The Vegetation Surrounding Mud Volcanoes in Trinidad

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Introduction

Until recently, little attention has been directed towards the natural vegetation associated with mud volcanoes, either worldwide or here in Trinidad. Interest has been focused mainly on the geology of these sites which is reflected in the number of publications dealing with this aspect. In Trinidad, mud volcanoes were mentioned in the literature as early as 1813 when Lavayssee described the ones in Cedros. Kugler (1933, 1938, 1968) made valuable contributions to the science of sedimentary volcanism with particular reference to Trinidad, while Higgins and Saunders (1974) examined all known Trinidad sites both terrestrial and marine with respect to their geophysical and chemical properties.

With regard to the vegetation associated with Trinidad mud volcanoes, there is an unpublished study by Sharma (1990) comparing two sites (Devil's Woodyard and Karamat) and an article by Farrell (1981) on the vegetation around Moruga Bouffe. Otherwise, botanical information is scanty (Ramcharan 1978-1979, 1980 refers to Bois Neuf, Comeau 1990, 1992 deals with Karamat and Moruga Bouffe).

Amongst the local population, mud volcanoes represent something mysterious and even demonic as indicated by the names given to them, e.g. Devil's Woodyard, Morne Diablo. They have been called "solfatare", referring to sulphur (Lavayssee 1813), "salses", referring to salt (Wall & Sawkins 1860) and "bouffe", a mis-spelling and mispronounciation of the French word "bouffée" which means puff, gust, blast, whiff (the word "bouffe" means comic). One of Trinidad's mud volcanoes, Columbus, serves as a Hindu prayer site where each year around Easter the local community gathers to offer prayers for the return of the rainy season.

The following paper attempts to shed some light on the type of natural vegetation that surrounds the mud volcanoes in south Trinidad and to establish any vegetational patterns that may exist between the various sites.

Background

There are 25 confirmed active mud volcanoes in Trinidad and all are located south of the Central Range (see Fig. 1). In addition, a few occur offshore as submarine vents and have occasionally broken the surface of coastal waters, e.g. Chatham Island (Arnold 1912, Weeks 1929, Wilson & Birchwood 1965). No two terrestrial sites have the same surface expression. There is great variation with respect to vent size and cone development. Venting activity varies at each location with occasional violent eruptions taking place (see Table 1). The historical records show that spectacular eruptions take place on average every 24.6 years.

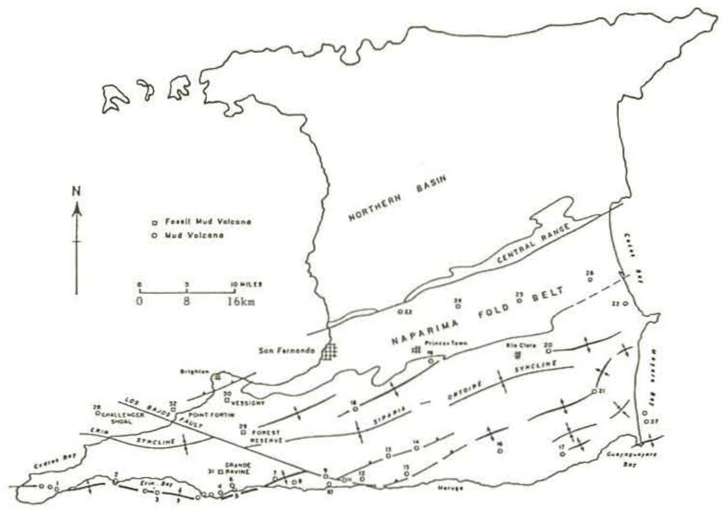

Figure 1. Map showing location of mud volcanoes in Trinidad (nos. 1-32). See Table III for corresponding names. Adapted from Higgins and Saunders.

However, mud volcanoes do have a number of physical features in common. Their venting activity is definitely elated to tectonic movement (Higgins & Saunders 1974) while their position and alignment are associated with anticlinal and fault features (Birchwood 1965). The parent bed common to all Trinidad's mud volcanoes is deep-water marine clay of Miocene age (22-25 mybp). This clay was deposited on an unstable submarine slope down which it slipped rapidly to give a low density deposit (Higgins & Saunders 1974). The pressure caused by gravity loading and tectronic movement foced the low density mud to migrate to the surface via weak spots in the earth's crust (fault lines). The mud's mobility is aided by gas and liquids embedded within.

Mud volcanoes are composed of sediment (mainly clay, see Table II), saline water (with high levels of exchangeable sodium), gas (mainly methane) and minor oil scum (approximately 40% of the Trinidad sites). The methane is colourless and odourless but burns with an orange flame. Three of Trinidad's oilfields have

Table 1 Violent Eruptions at Trinidad's Mud Volcanoes*

Mud Volcano No.	Mud Volcano	Year
1	Columbus	1906, 1966
	L'Envieuse	1860+, 1935
	Galfa Pt.	1946+
3	Chatham	1911, 1928, 1964
4	Erin	1934, 1940+, 1989 (May)o
5	Anglais Pt.	1900, 1906, 1960
15	Marac	1965
17	Lagon Bouffe	1991p
19	Devil's Woodyard	1852, 1888-9, 1906, 1942, 1969
23	Piparo	1953, 1968, 1969
24	Tabaquite	1918, 1930 (November)
27	(East Coast, Mayaro Bay)	1797
28	(Challenger Shoal)	1958

* Based on a total of 28 violent eruptions covering a period of 196 years from 1797 or 141 years from 1852. The sites in brackets are submarine. Source: Higgins and Saunders (1974).
\+ Source: Wilson and Birchwood (1965).
o Reported in the local press.
p Author's observations.

been developed within a thousand metres of active mud volcanoes, Moruga East (near Moruga Bouffe), Moruga West (near Karamat) and Barrackport-Penal (near Digity). Marac and Coora mud volcanoes have fairly large quantities of oil mixed in with the mud. Surface pH at the various sites tends to be alkaline.

