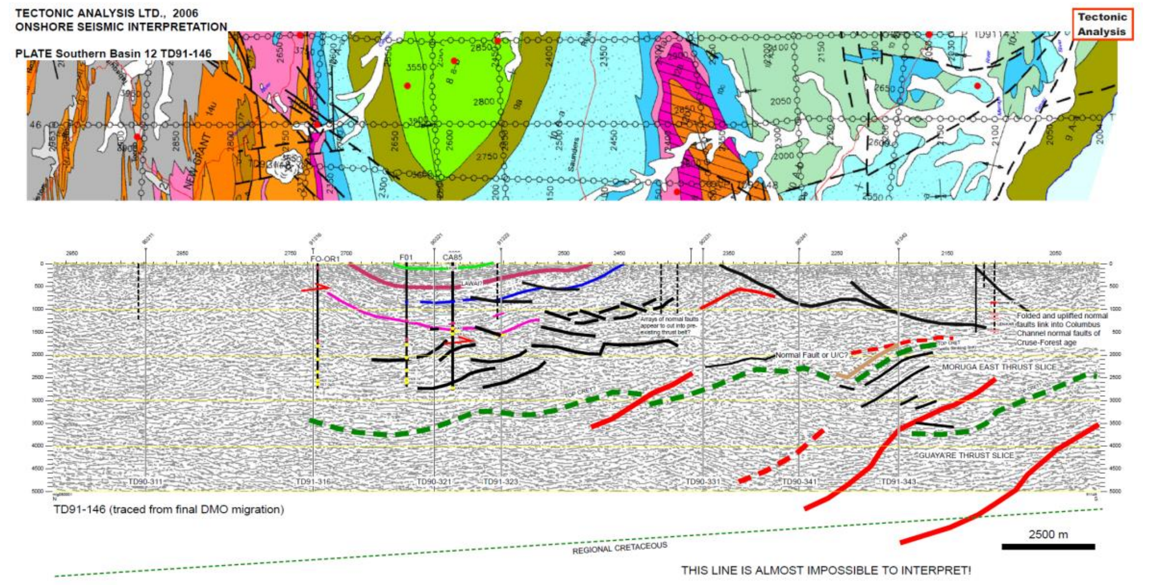
- Laterally extensive south easterly verging Mid Miocene reverse faults
- Proliferation of NNE-SSW and NW-SE trending tear faults – which offset Mid Miocene reverse faults
- Dominantly dextral motion
- Shallowest Overthrust slice of Penal Barrackpore Anticline

