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PN-ABK-272

FINAL REPORT
GEOTHERMAL RESOURCES PROJECT-STAGE ONE

PART 2

REGIONAL GEOLOGY
THERMAL MANIFESTATIONS OF WESTERN NICARAGUA

Prepared for

GOVERNMENT OF NICARAGUA
Ministry of Economy, Industry and Commerce

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August 1970

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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THERMAL MANIFESTATIONS OF WESTERN NICARAGUA

ABSTRACT

The geology of Western Nicaragua is dominated by the Nicaraguan Depression, a northwest-trending tilted fault block or graben. Along the southwest margin of the depression occur a chain of volcanic massifs and individual composite volcanoes of Quaternary (Pleistocene to Recent) age. Some of the volcanoes are intermittently active. Upper Cretaceous to Pliocene sedimentary rocks occur in the south part of the area west of the depression. Tertiary volcanic rocks, with minor igneous intrusions, Paleozoic metamorphic rocks, and Miocene sedimentary rocks in the north part, cover the area east of the depression.

A regional evaluation of thermal manifestations in Western Nicaragua from Sept. 1969 to July 1970 has revealed numerous fumaroles, hydrothermally altered areas, thermal springs, and thermal water wells.

These thermal manifestations are mostly associated with the young volcanoes and the adjacent Nicaraguan Depression, indicating a higher than normal heat flow.

The heat flow in the Pacific Coastal Plain and Interior Highlands is apparently near normal since few thermal manifestations are present.

Ten thermal areas, with varying attributes, indicate potential present or future geothermal power prospects. Five of these areas consist mainly of fumaroles, two of fumaroles and thermal springs, two of thermal springs, and one of thermal wells.

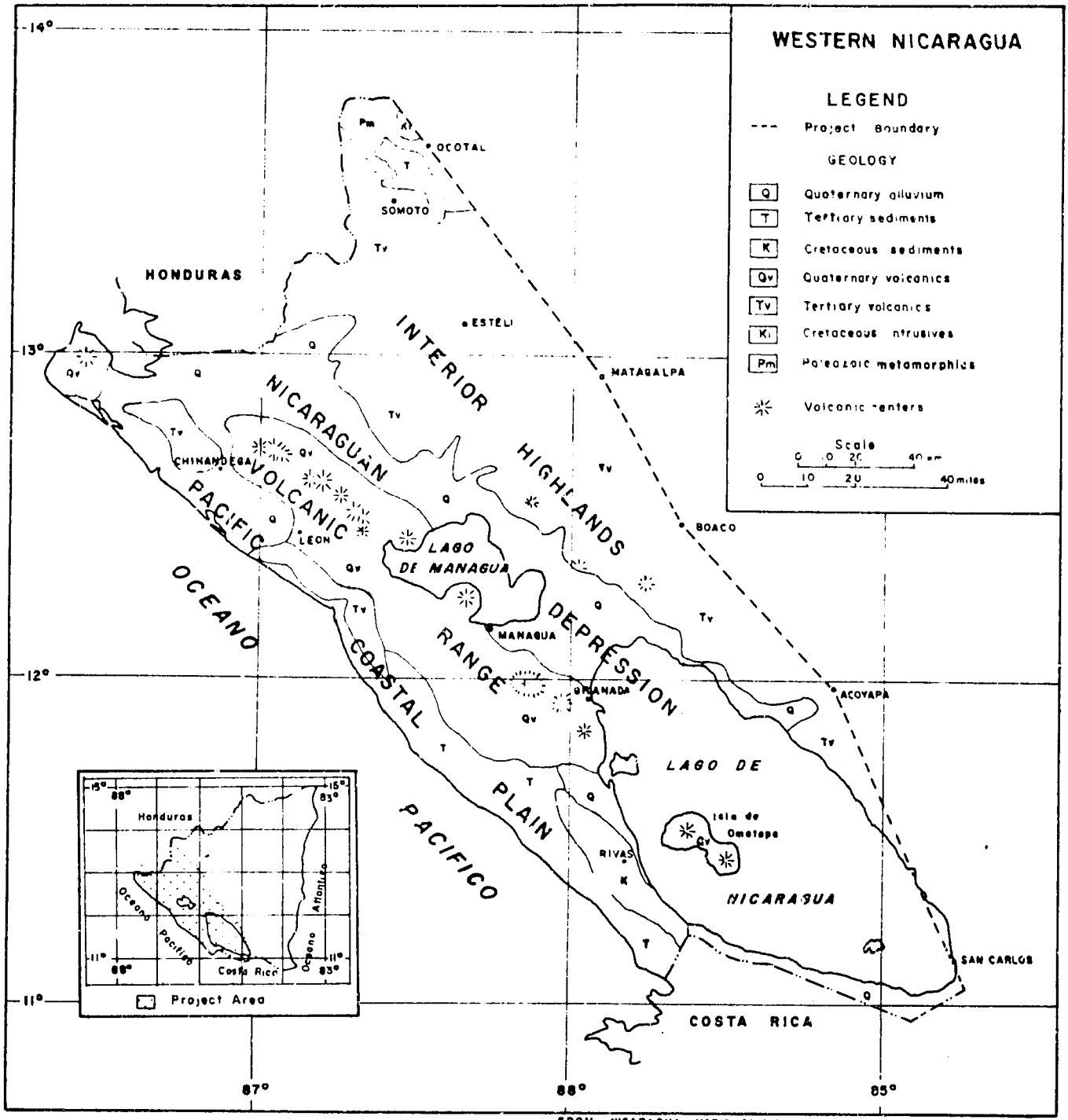
The two most favorable thermal areas, South Volcán Momotombo fumaroles and San Jacinto-Tisate fumaroles, have been selected for detailed geological, geophysical, geochemical, and drilling investigations.

INTRODUCTION

Location

This study covers an area of about 38,000 sq. km., being that part of Western Nicaragua west of a line from Ocotal southeasterly through Matagalpa, Boaco, Acoyapa, and San Carlos (fig. 1).

This area includes the majority of the thermal manifestations of Nicaragua. Only a few scattered thermal



FROM NICARAGUA, NATIONAL INVENTORY OF PHYSICAL RESOURCES (1966)

FIGURE 1 Project Area Index

springs are reported in Eastern Nicaragua.

Purpose

The purpose of this study was to locate and evaluate all thermal manifestations, with emphasis on features possibly indicative of hyperthermal zones with anomalously high subsurface temperatures. The thermal manifestations include fumaroles, hydrothermally altered areas, hot springs, and water wells with hot water.

The thermal manifestations were evaluated in order to select the most favorable sites for detailed study, with the ultimate objective of locating hyperthermal zones suitable for geothermal power development.

Method of Study

As originally planned, this study was to include analysis of existing data, followed by interpretation of air photographs and air reconnaissance, and field evaluation of the most promising sites.

The initial phase of the study was a review of all available pertinent data. The data collected by the Catastro e Inventario de Recursos Naturales project, hereafter referred to as Catastro, was particularly

valuable. The well and spring inventory by Catastro furnished several leads to thermal wells and springs, although this inventory is incomplete, particularly in remote areas. The photogeologic mapping by Catastro furnished helpful background information, but few specific thermal manifestations were noted. Data from the Servicio Geológico Nacional indicated some of the thermal manifestations. Some thermal manifestations, particularly thermal springs, were located by checking place names on 1:50,000 scale topographic maps.

No photographs were furnished to the project directly by the Government and coverage of only limited areas could be obtained by borrowing or other means. Flying time for air reconnaissance was much more restricted than planned. These factors forced a program revision to place more emphasis on field evaluation.

Interpretation of the few available air photographs and limited air reconnaissance was very helpful, especially in the location of fumarole areas in the Volcanic Range.

The extent of field reconnaissance varied in different parts of the project area. Since the entire area obviously could not be covered by one geologist

in the available time, emphasis was placed on evaluating those parts of the area where the geological environment is most favorable for thermal manifestations to be developed. Selection of these target areas was greatly facilitated by the existing data review, since thermal manifestations were indicated to be much more abundant in some regions than in others. An attempt was made to evaluate all leads possibly indicative of thermal manifestations. Local inquiries in the field were particularly helpful.

All available data, both pre-existing data and that developed during the course of the project, indicate that the thermal manifestations are concentrated in the Volcanic Range and in the Nicaraguan Depression. As a consequence, much of the field reconnaissance was expended in this part of the area, with little work in the Interior Highlands or the Pacific Coastal Plain. It is likely that other thermal manifestations are present, especially thermal springs in the Interior Highlands, but all significant manifestations are probably included in this study. With the available equipment it was not feasible to attempt an evaluation of probable underwater thermal manifestations in Lake Managua and Lake Nicaragua.

Previous Work

Until recently the geological work done in Nicaragua has been mostly of general reconnaissance nature with scattered detailed work. This previous geological work has been summarized in a notable paper by McBirney and Williams (1965).

The Catastro project, currently in progress, has prepared photogeological maps at 1:50,000 scale covering the project area. Field checking and preparation of geological reports is in progress. The Catastro project also has made an inventory of most of the wells and springs in the project area, usually with water temperature and chemical analysis data included.

Del Giudice (1959) published a preliminary compilation of the more obvious thermal manifestations of Nicaragua. An unpublished report prepared by Electroconsult (1966) also gives a brief description of the thermal manifestations considered most significant.

Problems Encountered

The lack of air photograph coverage of the project area was a very pronounced problem. No photographs were supplied directly from the Government of

Nicaragua as originally planned, and coverage of only a limited area along the central part of the Volcanic Range could be obtained by borrowing on a temporary basis. Air photograph coverage of the project area was needed for direct location of fumaroles and altered areas, local photogeologic mapping, and to be used in the field for location and access determination. The lack of these photographs prevented a complete evaluation of the project area.

A light plane and pilot for air reconnaissance was not available from the Government of Nicaragua as originally planned. Only limited air reconnaissance could be performed with alloted project funds, so this program had to be stopped at a very minimum level.

Unavailability of a suitable field vehicle and field assistant caused numerous delays in the first part of the project.

Acknowledgements

Appreciation is expressed to the Servicio Geológico Nacional for the support that was furnished to the project. The petrographic determinations were

made by José G. Viramonte and the water analyses under the direction of Eliseo Ubeda.

The cooperation and assistance of Catastro personnel, notably the Project Coordinator, Richard L. Hughes, and the hydrogeology and geology sections, is greatly appreciated.

Discussions with the United Nations Groundwater Project personnel were also helpful.

REGIONAL GEOLOGY

Physiography

Western Nicaragua can be divided into four principal physiographic provinces (figure 1). These are the Pacific Coastal Plain, the Volcanic Range, the Nicaraguan Depression, and the Interior Highlands.

The Pacific Coastal Plain extends as a narrow band from Cosigüina Volcano in the north to the Costa Rica border in the south. In general aspect the plain is flat and is covered by alluvium and volcanic sediments with scattered hills of Tertiary ignimbrite in the north. South of Poneloya, the plain is underlain by Upper Cretaceous and Tertiary sedimentary rocks, partially dissected into hills and valleys.

The Volcanic Range is the most imposing physiographic feature of Western Nicaragua. The range of Quaternary volcanoes extends from the isolated Cosigüina Volcano southeast to MaderasVolcano on Ometepe Island in Lake Nicaragua. The volcanoes are generally composite cones, but scattered cinder cones, collapse craters, and calderas are present. The section of the Volcanic Range from V. San Cristobal to V. Momotombo is called the Marabios Range. Presently active volcanoes include Telica - fumarolic activity in summit crater with occasional ash eruption, Cerro Negro - fumarolic activity with lava flow in 1968, El Hoyo - fumarolic activity from fissure at summit, Momotombo - fumarolic activity in summit crater, Santiago - fumarolic activity in summit crater, and Concepción - fumarolic activity in summit crater. Past activity and descriptions of the volcanoes were catalogued by McBirney (1958).

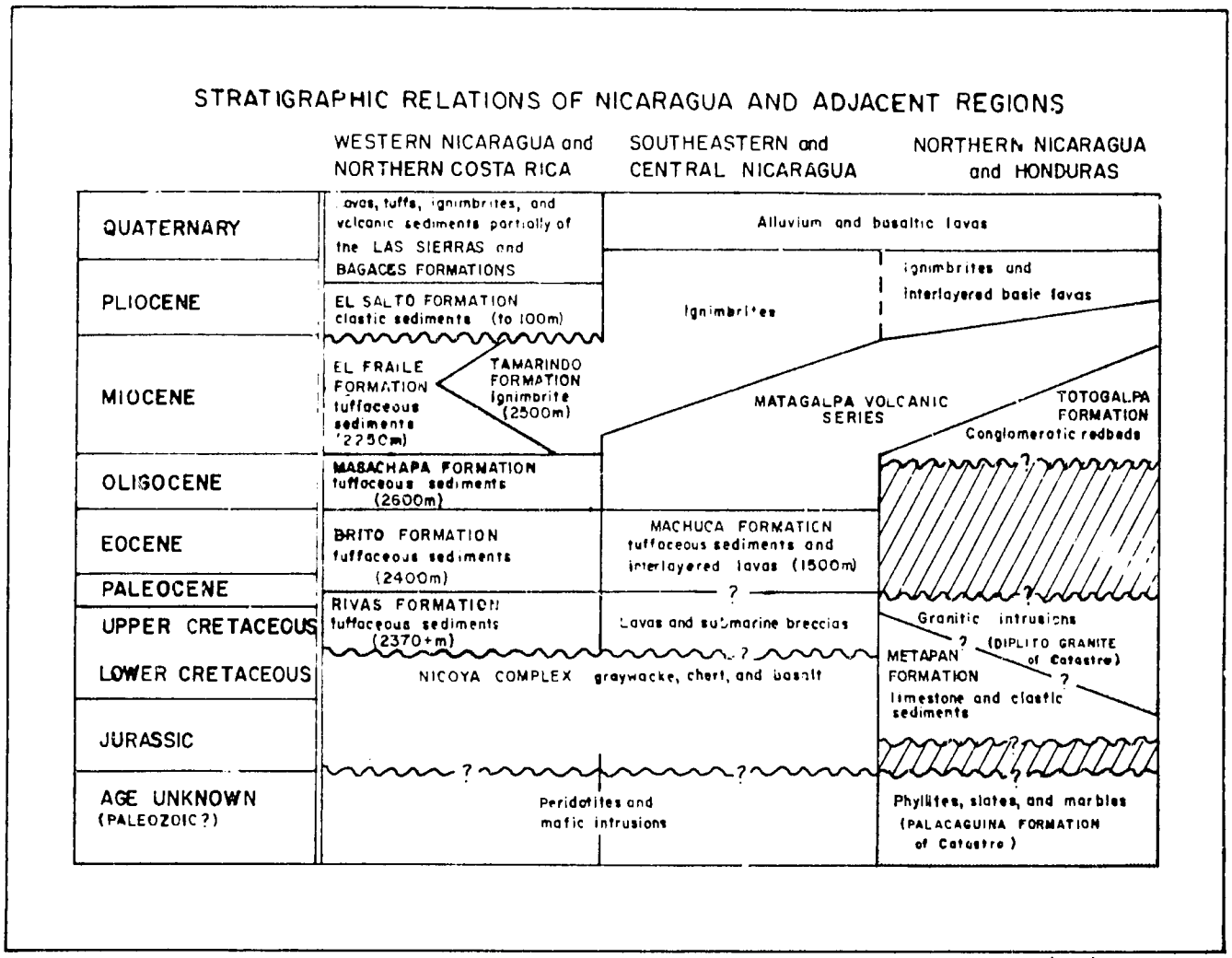
The Nicaraguan Depression is east of and parallel to the Volcanic Range. The depression, about 30 to 45 kilometers wide, is bounded on the east by the Interior Highlands. The depression has the surface aspect of a graben; the structure is probably more complicated, but is obscured by a fill of alluvium and volcanic debris. The surface elevation is near sea level, rising gently to a divide of about 100 me-

ters elevation at Malpaisillo, although probable fault blocks of Tertiary volcanics reach as high as 541 meters. Much of the depression is occupied by the Gulf of Fonseca, Lake Managua (elevation 39 meters) and Lake Nicaragua (elevation 31 meters). Three centers of Quaternary volcanic activity are located on or near the eastern boundary fault zone.