The clay at Trinidad's mud volcanoes is predominantly montmorillonite (Higgins & Saunders 1974) the formation of which appears to be favoured by the alkaline conditions. The high pH is due mainly to the hydrolysis of sodium carbonate (Brady 1984). Carbonate levels are quire substantial at mud volcano sites in Trinidad (Higgins & Saunders 1974).

Surface characteristics

Some of Trinidad's active mud volcanoes (60%) display a tassik, a term originating in the Moluccas (Indonesia) for a round clearing in the forest without vegetation owing to the abundance of clay (Higgins & Saunders 1974). The tassik represents the "tip of the iceberg" in relation to the subsurface volume of mud. When present, the tassik's shape is highly variable and is the result of frequent venting of the underlying mud which is at ambient temperature when it reaches the surface. With abundant clay, cones of various heights are formed from a few centimetres up to several metres. Cones tend to be absent when the mud contains higher levels of silt, e.g. Lagon Bouffe. The mud dries quickly once it is exposed at the surface and has a tendency to flake when thinly deposited over older mud but forms deeper cracks when more thickly laid down.

Table II Textural Analysis of Mud from Selected Volcanoes in Trinidad *

Site	% Sand	% Silt	% Clay
Devil's Woodyard	13	23	64
Anglais Point	6	25	69
Moruga Bouffe	11	38	51
Palo Seco	14	32	54

* Analysis carried out by BT 300 Class, U.W.I., St. Augustine.

The number of exotics, such as pebbles and small boulders found on the surface and embedded in the mud, varies with each site and may or may not fingerprint the passage of the mud through the earth's strata. Some of the exotics may have been part of the original deposit on the sea floor. Examples of exotics include rounded and angular fragments of siltstone, sandstone, baked clay, chert, lignite and laterite.

The natural vegetation surrounding Trinidad's mud volcanoes ranges from freshwater swamp in the southwest (Islote) and east coast (Bois Neuf) to Semi-evergreen Seasonal Forest (Beard 1946) in south Trinidad from Erin Bouffe to Marac and Evergreen Seasonal Forest dominated by mora (Marshall 1934, Beard 1946) in the southeast (Moruga and Lagon Bouffe). Cultivated land around the sites includes coconut plantation in the extreme southwest (Columbus), teak forest in the Southern Watershed Reserve (Coora, Landorf, L'Eau Michel, Marac) and at Brickfield (Tabaquite), sugar-cane (Digity, Devil's Woodyard) and bananas (Piparo).

Methods

Twenty mud volcano sites have been examined by the author, 15 of which have been sampled in detail (see Table III). The main selection criteia for in-depth analysis were adequate natural vegetation surrounding the site to give an indication of what the original forest was like and accessability. Five of the 20 sites were almost completely encroached upon by agricultural land or teak plantation. Within this group, some vegetational sampling was done at Piparo. The five mud volcanoes yet to be seen are all in remote areas where access is difficult.

Once a site was chosen for detailed study a vegetation survey of the peripheral forest up to 10 m from the tassik, or the vent, and the tassik (if present) was carried out, listing the species and noting presence, abundance, habit and habitat preferences. Plants that could not be identified in the field were collected and later determined at the National Herbarium of Trinidad

Table III Trinidad's Terrestrial Mud Volcanoes *

No	Name	Mudflow Area (ha)	Dimension (m)	Shape	Tassik	Size (m)	Shape	Cones	Maximum Height(m)	Oil Scum	Comments
1	Columbus group (5)	400	5km x 1km		x	60 (d)	circular	A	0.5		two adjacent tassiks
+2	Islote	12	360 (d)	circular	x			B D	4.5	x	tassik near the lagoon
- 3	Chatham										a submarine mud volcano
4	Erin group (12)	350	5 km x 1 km		x	75 x 45		A B	6.7 t		tassik occurs at Erin Bouffe
5	Anglais Point	16			x	60 x 260	shield-type	B			mud glacier descends to beach
6	Palo Seco	24			x	75 (d)		A B D			area of active cones 0.5 ha
- 7	Chagonaray		30 (d)	circular				B C			cones occur in swampy ground
8	Coora	14	500 x 275	oval				C O		x	surrounded by teak
+9	Morne Diablo	345	2400 (d)	circular				A B	0.6		mudflow caps a hill
10	Morne Diablo Beach	7	100 (d)	circular	x	10 (d)			10.0		tassik localised near vent
11	Landorf	120	2.5 km x 0.8 km		x	30 (d)		B O	x		gas has slight sulphur smell
12	L'Eau Michel (Bunsee)	22	600 x 450	oval	x	90 x 45	oval	B D			two adjacent tassiks
13	Karamat	50		circular	x		low shield	A B	0.5		main venting centre in bush
14	Rock Dome	45	750 x 600	oval				B C	0.5		active area 60 m (d) in bush
15	Marac	25	550 (d)	circular	x	90 x 45		A	3.0	x	contains the most oil scum
16	Moruga Bouffe	100		circular	x	120 (d)	slightly domed	A B C	2.0	x	tassik covers about 2 ha
17	Lagon Bouffe	2	175 x 110	oval	x		flat	C D		x	(NE) portion underwater
+18	Digity	1.2	180 x 75	oval	x			A	4.5	x	occurs on alluvial flats
19	Devil's Woodyard	18	900 x 750	circular	x	90 (d)	low shield	A	0.6		Tourist Board disturbance
- 20	Central Balata	1.5		circular							site poorly documented
- 21	Navette		1 (d)								immature development
+22	Cascadoux	50	1000 x 670	oval				A		x	most easterly terrestrial site
23	Piparo	180	2200 x 1000	oval				C			mudflow in cultivated area
+24	Tabaquite	80	1500 x 800	oval						x	isolated cone in teak
- 25	Colenso	75		oval	x						status considered unproven
26	Bois Neuf	50	900 x 670	oval	x	15 x 25					gas is non-flammable

