Field Guide

20th Caribbean Geological Conference (2015)

Port-of-Spain, Trinidad and Tobago

Mud Diapirs

May 22, 2015

Trip Leader: Mr. Curtis Archie

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Trip Locations

3A. Day 3: Mud Volcanoes

Trip Leader: Mr. Curtis Archie

Keywords: Mud Volcano, oil, gas

Access and Safety

The drive to these field localities may take as much as 2 hours due to traffic. If you suffer from motion sickness, it may be advisable to take appropriate medication. The temperatures can reach around 34^0C as such sunscreen is recommended; keep hydrated by drinking lots of water. Insect repellant is recommended as biting insects may be present at the Palo Seco. We will be walking on a clay rich surface that may become very sticky if it becomes wet so be prepared to have a backup pair of footwear, you do not need hiking boots. Long sleeves and pants are recommended for protection against the sun, insects and vegetation.

Overview

The term "mud-volcano" is generally applied to a more or less violent eruption or surface extrusion of watery mud or clay which almost invariably is accompanied by methane gas that commonly tends to build up a solid mud or clay deposit around its orifice; which may have a conical or volcano-like shape (Hedberg 1974).

This trip will visit 2 localities located on the southern edges of the Palo Seco and Erin fields, along the Southern Anticline. We will visit Erin Bouffe, the first locality which is a large deep mud filled pool that consists of associated small vents and cones. The second locality is at Beach Camp, Palo Seco, where we will visit two areas of activity, one inland at the end of James Trace; it consists of a number of large deep pools of mud, smaller pools and cones spread over a few acres. The second will be at Anglais Point. This involves a short walk along the coastline, and a short hike uphill. The mud volcanic activity consists of a number of small vents at the top of the hill. Down slope of these vents is a mud "glacier" that extends down to the coast.

Description

In the literature, there has been an association between hydrocarbon accumulations and mud volcanism. There is a poor correlation between the location of mud volcanoes and oil fields; however the mud volcanoes are more commonly located near the major thrust faults. In both the onshore and offshore the crest of the Southern Anticline is marked by several active mud volcanoes (Figure 1).

All of the fossil and present Mud volcanoes occur south of the Central Range / Warm Springs fault and can be grouped according to their geographic location and age of the material erupted. The northern group occurs in the Central Range and erupt Nariva age sediments. The second group is found to the north of the Los Bajos Fault in the 'Naparima fold belt' and in SE Trinidad, material of Cipero/Karamat age is erupted. South of the Los Bajos Fault the material is predominantly Lower Cruse and Lengua. All these formations are dominated by thick deepwater claystones that were later rapidly buried by Plio-Pliocene deltaics. This resulted in the development of overpressures that could have helped their later mobilization.

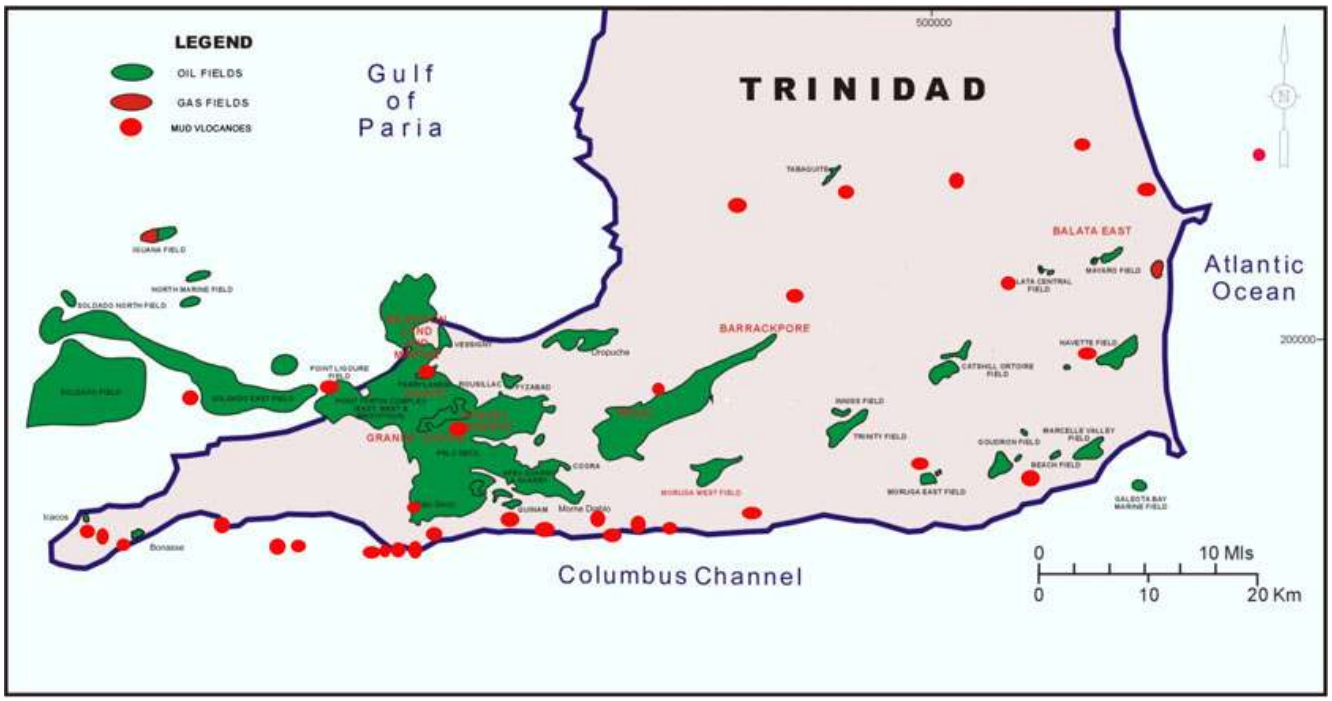


Figure 1: (Map showing oilfields and mud volcanoes) shows the location of oilfields in the southern half of Trinidad and Gulf of Paria.

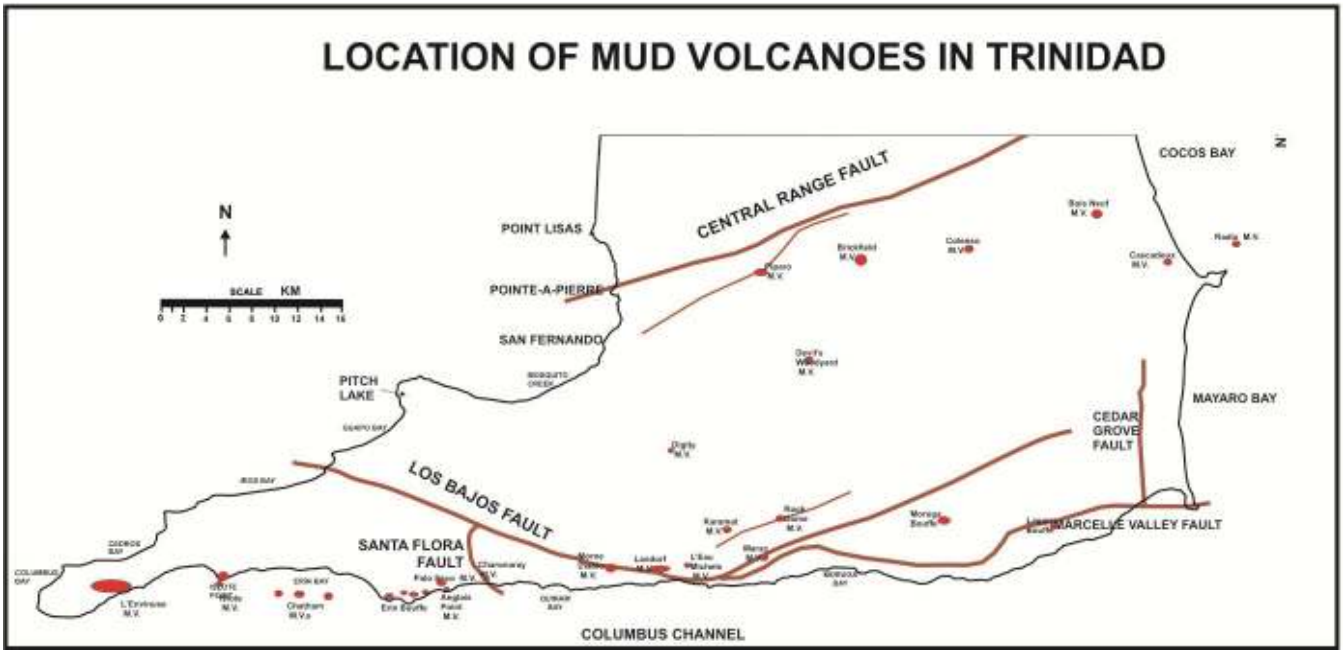


Figure 2: Location of Mud Volcanoes in Trinidad.