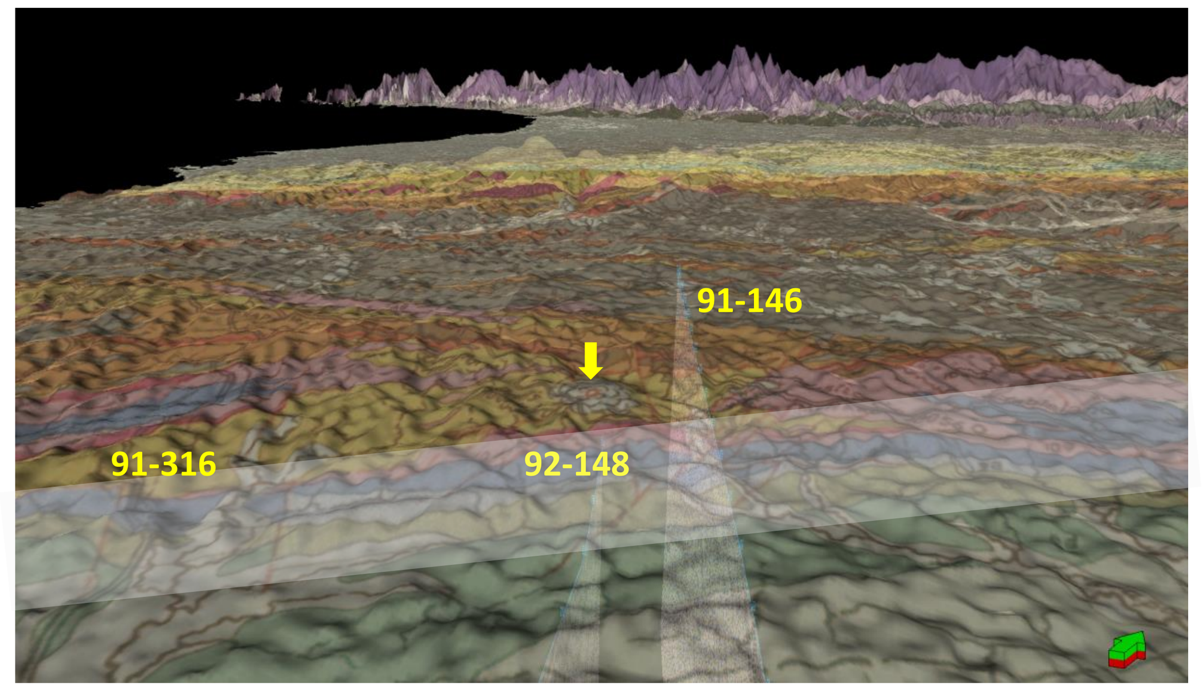


The Devil's Woodyard as sketched by Charles Kingsley in 1870.

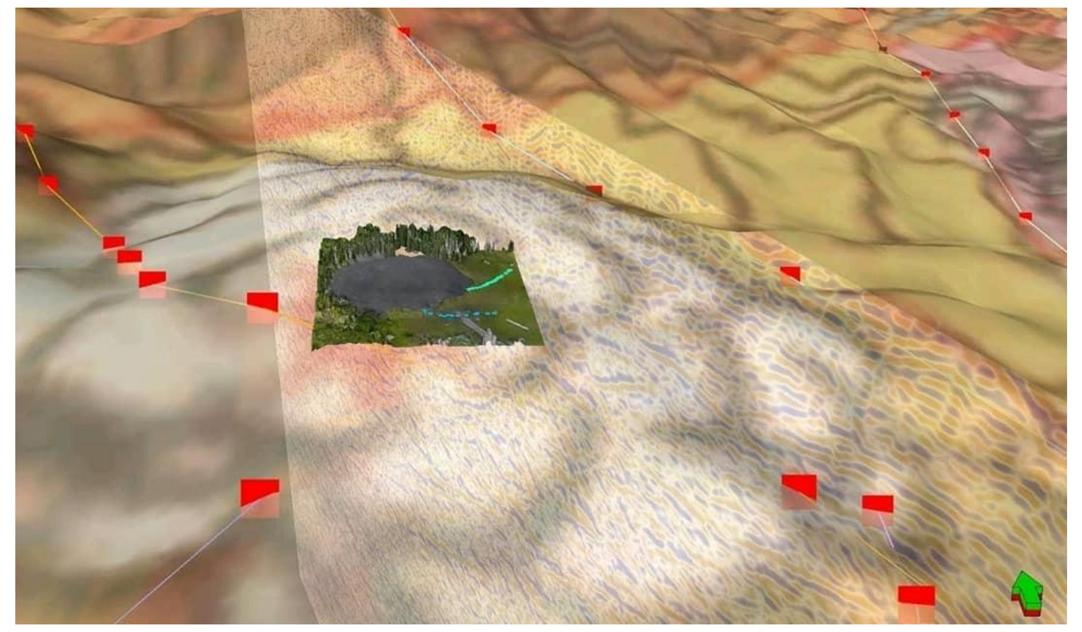
Spot maps suggest that Lengua beds attain steep southerly dips of 60-80°







3D Perspective of Devil's Woodyard Mud Volcano and adjacent 2D Seismic Lines



3D Perspective of Devil's Woodyard Mud with Drone Orthomosaic and mapped faults

3D Drone Orthomosaic of Devil's Woodyard in Drone Deploy

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