* Adapted from Higgins and Saunders (1974) - Not visited by the author + No sampling done

& Tobago with the aid of the Flora (1928) and reference collection. When identifications were complete, the species for each site were arranged initially according to Family (alphabetically) and categorized as tree, shrub, vine, climber, epiphyte, herb.

The natural vegetation of mud volcanoes

Three hundred and thirteen plant species representing 73 families (41% of the families known from Trinidad) were recorded in the survey of Trinidad's mud volcanoes. The most common families are the Leguminosae (Legumes), Bromeliaceae (Bromeliads, which may be terrestrial or epiphytic), Gramineae (Grasses) and Compositae (Composites). The legumes, grasses and composites are often common in other communities as well. These and other common families found at the sites are shown in Table IV.

When the species lists from the sampled mud volcanoes were compared, a number of plants showed up regularly. Those which occurred at 50% or more of the detailed sampled sites were designated as common and are listed in Table V. From this table it can be seen that only two families have more than one species commonly present, the Bignoniaceae with two and the Palmae with three. None of the species in Table V occurred at all the sites but a couple came close to total representation, namely, *Bactris major* (Roseau), a spiny palm that is often abundant on clay soils on alluvial terrain (Marshall 1934), and *Cordia curassavica* (Black Sage). Trees and shrubs make up the majority of the common plants at mud volcanoes followed by vines, climbers and epiphytes. Only two herbaceous ground dwellers are on the list of common species, *Cyperus ligularis*, a robust sedge usually found in coastal areas, and *Oeceoclades maculata*, a terrestrial orchid.

Common species at mud volcanoes, that also are characteristic of the natural forest in the Southern Watershed Reserve, include *Bravaisia integerrima* (jiggerwood), *Hura crepitans* (sandbox) and *Sabal mauritiaeformis* (Carat). These trees are important components of Marshall's (1934) *Trichilia-Brosimum* (Acurel-Moussara) Association and Beard's (1946) *Bravaisia* Faciation which belong to the same association.

There are no plants that are unique to mud volcano sites. *Croton corylifolius*, found at Morne Diablo Beach mud volcano, although previously known only from this area in Trinidad, occurs in other West Indian islands and Venezuela where it is found mainly in limestone. The species list for Trinidad's mud volcanoes includes several plants that

Table IV: Most Important Families at Mud Volcano Sites in Trinidad*

Family	No of Sites	No of Species	Frequency	Importance Value +
Leguminosae	15	25	56	96
Bromeliaceae	14	18	56	88
Gramineae/Poaceae	14	25	47	86
Compositae/Asteraceae	16	18	51	85
Palmae/Arecaceae	14	7	44	65
Moraceae	14	9	35	58
Bignoniaceae	14	10	30	54
Cyperaceae	14	13	27	54
Sapindaceae	13	9	30	52
Euphorbiaceae	12	11	28	51
Orchidaceae	13	11	26	50
Rubiaceae	12	11	25	48
Polypodiaceae	8	14	26	48
Araceae	11	8	24	43

* Based on 16 sampled sites
+ Importance Value = No. of Sites + No. of Species + Frequency

are considered to be rare or endangered in Trinidad and Tobago (see Table VI). Palo Seco mud volcano has the most of these species (six) followed by Morne Diablo Beach and Bois Neuf (four each). The criteria for determining what is a threatened plant have been dealt with by Adams and Baksh (1981-1982). Three of the species in Table VI are thought to be endemic, *Philodendron fendleri* (Trinidad), *Philodendron krugii* and *Basanacantha phyllosepala* (Trinidad and Tobago).

The following geographical areas have been designated in south Trinidad: the Southwest, which includes Columbus, Erin, Anglais Pt. and Palo Seco (all coastal or near-coastal), South Central Coastal, which includes Coora, Morne Diablo Beach, Landorf and L'Eau Michel, South Central Inland, which includes Karamat, Rock Dome and Marac, Southest, which includes Moruga and Lagon Bouffe (both inland), North Central, which includes Devil's Woodyard and Piparo, and East (Bois Neuf).