The Interior Highlands cover most of Central Nicaragua. Tertiary volcanic rocks, mostly ignimbrite, tuff, and lava flows, underlie the area along with a few small igneous intrusions and small areas of Quaternary volcanic rocks. The northern part of the Interior Highlands in the Ocotal area include Tertiary sedimentary rocks, probable Cretaceous granitic intrusives, and probable Paleozoic metamorphic rocks. Plateaus, mesas, and cuestas are the dominant landforms. Along the boundary with the Nicaraguan Depression an apparent hinge line has produced numerous small step faults and fault blocks tilted generally to the west.

Stratigraphy

The age relationships and age distribution of the principal rock units of Nicaragua and adjacent regions are shown in figure 2 from McBirney and



SLIGHTLY MODIFIED FROM MCBIRNEY AND WILLIAMS (1965)

EXPOSED IN PROJECT AREA

FIGURE 2

Williams (1965).

It should be noted that, within the project area, volcanic rocks of Tertiary to Recent age predominate. Exceptions are the Upper Cretaceous and Tertiary sedimentary rocks on the Isthmus of Rivas and probable Paleozoic metamorphic rocks, probable Cretaceous granitic intrusions, and Miocene sediments in the northern extremity of the project area.

Metamorphic and plutonic rocks include the oldest rocks in the project area, the metamorphic rock series exposed in the north extremity of the project area. These metamorphic rocks, named the Palacaguina Fm. in Catastro geological reports, are considered to be Paleozoic, possibly Permo-Pennsylvanian (Dengo, 1968) in age and consist mainly of phyllites and schists. This age is uncertain with a Mesozoic age possible. These metamorphic rocks have been intruded by granitic rocks of probable Cretaceous age (Zoppis Bracci, 1961). Other small granodiorite, diorite, and mafic intrusions of Tertiary age occur in the north-central part of the project area and on the Isthmus of Rivas.

As previously mentioned, volcanic rocks cover a large part of the project area. The following information is summarized mostly from McBirney and Williams (1965). Tertiary volcanic rocks cover most of Central

Nicaragua in the eastern part of the project area. These rocks are mostly andesitic and dacitic lavas with some basaltic lavas, and lahar and ignimbrite deposits, named the Matagalpa Series by McBirney and Williams (1965). These rocks are generally overlain by andesitic and dacitic ignimbrites and minor mafic lavas and volcanic sediments, with this upper series forming extensive plateaus. Differentiation of the two series is not feasible over the entire area.

Tertiary volcanic rocks are also exposed along the northwest coast of Nicaragua, where they are known as the Tamarindo Formation. Silicic ignimbrites predominate but silicic tuffs, lahars, mafic lavas, and shales are common to the south, where the Tamarindo Formation interfingers with the marine El Fraile Formation. Little is known about the volcanic rocks in the area southeast of Cosigüina Volcano.

Quaternary volcanic rocks, including important Recent rocks, are associated with the Volcanic Range, which, as previously mentioned, extends from Cosigüina Volcano southeast to Maderas Volcano. Pyroxene andesite, andesitic basalt, and basaltic lavas are interbedded with scoriaceous tuff and other pyroclastic deposits. Pumice, usually dacitic, is associated with

some of the volcanoes, particularly the calderas. In many instances the youngest lavas are olivine basalts.

Quaternary, probably Pleistocene, volcanic rocks are also present to a limited extent in and east of the Nicaraguan Depression. The Quaternary volcanic centers of Cerro El Ciguatepe, Cerro San Jacinto, and the Las Lajas Caldera along the eastern boundary of the depression are in general composed of andesitic and basaltic lavas and associated pyroclastic debris. Unmapped Quaternary volcanic rocks perhaps cover a large area in the vicinity of the Las Lajas Caldera. A small area of basaltic lava is present near Estelí.

Marine sedimentary rocks of Late Cretaceous and Tertiary age with more than 10,000 meters total thickness are exposed on the Isthmus of Rivas in association with a broad, northwest-plunging anticline. According to McBirney and Williams (1965) these rocks are mainly graywacke, sandstone, and shale but considerable volcanic material is included in some beds (figure 2).

Minor continental to marine sedimentary rocks of probable Miocene age are exposed in the north part of the project area near Ocotal.

Structure

The structure of Western Nicaragua is dominated by the Nicaraguan Depression and the associated range of Quaternary volcanoes. In general the depression has the aspect of a broad, shallow graben trending northwest-southeast between parallel fault zones, but in detail the structure is more complicated. The northeastern boundary of the depression is characterized by numerous more or less parallel gravity faults in a zone up to 10 or 20 km. wide. This band of generally small faults, with displacement both to the northeast and southwest, appears to represent a hinge zone. These faults could be the surface expression of a larger fault at depth. The apparent southwestern boundary of the depression is marked by an obvious zone of weakness represented by the chain of Quaternary volcanoes. The probable boundary fault zone, apparently with large vertical displacement, along the southwest side of the depression is mostly covered with volcanic debris. The conspicuous "Mateare Fault Scarp" south and west of Lake Managua was considered by McBirney and Williams (1965) to represent the boundary fault in this area. This scarp is about 70 km. long and rises to about 800 meters above the depression near the south end. While this scarp probably represents a fault associated with the western boundary fault system, the

trend is north-northwest, oblique to the trend of the depression (plate 1). This indicates that the fault involved is probably not the boundary fault per se, but that other faults are probably associated. No other definite surface expression of the fault zone can be seen, but, as pointed out by McBirney and Williams (1965), scarps are present on the southwest side of the continuation of the Nicaraguan Depression to the southeast in Costa Rica and to the northwest in El Salvador. Numerous hills, probably representing comparatively small fault blocks of Tertiary volcanic rocks occur in the Nicaraguan Depression near its eastern boundary. This seems to indicate that the depression is more shallow along the east side. In general aspect, considering this last evidence with the apparent fault zone along the apparent southwest boundary, the Nicaraguan Depression seems to represent a tilted fault block instead of a simple graben. More extensive faulting on the west side is also suggested by the predominance of young volcanoes and thermal manifestations along the west side.

The location of the western boundary of the Nicaraguan Depression is somewhat vague. The favored interpretation is that of a fault boundary along or

slightly west of the Volcanic Range. A less favored alternative is that the depression is a large synclinal feature modified by faulting, with the western boundary extending to the regional anticline along the coast. With the latter explanation the Volcanic Range might be localized along the deepest part of the synclinal structure, or along an associated fault zone.

A westward-tilted probable fault block west of the depression is represented by the Cordillera del Pacífico (Sierras de Carazo) west and south of Managua.

Folding is usually represented by broad, regional folds. The Rivas anticline, a conspicuous northwest trending and plunging structure well developed on the Isthmus of Rivas, has been traced as a regional anticline northwest along the Pacific Coastal Plain almost to Cosigüina Volcano by the photogeologic mapping of Catastro. The axis of the structure is offset by transverse faults and becomes poorly defined in some locations. As mentioned by McBirney and Williams (1965), in the Isthmus of Rivas area this anticline is asymmetric with the northeast flank more steep. This attitude, as well as small low-angle thrust faults mapped in the same area by Engels (1962), indicates compression toward the northeast. As shown on plate 1, other folds

are present in the Interior Highlands with a notable anticline trending northwest near the east boundary of the Nicaraguan Depression.

Other than the predominant northwest-southeast structural trend represented by the depression and some of the folds, other conspicuous structural trends are north-south and northeast-southwest faults and fractures. These trends are especially conspicuous in the Interior Highlands and in the Volcanic Range. Field work has substantiated the ideas of McBirney and Williams (1965) and Dengo (1968) that the north-south and northeast-southwest trends have controlled the location of volcanism. Location of thermal manifestations is also controlled in many cases by these structural trends, since many of the thermal manifestations are located on these apparently young faults and fractures, especially at intersections.

A gravity profile (figure 3) was made by this project from Poneloya to San Isidro. The complete profile and report are presented separately. A well defined anticlinal feature is interpreted with its axis just west of León. No major faulting is indicated by the gravity data in this area. A pronounced gravity high is present along the axis of the Volcanic

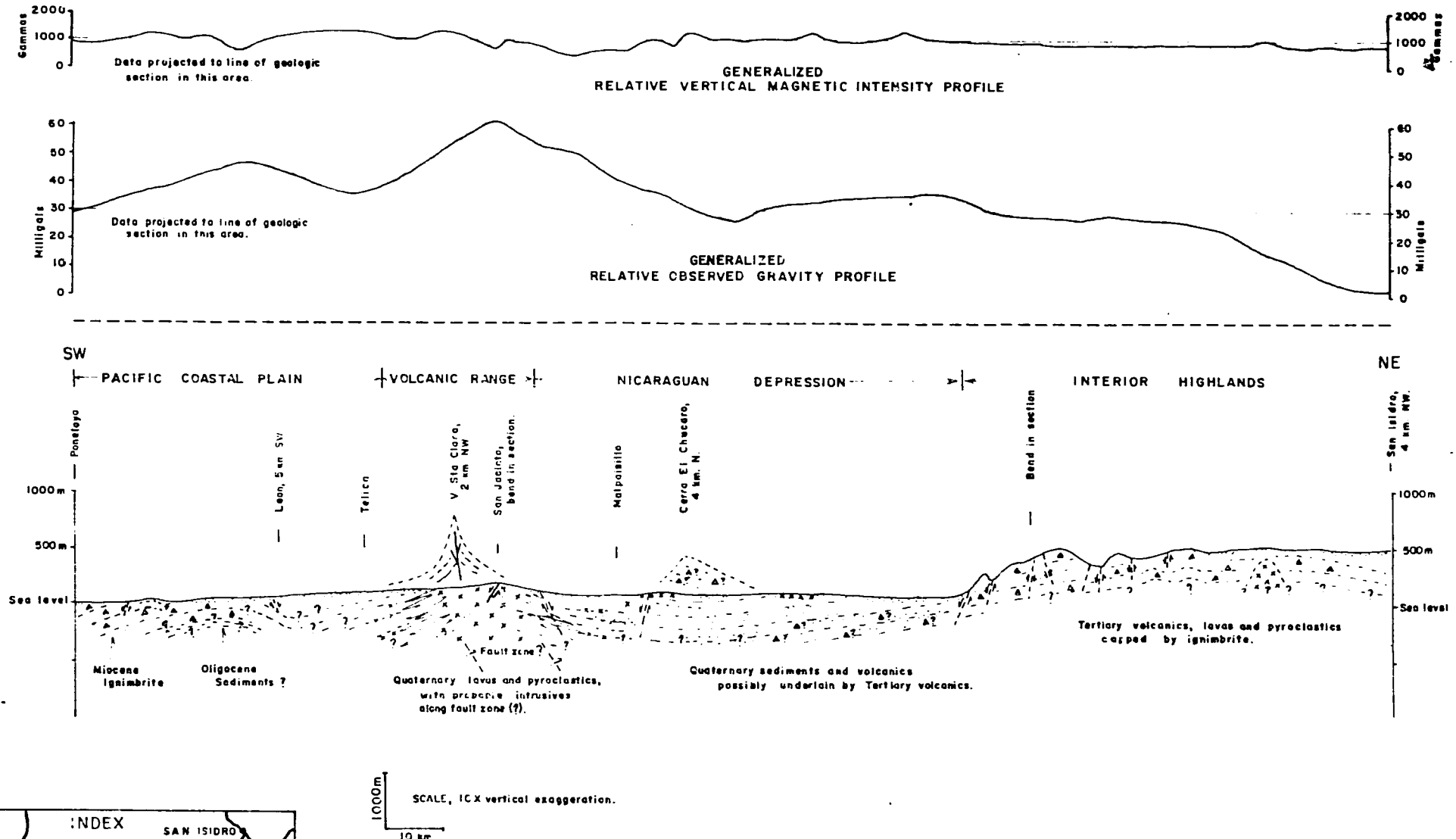


FIGURE 3 GENERALIZED GEOLOGIC CROSS-SECTION PONELOYA TO SAN ISIDRO
WESTERN NICARAGUA

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PROYECTO DE RECURSOS GEOTERMICOS DE NICARAGUA

Range. This high is interpreted as the result of intrusive and extrusive rocks, with one or more faults along the eastern side and regional west dip along the western side. The irregular extrusive and intrusive rocks in this area may conceal other structures. No large faults were located on the east side of the Nicaraguan Depression, again suggesting a westward tilted fault block or a synclinal structure. Regional folds and small faults, generally comparable to those mapped by the Catastro photogeologic evaluation, are indicated in the Interior Highlands.

The origin of the Nicaraguan Depression is unknown but some postulations can be made. It is possible that the depression is a feature directly related to the underthrusting of oceanic rocks beneath the continent along a Benioff zone which has as its surface expression the Middle America Trench. This trench is about 5000 meters deep and about 150 km. west of and parallel to the coast. Underthrusting of oceanic rocks along an eastward dipping fault zone from the trench would lead to melting at considerable depth beneath the edge of the continent producing the volcanoes which are localized along a zone of structural weakness, either the western boundary fault system of

the depression or, in the alternate synclinal explanation, along the deepest part of the depression. Ideas about this postulation and other regional tectonic features are summarized by Dengo (1968).