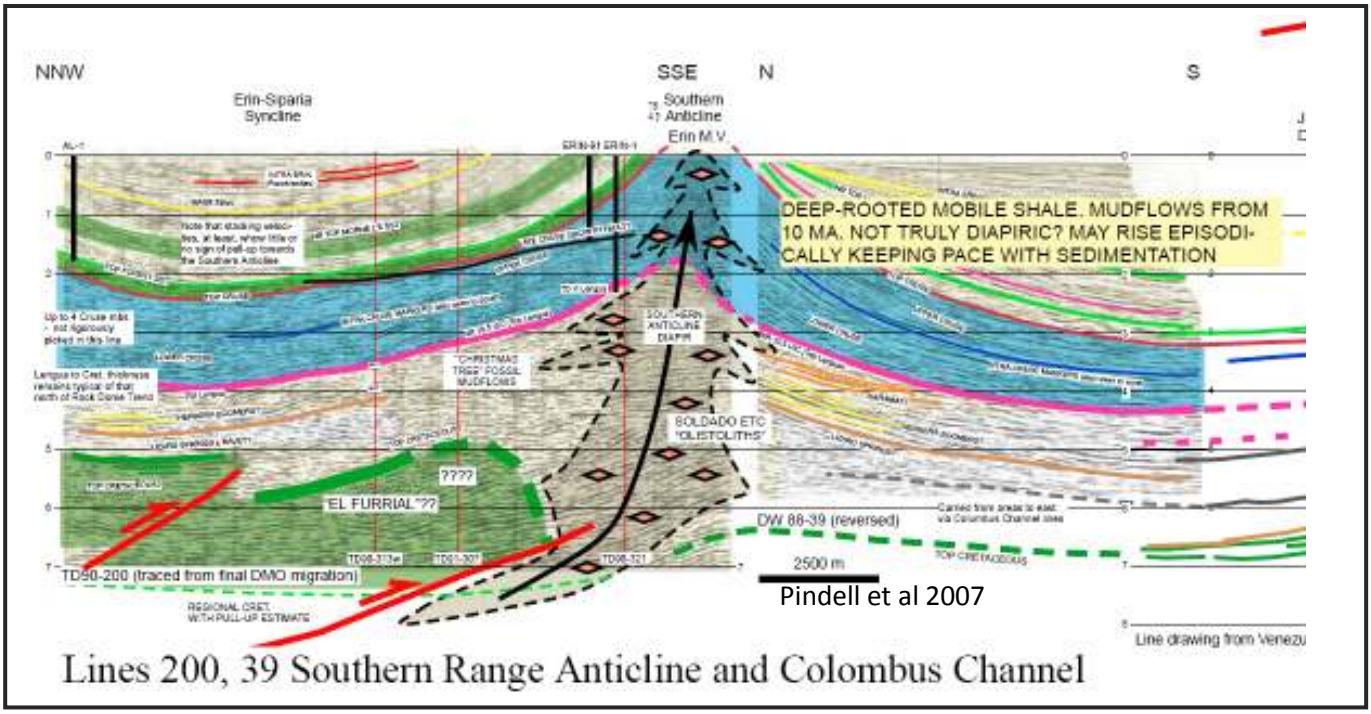


Figure 3: An Interpretation from Pindell et al 2007 using 2D seismic to explain the origin of the mud volcanism along the Southern Anticline.

Hydrocarbons generated from the Cretaceous source rock would migrate upwards along fractures associated with major faults that form anticlines. Fluids (connate water) and sediments from formations through which the hydrocarbons are migrating are incorporated to form a buoyant plastic mass.

The water expelled is less saline than seawater (the 3 chemical species accounting for more than 90% range for Cl between 80 and 400 mM, Na between 90 and 400 mM, and HCO3- between 17 and 70 mM) and pH values range between 7 and 8.2 (Dia et al., 1999). Based on Beryllium geochemistry, the maximum age of the water circulating in the mud volcano system is +/- 9 Myr (Castrec-Rouelle et al 2002).

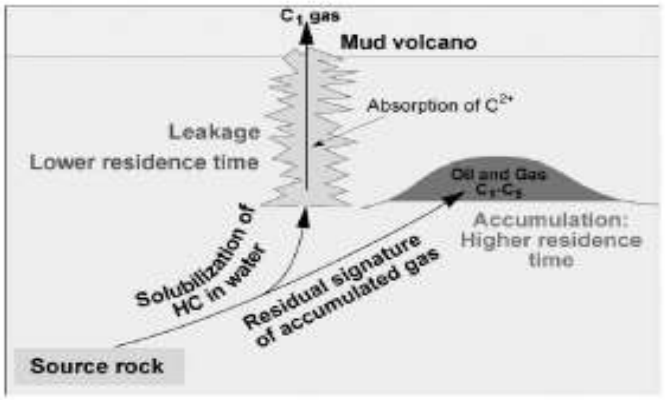


Figure 13. Summary model showing the various stages and the phenomena postgenetic process that affected hydrocarbons (HC). All the HC (except the Mahaica field, see the text) are produced from the same parent rock. A part of the HC, after dissolution and diffusion in water, takes a different pathway of migration toward mud volcanoes, whereas the oil and the residual gas move toward reservoirs for accumulation. Having undergone a process of surface adsorption, the mud volcano gas is almost essentially constituted by methane and expelled regularly in the atmosphere (low time of residence).

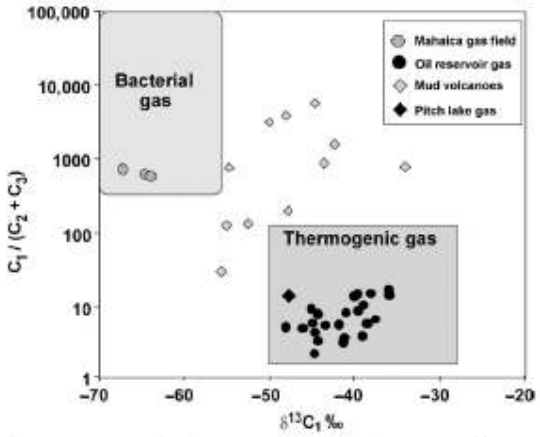


Figure 2. Bernard's diagram (Bernard et al., 1976), $\delta^{13}C_1$ versus $C_1/(C_2 + C_3)$ ratio. The *y* axis is logarithmic. We distinguish three groups of samples. The samples of reservoirs that are of thermogenic origin are in black. Three bacterial gas samples, also from deep reservoirs, taken in the Mahaica field are in gray circles. Almost all mud volcano samples lie in the intermediate range of values in this figure.

Battani et al 2010

Figure 4:

The sediments expelled with the mud of the mud volcanoes are very variable in size and type, including liquefied clays, very fine sandy material from various deep and shallower horizons penetrated by the mud conduits. The mud expelled is rich in thin, angular, and mechanically damaged quartz grains (locally up to 90%, Deville et al., 2003), which are probably cataclastic flows issued from sheared and collapsed deep sandy reservoirs. The exotic clasts and breccias result mostly from hydraulic fracturing along the mud conduits (Deville et al., 2003). Only one mud volcano has large clasts exposed on the tassik, the Piparo MV, the rest have only a trace of very fine sand or centimeter sized ironstone concretion fragments. It is only on the coast where some of the mudflows are affected by erosion do we see large sandstone boulders of different colours, Pyrites and occasionally oil impregnated sandstones.

In the onshore eruptions are of two types , a large explosive event (Devils Woodyard in 1995 and Piparo in 1997) followed by a period of quiescence and by areas continuous release of fluids and gas eg Palo Seco and Erin. No explosive eruptions have been recorded at both areas.

Stop 1: Erin Bouffe

Access and Safety

We would be able to drive at least 95% of the way by road, which in some places can become narrow and bumpy. After parking the bus there is a 5 minute walk through an undulating wooded area. The path is not paved and if wet, can become slippery. Some of the trees have thorns; the Bromeliads have a serrated edge to their leaves and are capable of cutting exposed skin. The Mud pools are very deep, please exercise caution near their edges.