Some mud volcano plants show distinct distribution patterns in relation to the mud volcanoes. The following eight plants occurred in two or more mud volcanoes in the Southwest geographical area: *Conocarpus erectus* (Combretaceae), *Anguira umbrosa* (Cucurbitaceae), *Hippomane mancinella* (Euphorbiaceae), *Paspalum vaginatum* (Graminaea), *Hiraea reclinata* (Malpighiaceae), *Chiococca alba* and *Genipa americana* (Rubiaceae) and *Fagara pterota* (Rutaceae). *Picramnia pentandra* (Simaroubaceae) was the only plant found at more than one site in the South Central Coastal area. In the Southeast geographical area the following species occured at both Moruga and Lagon Bouffe: *Mikania micrantha* (Compositae), *Epidendrum fragrans* (Orchidaceae), *Coccoloba latifolia* (Polygonaceae), *Nephrolepis biserrata* and *Polypodium piloselloides* (Polypodiaceae). *Isocarpha billbergiana* (Compositae) was the only plant found at more than one site in the North Central area while eighteen species were restricted in the

Table V: Most Common Plants at Trinidad's Mud Volcanoes*

Family	Species (Total: 21)	No of Sites	Percent	Habit
Acanthaceae	Bravaisia integerrima	11	69	T
Araceae	Philodendron acutatum	8	50	E
Bignoniaceae	Cresentia sp.	8	50	sT
	Phryganocydia corymbosa	8	50	C
Boraginaceae	Cordia curassavica	14	88	S
Bromeliaceae	Gravisia aquilega	12	75	t/E
Cactaceae	Hylocereus lemairei	9	56	V
Compositae	Baccharis trinervis	8	50	S
(Asteraceae)	Pluchea carolinensis	11	69	S
Cyperaceae	Cyperus ligularis	10	63	H
Ebenaceae	Diospyros inconstans	12	75	sT
Erythroxylaceae	Erythroxylum ovatum	9	56	S
Euphorbiaceae	Hura crepitans	10	63	T
Moraceae	Ficus amazonica	9	56	T
Nyctaginaceae	Pisonia salicifolia	9	56	sT
Orchidaceae	Oeceoclades maculata	8	50	tH
Palmae	Bactris major	14	88	sT
(Arecaceae)	Desmoncus orthacanthos	10	63	C
	Sabal mauritiaeformis	10	63	T
Sapindaceae	Paullinia fuscens	9	56	C
Vitaceae	Cissus sicyoides	11	69	V

* Based on 16 sampled sites.

T = tree	t/E = terrestrial or epiphytic	E = epiphyte
V = vine	sT = small tree	H = herbaceous
C = climber	tH = terrestrial herb	S = shrub

Table VI Rare Plants found at Mud Volcanoes in Trinidad +

Family	Species (Total: 13)	No. of Occurences
Araceae	* Philodendron fendleri	1
	* Philodendron krugii	2
Bromeliaceae	Bromelia plumieri	7
Compositae/Asteraceae	Pluchea quitoc	1
Euphorbiaceae	Croton corylifolius	1
Gramineae / Poaceae	Lasiacis sorghoidea	3
Moraceae	Ficus gomelleira	4
	Ficus schumacheri	2
Orchidaceae	Oncidium lanceanum	1
Polygonaceae	Coccoloba cruegeri	1
Rubiaceae	* Basanacantha phyllosepala	3
Sapotaceae	Sideroxylon quadriloculare	1
Tiliaceae	Corchorus siliquosus	1

+ Based on an unpublished Herbarium Checklist. * Endemic

East geographical area to Bois Neuf. Only one of these plants, *Stigmaphyllon granadense* (Malpighiaceae) has a mainly east coast distribution.

Higgins and Saunders (1974) place Trinidad's mud volcanoes into three stratigraphic groups, the Nariva Formation (Piparo and Tabaquite) which has mud dating from the Lower Miocene (22 mybp), the Karamat Formation (Karamat, Rock Dome, Marac, Central Balata and Navette) which has younger mud but still dating from the Lower Miocene, and the Lower Cruse-Lengua Formation with mud of Mid-Miocene age (12-14 mybp). This last formation is divided into the following subgroups: a) Southern Anticline (Columbus, Islote, Erin, Anglais Pt., Palo Seco, Chagonaray, Coora and Morne

Diablo Beach), b) Los Bajos Fault (Morne Diablo, Landorf and L'Eau Michel), c) those occurring above Cretaceous material (Moruga and Lagon Bouffe) d) Siparia-Ortoire Syncline (Digity and Devil's Woodyard) and e) the Rio Claro Boulder Bed (Cascadoux and Bois Neuf).

The only good correlations between the Higgins and Saunders stratigraphic groups and the geographical areas presented previously are the Southeast sites (Moruga and Lagon Bouffe), which correspond to Subgroup 3 of the Lower Cruse-Lengua Formation, and the East site (Bois Neuf), which corresponds with the Rio Claro Boulder Bed. Moruga and Lagon Bouffe of the Southeast area or Subgroup 3 have less clay in the mud (see Table II) and very few exotics (Higgins and Saunders 1974) which may have some bearing on the composition of plants at these sites. Of the five plants previously mentioned as being restricted to the Southeast mud volcanoes, three are mainly epiphytic and only *Coccoloba latifolia* shows a preference for sandy or silty soil being common in savannas in north Trinidad. Otherwise, it is difficult to determine a relationship between stratigraphical groups and vegetation distribution patterns.

