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FINAL REPORT
GEOTHERMAL RESOURCES PROJECT-STAGE ONE

PART 4
SURFACE GEOLOGY
SOUTH VOLCAN MOMOTOMBO FUMAROLES

Prepared for

GOVERNMENT OF NICARAGUA
Ministry of Economy, Industry and Commerce

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TEXAS INSTRUMENTS INCORPORATED
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PREFACE

This Final Report on STAGE ONE of the Nicaraguan GEOTHERMAL RESOURCES PROJECT is submitted to the Government of Nicaragua by TEXAS INSTRUMENTS INCORPORATED in Spanish and English versions.

The report is the work of several authors and consists of ten parts, or chapters, each of which is bound separately, as follows:

Part 1 - PROJECT SUMMARY, by D. E. Heilner and L. T. Braun

Part 2 - REGIONAL GEOLOGY: Thermal Manifestations of Western Nicaragua, by John B. Thigpen

Part 3 - SURFACE GEOLOGY: San Jacinto-Tisate-Najo Area, by John B. Thigpen

Part 4 - SURFACE GEOLOGY: South Volcan Momotombo Fumaroles, by John B. Thigpen

Part 5 - GRAVITY AND MAGNETIC SURVEYS, by Mario Mazzolini

Part 6 - ELECTRICAL GEOPHYSICAL SURVEYS in Relation to the Location of Geothermal Power Resources in Northwestern Nicaragua, by George Keller and Norman Harthill

Part 7 - GEOCHEMISTRY of the Nicaraguan Geothermal Project Area, by R. Bennett

Part 8 - TEMPERATURE GRADIENT WELLS at San Jacinto and South Volcan Momotombo, by R. Bennett

Part 9 - DEEP BOREHOLE TEST at the South Volcan Momotombo Fumarole Area, by John B. Thigpen

Part 10 - CONCLUSIONS AND RECOMMENDATIONS, by Texas Instruments Staff and Consultants

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Aerial view of South Volcan Momotombo fumarole area looking north.

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Vista aerea norte del area fumarola de Volcan Momotombo Sur.

SURFACE GEOLOGY
SOUTH VOLCAN MOMOTOMBO FUMAROLES

ABSTRACT

The hydrothermally altered areas, active fumaroles, and minor thermal springs occur on the south slopes of Volcán Momotombo near the shore of Lake Managua. This typical composite volcano is a still semi-active link in the chain of Quaternary volcanoes of Western Nicaragua.

Alteration is more extensive and pronounced and current fumarolic activity is more vigorous than at any other thermal area in Western Nicaragua.

This thermal area shows favorable possibilities as a geothermal power prospect, and is probably more favorable than any other known thermal area in Western Nicaragua.

Additional detailed studies and drilling of thermal gradient and steam exploration holes is believed justified.

INTRODUCTION

Location

The fumaroles are on the lower south slopes of Volcán Momotombo which is on the northwest shore of Lake Managua (figure 1).

The area is about 25 km. northeast of La Paz Centro, reached by a gravel road to Puerto Momotombo from the paved highway at La Paz Centro, then by a dirt vehicle trail around the shore of Lake Managua.

Purpose

The purpose of this investigation was to map the surface geology in as much detail as possible and to locate all hydrothermally altered areas and thermal manifestations as part of an evaluation of the geothermal power possibilities of the area.

Method

Field geology combined with photogeology was used to evaluate the area around the fumaroles. Field work was productive only in and near the altered areas since outcrops are very limited elsewhere. Photogeology with