Overview

Location: UTM Naparima N 651512 E 1112776, Altitude 209', Area: 70m X 55m

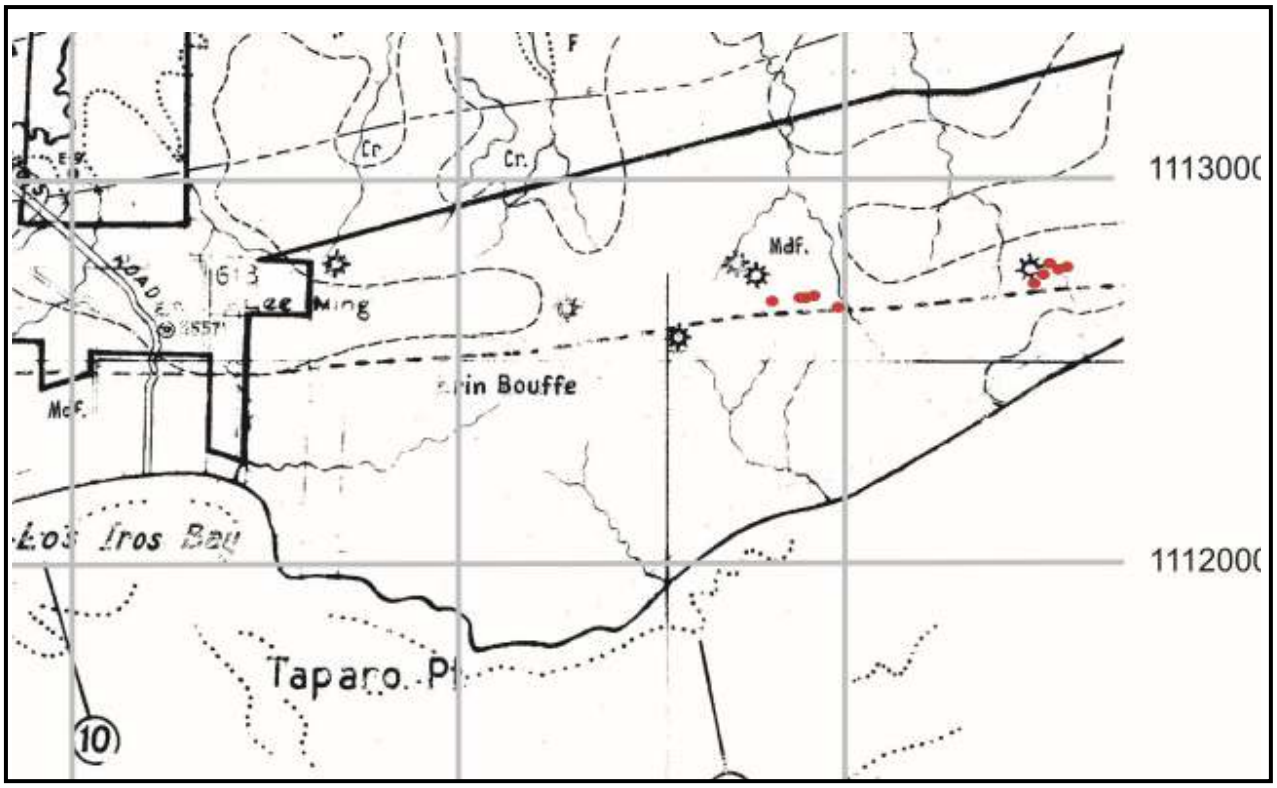


Figure 5: Surface Geology map showing the location of mud vents – red circles show the current centers of activity.

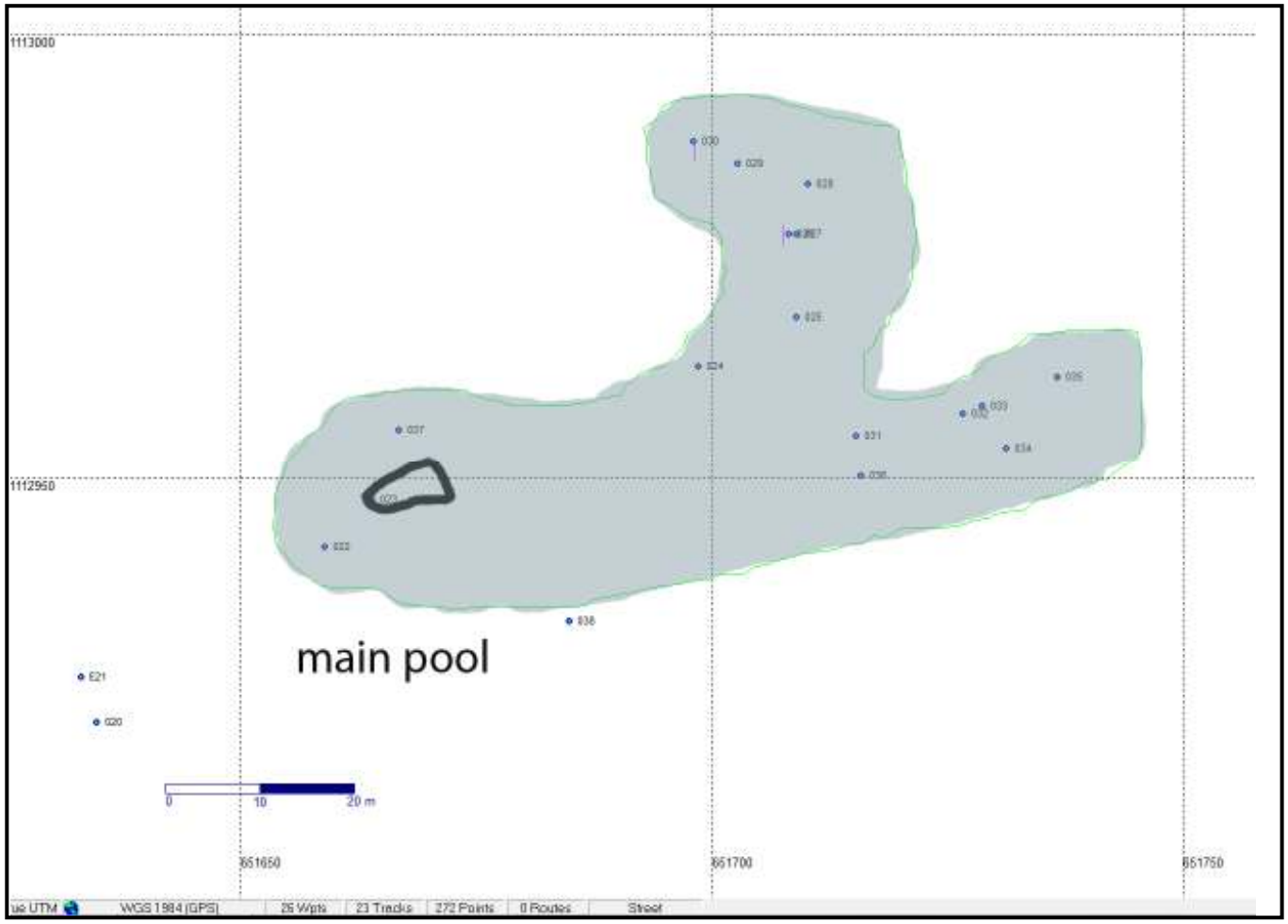


Figure 5: Map showing the shape of the tassik around the Erin Bouffe.

Figure 6: Panoramic view looking north of the tassik. No pebbles or boulders are currently seen around the eruptive centres; only very fine sand is seen in places where the mud has been washed away.

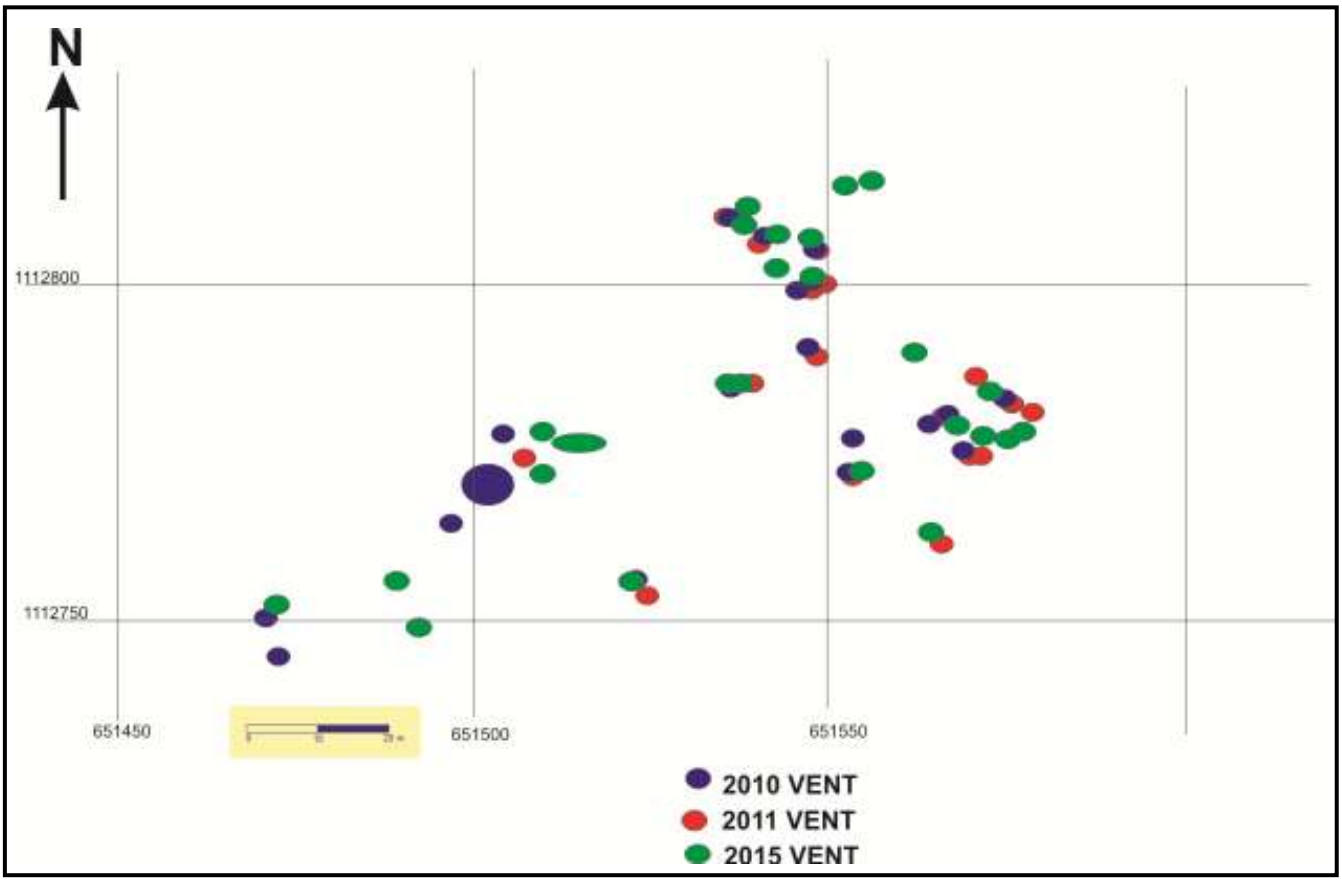


Figure 7: Map showing the location of mud vents, pools and cones for 2010, 2011 and 2015 in the main area. Most of the areas of activity have remained fairly fixed; in 2015 a few new vents have formed. Two linear trends appear to be present a NW – SE group and a NE – SW group.