A few plants found at mud volcanoes show a strong preference for dry areas and are restricted in their distribution to south or southwest Trinidad and the northwest part of the island where the driest conditions prevail (Marshall 1934). These include *Ditaxis polygama* (Euphorbiaceae), *Albizia caribaea* and *Machaerium robinifolium* (Leguminosae), *Hiraea reclinata* (Malpighiaceae) and *Guettarda farnesiana* (Rubiaceae). Based on Herbarium collections and field surveys, a small number of plants recorded at mud volcano sites appear to have only a south distribution in Trinidad. Included here are *Croton corylifolius*, which was mentioned earlier, plus *Mikania cordifolia* (Compositae), *Eugenia procera* (Myrtaceae), *Oncidium lanceanum* (Orchidaceae) and *Casearia decandra* (Samydaceae). Further collections and surveys may extend their range as was the case with *Oncidium luridum* which was believed to have been from the south only until it was recently picked up at Bois Neuf mud volcano and at a hillside quarry in north Trinidad.

Geochemical influences on mud volcano vegetation

Apart from the high clay content found at all the sites, high salinities and high alkalinity of mud volcanoes influence the type of vegetation that is likely to become established in the vicinity of the sites. Large numbers of coastal plants are found at mud volcanoes, even when the sites are located far from the sea. Devil's Woodyard, for example, is approximately 15km (9.5 miles) from the nearest coastline and has five coastal species present while the high salinity at Moruga Bouffe, located nearly five km (3 miles) inland from the south coast, attracts species like *Sesuvium portulacastrum* (Aizoaceae), an edible wild plant commonly known as Seaside Purslane.

Twenty six species with coastal affinity (see Table VII) were noted in the vegetation survey of 16 mud volcanoes. These plants form part of the vegetation component of every sampled site ranging from 22 percent of the species recorded for Columbus to three percent of those listed for Marac. Only one plant on the list did not occur at an inland location, namely *Ipomoea stolonifera* (Convolvulaceae) which was found at Anglais Pt. The two species with the highest number of occurrences are *Cyperus ligularis* (Cyperaceae) and *Diospyros inconstans* (Ebenaceae) which in combination are present at nearly all the sample sites, the exception being Marac. A few of the coastal plants are abundant or common at several mud volcanoes. For example, *Rhabdadenia biflora* (Apocynaceae) is abundant at Karamat, *Fimbristylis cymosa* (Cyperaceae) at Devil's Woodyard, *Hippomane mancinella* (Euphorbiaceae) at Erin and *Paspalum vaginatum* (Gramineae) at Columbus. At this latter site, *Conocarpus erectus* (Combretaceae) is ranked as being common and, together with *Hippomane*, has a similar status at Palo Seco. Hippomane is a poisonour plant with a toxic latex (Seaforth 1988).

Mud volcanoes surrounded by large tracts of natural vegetation (Columbus, Erin, Anglais Pt., Palo Seco, Morne Diablo Beach, Karamat, Moruga and Lagon Bouffe, Bois Neuf) have a higher average percentage of coastal plants (13%) than those sites encrouched upon by cultivated land (Coora, Landorf, L'Eau Michel, Marac, Rock Dome, Devil's Woodyard, Piparo) where the average is nine percent (Table VII). The percentage for Piparo is disproportionately large owing to the limited amount of vegetaional sampling done at the site. (This is also true of the weeds recorded at this site; see Table IX). Sites surrounded by teak plantation (Coora, Landorf, L'Eau Michel, Marac), have the fewest coastal plants, six percent on average, whereas the coastal mud volcanoes (Erin, Anglais Pt., Morne Diablo Beach) have the most, fourteen pecent on average.

There is also a tendency for coastal plants at the mud volcanoes in south Trinidad to increase their percentage values from east to west sites (see Table VII). Rainfall decreases as you move from the Evergreen Seasonal (Mora) Forest around Lagon Bouffe to the Semi-evergreen (Acurel-Moussara) Forest at Erin and Anglais Pt. (Marshall 1934). With this decrease in precipitation there is a decrease in atmospheric flushing which allows higher salt concentrations to persist in the mudflow at the volcanoes thus a higher percentage of coastal plants.

Table VII Coastal Plants Found at Mud Volcanoes in Trinidad

Family	Species (Total: 26)	Columbus	Erin	Anglais	Palo Seco	Coora	Morne DB	Landorf	L'Eau M	Karamat	Rock Dome	Marac	Moruga	Lagon	Devil's W	Piparo	Bois Neuf	No of Occurrences
Aizoaceae	Sesuvium portulacastrum												x					1
Apocynaceae	Rhabdadenia biflora		x							x			x	x	x			5
Asclepiadaceae	Sarcostemma clausum									x							x	2
Bromeliaceae	Tillandsia flexuosa	x	x		x				x									4
Burseraceae	Bursera simaruba					x	x		x	x		x						5
Capparidaceae	Capparis flexuosa	x	x	x	x		x											5
	Crateva tapia																x	1
Combretaceae	Conocarpus erectus	x			x													2
	Laguncularia racemosa												x					1
Compositae / Asteraceae	Wedelia trilobata															x		1
Convolvulaceae	Ipomoea stolonifera			x														1
Cyperaceae	Cyperus ligularis			x	x	x			x	x	x		x	x	x		x	10
	Fimbristylis cymosa														x			1
Ebenaceae	Diospyros inconstans	x	x	x	x	x	x	x	x	x			x			x	x	12
Euphorbiaceae	Hippomane mancinella		x	x	x													3
Gramineae / Poaceae	Brachiaria distachya	x																1
	Panicum milleflorum														x			1
	Paspalum vaginatum	x			x													2
Leguminosae - M *	Entada polystachya		x	x	x		x					x	x					6
Malvaceae	Hibiscus tiliaceus													x				1
Marantaceae	Maranta gibba						x							x				2
Palmae / Arecaceae	Coccothrinax barbadensis		x	x						x								3
Polypodiaceae	Acrostichum aureum							x	x	x								3
	Acrostichum danaefolium										x		x	x				3
Verbenaceae	Citharexylum fruticosum	x	x						x						x			4
	Stachytarpheta jamaicensis															x		1
	No. of coastal plants at each site	7	8	7	8	3	5	2	6	7	2	2	7	5	5	3	4	
	Total no. of species at each site	32	57	43	68	32	46	45	80	41	21	58	71	95	54	15	70	
	Coastal plants as a percent (%) of total	22	14	16	12	9	11	4	8	17	10	3	10	5	9	20	6	