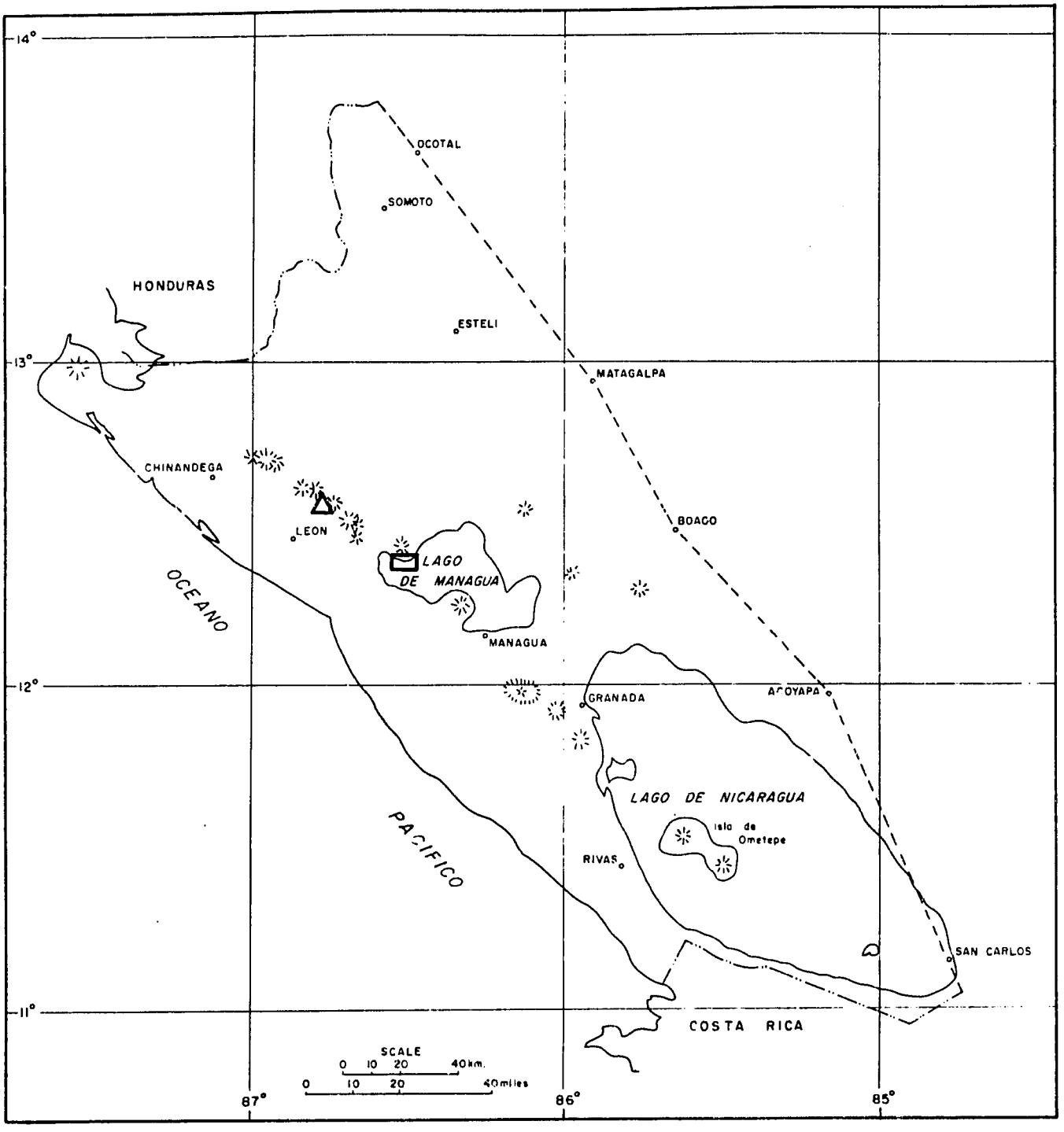

FIGURE 1 INDEX MAP

▭ SOUTH VOLCAN MOMOTOMBO FUMAROLES

△ SAN JACINTO – TISATE FUMAROLES

some field checking of accessible areas was relied upon to map the surrounding area in a reconnaissance manner. About one week of field work was done during regional evaluation studies of the area in January 1970 and about one more week of field work was done in September 1970 to finalize, as much as possible, the local geology.