In El Salvador the prolongation of the Nicaraguan Depression was thought to have developed in the crest of a geanticlinal structure by Williams and Meyer-Abich (1955). It would appear that a somewhat similar feature could be present in Nicaragua, as the regional west dip to the west of the depresión is well established but northeast of the depression the regional structure is flat or also westward dipping. Such a regional arch may be required in order to allow tension to form the depression in the crest and compression to form smaller folds on the flanks. The synclinal postulation for the origin of the depression would be easier to explain as due to more or less horizontal compression, but a serious problem with this explanation is the great longitudinal extent of the depression into areas to the northwest and southeast where no convenient folds are associated with it.

The age of the various structural features is not certain but a probable sequence can be postulated. The folding affects Miocene rocks, with the Rivas anticline dated as Late Miocene or Early Pliocene by the

angular unconformity between Middle Miocene and Pliocene sedimentary rocks (McBirney and Williams, 1965). The Nicaraguan Depression also affects Late Tertiary volcanic rocks, especially along the east boundary. The depression probably started its development approximately contemporaneous with the folding, whichever type of origin is assumed for it. There is no evidence to assume a separate phase of major tectonic tension after the folding. The north-south and northeast-southwest faults and fractures appear to be young features, controlling and in some cases developing during Recent volcanism. (McBirney and Williams, 1965; McBirney 1955a, 1955b). Right-lateral movement along a zone parallel to the Middle America Trench is postulated to explain these younger structural trends by McBirney and Williams (1965).

THERMAL MANIFESTATIONS

Introduction

Most of the thermal manifestations of Western Nicaragua are associated with the Volcanic Range and the Nicaraguan Depression (plate 1).

All of the fumaroles noted are associated with the young volcanoes of the Volcanic Range. The maximum recorded steam temperature at the surface is 101°C. Some thermal springs and wells are located in the Volcanic Range but thermal springs and wells are most common in the Nicaraguan Depression where water temperatures up to 96.5°C were recorded. The shortage of thermal springs and wells in the Volcanic Range is partially due to the generally deep water table in this area, favoring the development of fumaroles instead. The heat flow in the Pacific Coastal Plain is apparently normal since only three or four warm springs and wells were located despite good data. Several warm to hot springs and wells are scattered over the Interior Highlands but these are rather unimpressive features in general. In several instances the warm to hot springs are directly associated with relatively old igneous intrusions now exposed at the surface. It is probable that underwater thermal manifestations occur in Lake Managua and Lake Nicaragua.

For the purpose of this study thermal manifestations of interest can be divided into three very general groups as follows: (1) volcanic high temperature fumaroles resulting from active volcanism, usually in a summit crater or associated with lava flows; (2) low temperature fumaroles and hot springs with the heat source from a generally young, still cooling intrusion at relatively shallow depth in areas of recent volcanism; and (3) manifestations with no direct relationship to recent volcanism such as scattered warm to hot springs generally due to a disseminated, deep, or old heat source.

Of these three general groups, the second (thermal manifestations related to young, shallow intrusions such as volcanic magma chambers) is most favorable for providing potential geothermal power prospects. Surface temperatures are rarely above 100°C but may increase rapidly with depth, so that high temperature steam and/or water may be tapped by drill holes with relative ease and safety.

The first group, usually volcanic fumaroles in active volcanic craters or on recent lava flows, is not favorable as a geothermal power prospect due to engineering and safety problems as well as general undependability of these features.

The third group of thermal manifestations, usually with a disseminated, deeper, or older heat source, should be considered in any investigation of potential geothermal power prospects since these manifestations may represent diluted leakage from a hidden geothermal reservoir. However, the desirability of these thermal manifestations in the initial stages of geothermal power evaluation is usually secondary to the second group of thermal manifestations, since the latter manifestations directly suggest a favorable geothermal power prospect.

For this study a somewhat arbitrary temperature of 32°C (89.6°F) was selected as the minimum for thermal water, based on mean annual air temperature. The mean temperatures in most of the project area average 27-30°C, with lower mean temperature at various points in the Interior Highlands of 21-26°C according to data in Nicaragua, National Inventory of Natural Resources (1966). The 32 °C minimum temperature for thermal water appears to serve well except in the Interior Highlands where this minimum is perhaps too high. It is thought that all meaningful thermal manifestations are included in this 32°C or above temperature range. Some representative normal spring and well water temperatures from Catastro data

are indicated on plate 1 for comparison.

During this evaluation it was noted that many if not most of the thermal manifestations which were field checked are directly associated with structural features, usually fractures or faults. This is due, of course, to the fact that fractures and faults may provide high permeability conduits which allow water and steam to rise rapidly from a heat source at depth.

Also noted was that active or recently active hydrothermally altered areas are typically barren of vegetation except for grass and minor shrubs in contrast to nearby abundant vegetation, which is jungle type growth in some cases. This is probably related to chemical changes in the soil and/or increase in soil temperature. The long period of time required to revegetate old altered areas indicates that changes in the soil chemistry are involved. Recent tree kills around the margins of areas with active hydrothermal alteration occur in several instances; this phenomenon appears to represent recent extension or amplification of hydrothermal activity.

Hydrothermally altered areas are generally easy to locate visually from a favorable vantage point as

the altered areas typically are barren of vegetation and show bleached or oxidized rock colors. Low altitude aerial observations are especially helpful for location of active or recently active altered areas because of the colors involved. Air photographs are also very helpful. It should be noted that in the tropical climate of Nicaragua, steam is often difficult to sight except when very abundant or when weather conditions (particularly high humidity, low barometric pressure, lower temperatures or recent rainfall) are especially favorable.

Most of the highly and severely altered rock at the surface of the fumaroles has probably been altered comparatively recently since such deposits are rapidly eroded and removed by water action during the wet season.

Water samples for chemical analysis were taken of all applicable thermal springs and wells. Gas samples were taken from the major fumarole areas by the project geochemist. Geochemical aspects are reported separately.

Most of the data were obtained during the dry season, Nov.-April. Increased flow of springs and removal of sublimate-efflorescence deposits occurs during the wet season, May-October.

Description of Thermal Manifestations

The most important thermal manifestations are individually described below and are shown on large scale maps where required. All thermal manifestations noted during this evaluation are indicated on plate 1 and are summarized in table 1-3 in the appendix of this report.

The most important thermal manifestations (figure 4) possibly indicative of hyperthermal zones and possible present or future geothermal power prospects are ranked as follows: S. Volcán Momotombo fumaroles, San Jacinto-Tisate fumaroles, Volcán Casita fumaroles, N. Volcán Telica-Ñajo fumaroles, Lake Jiloá-Apoyeque thermal area, Volcán Mombacho thermal area, Cerro Colorado fumaroles, Tipitapa hot springs, Hda. Agua Caliente-Villa Salvadorita thermal wells, and San Luis hot springs. The last areas probably have only a minimal possibility of being a geothermal power prospect. This ranking, further explained below, is based mostly on qualitative surface geologic aspects such as size, temperature, and degree of alteration. Chemical data are not considered to a large extent; these data are reported separately.

The thermal areas of S. Volcán Momotombo and San Jacinto-Tisate appear to be the most favorable areas

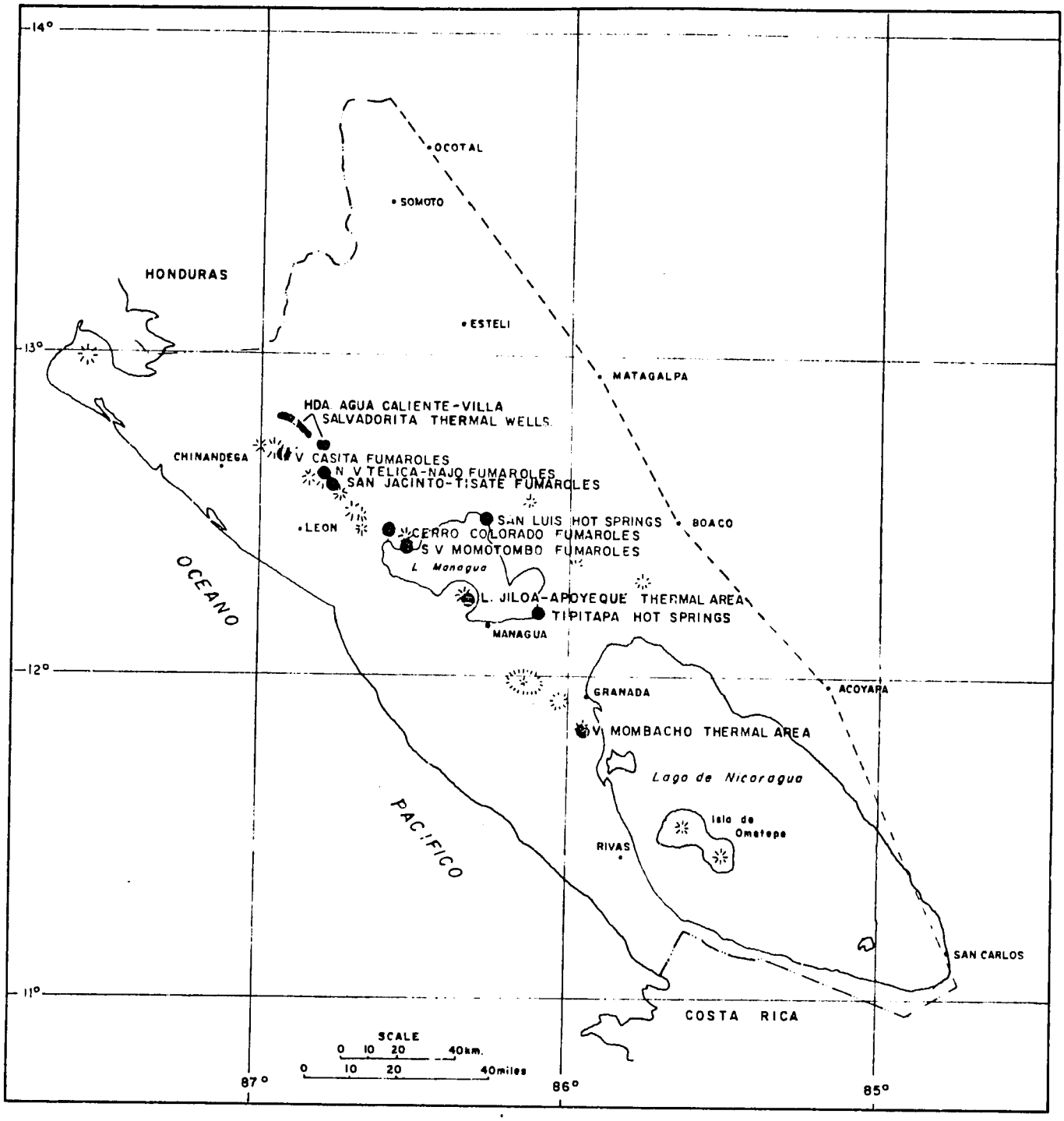


FIGURE 4 MAJOR THERMAL AREAS WESTERN NICARAGUA

for geothermal power prospects. At this stage the two areas appear to be of about equal merit. Detailed geological, geophysical, and geochemical surveys, reported separately, have been performed by this project at both of these areas. Drilling of thermal gradient holes and possible later deep holes is in progress.

SOUTH VOLCAN MOMOTOMBO FUMAROLES

A summary of this area is presented here. Detailed geology and maps are presented in a separate report.

This is the most extensive thermal area located in Western Nicaragua. Several hydrothermally altered zones with scattered fumaroles and steaming ground are present in an area about 2.0 km. square. The area of surface alteration is about 0.75 sq. km. total, with the largest altered zone accounting for about half of this total area. The altered zones are located in conspicuous unvegetated areas, where only grass and occasional trees grow instead of the rather thick stand of trees in surrounding areas. Elevation ranges from 39 meters at the shore of Lake Managua to about 340 meters at the upper fumaroles (figure 5).

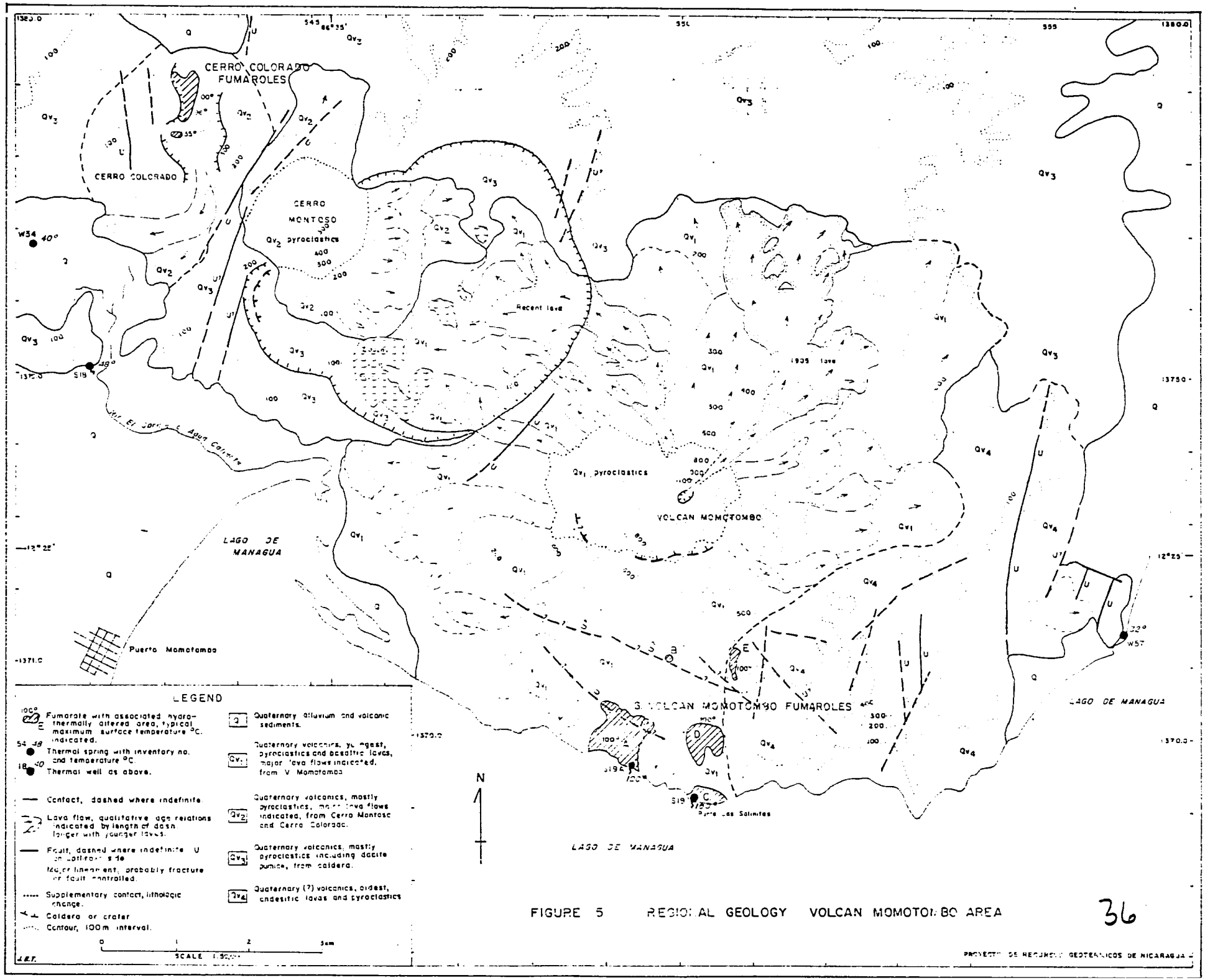


FIGURE 5 REGIONAL GEOLOGY VOLCAN MOMOTOMBO AREA

Alteration is generally slight to moderate but near the active fumaroles alteration is often severe with some argillization. Bleached rock and oxidization colors are also common at the active fumaroles. The steam, usually in very sparse quantities except at the upper fumarole (E), is at temperatures up to 100°, occasionally to 101°C. Sublimates of native sulphur formed by oxidation of hydrogen sulfide are present as crystals in small to very small amounts around the fumarole orifices. White to yellow efflorescence deposits, as yet unidentified, are common in the dry season especially near Lake Managua. These deposits are caused by evaporation of seeps of mineralized ground water. Boiling hot springs with temperatures of 100-101°C and with comparatively small flow are present at Punta Las Salinitas on the shore of Lake Managua. Minor deposits of probable siliceous sinter are associated with the springs. Another area of very small boiling hot springs with conspicuous white efflorescence deposits is located further west on the shore of Lake Managua at fumarole "A". Numerous thermal seeps occur along the edge of Lake Managua during the wet season. No hot springs are present higher on the slopes of Volcán Momotombo.