* M = Mimoseae

Another interesting feature to emerge from the vegetational analysis of the mud volcano sites is the large number of species present that are known to grow in limestone areas (see Table VIII). Plants like *Erythroxylum ovatum* (Erythroxylaceae), *Chlorophora tinctoria* (Moraceae) and *Randia aculeata* (Rubiaceae) are found at many of the sampled sites. Mud volcanoes with the highest number of plants with limestone affinities are L'Eau Michel, Palo Seco and Columbus, while none was noted at Rock Dome and one each were recorded for Lagon Bouffe and Piparo. All the mud volcanoes occur in non-limestone areas south of the Central Range where sandstone is the predominant parent rock type. It seems likely that the controlling factor here is the slight alkalinity of the volcano mud which attracts plants that also prefer the slightly alkaline environment of limestone areas.

Another geochemical factor that may influence the vegetation around mud volcanoes is the presence of oil scum which occurs at about 40 percent of the sites but is most pronounced at Coora and Marac, especially the latter where it forms a coating over the surface of the mud which is firm enough to walk on. Two species were found which are almost exclusive to these two sites, *Rauwolfia ligustrina* (Apocynaceae), which also occurs at Moruga Bouffe, and *Malachra fasciata* (Malvaceae), which is also present at L'Eau Michel. What may be more significant are the families that are absent from these oil bearing sites but which are often found at other mud volcanoes, namely the Asclepiadaceae, Guttiferae and Rubiaceae but especially the Cactaceae (Cacti) and Polypodiaceae (ferns) which may be sensitive to oil pollution.

Little information is available about the effect methane gas has on natural vegetation, but its levels are high at mud volcanoes compared to other gasses being vented at the sites (Higgins and Saunders 1974). As far as is known, methane has no adverse effect on the vegetation in the vicinity of the volcanoes but the matter warrants further investigation.

Human impact on the vegetation at mud volcanoes in Trinidad.

Weeds are a good indicator of disturbance in the natural environment. In this paper, a weed is defined as a plant that usually grows in waste places (roadsides, abandoned land), pastures or cultivated ground. Weeds form a large component of the vegetation at three mud volcanoes, L'Eau Michel, Marac and Devil's Woodyard (see Table IX) where human disturbance is significant. The average percent of weeds at these sites is quite high (31%) compared to that at mud volcanoes surrounded by tracts of natural forest where human impact is low (7%). The average percentage becomes even lower (4%) when only the remote sites (Morne Diablo Beach, Landorf, Karamat, Moruga and Lagon Bouffe) are considered.

Both L'Eau Michel and Marac are surrounded by teak plantation. L'Eau Michel has a buffer zone of natural vegetation but at Marac the teak forest borders right on the tassik. Fire, which frequently occurs in teak stands during the dry season, will affect the Marac site which is covered in oil scum. Weeds, which can tolerate this type of disturbance, will prevail. Marac also has the lowest percent of coastal plants. As these plants normally grow where fire is not a factor, they are very vulnerable to this type of disturbance having no propagation modes adapted to frequent burning. A good example is *Cyperus ligularis*, a robust coastal sedge often found at mud volcanoes but absent from Marac.

L'Eau Michel and Devil's Woodyard are subject to frequent visitor use, especially the latter, which may help to explain the large number of weeds at these sites. The weeds at L'Eau Michel are concentrated near the entry point onto the tassik, being scanty around the rest of the perimeter. Devil's Woodyard is located in a sugar cane region and most of its natural forest border has been removed by cutting and fire. Livestock are allowed to graze around the perimeter which influences plant growth near the tassik (Sharma 1990).

Slightly more than 50 percent of the weedy species found at mud volcano sites belong to three families (Compositae, Gramineae, Leguminosae). The most common genus is *Solanum* (Solanaceae) while *Eupatorium odoratum* and *Vernonia cinerea* (Compositae) plus *Enicostema verticillatum* (Gentianaceae) occur at the largest number of sites.

Some weeds are known to have medicinal properties and have been used in folk medicine. Several of these occur at the mud volcano sites, for example *Lantana camara* (Verbenaceae), the young shoots of which are used to make a tea for the treatment of colds and fever (Seaforth 1988). *Lantana* is also a poisonous plant, especially the immature berries (Lampe and McCann 1985).