Previous Work

The only previous geological work was the generalized photogeologic mapping by Catastro (Kuang Sanchez, 1969) and general comments by McBirney and Williams (1965). The fumaroles are briefly mentioned by McBirney (1958) and in an unpublished report prepared for Enaluf (Electroconsult, 1966).

Problems Encountered

Most outcrops are in or near the altered areas; elsewhere outcrops are very limited. The lack of outcrops is related to a mantle of variable thickness of Recent volcanic cinders, especially in the northwest part of the area. Thick vegetation, trees and undergrowth, covers much of the area apart from the altered areas.

Unfortunately facilities were not available for precise determinations of sublimate-efflorescence deposits and alteration products.

Acknowledgements

The assistance of the Servicio Geológico Nacional is appreciated. The petrographic analyses were made by José Viramonte O. Minor field geology was done by F. L. Doyle of this project.

REGIONAL SETTING

Volcán Momotombo is a still semi-active composite volcano in the Quaternary Volcanic Range of Western Nicaragua. This range of volcanoes is localized along a northwest-trending structurally weak zone, probably a major fault zone, along or near the western side of the Nicaraguan Depression. The depression has the general surface characteristics of a broad graben but the structure is probably more complicated, involving fault block structures or downfolding.

The volcanoes are mostly composite cones although scattered calderas and cinder cones are present. Se-

veral of the volcanoes have had recent ash or lava eruptions.

Pyroclastic rocks predominate in the Volcanic Range but varying amounts of andesitic and basaltic lavas are present. Most of the younger lavas are basalts, often olivine basalts. In the vicinity of Volcán Momotombo, Quaternary pyroclastic rocks including tuffs and dacitic pumice cover the area north of the volcano (part 2, fig. 5).

The fumaroles south of Volcán Momotombo are one of several groups of fumaroles, thermal springs, and thermal wells located in Western Nicaragua. The nearest of these thermal manifestations are the fumaroles at Cerro Colorado, about 10 km. north-northwest, and the thermal springs at Hda. California, about 8 km. northwest. Thermal water wells exist at greater distances to the northwest.

See the regional evaluation, "Thermal Manifestations of Western Nicaragua" (part 2), section of this project report for additional background information.

The summit of Volcán Momotombo at about 1200 meters elevation is about 2.0 km. north of and about 900

meters above the highest and most northerly of the fumaroles on the south side of the volcano. Momotombo has continuous high-temperature fumarolic activity in its summit crater, often with a plume of volcanic gases, probably mostly water vapor. The last lava eruption in 1905 covered an extensive area on the north side of the volcano, following the path of previous lava flows. No comparatively recent lava flows have occurred on the south side of the volcano.

ROCKS AND DEPOSITS

Two main groups of rocks are present in the mapped area in the vicinity of the fumaroles. These rocks are the young volcanic deposits composing Volcán Momotombo, which abut against and/or overlie older volcanic rocks that form a low plateau southeast of Volcán Momotombo.

"Older Volcanic Rocks"

These deposits of possible early Quaternary (?) age form the low plateau southeast of Volcán Momotombo. Poorly exposed pyroclastic rocks, including well indur-

ated tuff and agglomerate-volcanic breccia zones, predominate with subordinate interbedded lava flows of andesite, andesitic basalt, and basalt. A distinctive microscopic and occasionally megascopic characteristic of some of the andesite is the presence in many instances of small lithic fragments or xenoliths with diabasic texture. Many of these older rocks are slightly to moderately altered by weathering and/or minor, presently inactive, hydrothermal alteration.

The contact between these older rocks and the "Volcán Momotombo Rocks" is poorly exposed but it appears to be an unconformity with the younger "Volcán Momotombo Rocks" abutting against and in some cases definitely overlying the "Older Volcanic Rocks".

"Volcán Momotombo Rocks"

Basaltic cinders and ash, grading into tuff of varying degrees of induration, and other pyroclastic deposits are the most conspicuous rocks. They probably comprise much of the cone of the volcano, which is probably mostly of Pleistocene age but some Recent volcanics are present, i. e. Recent lava flows and pyroclastics.