The extensive fumaroles along and near the shore of Lake Managua are separated at the surface from the smaller fumaroles higher on the slopes of Volcán Momotombo. This separation is apparently related to structure, possibly a northwest trending series of faults.

Pyroclastic rocks predominate as would be expected on the slopes of a composite volcano like Momotombo. The pyroclastic rocks are mostly poorly consolidated cinders or lapilli tuff, with some agglomerate, volcanic breccia, and probable lahar deposits. Basaltic lava is present in a few scattered outcrops, but most of the area is mantled by a layer of comparative recent cinders averaging about one meter in thickness covering older cinders and lava flows. Several relatively narrow old lava flows, interpreted from air photographs as present at a shallow depth beneath the mantle of cinders, extend down the slopes of Momotombo in the vicinity. Some of these covered lava flows appear to extend between but not into the active thermal zones. Basaltic blocks and boulders, apparently from pyroclastic deposits, are common in most thermal zones. Alteration of the permeable pyroclastics is much more severe than the dense lavas. In general, exposures are rather poor, due to the mantle of cinders and thick vegetation outside the thermal zones.

The summit of Volcán Momotombo at 1280 meters elevation is about 2.0 km. north of and about 900 meters above the upper, north fumaroles. Momotombo has continuous fumarolic activity in its summit crater, often with a plume of volcanic gases, probably mostly steam. 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 relatively recent lava flows have occurred on the south side of the volcano.

SAN JACINTO-TISATE FUMAROLES

A summary of this area is presented here. Detailed geology and maps are presented in a separate report.

An active fumarole area is located on the northwest side of the village of San Jacinto which is on the highway between León and Malpaisillo at the axis of the Volcanic Range (figure 6). This fumarole covers an area of about 200 sq. meters of surface alteration, at an elevation of about 190 meters, with the surrounding terrain covered by relatively young lava. In the fumarole area moderate to large quantities of steam escape at temperatures up to 100°C from scattered vents and other manifestations such as active mudpots. Alter-

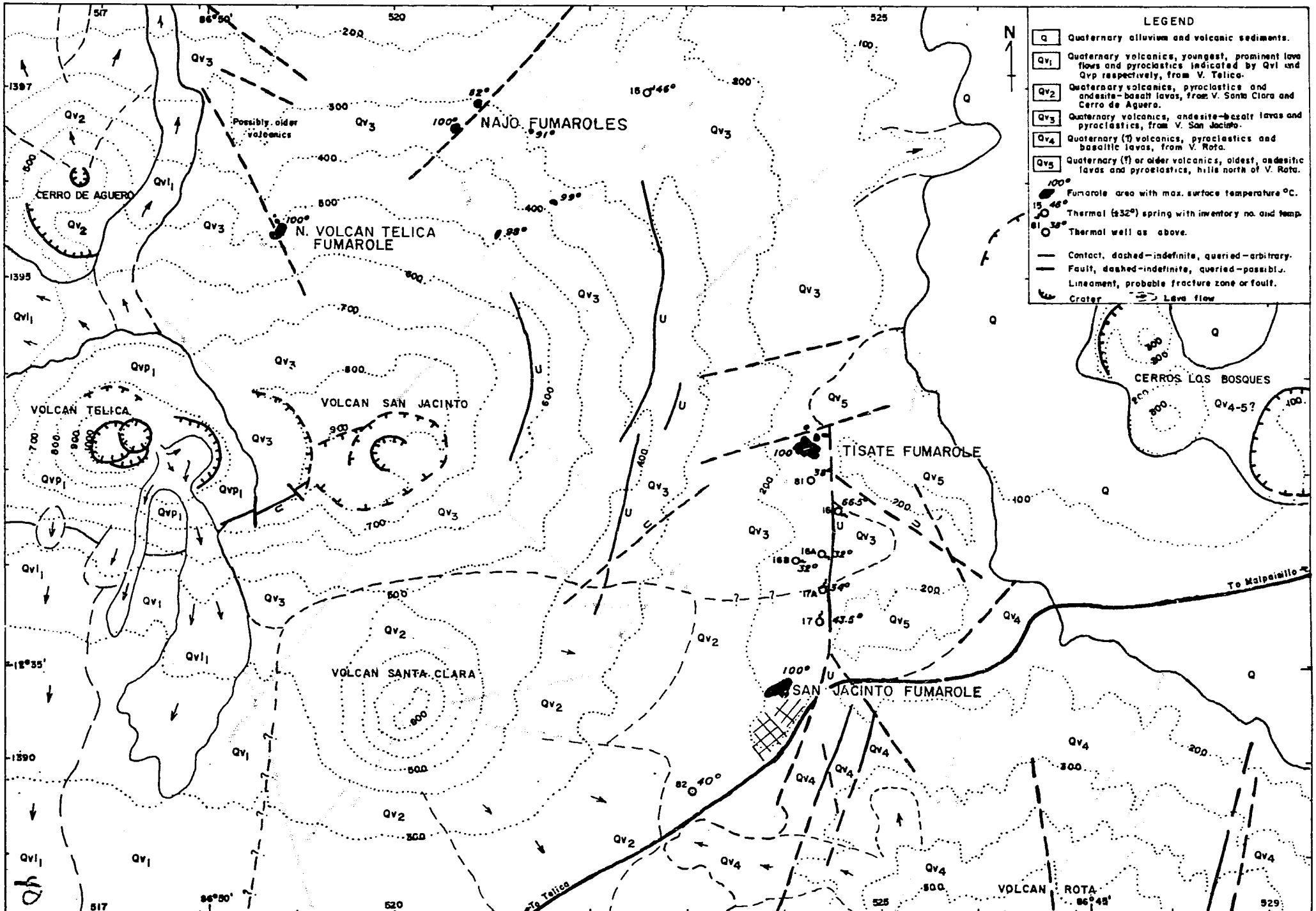


FIGURE 6 REGIONAL GEOLOGY SAN JACINTO AREA

ation of basaltic and andesitic lava with probable pyroclastics is generally high to severe with considerable argillization, especially in the central part. White to yellow sublimates and efflorescence deposits, as yet unidentified, are common in the dry season. Some pyritization is present in the most altered rock. The water in the mudpots and hot pools is probably almost entirely meteoric, since the presence or absence of water is directly related to the wet and dry seasons.

At the Tisate fumarole about 2.5 km. north of San Jacinto, several altered areas are present. The total area of surface alteration is about 600-800 sq. meters at an elevation of about 160 meters, but the area of present activity is much less than this. The present fumarolic activity is less than at San Jacinto, consisting of a few scattered steam vents with very sparse steam at temperatures to 100°C. Very sparse sulphur sublimates occur at most of the active vents. Predominately andesitic lavas and some pyroclastics are slightly to severely altered with some argillization. At the largest altered area a quite large clayey residual mound is present. Sparse efflorescence deposits and sublimates of unidentified white to yellow minerals are scattered around the more active fumaroles. An inclined hole drilled to a vertical depth

of 287 feet in 1953 in the north part of the altered area still vents a small amount of steam and water through a choke about one-half inch in diameter.

Several thermal springs with temperatures of 33 to 66.5°C occur between San Jacinto and Tisate. The only highly mineralized spring noted in the entire area is the 66.5°C spring about 1.0 km. south-southeast of Tisate.

The north-south alignment of the fumaroles and hot springs is probably related to a major north-south fault (figure 6), which is apparently downthrown to the west. Older volcanic rocks are exposed to the east in the apparent upthrown block. This fault, represented by an eroded linear escarpment and strong lineament, is associated with relatively minor faults and fractures which appear to localize the thermal manifestations. All of the thermal manifestations are west of or along the major fault.

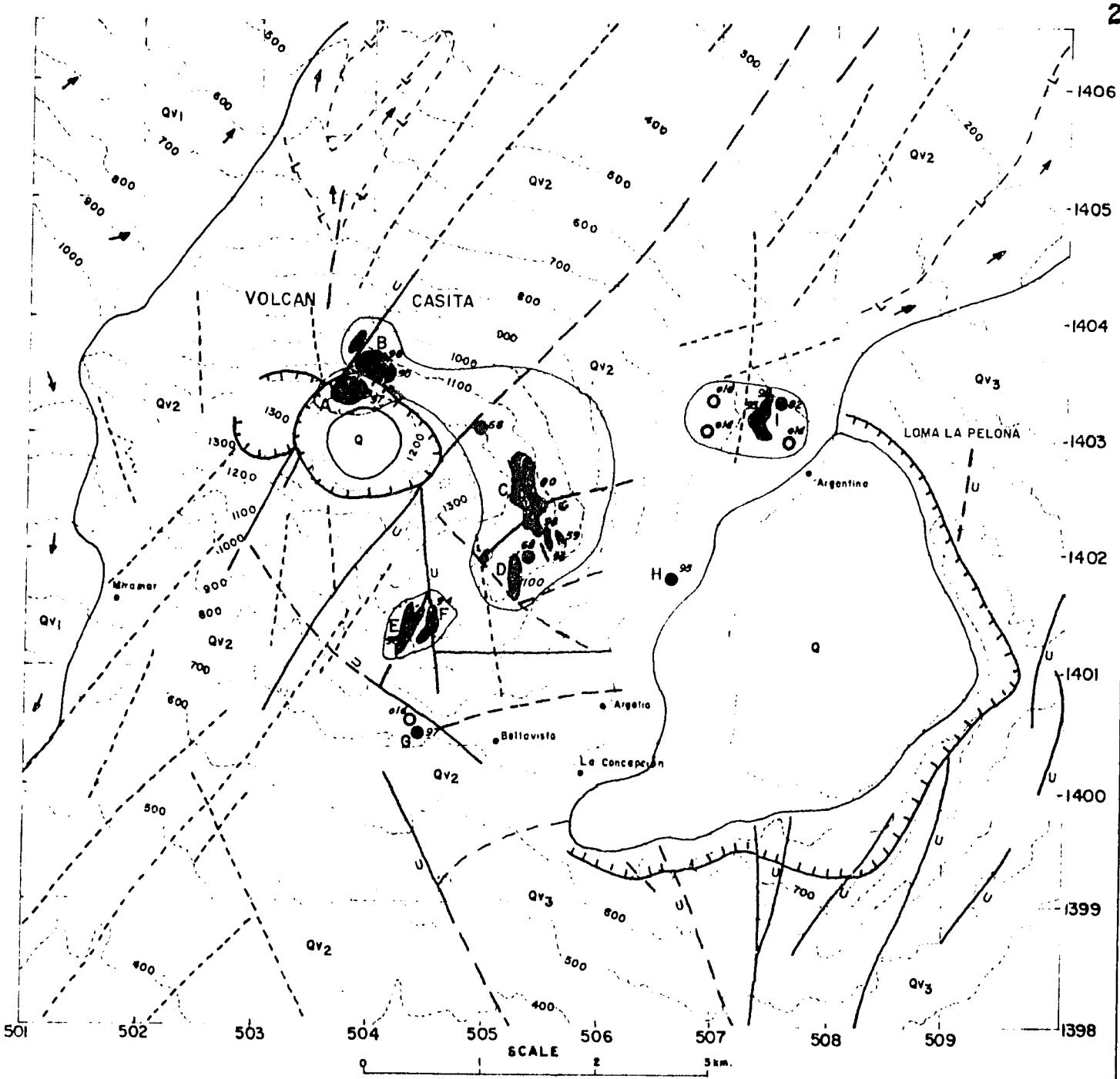
The San Jacinto-Tisate area is on the lower eastern slopes of the inactive Santa Clara and San Jacinto volcanoes. Telica volcano, with current fumarolic activity and occasional minor ash eruptions from its summit crater, is 7.0 km. west of Tisate. Inactive, partially eroded Rota volcano is southeast of San Jacinto.

VOLCAN CASITA FUMAROLES

Numerous fumaroles were located on the south and east slopes of Volcán Casita (formerly Chichigalpa) as shown on figure 7. These active areas probably occur over a larger area than shown, especially on the southeast and east slopes where a large unvegetated area appears to correspond more or less to the limit of alteration. This inferred extent of alteration is shown on figure 7.

In general a small to moderate amount of steam at temperatures of 90-100° is present at these fumaroles with sparse white efflorescence deposits and sublimates present at some of the fumaroles, but sparse sulphur sublimates are present only at the summit crater fumarole. The steam is generally wet and apparently rather clean. Alteration at the fumaroles is generally moderate to high with a few areas of severe alteration resulting in argillization.

Volcán Casita is an inactive, partly eroded volcano composed mostly of pyroclastics and basaltic lavas. Exposures are generally poor except in fumarole areas, where alteration hinders determination of original rock types. In the fumarole areas, pyroclastics are often severely altered, while basaltic blocks and boulders are



LEGEND

A 97 Large, G 97 Small, O Inactive — Hydrothermally altered area with active fumaroles (often scattered over area). Typical maximum surface temperatures °C are indicated. Letter designation is for location reference only.

Probable maximum extent of hydrothermal alteration at surface.