The uniqueness of mud volcano vegetation

As already stated, mud volcanoes in Trinidad have no plant species that are restricted to the sites and are found nowhere else. The plants that do grow at or near the active vents, however, have to tolerate rather unusual adverse physical and chemical conditions. They are subject to burial by mud which can damage the vegetation. Recent eruptions (1992?) at Lagon Bouffe have killed a section of the peripheral forest. The eruption from two vents came from within the forest itself and not from the open tassik area. A new tassik is forming also inside the forest at Karamat mud volcano two hundred metres east of the old tassik. Here too, trees

Table VIII: Species known to occur in Limestone Areas that are also found in Mud Volcanoes in Trinidad

Family	Species (Total: 20)	Columbus	Erin	Anglais	Palo Seco	Coora	Morne DB	Landorf	L'Eau M	Karamat	Marac	Moruga	Lagon	Devil's W	Piparo	Bois Neuf	No of Occurrences
Bromeliaceae	Guzmania lingulata								x								1
	Guzmania monostachia				x												1
Burseraceae	Bursera simaruba					x	x		x	x	x						5
Compositae/Asteraceae	Eupatorium odoratum				x		x		x		x		x			x	6
Erythroxylaceae	Erythroxylum ovatum	x	x	x	x	x	x		x	x		x					9
Euphorbiaceae	Croton corylifolius						x										1
Gramineae/Poaceae	Oplismenus hirtellus			x	x	x	x	x	x								6
Leguminosae - M *	Acacia farnesiana	x															1
Moraceae	Brosimum alicastrum															x	1
	Chlorophora tinctoria	x		x		x		x	x					x		x	7
	Fiscus maxima															x	1
Piperaceae	Peperomia glabella															x	1
Rubiaceae	Chiococca alba	x	x		x												3
	Randia aculeata	x	x	x	x		x			x		x					7
Rutaceae	Fagara pterota	x	x		x												3
Samydaceae	Casearia sylvestris				x												1
Sapindaceae	Sapindus saponaria					x			x								2
Tiliaceae	Corchorus siliquosus														x		1
	Muntingia calabura						x	x	x								3
Verbenaceae	Citharexylum fruticosum	x	x						x					x			4
	No. of sp. with limestone affinities	7	5	4	8	5	6	3	9	4	2	2	1	2	1	5	
	Total no. of species at each site	32	57	43	68	32	46	45	80	41	58	71	95	54	15	70	
	Limestone affiliates as (%) of total	22	9	9	12	16	13	7	11	10	3	3	1	4	7	7	

* M = Mimoseae

Table IX: Weeds Found at Mud Volcanoes in Trinidad

Family	Species (Total: 58)	Columbus	Erin	Anglais	Palo Seco	Coora	Morne DB	Landorf	L'Eau M	Karamat	Rock Dome	Marac	Moruga	Lagon	Devil's W	Piparo	Bois Neuf	No of Occurrences
Acanthaceae	Blechum pyramidatum								x			x			x	x		4
	Ruellia tuberosa	x							x						x	x		4
Amaranthaceae	Achyranthes indica			x														1
Boraginaceae	Tournefortia hirsutissima											x						1
Compositae/Asteraceae	Bidens cynapiifolia								x									1
	Brickellia diffusa											x						1
	Calea solidagnea			x														1
	Eclipta alba											x					x	2
	Emilia sonchifolia														x			1
	Erechthites hieracifolia																x	1
	Eupatorium odoratum			x			x		x			x		x			x	6
	Synedrella nodiflora															x		1
	Vernonia cinerea		x				x					x		x	x		x	6

Table IX: Continued

Family	Species (Total: 58)	Columbus	Erin	Anglais	Palo Seco	Coora	Morne DB	Landorf	L'Eau M	Karamat	Rock Dome	Marac	Moruga	Lagon	Devil's W	Piparo	Bois Neuf	No of Occurrences
Cyperaceae	Abildgaardia ovata										x							1
	Wedelia trilobata															x		1
	Cyperus articulatus											x						1
	Cyperus rotundus			x														1
Euphorbiaceae	Euphorbia glomerifera														x			1
	Phyllanthus urinaria								x									1
Gentianaceae	Enicostema verticillatum								x	x		x		x	x			5
Gramineae/Poaceae	Acroceras zizanioides														x			1
	Andropogon bicornis											x			x			2
	Brachiaria fasciculata		x															1
	Brachiaria reptans								x									1
	Chloris barbata		x	x							x							3
	Chloris radiata														x			1
	Cynondon dactylon				x				x									2
	Dichanthium annulatum														x			1
	Enchinochloa colonum								x									1
	Eleusine indica														x			1
	Leptochloa virgata				x							x						2
	Panicum maximum	x																1
	Paspalum conjugatum								x								x	2
Labiatae/Lamiaceae	Hyptis capitata								x							x		2
	Hyptis pectinata											x						1
Leguminosae - P *	Aeschynomene americana								x									1
– P	Alysicarpus vaginalis														x			1
- P	Centrosema pubescens											x						1
- P	Desmodium adscendens													x				1
- P	Desmodium canum											x						1
- P	Flemingia strobilifera								x			x			x	x		4
- M	Mimosa pudica								x						x			2
Malvaceae	Malachra alceifolia								x					x	x			3
	Malachra fasciata					x			x			x						3
	Sida acuta								x			x			x			3
Myrtaceae	Psidium guajava														x			1
Rubiaceae	Borreria ocymoides								x									1
	Hamelia erecta							x										1
	Hemidiodia ocymifolia														x			1
Scrophulariaceae	Stemodia durantifolia														x			1
Solanaceae	Solanum jamaicense									x	x	x			x			4
	Solanum scabrum																x	1
	Solanum stramoniifolium											x	x	x			x	4
	Solanum torvum		x	x		x	x											4
Tiliaceae	Corchorus siliguosus															x		1
Verbenaceae	Lantana camara											x						1
	Stachytarpheta cayennensis	x										x						2
	Stachytarpheta jamaicensis															x	x	1
	No. of weedy species at each site	3	4	5	3	2	3	1	18	2	3	20	1	6	20	8	7	
	Total no. of species at each	32	57	43	68	32	46	45	80	41	21	58	71	95	54	15	70	
	Weeds as a percent (%) of total	9	7	12	4	6	7	2	23	5	14	34	1	6	37	53	10	