Lava flows of basalt, andesitic basalt, and olivine basalt are erratically distributed vertically and laterally through the pyroclastic deposits. The flows are typically lobate in plan view and generally thin, 10 meters or less in thickness. The lava flows probably comprise 15 to 25 per cent of the stratigraphic section.

Surface lava flows, well expressed topographically, are more common in the west part of the mapped area (plate 1), but recent lava flows are best developed on the north and east sides of Momotombo (part 2, fig. 5). All of the mapped lava flows on the south and west slopes of Momotombo are fresh to slightly weathered, relatively old flows that are covered with vegetation in contrast to the quite young, unvegetated flows on the north and east sides of Momotombo.

Surface lava flows do not occur in the hydrothermally altered areas, although surface flows occur nearby in some instances, and lava flows are present at various depths below the altered area. The south slopes of Momotombo have been somewhat protected from recent lava flows by the fact that the summit crater is breached to the northeast. An additional factor in diverting flows from the south slopes is the low somma ridge across the

upper south flank of Momotombo at about 850 meters elevation (plate 1).

Surficial Deposits

Alluvial fan and/or pediment deposits (fanglomerate) formed by stream erosion-deposition and by volcanic mud flows are locally important on the lower slopes of Volcán Momotombo. These deposits consist of unsorted sand, gravel, and small to large boulders, which average 50 cm. or less in diameter, but some reach 2 to 4 meters in diameter. The boulders consist of widely varying rock types corresponding to the different types of volcanic rocks. Tuff layers occur in some cases. In the western part of the mapped area these Quaternary deposits may consist more of colluvium and possible terrace deposits. The thickness of these deposits is unknown but probably is generally thin. These deposits are important since some of the altered areas are localized in or partially covered by these deposits.

A zone of raised shorelines and associated beach deposits above the present shore of Lake Managua truncates older deposits. The upper shoreline is about 4.5 meters above the present average lake level. These

beach deposits, generally less than one meter in thickness, and shorelines are indicated on plate 1. A terrace of variable width, usually minor, is associated with the upper raised shoreline.

A possible large landslide inferred mostly from topographic form is indicated on plate 1. The typical bowl-shaped escarpment at the top and hummocky debris at the bottom is present. If this feature is in fact a landslide it is old and inactive, probably of little concern to possible nearby geothermal power developments. The inferred landslide extends southwest from the plateau of older volcanic rocks for about 1.5 km. with a width of 500 to 700 meters.

STRUCTURE

The dominant structural feature in the area is the northwest-trending probable major fault zone represented by the alignment of the Volcanic Range. There is no surface evidence for this probable fault in the Volcán Momotombo area, but it could be concealed by the Quaternary volcanic deposits. The small, northwest - trending inferred faults described below are probably

local features related to Volcán Momotombo.

The deposits of Volcán Momotombo dip away from the summit, in a southerly direction at the fumaroles, generally parallel to the topographic slopes. Dips are around 30° on the upper slopes, decreasing to gentle dips on the lower slopes. The older volcanic deposits in the plateau southeast of Momotombo are apparently relatively flat-lying.

Several faults have been inferred in the mapped area. Two inferred faults are thought to be especially significant in possibly controlling the hydrothermal alteration. Both of the inferred faults are northwest-trending, apparently normal, steeply dipping, and downthrown to the southwest. One of these faults is located along the north side of the southern fumaroles and the other is along the south side of the northern fumaroles (plate 1 and figure 2). The basis for mapping these faults is a low linear escarpment, a poor alignment of some of the individual altered areas, and a prominent lineament on air photographs. The other inferred faults are generally of the same type with similiar evidence.

The area between the two northwest-trending inferred faults discussed above is characterized by relatively numerous lineaments probably controlled by fractures or small faults and is also characterized by the lack of hydrothermally altered areas except very near the faults.