Q — Quaternary alluvium

Qv_1 — Quaternary volcanics, youngest, mostly lavas, from V. San Cristobal.

Qv_2 — Quaternary pyroclastics and lavas from V. Casita.

Qv_3 — Quaternary (?) volcanics, oldest, from Loma La Pelona.

Contact

Fault, dashed where inferred. U indicates upthrown side.

Lineament, probably fracture or fault controlled.

Lava flow.

Crater

FIGURE 7 VOLCAN CASITA FUMAROLES

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only slightly to moderately altered, corresponding to differences in permeability of the rocks. Fault and fracture zones, usually with northeast-southwest or north-south trends are quite prominent as shown on figure 7. Many of the fumaroles are localized along these faults and fractures, especially at their intersections.

The more important areas of fumarolic activity are described below. The letter system used is for location purposes only. Elevations are indicated on the base map. All of the altered areas are unvegetated except for minor shrubs and grass.

Area "A" is located on the north wall of the well defined but inactive summit crater. The area of alteration is about 400 meters long east-west and 200 meters wide north-south, extending from the crater floor about 100 meters up the side to the top of the crater wall. Several small vents with very sparse steam at a temperature of 97°C are present. Sparse sulphur sublimates and more abundant white efflorescence deposits and sublimates are present in the more active areas. The odor of sulphurous gases is noticeable. The fumarole is in pyroclastics with associated large basaltic lava blocks and minor lava flows. Alteration is high to severe with considerable argillization of pyroclastics in the central, most active part.

Area "B" includes several scattered active fumaroles separated by altered areas with an extent of about 4000 sq. meters located north of and on the outside wall of the crater near fumarole "A". The active fumarole areas with very sparse steam, are relatively small, about 10-15 meters or less in diameter, and are situated in highly to severely altered and argillized pyroclastics with minor basaltic lava blocks. Steam temperature averages 95°C, but at one particularly active fumarole the temperature is 98°C. Sparse white efflorescence deposits and sublimates are associated with most of the fumaroles. Many temperatures in the 60-90°C range were observed in the less active zones between fumaroles. A prominent northeast trending fault marks the northern boundary of this area of fumaroles.

Area "C", on a ridge southeast of the crater, consists of several active fumaroles scattered over a slightly to moderately altered zone. This zone is about 900 meters long north-south and 200-300 meters wide, with an area of 0.2 sq. km. of alteration. The zone probably extends farther to the east, downslope, and farther to the north where scattered small fumaroles were located. Moderately abundant (very visible) apparently "clean" steam at 90-96°C with little odor and only sparse white efflorescence deposits and subli-

mates characterize these fumaroles. At the fumaroles alteration of tuff and associated minor lava flows and volcanic breccia is moderate to severe, with some argillization. Two prominent but probably minor faults, one trending northeast and the other north-northwest, appear to control the location of these fumaroles.

Area "D" is a very active fumarole area. Steam at 100°C with a sulphurous odor is abundant (visible from a distance) in the central and lower (southern) part of the fumarole. Scattered white efflorescence deposits and sublimates are present. This area is located in a north-northwest-trending gully with the fumarole extending about 200 meters along the gully and about 30-50 meters across the gully. The fumarole appears to be concentrated in a breccia zone below a lava flow. Other thin lava flows and tuff layers are present in the area. Alteration is high to severe with considerable argillization of the tuff. A small fumarole about 10 meters in diameter with very sparse steam at 96°C is situated about 100 meters northeast of the main fumarole. Another slightly larger fumarole with a moderate amount of steam is located about 150 meters northwest of the main fumarole.

Area "E" is in the bottom of a northeast trending canyon controlled by a fault or fracture zone. This altered area extends for 300-400 meters along two nearly parallel canyons which join in the lower portion of the area. Overall width is 50-150 meters. Interbedded tuff and thin lava flows are present, with the tuff severely altered and argillized and the lava slightly to moderately altered. Scattered small fumaroles with very sparse steam at 90-96°C are present with associated sparse white efflorescence deposits and sublimates.

Area "F" is located along a north-south fault escarpment, downthrown to the west, above and east of the canyon of area "E". Scattered small fumaroles with very sparse steam at 86-94°C issue from slightly to moderately altered andesitic lava flows and volcanic breccia near the top of the escarpment and from highly to severely altered tuff in the middle part of the escarpment. Sublimates are very sparse. Recently killed trees nearby to the south possibly represent an extension or amplification of fumarolic activity.

Area "G" is a small altered area about 70 meters long north-south and 20-30 meters wide located on a small north-south escarpment caused by a fault or possibly the edge of an old lava flow. Several small

steam vents with very sparse steam at 89-97°C and very sparse white efflorescence deposits and sublimates are present. Alteration of vesicular to dense, thin basaltic lava flows and blocks and associated tuff is generally moderate to very high with some severe alteration and argillization of associated tuff. Recently killed trees to the west possibly indicate an extension or amplification of fumarolic activity.

Area "H" is a small area of moderate alteration about 30 meters long and 5-10 meters wide along a probable small fault scarp. Blocks of andesitic lava and minor tuff are exposed in the altered area. Very small fumaroles with very sparse steam at 97-98°C and sparse white efflorescence deposits and sublimates are present, although most of the altered area has lower temperatures of 40-70°C at about 8-10 cm. depth.

Area "I" is an altered area about 300 meters long northeast-southwest and 50-100 meters wide located on the east slopes of Volcán Casita. It is located near the north boundary of the Loma La Pelona caldera, a structure older than Volcán Casita. Most of this altered area is now inactive and littered with large basalt blocks. Scattered small active fumaroles with temperatures of 93-99°C are present in the central part and northeast end of the altered area, with very

sparse steam and sublimates only in the northeast end. One small active fumarole area and three inactive altered areas are located nearby as shown on figure 7.

The above data combined with available chemical data, reported separately, seem to indicate the heat source may be relatively deep or weak. The 700 to 1200 meters elevation of the fumaroles, with probable considerable depth to the water table, is a detrimental factor for a geothermal prospect. Rough terrain is an additional factor. With all factors considered this thermal area is not as favorable for a geothermal prospect as other areas such as S. Volcán Momotombo and San Jacinto-Tisate. It should definitely be considered after the better areas are evaluated.

N. VOLCAN TELICA-ÑAJO FUMAROLES

The N. Volcán Telica fumarole is located, as shown on figure 6, 2.4 km. N 35°E from the summit of Volcán Telica, which is currently in a fumarolic stage of activity.

The main hydrothermally altered area is about 100 meters in diameter but in detail consists of two bowl-shaped depressions eroded in altered rock along

parallel north-northwest trending stream canyons and the intervening ridge at an elevation of about 500 meters. The larger portion of the area in the eastern canyon is about 50 by 100 meters in size with smaller areas about 10-15 meters in diameter extending north along the canyon.

Current fumarolic activity involves very sparse steam which issues from small scattered vents with temperatures up to 100.5°C. Sparse sulphur sublimates and unidentified white and yellow sublimates and efflorescence deposits are associated with the active fumaroles. No thermal springs were located although local reports are that a wet season hot spring is located in the canyon north of the fumarole.

Alteration of aphanitic, dense, dark gray, closely jointed basalt is high to severe with some argillization. Alteration products vary from white, opalized rock, which is widespread in the area, to light gray, bleached, soft to moderately hard, clayey material associated with the active fumaroles, sometimes forming small residual mounds.

The older, less active parts of the altered area are generally red-brown in color with ground temperatures of 70-90°C. Most of the altered rock is rapidly removed by erosion processes.

The north-northwest trending stream canyons appear to be fault or fracture controlled.

Two main hydrothermally altered areas occur at Ñajo, about two km. northeast of the above fumarole area, as shown on figure 6. Each of the areas is about 100 meters in diameter and is at an elevation of about 300 meters. As reported during detailed geological studies of the area, the northerly altered area shows some argillization and minor fumarolic activity. The southerly altered area shows more fumarolic activity and alteration. Sparse steam at 100°C temperature is present. Small thermal springs at 59-67°C are associated with both of the fumaroles. The two areas are associated with a prominent northeast trending fracture which appears to serve as the conduit for the hydrothermal fluids.

Other small, less active hydrothermally altered areas are located east and south of Ñajo as shown on figure 6.

At Hda. Santa Clara, east of Ñajo, a large, apparent lava-contact type spring area flows about 1500 gal/min at 42-46°C.

These fumaroles are interesting as a possible geothermal power prospect but their dispersion, gener-

ally low intensity of fumarolic activity, and chemical data, reported separately, indicate this possible prospect is less favorable than other, more active fumaroles. Access is relatively poor. This possible prospect should be further investigated after more favorable areas are evaluated.

LAGUNA DE JILOA - APOYEQUE THERMAL AREA

This area is on the Chiltepe Península northwest of Managua (plate 1).

A rather small fumarole area is located on the north side of L. Jiloá, which is in an apparent explosion crater on the southeast side of the inactive Apoyeque volcanic structure. The fumaroles are on the outer edge of an alluvial fan, along the shoreline of the lake. Two currently active fumaroles occur with a total area of about 1200 sq. meters at an elevation of about 40 meters.

Current activity consists of very sparse steam at a temperature of 100°C which issues from scattered very small steam vents with sparse associated sulphur sublimates. The steam has a slight sulphurous odor. Gas bubbles occur in the margin of the lake adjacent to the fumaroles. No springs were located; apparently all the activity in the edge of the lake (average sur-

face temperature 29°C, higher adjacent to the fumaroles) is caused by escaping gas although underwater springs are possible. Abundant white and yellow, as yet unidentified, efflorescence deposits and sublimates occur in the fumaroles. Alteration of the alluvial fan material, which is unsorted sand, gravel, and lava boulders, varies from slight to very high with small areas of severe alteration and argillization. The variation in alteration is due to migration of the active vents as well as differences in the alluvium.

A warm spring seep area was located on the south side of L. Jiloá in a gully west of the restaurant. No visible water flow can be seen in the sandy gully bottom, but temperatures up to 41°C were measured within four inches of the surface. Very sparse efflorescence deposits are present.

Several thermal springs were located at L. Apoyeque which occupies a caldera with walls 300-400 meters in height above the lake and 2 km. in diameter located in the center of the Apoyeque volcanic structure. Two spring areas with minor gas and temperatures of 36 and 37°C were located along the east side of the lake at about 40 meters elevation, separated by a divide about one km. in width from the fumaroles

at L. Jiloá. No doubt other springs occur in L. Apoyeque since the water is highly mineralized and has an average temperature around the margin of about 32°C. A reported fumarole area on the northeast side of the lake could not be located by air and ground search. If present, this area must be very small.

Water wells with temperatures of 32-45°C are located around the edge of the Chiltepe Península.

The surface thermal manifestations in this area are relatively minor but chemical data, reported separately, indicate that further investigation may be worthwhile. Access to parts of the area is difficult.

VOLCAN MOMBACHO THERMAL AREA

Volcán Mombacho is an inactive, vegetation-covered volcano with a prominent breached summit crater.

A fumarole of moderate size and with a moderate amount of steam with a slight sulphurous odor was located on the north wall of the summit crater at about 1200 meters elevation, but was observed only from a distance. Local reports indicate that sparse sulphur sublimates are present.

Thermal springs with temperatures of 34-55°C occur in the summit crater, and at the northeast and southeast base of the volcano (plate 1).

This area was not investigated as thoroughly as other areas so its full potential is poorly known.

At the present time, this area does not appear to be especially favorable as a geothermal power prospect. Further investigation may improve its standing.

CERRO COLORADO FUMAROLES

This area of hydrothermal alteration and minor active fumaroles is located in an eroded cinder cone, Cerro Colorado, which is on the axis of the Volcanic Range, northwest of Volcán Momotombo and southeast of Volcán El Hoyo (figure 5).

The area of hydrothermal alteration is about 1000 meters long overall and up to 400 meters wide with an estimated area of 0.2 sq. km. at the surface, as shown on figure 5. Fumaroles with very sparse steam at 100°C and sparse to very sparse white efflorescence deposits and sublimates are scattered over the area. The hydrothermal activity has apparently recently decreased to a currently rather low

level of intensity over the entire area, but especially in the center of the cone where no steam now escapes from "fossil" fumaroles with much argillization. The general elevation of the thermal area is 100-200 meters.

The volcanic cinder cone has been breached by stream erosion, probably facilitated by the hydrothermal alteration. The thermal area is situated in the center of the cone and along the west side of the valley extending north from the center of the cone. In the thermal areas, the pyroclastic rocks, mostly poorly consolidated lapilli tuff with some volcanic breccia, have been highly altered. Near the active fumaroles, alteration is very high with some argillization and considerable bleaching of the original rocks. Alteration is more extensive in some tuff layers than in others probably due to differences in permeability.

This thermal area is relatively small with apparently a recent general decrease in fumarolic activity to a currently relatively low level of intensity. These factors indicate that this area is only moderately favorable for further investigations. The position of the thermal area on the volcanic axis between two volcanoes currently in a fumarolic stage of activity is perhaps a positive factor for a geothermal prospect. This area should be considered after more favorable zones have been evaluated.

The 48°C thermal springs at Hda. California are located about four km. south-southwest of this thermal area. Water wells with warm water near 40°C are located to the southwest and north.

TIPITAPA HOT SPRINGS

These springs are located at the village of Tipitapa, which is on the Pan American Highway about 20 km. east of Managua in the central part of the Nicaraguan Depression. The main hot spring, located about 500 meters east of the Pan American Highway at Tipitapa, has been enclosed by concrete walls to form a triangular pool about 12 meters long which serves as a water supply for a thermal bath development. A moderate quantity of gas bubbles with a slight sulphurous odor issue from several vents on the bottom of the pool. The average water temperature in the pool and at some of the vents is 71°C, but higher temperatures to a maximum of 96.5°C were measured at other vents. The combined water flow is small, about 50 gal/min.

The main hot spring at Tipitapa is immediately east of the south abutment of an old bridge across the usually dry channel of Río Tipitapa. Immediately west of this bridge abutment a very small hot spring

at 63°C is located in a small concrete well. Small thermal springs at a temperature of about 38°C are present in the southeast edge of a pond in the stream channel just west of the bridge.

Farther west along the channel of Río Tipitapa, west of the Pan American Highway, small hot springs with a temperature of 76°C and a minor black sulphide precipitate were located on the north bank about 100 meters west of the highway. Another spring with an approximate temperature of 35°C is located about 500 meters west of the highway on the south bank of Río Tipitapa. The water from this spring is contaminated for chemical analyses by its use as a wash basin for clothes. Unverified reports are that other small thermal springs are present downstream toward Lake Nicaragua.