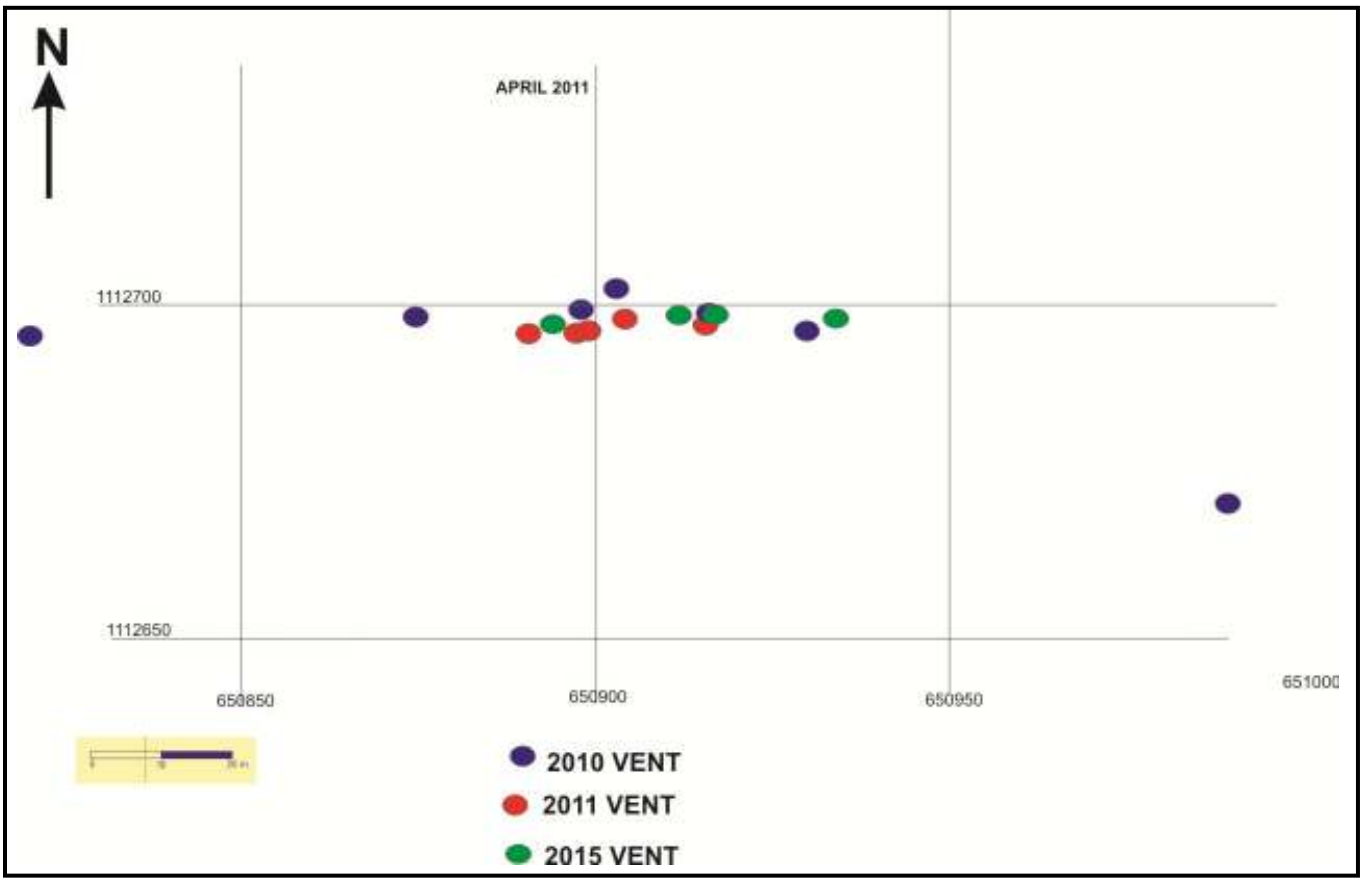
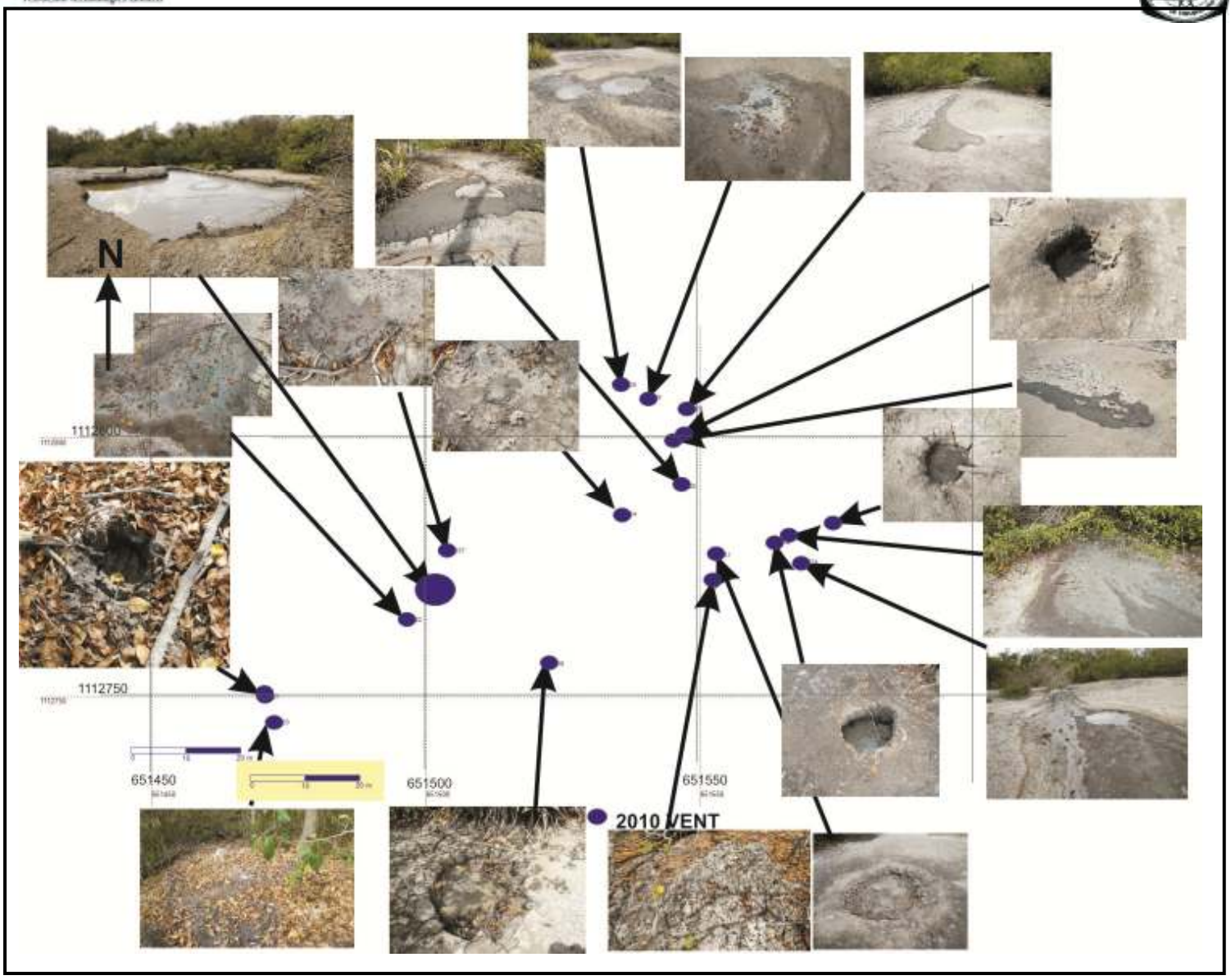
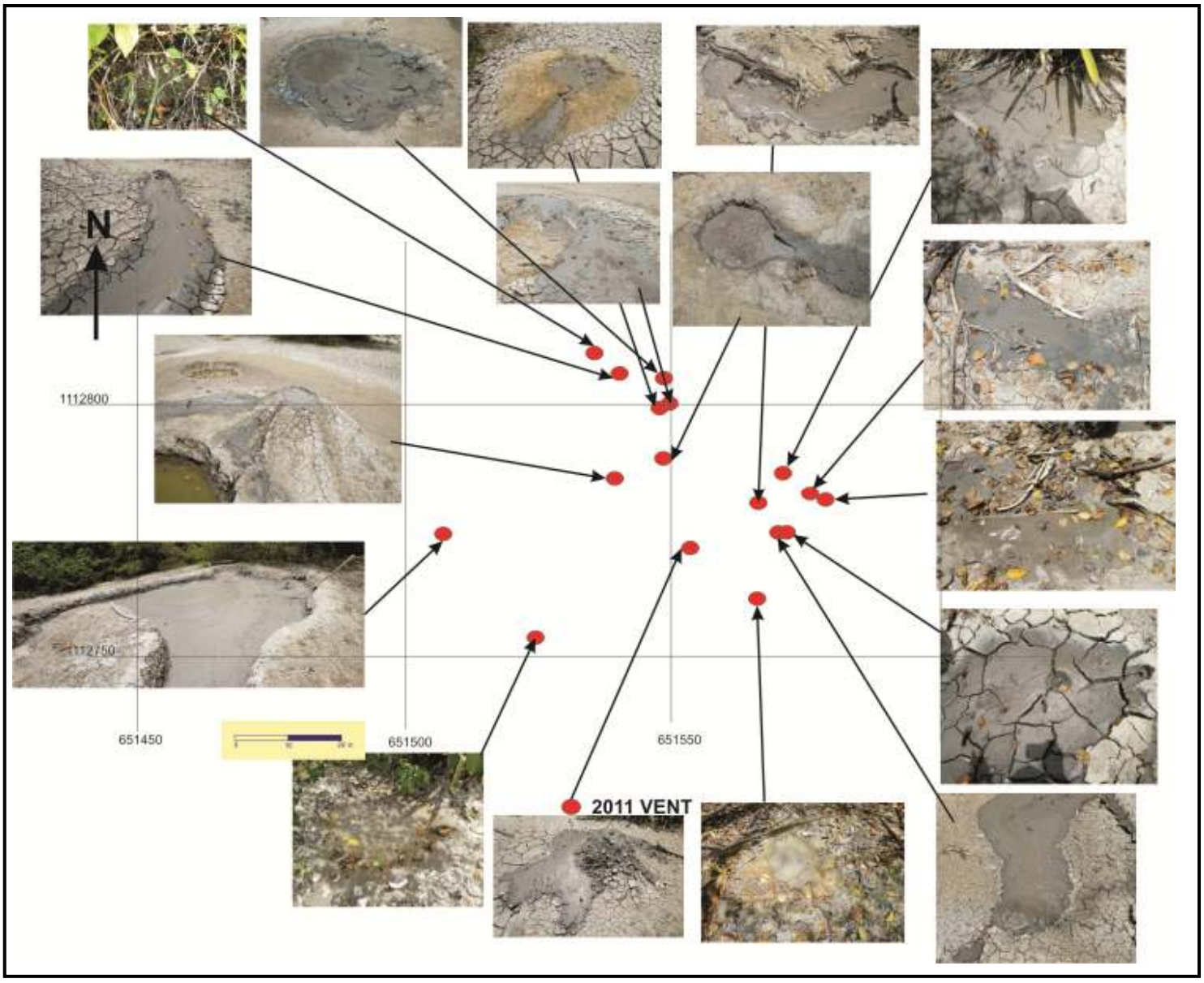