A possibility that must be considered is that the north-south segment of the contact between the "Volcán Momotombo Rocks" and the "Older Volcanic Rocks" may be a fault contact. There is no good surface evidence for such a fault other than the north-south alignment of altered areas "C", "D", and "E" along or near the contact.

Several lineaments were located from air photographs where they are expressed by linear vegetation, topographic, or tonal alignments. Only the more pronounced, better expressed lineaments were mapped. These are divided into two groups, major and minor lineaments, based on the degree of expression on the air photographs. The major lineaments probably represent faults or fracture zones while the minor lineaments are more likely to represent fractures. Since exposures are poor and much of the mapped area is thickly vegetated, the lineaments are an important part of the struc-

tural picture. In the mapped area the lineaments are most abundant on the south slopes of Volcán Momotombo where partial erosion has etched out the lineaments. Structural activity also may have been more important here. The number of mappable lineaments is much less in the relatively young lava-covered areas due to the mantling effect of the lava.

GEOMORPHOLOGY

Volcań Momotombo is a typical composite volcanic cone with an elevation of about 1200 meters. The cone forms a peninsula into Lake Managua which has a water level of about 39 meters elevation.

Most surface features are of constructional origin, consisting of cinders and lava. The area around the fumaroles on the lower south slopes of Momotombo has the oldest surface deposits of the volcano. These deposits have been partially dissected by subparallel to radial streams with the eroded deposits forming alluvial fans and/or pediments and minor terraces downslope near Lake Managua.

Along the shoreline of Lake Managua several raised shorelines, associated beach deposits, and minor terraces extend to about 4.5 meters above the present average water level (39 m.). Their presence implies either tectonic uplift or a general decline of the lake level. Observations here combined with the presence of similiar raised shorelines in another area of investigation, the San Luis hot springs on the northeast side of Lake Managua, indicate that the water level of Lake Managua has probably fallen instead of local tectonic uplift being responsible for these raised shorelines. The less favored alternative is that regional tectonic uplift has occurred.

The "plateau" southeast of Volcán Momotombo is developed on a series of older volcanic rocks which have been extensively eroded. The top surface of the "plateau" is somewhat irregular, probably due to faulting and differential erosion. Deep stream canyons have been developed around the margin of the "plateau".

As previously mentioned a large possible landslide has been inferred to extend southwest from the margin of the "plateau".

Several of the stream canyons are linear, suggesting structural control, especially some canyons that trend across the general topographic slopes.

THERMAL ACTIVITY

Hydrothermally altered zones and associated active fumaroles with a total surface area of about 0.75 to 1.0 sq. km. occur in five general groups as shown on plate 1. Comparatively minor thermal springs are also present. This is the most extensive thermal activity located in Western Nicaragua.

Steam at temperatures of 100°C, occasionally to 101°C, occurs in very sparse (invisible except at a very close distance) to moderate (usually conspicuously visible) amounts at the active fumaroles. The amount of steam usually increases after rainfall. All of the exposed altered zones show at least some fumarolic activity. Inactive altered areas would probably be hidden from view by the prevalent surface mantle of Recent cinders. Sparse sulphur sublimates are present at most of the fumaroles.

Hydrothermal alteration varies in intensity from slight to very severe, with bleaching, argillization, and silicification at the more active or previously more active fumaroles. Only the visibly altered zones are shown on plate 1. Microscopic examination of a few thin-sections of altered basaltic lava has indicated

complete alteration of plagioclase to kaolinite (?), complete alteration of mafic minerals and opalization of the matrix.

Hot springs with temperatures of up to 100° and occasionally 101°C occur near to and just above the shore of Lake Managua.