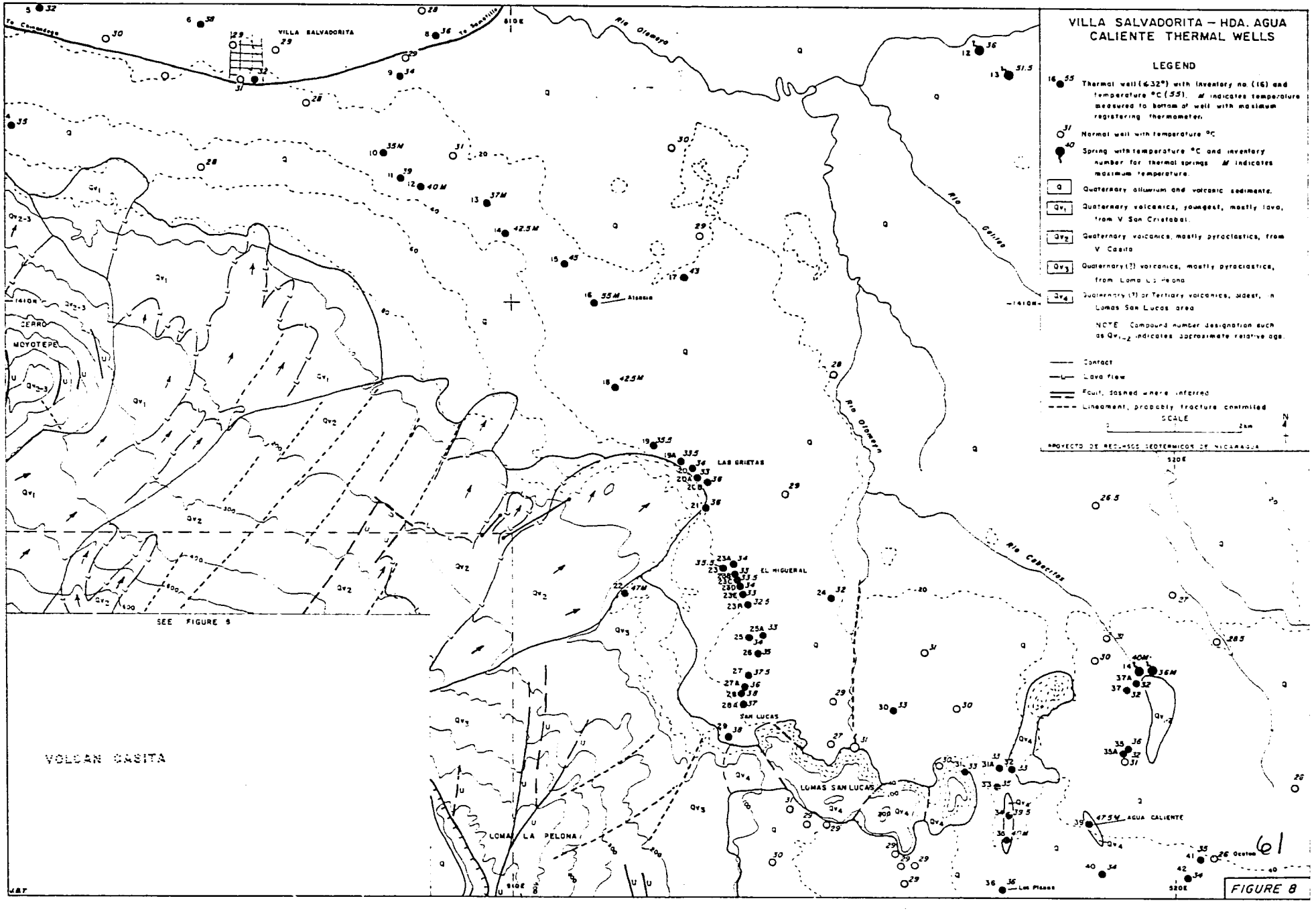
Small outcrops of lapilli tuff or lahar deposits, apparently from the Volcanic Range, were located near the main hot spring. The surrounding area is covered by Quaternary alluvium and volcanic sediments. The nearest volcanic activity is at Volcán Santiago, located 25 km. south-southwest of Tipitapa. An en echelon fault system extending from the Volcán Santiago area north-northeast toward and to within 5 km. of Tipitapa was mapped on air photographs by

Catastro. These en echelon faults are probably the surface manifestation of a larger fault at depth. Possibly this fault at depth extends to Tipitapa and serves as the main conduit for the hot water. This postulation is further substantiated by data in Hazen and Sawyer (1964), which shows a similar-trending thermal ridge with a higher concentration of total dissolved solids in groundwater, but their system of contouring the data is questionable.

HDA. AGUA CALIENTE - VILLA SALVADORITA THERMAL WELLS

Numerous water wells with anomalous water temperatures with a range of 32-55°C occur along the west side of the Nicaraguan Depression east and north of Volcán Casita as shown on figure 8. A narrow linear zone of anomalous wells extends from Villa Salvadorita southeast to Loma San Lucas where hills of possible Tertiary volcanic rocks stop the trend. Southeast of these hills, farther east into the depression, another irregular zone of anomalous wells occurs in the Hda. Agua Caliente area.

The outline of the zones of thermal wells is partially related to available control. No control is available to the west on the volcanic slopes in an area with a deep water table and little control is


VILLA SALVADORITA – HDA. AGUA CALIENTE THERMAL WELLS
LEGEND
Thermal well (632°) with inventory no. (16) and temperature °C (55). M indicates temperature measured to bottom of well with maximum registering thermometer.
Normal well with temperature °C
Spring with temperature °C and inventory number for thermal springs. M indicates maximum temperature.
Q Quaternary alluvium and volcanic sediments.
Qv1 Quaternary volcanics, youngest, mostly lava, from V. San Cristobal.
Qv2 Quaternary volcanics, mostly pyroclastics, from V. Casita
Qv3 Quaternary (?) volcanics, mostly pyroclastics, from Loma La Pelona
Qv4 Quaternary (?) or Tertiary volcanics, oldest, in Lomas San Lucas area
NOTE: Compound number designation such as Qv1-2 indicates approximate relative age.
Contact
Lava flow
Fault, dashed where inferred
Lineament, probably fracture controlled
SCALE
PROYECTO DE RECURSOS GEOTERMICOS DE NICARAGUA
VILLA SALVADORITA
Río Olomega
Río Galiso
Río Cabezitas
CERRO MOYOTEPE
LAS GRIETAS
EL HIGUERAL
SAN LUCAS
LOMAS SAN LUCAS
LOMA LA PELONA
AGUA CALIENTE
VOLCAN CASITA
SEE FIGURE 9
FIGURE 8

available to the east in an area with an often very shallow water table. Sufficient control is available, however, to indicate a linear zone.

The most likely explanation for this area of warm to hot water is a fracture system in the underlying bedrock which allows water to rise rapidly to the surface, due to lower density, after it has been heated at depth. Simple groundwater flow from the volcanic slopes down to a heat source at depth and return to the surface at the edge of the lowlands does not appear likely due to the large amount of heat involved, which seems to require rapid upward flow of hot water, probably along fractures. A fracture system conduit is further substantiated by the apparent linearity of the anomalous wells northwest of Loma San Lucas. The proximity of these thermal wells to the Volcanic Range and western boundary fault of the Nicaraguan Depression indicates the possibility that the heat source is related to these features.

The apparent general decrease in water temperature toward the east in the linear zone northwest of Loma San Lucas indicates that much of the thermal water is rising along fractures underneath the lower volcanic slopes and flowing downslope to the east within the

eastward dipping volcanic deposits. Insufficient data are available to confirm this tentative idea. The higher temperature wells are probably due to higher permeability zones which either allow faster lateral flow as discussed above or more rapid vertical water flow. In the Hda. Agua Caliente area the available control seems to indicate a more or less point source for the thermal water, probably the intersection of fracture systems. The thermal spring on the east side of the Hda. Agua Caliente area is possibly associated with a fracture system on which relatively recent lava flows have apparently issued.

Most of the water wells occur in areas of Quaternary alluvium and volcanic sediments as shown on figure 8. Northwest of Loma San Lucas most of the thermal wells occur in the alluvium just east of the base of the lava flows and pyroclastic deposits on the slopes of the Quaternary volcanoes. Loma San Lucas and associated hills appear to be older volcanic features, possibly early Quaternary or late Tertiary age, which have been greatly eroded and partly covered by Quaternary alluvium and volcanic sediments. Andesitic rocks, often altered and silicified, with conspicuous micro-xenoliths similar to the rocks of Los Bosques east of San Jacinto predomi-

nate in these hills although other volcanics are also present. The Quaternary volcanic rocks are mostly basaltic and andesitic lavas and associated pyroclastics. Numerous strong, usually northeast trending lineaments, probably representing fractures or faults, were noted from air photographs on the volcanic slopes. Few major lineaments were noted in the alluvium-covered areas of the Nicaraguan Depression.

Three large hot springs with temperatures of 51, 68, and 80°C occur 10-20 km. northeast of the Loma San Lucas-Villa Salvadorita zone of thermal wells (plate 1). There is no present evidence to consider these springs to be part of the same system as the thermal wells; rather the springs probably represent water rising on fractures which cut the Tertiary volcanics in the area. These Tertiary volcanics and associated fractures are inferred to underlie the Quaternary alluvium in this area of the Nicaraguan Depression.

At Mina Santa Pancha, southeast of the above springs and east of the Hda. Agua Caliente thermal wells, a water temperature of 70°C was measured as the water flowed from a fracture at the 700 ft. depth level. Other workings of the Mina Limón complex reportedly have more or less normal water temperatures.

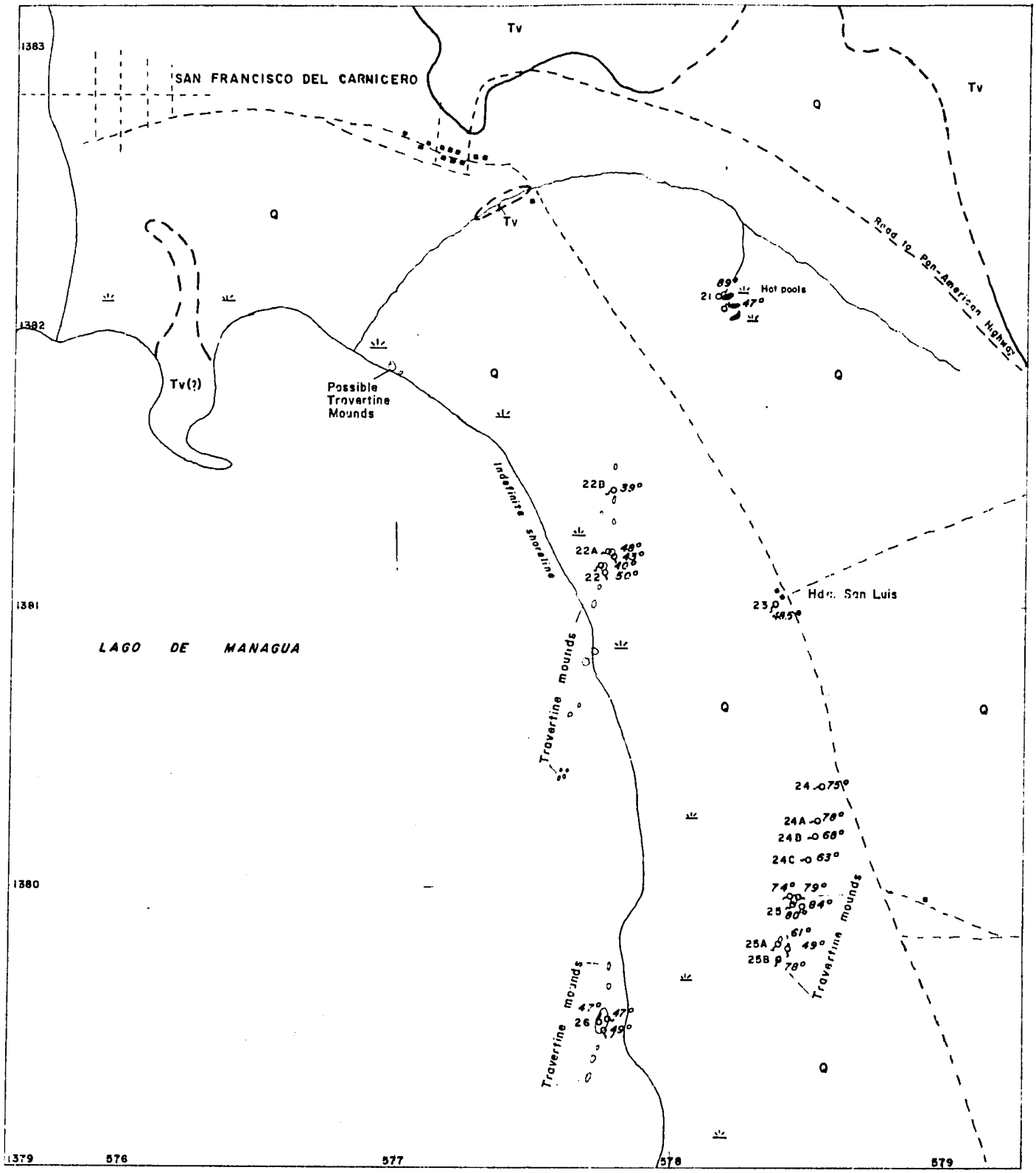
The hot water is reportedly associated mostly with northeast trending fractures.

SAN LUIS HOT SPRINGS

These thermal springs are located near Hda. San Luis, southeast of San Francisco del Carnicero, on the northeast side of Lake Managua.

As indicated on figure 9, the springs occur over a large area about two km. north-south and one km. east-west. Temperatures at scattered springs range from 89°C at the north end to 84°C maximum at the south end with temperatures decreasing westward toward the lake to 48-50°C (possibly increased lake-water dilution to west). The flow from these springs is mostly very small.

The most conspicuous feature noted in the area is the presence of aligned mounds of travertine near and in the lake. The alignment of these mounds and associated thermal springs, probably representing fracture control, is oriented about N15°E as shown on figure 9. The mounds are small, about one meter in diameter, but coalesce to form larger structures up to 10 or 15 meters, sometimes 50 meters, in diameter. The mounds exhibit travertine banding and other spring features such as inactive vents. These mounds appear



LEGEND

21 89° Hot spring with inventory number and temperature °C.

Travertine mound (spring deposits), mostly old, inactive.

Q — Quaternary alluvium and volcanic sediments, includes lacustrine deposits west of raised shoreline.

Tv — Tertiary volcanics, undifferentiated lavas and pyroclastics

Contact, dashed where indefinite.

Prominent raised shoreline.

Road, trail

FIGURE 9 SAN LUIS HOT SPRINGS

6b

to be inactive in general although they are usually associated with thermal springs with very little present discharge.