* P = Papilionatae; * M = Mimoseae

are being buried and killed by the mud which flows easily when freshly vented.

In addition to burial by mud, the frequent expansion and contraction of the montmorillonite clay causes damage to the plant roots. When thick mud deposits dry quickly, large cracks occur. These will disappear once the rains return. The clay at mud volcano sites is very compact which retards root penetration.

The chemical composition of the mud at the volcanoes makes it quite toxic to vegetation when it first reaches the surface. The pH values obtained by Higgins and Saunders (1974) at nine sites ranged from 7.6 to 9.4 (average 8.7). Sharma (1990) also did pH determinations for Karamat and Devil's Woodyard. The former had values ranging from 9.0 in the centre of the tassik to 8.0 inside the forest while the latter had pH values ranging from 8.5 to 7.7 (8.1 at the centre of the tassik). Farrell (1981) in his study of Moruga Bouffe, obtained a pH value of 8.2. These readings give an indication of the alkaline conditions at various sites. It addition to high pH, very high salinity levels which approximate sea water are characteristic of the mud volcanoes. In their analysis of water samples from eight sites, Higgins and Saunders (1974) had salt concentrations ranging from 45,373 ppm at Moruga Bouffe to 2,766 ppm at Piparo (average of 17,642 ppm). Farrell's (1981) analysis of a water sample from Moruga Bouffe showed a composition of 0.96% salt. These high levels will only be maintained near the active vents, otherwise precipitation will flush out and dilute these high salt concentrations making the non-venting areas a less toxic environment for plant growth. The increase in the percentage of costal plants at mud volcanoes in southwest Trinidad (see Table VII) where less rainfall occurs helps to substantiate this hypothesis. It should also be mentioned that ferns, which are good indicators of wetter conditions, are noticeably absent from the southwestern mud volcano sites. Atmospheric flushing also may reduce the pH levels as these are maintained by the hydrolysis of sodium carbonate. Once hydrolysis takes place and no more sodium carbonate is added, then flushing will dissipate the bicarbonate and hydroxide ions and lower the pH.

Once venting ceases at a site then colonization of the tassik can progress rapidly. Some of the early colonizers will be sedges like *Cyperus ligularis*, vines and creepers like *Rhabdadenia biflora* (Apocynaceae) and shrubs such as *Pluchea carolinensis* (Compositae). Sometimes a species will establish itself so successfully it will dominate large sections of the dormant tassik. This is the case at Devil's Woodyard where *Fimbristylis cymosa* (Cyperaceae) forms a discontinuous mat over large sections of the surface, but it is the only site where this species has been observed, so its presence must be due purely to the chance that it was the first to arrive and the one to survive. This may be the case as well for *Paspalum vaginatum* (Gramineae) at Columbus which dominates the dormant tassik to the exclusion of most other species. It too is not a "typical" or common mud volcano plant and chance, therefore, may have been a factor in establishment. Both these species can proliferate vegetatively by rhizomes which has probably contributed to their abundance at their respective sites. Once dominance is established then succession can be slowed down.

This is certainly not the case at Karamat mud volcano where the large dormant tassik is being quickly colonized by vegetation. This rapid succession has taken place since 1990 when Sharma did a detailed vegetation survey of the site and found little vegetation on the tassik's surface. In addition to some of the early colonizers already mentioned, another creeper *Sarcostemma clausum* (Asclepiadaceae) and *Gravisia aquilega* (Bromeliaceae) are well established around the margin. If the site remains dormant for a prolonged period, natural reafforestation will take place with trees like *Bravaisia integerrima* (Acanthaceae), *Cresentia* sp. (Bignoniaceae), *Diospyros inconstans* (Ebenaceae), *Bactris major* and *Sabal mauritiaeformis* (Palmae) forming part of the forest cover.

Mud volcanoes, because of their nature and unpredictability, attract attention and can become vulnerable to exploitation. This has already happened at Devil's Woodyard while other sites have been impacted upon by plantation forestry and agricultural development (Digity and Cascadoux). This paper has attempted to show plant composition and vegetational patterns at the sites and establish the floristic and ecological framework upon which other studies can proceed. A number of interesting physiological problems need to be investigated such as the effects of methane on plant growth, whether or not some of the terrestrial Bromeliads develop a soil dependency and the various adaptive mechanisms plants at mud volcanoes have developed to help them survive the toxic conditions. The answers to these problems will increase our awareness and understanding of the uniqueness and importance of mud volcanoes in Trinidad.

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