The hydrothermally altered areas have a close association with zones barren of vegetation. Typically, only short grass and a few scattered shrubs grow in and near the surface expressions of altered areas. These barren areas are in contrast to the nearby thick vegetation, often consisting of a thick growth of trees and undergrowth. The lack of vegetation is probably because of changes in the soil chemistry due to the alteration as well as an unknown contribution due to direct thermal affects. In most cases the margin of the typical unvegetated areas probably corresponds closely to the maximum extent of surface and near surface alteration. There is also a relationship to present or past elevated soil temperatures due to direct thermal affects, but the relationship is poorly known since a shallow (one meter depth) temperature survey was not done due to questionable value of such a survey. For these reasons the unvegetated areas are shown on

plate 1.

The associated fumaroles are low-temperature, with maximum surface temperatures at or below the boiling point of water. Volcanic, high-temperature fumaroles occur only in the summit crater of Volcán Momotombo.

HYDROTHERMALLY ALTERED AREAS AND FUMAROLES

Area A

This group of small, scattered but often nearly contiguous altered zones and associated fumaroles has an area of about 27,000 sq. meters of visible surface alteration. The visible alteration is within a larger zone of about 0.45 sq. km. which is barren of all vegetation except short grass and a few scattered shrubs. As discussed above the boundaries of the unvegetated area (plate 1), excluding the east and west prolongations along the lake shore, probably correspond closely to the maximum extent of surface and near surface alteration, and to high or previously high soil temperatures. The elevation of the altered zones is 40-110 meters.

As shown on plate 1 most of the altered zones have active associated fumaroles. The maximum temperatures at a 8 to 10 cm. depth in the more active parts of each zone are near or at 100°C, rarely to 101°C. Steam is

usually sparse except at a few local spots where small puffs of steam are occasionally visible. Very sparse to sparse native sulphur sublimates are scattered around the active vents. White to yellow efflorescences are also common in some spots, particularly near the lake where the water table is shallow. Many of the sublimates and efflorescences are washed away in the rainy season.

Very small hot springs with temperatures of 95-100°C are localized in a small gully near and less than one meter above Lake Managua (plate 1). A high percentage of gas is associated with the water flow. The very small flow is nil in the latter part of the dry season. Additionally, thermal seeps and very small thermal springs occur in the wet season. These are scattered along the shore of Lake Managua from the west edge of Area "A" to the east part of Area "C".

Alteration is usually moderate to severe in the individual mapped zones. The rocks between the active zones are variably altered, but not enough to be visibly mapped because of the mantle of Recent cinders. Most of the altered rocks are pyroclastics which have been bleached, silicified, and argillized by the chemical action of the fumaroles. Much of the alteration

is probably due to sulphuric acid derived from oxidation of hydrogen sulphide from the fumaroles. Typically, the altered zones have a bleached, silicified, brittle crust overlying clay mixed with less altered rock fragments. Where well exposed the clay shows the surface aspect of saprolite, with the original rock textures preserved but consisting of soft clay. Stream erosion tends to rapidly remove the highly altered rocks, often producing bowl shaped depressions or gullies depending on the local topography.

Alteration is of course closely related to the permeability of the rocks involved. Dense lavas are generally altered only around their outer periphery, but are completely altered with sufficient time, while cinder and tuff layers are often completely altered.

Surface lava flows occur west of the area and interbedded lava flows and pyroclastics occur to the east of the area, possibly serving to limit surface alteration in either direction. Much of the central part of the area is covered by a small alluvial fan. Recent cinders mantle the area between the altered zones.

An inferred normal fault, downthrown to the south, is mapped across the north margin of this group of fuma-

roles.

Area B

These small altered zones with active fumaroles have an area of about 100 sq. meters of pronounced surface alteration. The altered zones are in the lower, downslope end of a typical unvegetated area of about 0.1 sq. km. The elevation of the altered zones is about 270 meters.

Alteration of pyroclastics, mostly lapilli tuff, is high to severe with local argillization, similar to the alteration described in Area "A" but on a much smaller scale.

Steam is very sparse (usually invisible) with sparse white efflorescences but no sulphur sublimates. Temperatures at a 8 to 10 cm. depth are as high as 100°C in the more active spots.