The surrounding area is covered by alluvial deposits. Raised shorelines are common in a strip about one km. wide adjacent to Lake Managua. Many of the thermal springs occur within this strip of raised shorelines. It is very likely that other thermal springs occur beneath the present Lake Managua. Tuff of apparent Quaternary or Tertiary age crops out on the peninsula south of San Francisco del Carnicero. Tertiary or Quaternary volcanic rocks, andesitic lava and tuff, crop cut just east of San Francisco del Carnicero. Tertiary volcanic rocks appear a short distance to the north, at the northeast margin of the Nicaraguan Depression. The north-northeast trending faults or fractures, which are represented by the alignment of travertine mounds and thermal springs, appear to be the conduit for hot water from depth. This area is near the east boundary fault of the Nicaraguan Depression. The boundary faults may be the large-scale heat conduit.

This thermal area does not appear to be a favorable geothermal prospect at present, but should be considered after more favorable areas are developed.

The old travertine deposits are a qualitative indicator of, at least formerly, comparatively low temperature at depth in the spring system.

CONCLUSIONS AND RECOMMENDATIONS

Twenty-one hydrothermally altered zones and fumaroles, 83 thermal springs and 102 thermal wells, with some of these features closely associated, have been located during this regional evaluation of the geothermal power possibilities of Western Nicaragua.

Ten thermal areas consisting of fumaroles, fumaroles and thermal springs, thermal springs, or thermal wells have been designated. Some of the areas are much more favorable than others as possible geothermal power prospects. The thermal areas have been ranked in relation to qualitative surface geology aspects. Six of these areas are associated with the Quaternary volcanoes and the others are in the Nicaraguan Depression.

As previously mentioned and explained the tentative ranking of the thermal areas is as follows: S.

Volcán Momotombo fumaroles, San Jacinto-Tisate fumaroles, Volcan Casita fumaroles, N. Volcán Teliça-Ñajo fumaroles, Laguna de Jiloá-Apoyeque thermal area, Volcán Mombacho thermal area, Cerro Colorado fumaroles, Tipitapa hot springs, Hda. Agua Caliente-Villa Salvadorita thermal wells, and San Luis hot springs. Evaluation of geochemical results may influence this ranking.

It has been recommended that detailed studies be done at the S. Volcán Momotombo fumaroles and the San Jacinto-Tisate fumaroles. Most of this detailed work has already been done. It is recommended that further studies should include detailed evaluation of some or all of the other listed thermal areas.

A P E N D I C E

A P P E N D I X

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TABLE 1 THERMAL SPRINGS

No.*	Name or General location	Temp.** (°C)	Flow Gal/Min	Data*** Source	Location Coordinates UTM N	E	Elev. (meters)	Comments
1	Cosigüina	38	-	C	1431.8	445.8	15	From alluvium near Pleistocene volcanics.
2	NE of Villanueva	55	100	P	1437.0	528.8	60)	From fractures in igneous intrusive contact area, numerous other small springs.
3	do.	59	50	P	1436.9	529.7	70)	
4	do.	50	50	P	1437.7	529.7	80)	
5	SSE of El Espino	31	700	P	1479.7	532.5	780	From fault in Tertiary volcanics.
6	W of Somoto	32	200	P	1488.8	540.0	660	From fractures in Tertiary volcanics.
7	W. of Ocotal	74	900	PG	1507.3	546.6	620	Several springs from fractures in schist near igneous intrusive.
8	El Boniche	69	-	C	1464.8	591.2	1240	Tertiary volcanics.
9	Laguna El Tule	68	500	P	1419.3	520.4	25	From alluvium, forms hot pool in marshy area.
10	Mayocunda N	61	1	P	1417.7	524.0	25	From fracture in Tertiary tuff.
11	Mayocunda S	80	2500	P	1417.2	523.7	25	From fractures in Tertiary tuff, forms hot stream.
12	Palmica N	36	5	P	1413.9	517.1	10	From alluvium, marshy area.
13	Palmica S	51.5	-	P	1413.5	517.5	12	From alluvium, marshy area, forms hot pool.
14	S of Paso Picado	40	3000	P	1404.4	519.5	22)	Two main sources from Pleistocene (?) lava, forms hot stream.
14A	do.	36	2500	P	1404.4	519.7	22)	
15	Santa Clara	46	1500	P	1397.0	522.8	230	Three main sources, 42, 44, 46°C, issues from lava flow breccia.
15A	Ñajo N	67	6	P	1396.8	520.8	300	Near north fumarole.
15B	Ñajo S	59	1	P	1396.5	520.7	340	Near south fumarole.

No*	Name or General location	Temp** (°C)	Flow Gal/Min	Data*** Source	Location Coordinates UTM N	E	Elev. (meters)	Comments
16	S of Tisate	66.5	1	P	1392.6	524.6	150	Highly mineralized, from fractures in Quat. volcanics.
16A	do.	32	100	P	1392.1	524.4	160	Springs on hillside prob. at lava contact.
16B	S of Tisate	32	100	P	1392.1	524.1	180	Springs at head of stream, prob. at lava contact.
17	N of San Jacinto	43.5	30	P	1391.4	524.3	160	From fractures and between Quat. lava flows at "waterfall", several springs 33-43.5°.
17A	do.	34	350	P	1391.8	524.4	160	From lava flow breccia, 3 assoc. springs, N one used as village water supply.
18	Hda. Calif.	48	4000	P	1375.1	542.0	60	From base of Quat. volcanic hill, several sources 46-48° form Río Agua Caliente.
19	S.V. Momotombo	101	100	P	1369.1	550.2	41	Several highly mineralized boiling spr., minor assoc. tufa w/siliceous sinter, from Quat. pyroclastics, numerous thermal seeps along lakeshore in wet season.
19A	do.	100	5	P	1369.6	549.4	41	Very small boiling springs in fumarole "A" at lake, numerous thermal seeps along lakeshore in wet season.
20	Santa Rita	32	-	C	1396.7	571.5	100	Near or at fault in Tert. volc.
21	San Luis N	89	50	PG	1382.1	578.2	45	From fractures in Tert. volcanic ss, forms hot pools, sparse white encrustations and efflorescence.
22	San Luis W	50	1	P	1381.1	577.8	40	From inactive travertine mound aligned w/others N15E, probable fracture control. Another spring 40°.

No.*	Name or General location	Temp.** (°C)	Flow Gal/min	Data*** Source	Location Coordinates UTM N	E	Elev. (meters)	Comments
22A	San Luis W	48	2	P	1381.2	577.8	40	do., another spring 43°.
22B	do.	39	1	P	1381.4	577.8	40	do.
23	Hda. San Luis	48.5	1	PG	1381.0	578.4	43	From alluvium at well.
24	Hda. San Luis S	75	5	P	1380.4	578.5	43)	From alluvium at corral,
24A	do.	78	5	P	1380.2	578.5	43)	aligned N15E w/#25, 26.
24B	do.	68	5	P	1380.2	578.5	40	Small inactive travertine mound.
24C	do.	63	5	P	1380.1	578.5	40	From 15' dia. inactive travertine mound.
25	do.	84	10	P	1379.9	578.4	40	From inactive travertine mound 25' dia., other springs 74, 79, 80°C, aligned N15°E w/#24, 26.
25A	do.	61	5	P	1379.8	578.4	40	From inactive travertine mound, also 49°C spring.
25B	do.	78	15	P	1379.7	578.4	40	From inactive travertine mound aligned N15°E w/#24, 25.
26	Island S of San Luis	49	25	P	1379.5	577.7	40	From inactive travertine mounds which form island 35m. in dia., two other springs at 47°C.
27	L. Apoyeque N	36	5	P	1353.4	572.5	40	From Quat. volcanics at edge of lake.
28	L. Apoyeque S	37	1	P	1353.1	572.3	40	From Quat. volcanics at edge of lake, mostly gas w/sli. sulphurous odor.
29	L. Jiloá S	41	0	P	1349.8	573.8	40	Seeps in alluvium at edge of lake, see #53.
30	Laguna El Playón	73	500	P	1373.3	597.3	55	Main adjacent springs, others minor, from alluvium, minor gas bubbles w/sulphurous odor, other small hot spring reported to N.
31	Tipitapa W	35	-	P	1348.9	597.7	40	Bank Río Tipitapa, used for

No.*	Name or General location	Temp.** (°C)	Flow Gal/min	Data*** Source	Location UTM N	Coordinates E	Elev. (meters)	Comments
								laundering, 660 m. W of Pan American Highway.
32	Tipitapa W	76	10	P	1349.0	598.2	40	Bank Río Tipitapa, 100 m. W Pan American Hwy., minor blk. sulphide (?) precip.
33	Tipitapa	96.5	50	PG	1349.0	598.8	40	Main spring, used in thermal baths, minor sulphurous odor, Quat. tuff or lahar deposits crops out nearby, concrete pool.
33A	do.	68	1	P	1349.0	598.7	40	Just W of #33, concrete well, 35°C springs in edge of adj. Río Tipitapa.
34	Santa Isabel	37	50	P	1343.3	593.8	40	Forms pool 10 m. dia. (La Perla).
35	Las Positas	36	1000	PG	1342.8	594.3	45	Data from stream draining springs nearby in marsh.
36	Santa Cruz	46.5	300	P	1373.7	625.7	130	From Tertiary volcanics.
37	Agua Caliente S of Teustepe	31	25	P	1369.5	632.6	180	From Tertiary volcanics, locally considered warm.
38	Monte Fresco	38	300	P	1350.1	638.0	75	From fractures in small otcp. of Tertiary tuff.
39	San Nicolás	35	500	P	1350.7	641.5	60	From alluvium, Tert. vol. nearby.
40	Aguas Caliente N of Juigalpa	62	25	PG	1344.0	677.2	95	From alluvium in small stream channel, overlies Tertiary volcanics.
41	Santa Ana	32	-	C	1337.7	681.5	130	Tertiary volcanics.
42	Laguna Apoyo N	50	0	P	1316.5	603.0	78	Seeps along SW side at lake, old spring deposits between #42 and 43.
43	Laguna Apoyo S	50	0	PG	1316.3	603.3	78	Mineralized seeps-old spring deposits nearby.
44	La Calera	34	1000	P	1310.9	615.1	240	Data from stream draining several nearby lava flow contact springs.

No*	Name or General Location	Temp** (°C)	Flow Gal/min	Data*** Source	Location Coordinates UTM N	E	Elev. (meters)	Comments
45	S of La Granja	55	-	P	1311.9	617.4	32	From lava flow breccia in edge of pond, other springs nearby.
45A	do.	54	600	P	1311.8	617.3	32	About 100 m. W of 55, similar.
46	Mombacho crater	36	300	P	1307.4	511.7	800	Several adjacent springs prob. lava flow contact, on wall SW and below fumaroles.
47	S of Mombacho crater	54	50	P	1305.6	511.6	420	Several adjacent springs S of crater, others at 43, 46°.
48	Las Plazuelas	43	200	P	1301.8	613.9	45	Forms hot pool in marshy area lava flows nearby, other spring reported to north.
49	Mecatepe	48	100	P	1301.4	614.9	50	From beneath lava flow.
50	Agua Caliente de Acayo	33	50	P	1284.3	586.6	100	From fractures in dioritic intrusion.
51	Las Salinas	hot	-	O	1268.2	597.3	10	From alluvium, reported by G. Hodgson, Catastro.
52	Río Limón	35	-	C	1249.9	634.2	50	Stream sample, thermal spring nearby (?), possibly only solar heating of stream water.
53	L. Jiloá at fumaroles	80	-	P	1372.0	573.5	40	Probably spring water issues underneath lake at fumaroles, high % is gas.
54	L. Nejapa	41	-	O	1349.7	574.0	40	Reported by McBirney (1955b), highly mineralized.
55	Santa Rita	hot	-	O	1358.5	535.3	30	Reported by G. Hodgson, Catastro.
56	Mina Santa Pancha	70	large	P	1407.9	532.9	65	In mine workings at 700′ depth.
57	Aguas Calientes NW of Dipilto	-	-	O	1515.8	528.5	-	Place name on topographic map.
58	Aguas Calientes NW of San Juan de Limay	28?	[illegible]	C	1461.4	532.2	-	Place name on topographic map. Catastro data may be for same spring.

No.*	Name or General location	Temp.** (°C)	Flow Gal/min	Data*** Source	Location Coordinates UTM N	E	Elev. (meters)	Comments
59	Aguas Calientes NE of San Juan de Limay	-	-	O	1464.8	549.8	-	Place name on topographic map.
60	Hda. Betania	thermal	-	G	1458.2	567.9	800	Two thermal springs 15 km. N of Estelí.
61	Santa Rosa	30	]	G	1481.3	577.7	1000	E of Condega "Valle Santa Rosa a 3 leguas sobre la carretera a Yalí".
62	Hda. Boquerón	thermal	-	G	1358.3	551.8	50	Location uncertain.
-	Puerto Morazan	thermal	-	G	-	-	-	"A 5 kms. en la margen del Estero Real".
-	El Sauce	thermal	-	G	-	-	-	"Del Charco (4 ó 5 kms.) del pueblo".
-	Larreynaga	thermal	-	G	-	-	-	"Cerca del pueblo".
-	El Molino, Sébaco	thermal	-	G	-	-	-	"El Molino a 5 kms." de Sébaco. Río El Molino is east of Sébaco.
-	El Tempisque, Cd. Darío	thermal	-	G	1392.7 ?	606.8 ?		Southeast of Cd. Darío (?)

* Number - letter designation used when data points are too close to indicate on map.
** Temperature listed is maximum at spring or close group of springs.
*** P - Proyecto Geotérmico de Nicaragua, C - Catastro well and spring inventory, G - Del Giudice 1959a, 1959b, O - other.