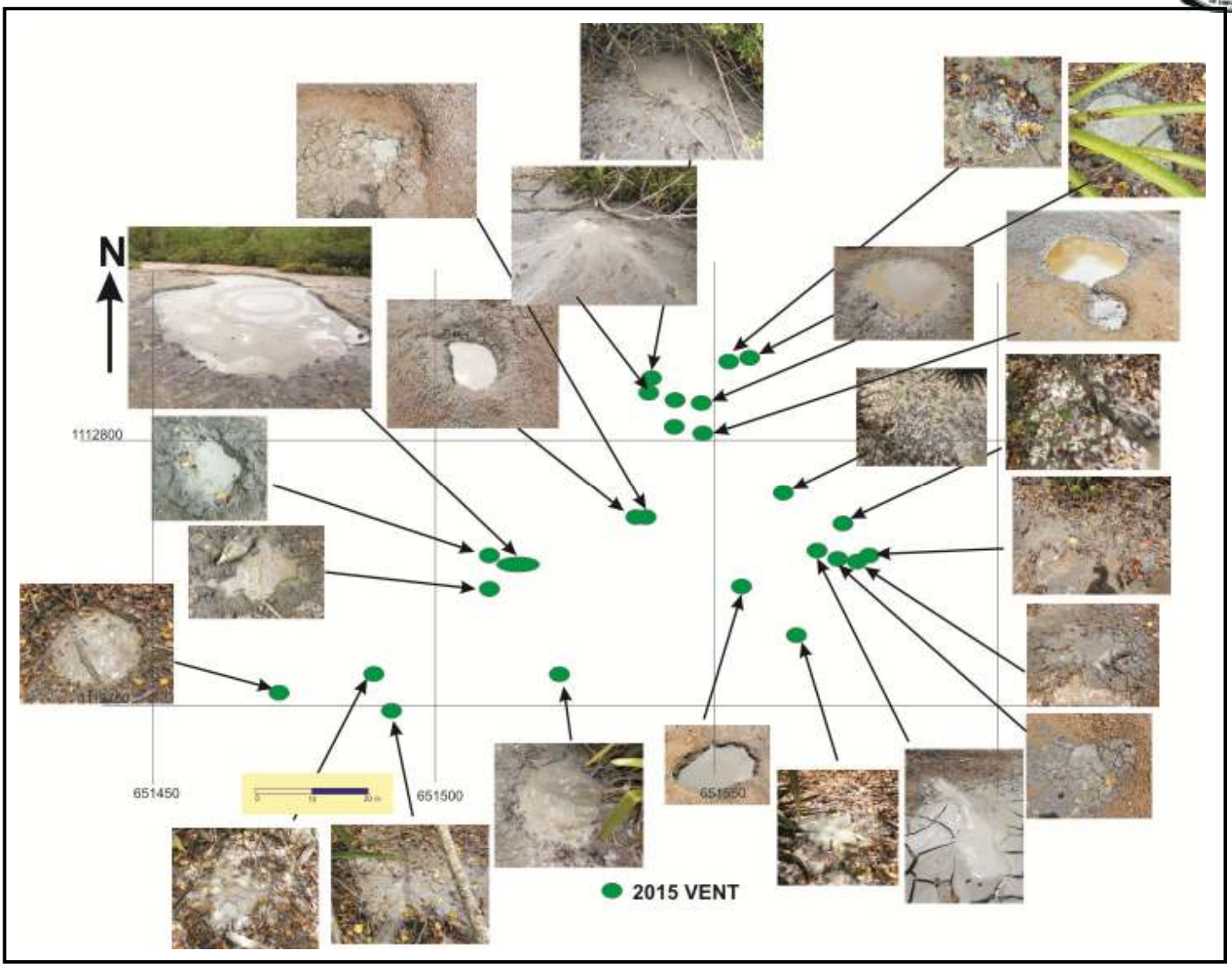
Figure 7: Map showing the location of mud vents, pools and cones for 2010, 2011 and 2015 in the western area. While most of the activity is concentrated in the same area, the actual points of activity have migrated a bit, but maintain an E – W trend.



Montage 1: Shows the location of mud vents, pools and cones for 2010 in the main area.



Montage 2: Shows the location of mud vents, pools and cones for 2011 in the main area



Montage 3: Shows the location of mud vents, pools and cones for 2015 in the main area

Location and chemical characteristics of fluid samples.

	pH	Cl (mM)	Alk (mM)	Na (mM)	K (mM)	Ca (mM)	Mg (mM)	B (mM)	SO4 (mM)	Br (mM)	SiO_2 (mM)	Li (mM)	I (mM)	Ba (μM)	Sr (μM)	Al (μM)	Rb (μM)	Cu (μM)	Mn (μM)	Zn (μM)
TD 16	7.44	318.9	21.2	341.3	0.59	2.15	6.17	2.14	<0.02	1.67	0.20	0.01	0.45	15.4	82.7	0.07	<dl	<dl	0.25	<dl
TD 17	7.22	304.4	32.3	337.9	0.56	2.35	4.03	1.65	<0.02	1.57	0.19	0.02	0.35	30.8	88.1	<dl	<dl	<dl	<dl	<dl

Table 1: Analysis of expelled water Dia et al (1999) the Bouffe was sampled.

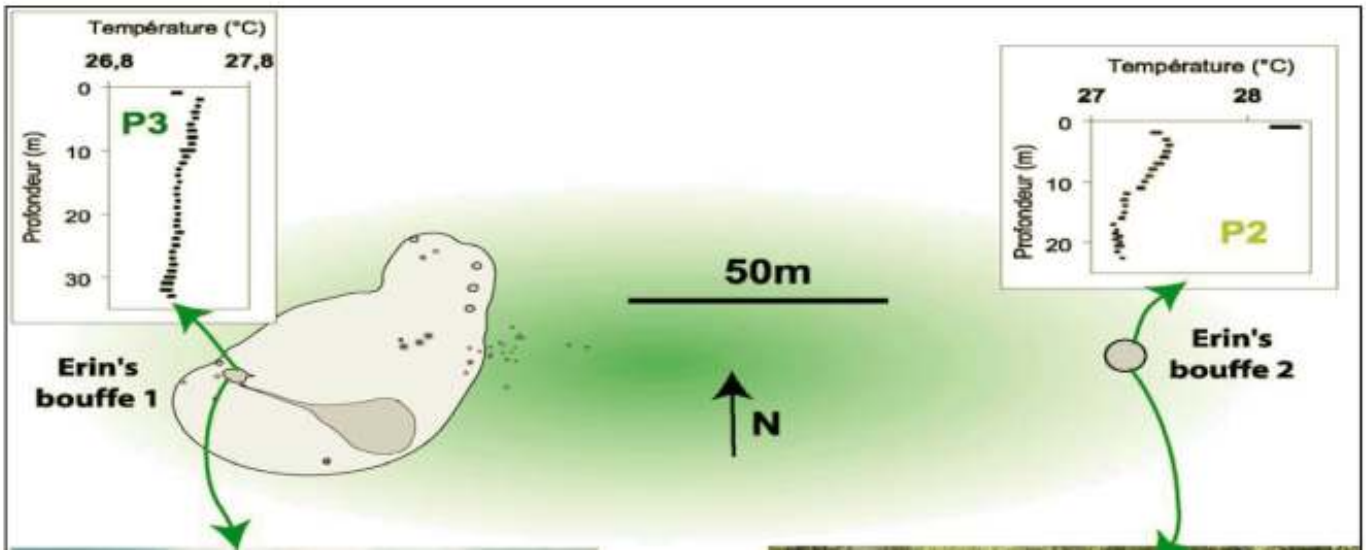


Figure 8: Temperature characteristics of Erin Bouffe (1) & (2). Deville & Guerlais 2009

Stop 2: Palo Seco Mud Volcanoes

The Palo Seco – Anglais Point area lies near the crest of the Southern Range Anticline. Downdip and to the north lies the Palo Seco field which produces oil from as shallow as 500 ft.