These altered zones are on the north, upslope side of an inferred northwest-trending, normal fault apparently downthrown to the southwest.

Area C

This zone of hydrothermal alteration, hot springs, and minor fumaroles has an area of about 20,000 sq. meters of surface alteration, located in a larger un-

vegetated area of about 0.15 sq. km.

The altered zones and associated fumaroles occur on the surface of a small lacustrine terrace which is gradational upslope into an alluvial fan, while the hot springs and local fumaroles occur along the shore of Lake Managua where the terrace deposits have been truncated by wave action. The alluvial fan and terrace include volcanic mud flow (lahar) and tuff layers. Near the hot springs the mapped beach deposits are very thin. The hot springs issue from the more permeable layers of the terrace deposits after flowing laterally from upslope (north), but are possibly further localized by fractures. The springs are from 1 to 3 meters above the lake (elevation 39 meters) while the fumaroles are as much as 4 or 5 meters above the lake.

The water temperature of the highly mineralized springs is mostly 96-101°C, with rather small flow. Chemical aspects of the springs are reported separately. Much gas is associated with the water discharge so that several of the springs boil violently. Associated deposits consist of siliceous sinter and other undetermined substances. There are no pronounced seasonal changes in the rate of flow of the main springs. Ad-

ditionally, as previously mentioned, wet season thermal seeps and very small thermal springs occur along the shoreline of Lake Managua west to Area "A".

The fumaroles in the altered zones have average shallow soil temperatures of about 60°C but locally reach 100°C, with very sparse steam except at the springs. Alteration is generally slight to moderate with very local argillization. Alteration of the finer constituents of the deposits is of course more pronounced than the boulders. White efflorescences are locally abundant. No sulphur sublimates are present.

Area D

Several small hydrothermally altered zones with active fumaroles are scattered over the surface of an alluvial fan. Lahar and tuff layers are included in the fan deposits (fanglomerate).

About 1,000 sq. meters of surface alteration is included in a larger unvegetated area of about 0.14 sq. km. with the barren area again probably corresponding to the limit of near surface alteration and high or previously high soil temperatures. The elevation of the altered zones is 90-100 meters.

Sparse steam (usually invisible) at temperatures up to 100°C issues from local vents in the altered areas. Very sparse sulphur sublimates and sparse white efflorescences are present.

Alteration varies from slight to severe with local argillization at the more active fumaroles. The alteration is locally similiar to that described for Area "A" , except here fanglomerate and lahar deposits with tuff layers are involved and also the locus of activity appears to have shifted from place to place. Several of the active fumaroles exhibit only slight to moderate alteration. It appears that this alteration is relatively young, unless recent lahar or tuff layers conceal old inactive altered zones.

The fumaroles extend eastward to and slightly into the toe of the inferred landslide (plate 1).

Area E

This group of hydrothermally altered zones and fumaroles is relatively compact, with almost continuous activity over an area of about 26,000 sq. meters in a slightly larger unvegetated area of about 0.06 sq. km. Elevation of the altered zones is 300-340 meters. This activity is on the middle slopes of Volcán Momotombo, but in particular, appears to be developed

in the "Older Volcanic Rocks" along or just east of the contact with the "Volcán Momotombo Rocks".

Moderate quantities of steam, with almost continuous activity often visible to the unaided eye from the lakeshore 2 km. away, are associated with these altered zones. Most of the alteration mapped has active fumaroles associated. Sulphur sublimates in moderate quantities, consisting of thin crusts and visibly conspicuous crystals up to about 8 cm. in length are associated with the active vents. There are more sulphur sublimates and a greater sulphurous odor than occurs at any other low-temperature fumarole studied in Western Nicaragua.

Alteration of pyroclastics and included basaltic to andesitic boulders is high to severe, similar to but slightly more severe than the alteration described in Area "A".

Gullys and bowl-shaped depressions correspond to the removal of altered rocks by stream erosion. The alteration shows all appearances of relatively greater age or more pronounced chemical activity than any of the other above described alteration zones except perhaps the main, large zone of Area "A".

Other Areas

A large unvegetated area, similar to that associated with hydrothermal alteration elsewhere, is located on the slopes of Volcán Momotombo between Area "B" and "E". Field examination of this area failed to reveal any surface evidence of hydrothermal alteration.

The resistivity low*indicated to the west of the altered areas was examined in the field and on air photographs. No surface evidence of alteration associated with this resistivity low was found. The mantle of Recent cinders is relatively thick here.

Vigorously active high-temperature fumaroles (J. Viramonte, oral comm., 1970) occur in the summit crater of Volcán Momotombo at about 1200 meters elevation. Much white fume, probably mostly steam, issues from these fumaroles. Close air observation indicates that the general alteration is probably rather severe with abundant sublimates.

*See Part 6: Electrical Geophysical Surveys

LOCALIZATION OF THERMAL ACTIVITY

Two general alternatives for localization of the thermal activity are more or less vertical rise of hydrothermal fluids along fractures or in the other case, lateral, downslope movement of hydrothermal fluids within the more permeable layers of the volcanic deposits, from a source along probable concealed fractures or faults higher on the slopes of Volcán Momotombo, or from the central conduit of the volcano. The distinction is important because if shallow lateral flow is predominant, then the area is less favorable as a geothermal power prospect, since exploratory holes would probably encounter a reversal of the geothermal gradient at depth.

It is obvious that some general downslope movement of meteoric water occurs in the more permeable layers of the volcanic deposits. The following discussion is related only to hydrothermal fluids.

The situation is not clear because of poor exposures but, in general, vertical flow of hot fluids along faults and fractures from a reservoir at considerable depth is inferred to be more important. Some lateral flow is probably involved in Area "A", "C", and "D" and is de-

finitely at least locally important at the hot springs of Area "C", which issue from permeable layers of stratified terrace and alluvial deposits. Opposed to the lateral flow hypothesis, at least for Area "B" and "E", is the occurrence of the fumaroles of Area "B" and "E" upslope from the northerly inferred fault instead of downslope. On the other hand, in the unlikely event that this fault marks a groundwater barrier to flow from upslope, then the lateral flow hypothesis could be substantiated. It should be noted that the relationship between the southerly inferred fault and Area "A" and less clearly, Areas "C" and "D", is reversed from the above described situation, with thermal activity downslope from the inferred fault, so that this thermal activity does not appear to be related to a groundwater barrier along the southerly fault.

The lack of thermal activity in the zone between the two northwest-trending inferred faults or fault systems supports the interpretation of vertical flow along fractures. In general, if large-scale, lateral flow of hydrothermal fluids is involved, the thermal activity should be regularly distributed and controlled only by the distribution of the permeable vs. impermeable deposits. The alternate possibility, that a zone of deposits of lower permeability between the two inferred faults

has prevented development of thermal activity, has no field evidence to support it. Additionally, opposed to the lateral flow hypothesis, if a low permeability zone exists here, this zone would impede lateral flow down to Areas "A", "C", and "E".

I conclude that vertical flow of hydrothermal fluids is probably more important than lateral, downslope flow. The previous discussion concerns lateral, downslope flow only at a relatively shallow depth. If lateral flow at great depth is involved, there would be no qualitative surface distinction between thermal activity related to such a reservoir in one case and strict vertical flow in the other case.

Hopefully the distinction between lateral and vertical flow will be further clarified by the temperature gradient wells.

CONCLUSIONS

The thermal activity at the S. Volcán Momotombo fumaroles is more extensive and vigorous than at any

other site located in Western Nicaragua.

The area shows favorable indications for geothermal power development, probably slightly more favorable than the San Jacinto-Tisate fumaroles.

Additional investigations involving geophysics, geochemistry, and drilling of temperature gradient holes are warranted. These investigations are either in progress or already completed.

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