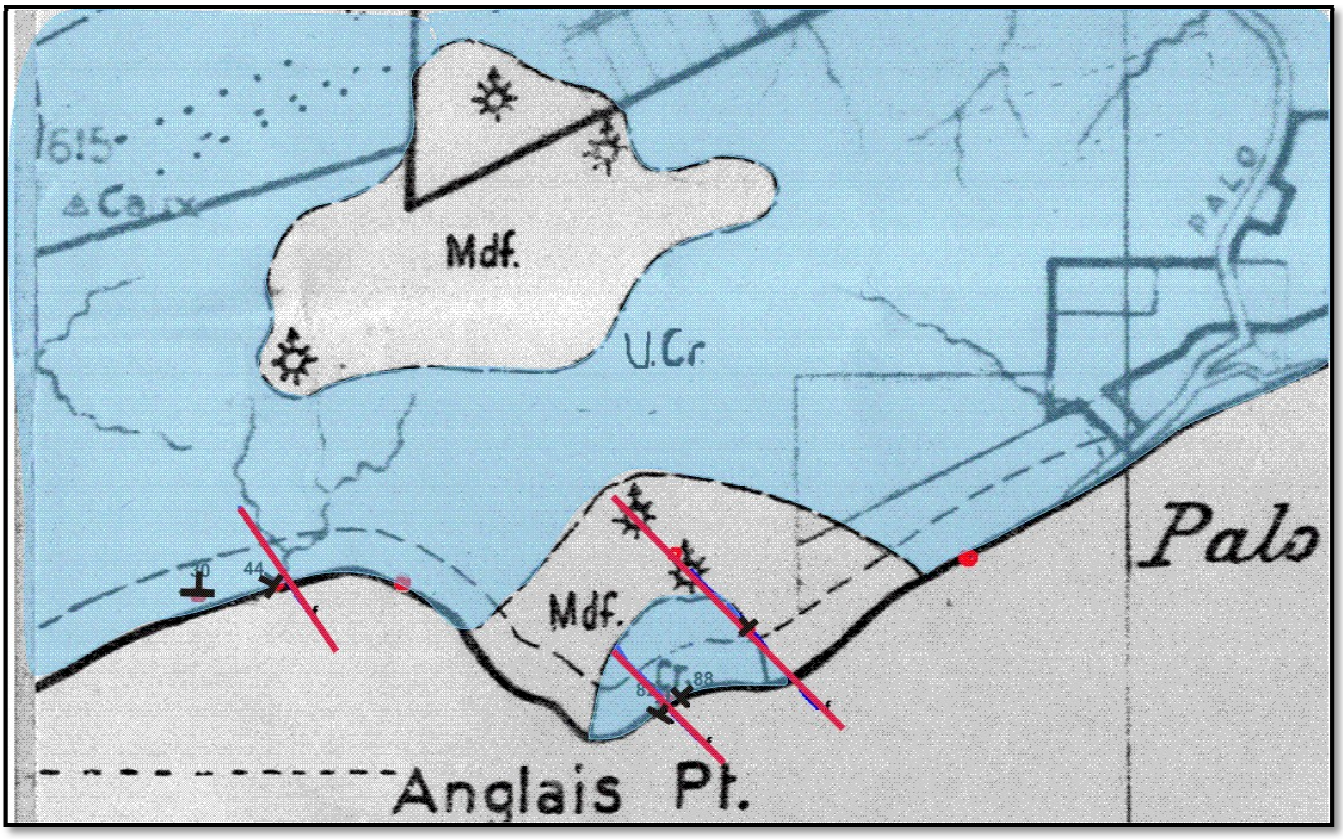


Figure 9: The Kugler surface geological map

The map above indicates that the Upper - Lower Cruse outcrops and a number of mud volcanoes exist. Nearby coastal outcrops were examined by Lackhan et al. (2005), foraminifera and pollen were recovered from samples. The forams indicated that the section lies in the N17-19 zone of L. Miocene – E. Pliocene age, Epistominella vitrea indicates a shallow water/abandonment facies, while the pollen, Dinos Symphonia, M. howardii, Mauritia and fern spores indicates a marine environment.

Location: N 1113731, E 653246 (UTM, Naparima), Elevation: 146', Area : 0.5 hectacres, 75 m in diameter. There is no real tassik in this area and the cones and pools are found in thick bush, old surveys show that the mudflows once covered 24 hectacres. No pebbles or boulders are seen around the eruptive centres, only very fine sand is seen in places where the mud has been washed away. Closer examination of the area shows that instead of a single mud volcano edifice it consists of a number of small mud pools and cones oozing mud and bubbles of gas.

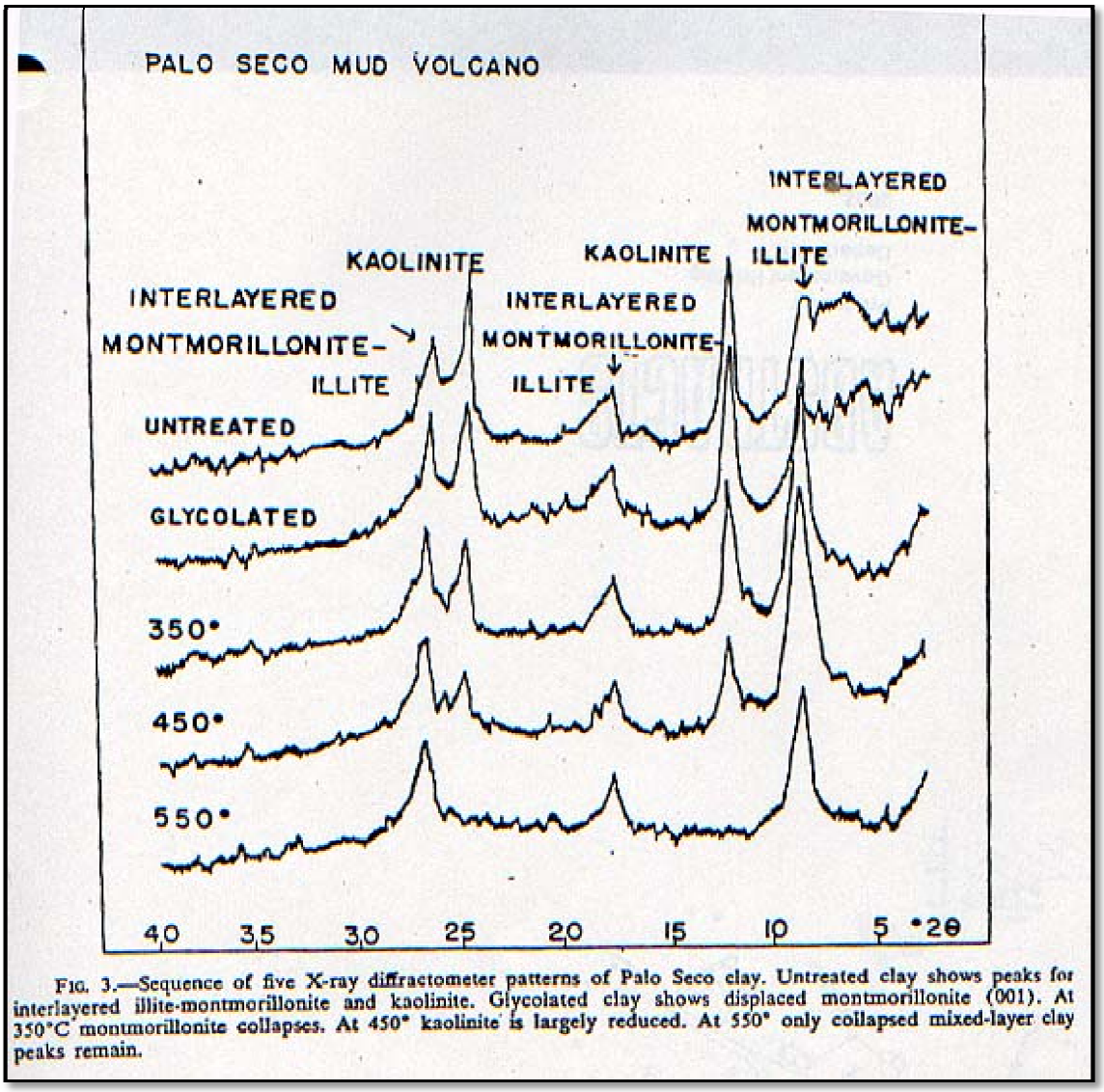


FIG. 3.—Sequence of five X-ray diffractometer patterns of Palo Seco clay. Untreated clay shows peaks for interlayered illite-montmorillonite and kaolinite. Glycolated clay shows displaced montmorillonite (001). At 350°C montmorillonite collapses. At 450° kaolinite is largely reduced. At 550° only collapsed mixed-layer clay peaks remain.

Figure 10: Sequence of five X-ray diffractor patterns of Palo Seco clay. Kerr et al 1970

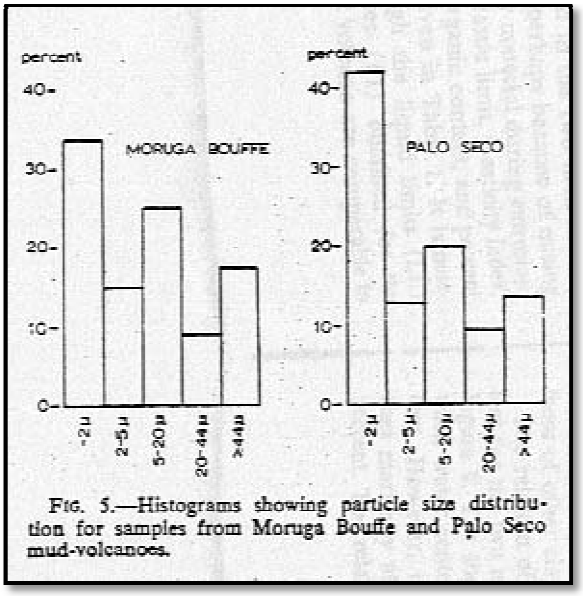


FIG. 5.—Histograms showing particle size distribution for samples from Moruga Bouffe and Palo Seco mud-volcanoes.

Figure 11: Histograms showing particle size distribution for samples from Moruga Bouffe and Palo Seco mud volcanoes. Kerr et al 1970

The coarser particles microscopically appear to consist of fine quartz.

Table 2. Location and chemical characteristics of fluid samples.

	pH	Cl (mM)	Alk (mM)	Na (mM)	K (mM)	Ca (mM)	Mg (mM)	B (mM)	SO4 (mM)	Br (mM)	SiO_2 (mM)	Li (mM)	I (mM)	Ba (μM)	Sr (μM)	Al (μM)	Rb (μM)	Cu (μM)	Mn (μM)	Zn (μM)
TD 18	7.21	297.2	40.1	321.2	0.54	1.97	2.39	6.58	<0.02	1.42	0.34	0.03	0.32	29.5	91.0	0.03	<dl	<dl	<dl	<dl
TD 20	7.53	330.3	28.0	351.3	0.54	2.02	2.47	1.45	<0.02	1.44	0.24	0.01	0.32	42.3	110.4	<dl	<dl	<dl	<dl	<dl

Table 2: Location and chemical characteristics of fluid samples.

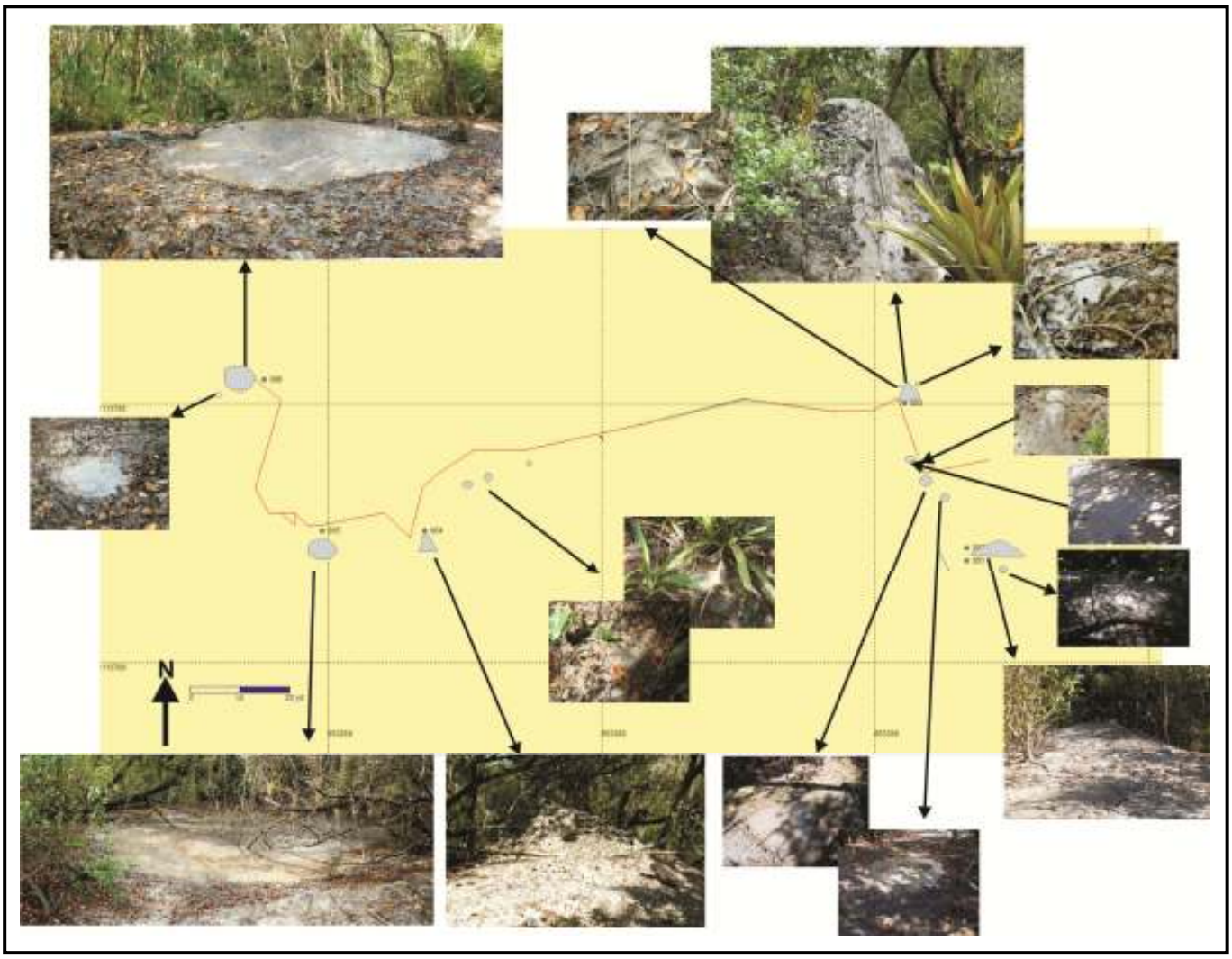
Water Analysis

PH	9.3	HCO_3	214
Cl	10,800	Fe	1
SO_4	12	Ca	4
CO_3	600	Mg	56
Total Solids	17,090	Mud density lbs/ft^3	85
Viscosity	60	Equivalent ppm NaCl	18,493
Rw	0.325		

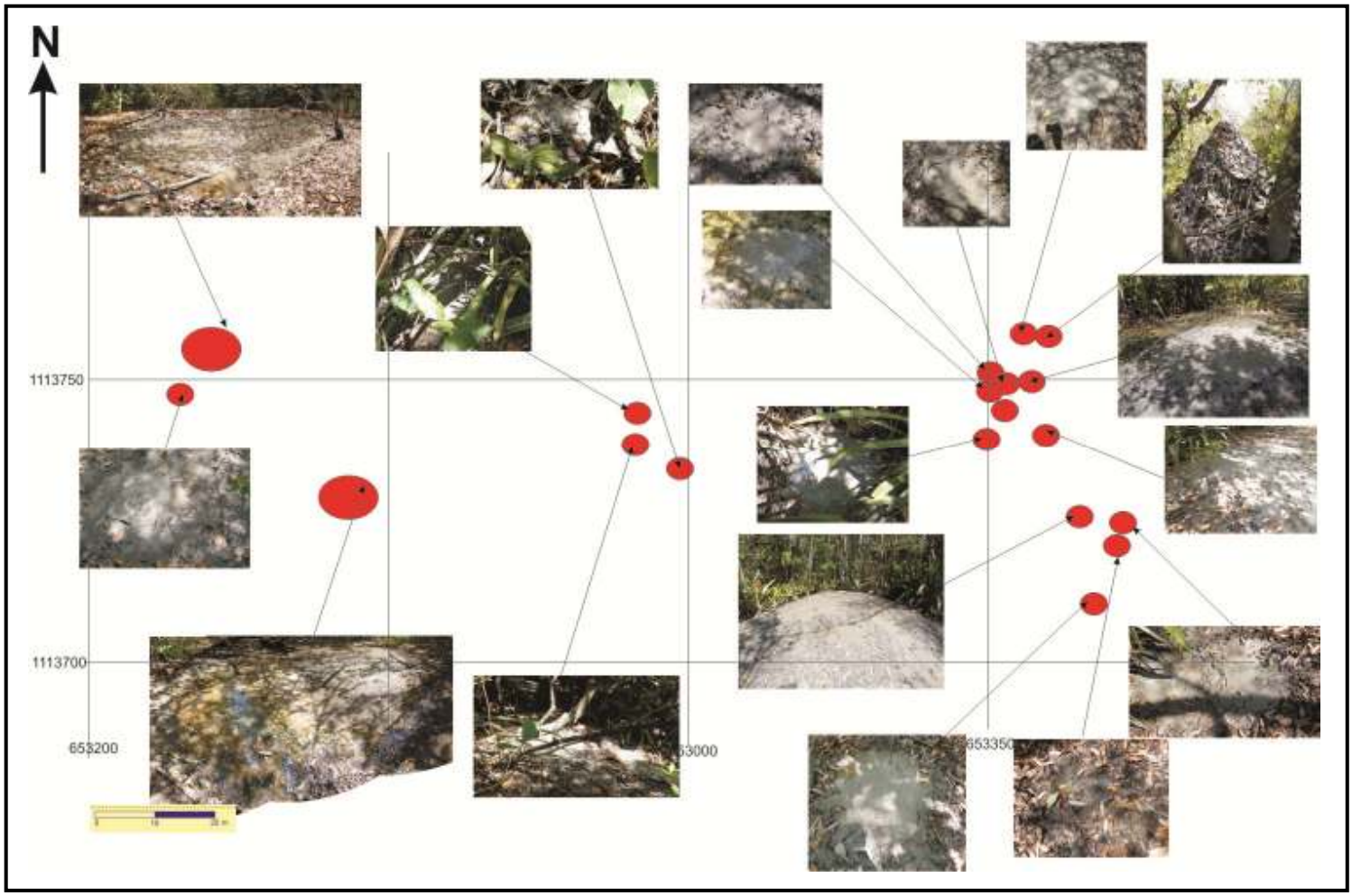
Gas Analysis

Acid Gasses – nil	Butane - nil
Methane – 97.3	Air – nil
Ethane – 1.0	Hydrogen Sulphide - nil
Propane - nil	Permanent gasses – 1.7

The gases burn with a yellow to orange, smokeless flame. DeVille et al (2002, 2003, and 2009) indicates that the gas is thermogenic in origin. Analysis of noble gas radiogenic isotopes ($^{40}Ar^*/^{20}Ne$ vs $^4He/^{20}Ne$) has shown that the residence time is shorter for the gas expelled by the mud volcanoes than for gas present in producing fields. Thus gas expelled is not from fields but from deep kitchens.



Montage 4: Location of mud vents, pools and cones in 2009



Montage 5: Location of mud vents, pools and cones in 2015

Figure 12: Principal vent, it has been classed as a caldera type by Barr and Saunders (1974).

This is the principal vent; it has been classed as a caldera type by Barr and Saunders (1974). There is a visible oil ring in the mud and sheen on the surrounding mud. A gas bubble is seen approximately every 10 seconds. The depth of this pool exceeds 150' according to DeVille (2002) and the mud temperature is slightly below atmospheric. The temperature profile down the vent continues to be below the normal geothermal gradient, probably due to cooling of the mud by gas expansion.

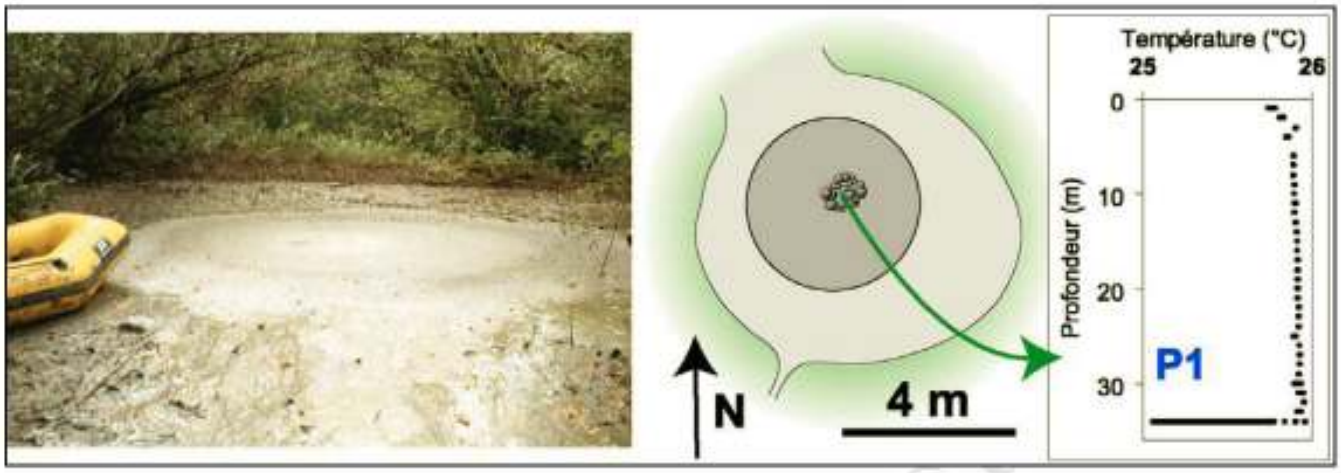
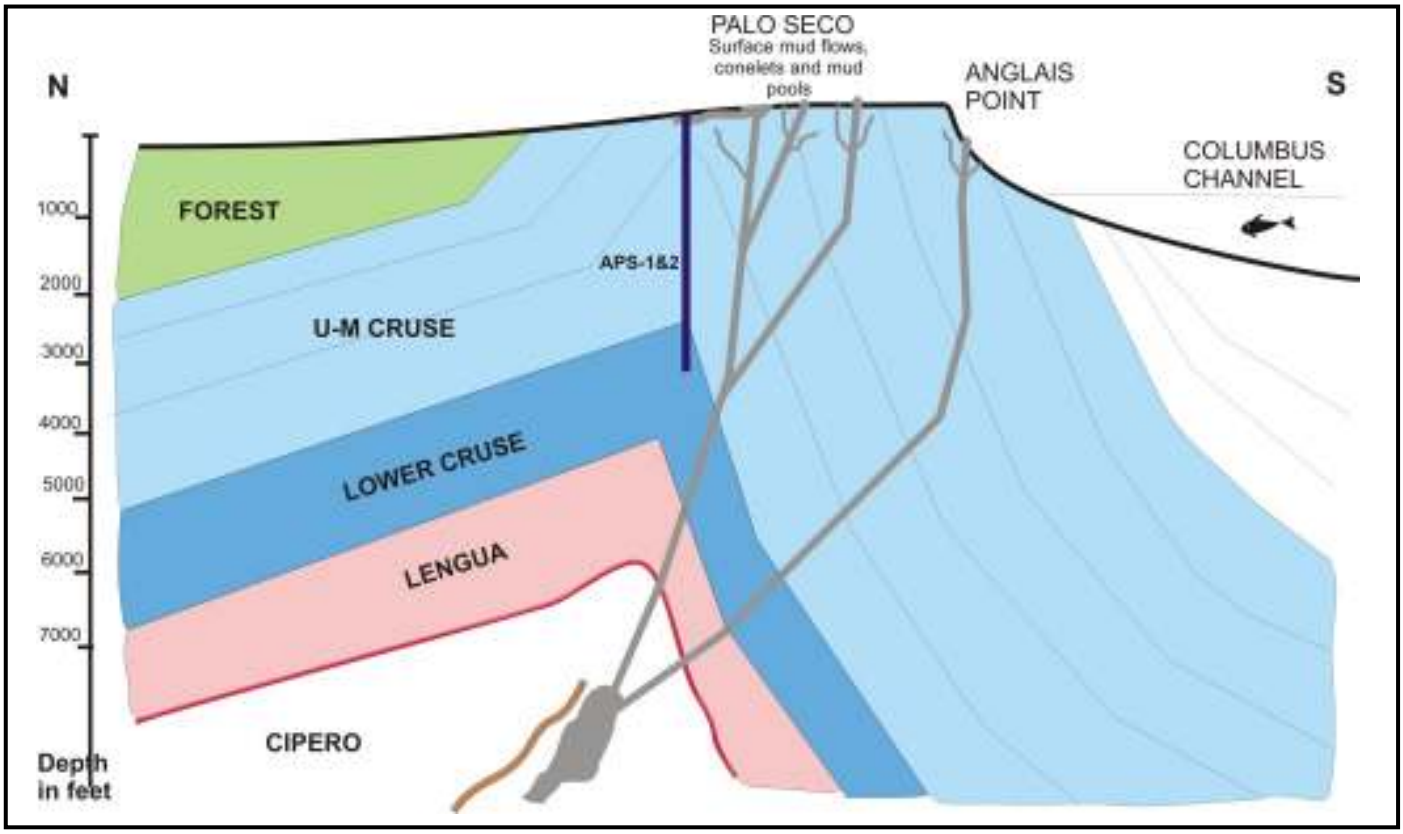


Figure 13: Temperature profile recorded in the Palo Seco mud volcano of Trinidad. Deville & Guerlais 2009



In the 1940's two wells APS-1 and 2 were drilled in the vicinity of the mud vents at Palo Seco and their lithology is claystone dominated with minor sands. This is similar to the coastal outcrops where most of the claystones are parallel laminated and individual sands range from 2-4 ft in thickness. Considerable difficulty was experienced in drilling APS-1 due to the presence of mudflows near the surface. When mud weights were raised to control the mud, circulation was lost and the well had to be abandoned (Archie 2007).