TABLE 2 THERMAL WELLS

No*	Name or General location	** Temp. (°C)	Water Level Meters	Total Depth Meters	**** Data	Location UTM Coord. N	E	Elev. Meters	Comments
1	Los Placeres	35	16.1	16.6	C	1439.8	434.5	45	Alluvium, near Quat. vol.
2	Santa Cruz	32	0.0	1.2	C	1406.9	463.7	30	Alluvium
3	Los Dos Pozos	32.5	7.6	10.6	C	1419.9	477.3	20	Tertiary volcanics.
4	Santa Rita	35	31.2	31.9	C	1412.7	502.4	50	Alluvium
5	El Obraje	32	2.4	4.6	C	1414.5	502.9	10	Alluvium (No. 4 - 30 comprise
6	San Luis	38	4.1	10.5	C	1414.2	505.3	10	do. (Villa Salvadorita-San
7	Villa Salvadorita	32	14.5	-	C	1413.4	506.1	20	do. (Lucas thermal wells.
8	Candelaria N	40	1.7	141.8	C	1414.1	508.8	15	do.
9	Candelaria S	34	5	-	P	1413.5	508.3	15	do.
10	Sta. Ernestina	35M	21	-	P	1412.3	508.1	30	do.
11	Casa de Zin	39	31.0	32.1	CP	1411.9	508.3	35	Alluvium, dry when visited.
12	Rancho Pando	40M	25	-	P	1411.8	508.7	35	Alluvium
12A	NW of San Juan	42	-	-	C	1412.0	508.8	35	do.
13	San Juan	37	8	21.5	P	1411.4	509.5	35	do.
14	Santa Cecilia	42.5M	18	-	P	1411.1	509.9	35	do.
15	NW of Alsacia	45	-	-	P	1410.7	510.8	35	do.
16	Alsacia	55M	19.6	21.1	P	1410.0	511.3	35	do.
17	Alsacia	43	-	100.8	C	1410.4	512.6	20	Alluvium, Catastro test well VS-3.
18	S of Alsacia	42.5M	12	-	P	1408.7	511.6	35	Alluvium
19	Hda.Las Grietas	35.5	15.9	16.5	P	1407.8	512.2	30	Alluvium at edge of Quat. lava.
19A	Las Grietas	33.5	10	-	P	1407.6	512.5	30	do.
20	do.	34	12	-	P	1407.5	512.7	30	do.
20A	do.	33	12	-	P	1407.3	512.8	30	do.
20B	do.	36	9	-	P	1407.2	512.9	30	do.
21	do.	36	16.9	17.4	P	1406.9	512.9	35	do.
22	Lourdes	47M	50	53.9	P	1405.6	511.7	80	Poss. fracture, edge of Quat.lava
23	La Victoria	35.5	19.6	20.4	P	1405.9	513.2	40	Alluvium
23A	do.	34	12	-	P	1406.0	513.3	38	do.
23B	El Higueral	33	12	-	P	1405.8	513.3	38	Alluvium, SE of 23
23C	do.	33.5	12	-	P	1405.7	513.3	38	do.
23D	do.	34	12	-	P	1405.6	513.4	38	do.

No*	Name or General location	** Temp. (°C)	Water Level Meters	*** Total Depth Meters	**** Data	Location UTM Coord. N	E	Elev. Meters	Comments
23E	El Higueral	33	11	-	P	1405.5	513.5	38	Alluvium, SE of 23
23F	do.	32.5	11	-	P	1405.4	513.6	38	do.
24	Olomega	32	2.9	4.4	C	1405.5	514.8	25	Alluvium, E of main thermal zone
25	La Española	34	15	-	P	1404.9	513.6	35	Alluvium
25A	do.	33	15.0	15.2	P	1404.9	513.8	35	do.
26	do.	35	15	-	P	1404.7	513.7	35	do.
27	do.	37.5	20	-	P	1404.4	513.6	35	do.
27A	San Lucas	36	24	-	P	1404.2	513.5	36	do.
28	do.	38	22	39.0	P	1404.0	513.4	38	do.
28A	do.	37	25	-	P	1403.8	513.5	40	do.
29	do.	38	30	-	P	1403.3	513.3	55	N side Loma San Lucas
30	Santa Ana	33	1.3	4.0	P	1403.7	515.7	25	Alluvium
31	Santa Rita	33	15	-	P	1402.8	516.8	60	N side Loma San Isidro
31A	E of Loma San Isidro	33	14	-	P	1402.8	517.4	35	(#31-42 comprise Hda. Agua Caliente Subarea of Hda. Agua Caliente-Villa Salvadorita thermal wells.
32	do.	33	12	-	P	1402.8	517.6	35	
33	Los Angeles	35	15	-	P	1402.6	517.3	35	
34	N of Los Planes	39.5	19.3	-	P	1402.2	517.5	35	
35	El Rosario	40M	-	-	P	1401.8	517.5	40	
36	Los Planes	36	28.5	29.4	P	1401.0	517.4	55	Possibly to 39°M
37	E of Loma Taolinga	32	4.4	5.2	P	1404.1	519.3	25	Near Quat. fissure (?) basalt & springs.
37A	do.	32	15	-	P	1404.2	519.4	25	do.
38	Agua Caliente	36	20	-	P	1403.2	519.3	35	Quaternary volcanics (?)
38A	do.	32	20	-	P	1403.1	519.2	35	do.
39	Hda. Agua Caliente	47.5M	15.7	17.2	P	1402.0	518.7	45	do.
40	S of #39	34	-	-	P	1401.3	518.9	42	Alluvium
41	Ocoton	35	12	-	P	1401.5	520.4	40	do.
42	S of #41	34	12	-	P	1401.2	520.2	40	do.
43	W of Mina El Limón	33.5	4	-	P	1409.1	525.4	70	Tertiary volcanics
44	Jesús María	32	10.1	11.9	C	1400.8	550.4	75	Alluvium
45	Los Espinozas	39	12.3	12.5	C	1399.9	559.2	75	do.
46	El Jicaral	36	-	-	C	1406.9	567.2	120	Alluvium - Tertiary vol.

No.*	Name or General location	** Temp. (°C)	Water Level Meters	*** Total Depth Meters	**** Data	Location UTM Coord. N	E	Elev. Meters	Comments
47	Santa Rosa del Peñón	32	-	-	C	1414.9	568.4	220	Tertiary volcanics
48	S of Malpaisillo	35	45	51.5	P	1389.2	535.5	120	Quaternary vol. depression
49	Caoba	34	33	-	P	1387.2	540.2	110	Alluvium near Quat. lava
50	La Fuente	33	17.1	18.0	C	1385.8	544.9	95	Alluvium near Quat. volcanics.
51	La Esperanza	33	29.5	31.1	P	1384.5	543.2	95	Alluvium
52	Santa Rosa	39	43	-	P	1383.4	542.3	110	do.
53	El Tránsito	39.5	27	36.0	P	1382.4	542.7	110	do.
54	El Obraje	40M	11	12.8	P	1376.8	541.2	70	do.
55	Baronesa	40.5M	35	-	P	1375.7	539.9	90	Alluvium near Quat. lava
56	La América	32	38.8	43.9	C	1371.9	538.1	90	Quaternary volcanics
57	El Cardón	32	0.5	0.9	C	1371.3	556.0	40	Alluvium near L. Managua
58	Los Angeles	35.5	17.7	18.2	C	1356.5	567.0	50	Alluvium
59	Corpus Cristi	35.5	11.4	12.5	C	1357.7	568.5	40	do.
60	El Tamagas	hot	16.5	72.2	C	1357.5	514.5	50	Deep irrigation well, shut-in.
61	Sta. Catalina	33	61.7	62.1	P	1351.4	567.6	110	Quaternary volcanics
62	NW of Los Brasiles	32	34.8	35.1	C	1348.9	567.2	75	Alluvium
63	E of Jiloá	45	-	-	C	1349.6	575.1	50	Probably deep, Quat. vol.
64	San Antonio	32.5	34.5	36.0	C	1367.2	592.5	80	Quaternary volcanics.
65	San Francisco del Peñón	33	26.3	27.4	C	1372.9	602.4	90	Alluvium
66	Las Pilas	32	21.6	27.7	C	1396.8	607.2	410	Tertiary volcanics.
67	San Francisco del Peón	33	35.1	35.4	C	1372.0	604.3	90	Alluvium
68	Los Novios	32	25.3	51.5	C	1363.0	603.1	70	Quaternary volcanics.
69	SW of Las Banderas	38	44.1	48.4	C	1362.0	610.8	105	do.
70	N of Tipitapa	32	24.3	42.7	C	1349.3	598.3	40	Alluvium
71	Tipitapa	32	12	51.2	C	1348.3	599.0	45	do.
72	Finca Fátima	32	19.1	20.3	C	1350.1	604.2	55	do.
73	E of Tipitapa	32	-	-	C	1347.4	603.6	40	do.
74	Lourdes	32	-	-	C	1346.5	604.7	45	do.
75	El Panamá	39	9.7	24.8	C	1346.2	598.2	60	Alluvium, Catastro well TP-2
75A	Carr. Tipitapa	39	-	-	C	1347.0	598.3	50	Data from Hazen & Sawyer (1964)

No.*	Name or General Location	Temp. (°C)**	Water Level Meters	Total Depth Meters***	Data****	Location UTM Coord. N	E	Elev. Meters	Comments
75B	Carr. Tipitapa-Masaya	34	-	-	O	1346.7	598.3	50	Data from Hazen & Sawyer (1964)
76	Escuela Ag.	32	33.5	38.4	C	1342.4	591.3	55	Quaternary volcanics
77	San Martín	37.5	101.4	-	C	1332.3	585.4	330	Alluvium and Quat. vol.
78	NW of Tisma	32	18.9	41.1	C	1337.8	604.0	70	Alluvium, Catastro well TP-6
79	Batavia	33	0.4	3.5	C	1335.1	679.5	80	Tertiary volcanics
80	El Chuzo	32	0.1	5.0	C	1336.2	681.4	100	do.
81	Finca Tisate	38	3.3	11	P	1392.8	524.3	160	Quaternary volcanics
82	San Jacinto cotton gin	40	79	128	P	1389.7	523.1	215	Quaternary volcanics with numerous lava flows.
83	San Cristobal	35	-	-	O	1340.8	592.9	65	Data from Hazen & Sawyer (1964)
84	San Miguel	36	-	-	O	1331.6	590.9	210	do.

* Letter-number designation used when data points are too close to indicate on map.
** Temperatures with M suffix measured with maximum-registering thermometer to bottom of hole.
*** Most of total depth data is from Catastro.
**** Main source of data: P-Proyecto Geotérmico de Nicaragua, C-Catastro well and spring inventory, O-other.

TABLE 3 FUMAROLES

A - LOW TEMPERATURE FUMAROLES

Name	Temp.* °C	Size** Km^2	Location UTM Coord. N	E	Elev. Mtrs.	Activity
Volcán Casita						
A	96-97	0.06	1403.3	503.7	1200	Very active with minor amount of steam, sulphur sublimates, white efflorescence; considerable argillization of pyroclastics.
B	95-98	0.04	1403.5	503.8	1200	Scattered fumaroles with sparse steam, minor white efflorescence, localized argillization, otherwise slightly-highly altered.
C	90-96	0.2	1402.4	505.3	1150	Moderate to abundant steam at localized fumaroles, very few deposits, moderately to highly altered with minor argillization.
D	99-100	0.01	1401.8	505.2	1050	Abundant steam, sulphurous odor, highly altered with considerable argillization, sparse white efflorescence.
E	90-96	0.04	1401.3	504.3	900	Severely altered pyroclastics with scattered small steam vents, some argillization.
F	85-94	0.02	1401.3	504.5	1000	Scattered fumaroles in altered zone along fault scarp, local argillization, sparse white efflorescence.
G	89-97	0.004	1400.4	504.5	920	Scattered fumaroles in highly to severely altered zone, some argillization, sparse white efflorescence.
H	97-98	0.0003	1401.8	506.7	650	Small altered area with scattered fumaroles, sparse white efflorescence.
I	93-99	0.03	1403.1	507.3	650	Altered area mostly inactive with small local fumaroles, sparse white efflorescence, several other old altered areas nearby.
N. Volcán Telica	96-100.5	0.015	1395.4	518.8	490	Active altered area with numerous fumaroles with sparse to moderate amount of steam, sparse sulphur sublimates and white efflorescence.

Name	Temp.* °C	Size** Km^2	Location UTM Coord. N	E	Elev. Mtrs.	Activity
Ñajo	to 100	0.01 0.01	1396.8 1396.5	520.8 520.7	300 350	Two altered areas, north one practically inactive, south has considerable fumarolic activity, local severe alteration, other smaller altered areas nearby.
Tisate	to 100	0.02 (active) 0.06 (alt.)	1393.2	524.3	160	Much of altered area is now practically inactive, small scattered fumaroles, very sparse sulphur sublimates, sparse white efflorescence, considerable argillization.
San Jacinto	to 100	0.02	1390.8	523.8	190	Active fumaroles with moderate to abundant steam, sulphurous odor, sparse white efflorescence, some pyritization, mud pots.
Cerro Colorado	96-100	0.2	1378.6	543.5	160	Altered area in eroded cinder cone, most is now inactive, scattered fumaroles with very sparse steam and sparse white efflorescence, local argillization.
S. Volcán Momotombo						
A	98-101	0.46	1370.0	549.2	40-110	Large area of moderate to high alteration mostly of pyroclastics, severe alteration and some argillization at scattered active fumaroles, sparse steam with sulphur sublimates at fumaroles, very small boiling hot spring (#19A) on southeast side at lake, size is prob. maximum.
B	95-100	0.002	1371.1	549.9	270	Small area of moderate to severe alteration with active fumaroles, very sparse steam and white efflorescence.
C	to 101	0.15	1369.2	550.2	40-45	Minor fumaroles are associated with local area of boiling hot springs (#19) which are highly mineralized with temperatures to 101°. Other than at springs, steam at 85-100° is very sparse, alteration is moderate to locally severe. Springs and fumaroles developed in layered alluvial fan and lahar deposits.
D	98-100	0.14	1370.0	550.3	90-100	Scattered active fumaroles in alluvial fan deposits, little visible alteration except locally

Name	Temp.* °C	Size** Km^2	Location UTM Coord. N	E	Elev. Mtrs.	Activity
D						severe at active fumaroles. Sparse steam with sparse sulphur sublimates and white efflorescence.
E	99-100	0.04	1370.1	550.8	360	Very active fumarole with severe alteration and argillization, moderate amount of steam and sulphur sublimates.
L. Jiloá	100	0.001	1352.0	573.6	40	Small fumarole area on N shore of lake in alluvial deposits, very sparse steam and sulphur sublimates, moderate amount white efflorescence, gas and probably spring issues in edge of lake at fumarole.
V. Mombacho	(steam)	small	1307.8	611.8	1000	Small to moderate size fumarole area on north inside wall of breached crater, moderate amount of steam, sparse sulphur sublimates reported locally, not visited.

* Average ground temperature in most active zones.
** Approximate maximum extent of surface hydrothermal alteration.

B - HIGH TEMPERATURE, VOLCANIC FUMAROLES

Name	Temp. °C	Size	Location UTM Coord. N	E	Elev. Mtrs.	Activity
V. Cosigüina	low?	large	1434.0 1435.2	438.0 439.4	400 300	Extensive but apparently inactive fumarole areas on south and east walls of 1835 crater, no activity seen during air reconn., also see Williams (1952).
V. Telica	high	medium	1393.3	517.3	900	Numerous active fumaroles inside summit crater,

Name	Temp. °C	Size	Location UTM Coord. N	E	Elev. Mtrs.	Activity
V. Telica						conspicuous sulphur sublimates, usually fume issues from crater occasionally with ash, sporadic lake (H_2O) in conduit.
V. Cerro Negro	high	small	1382.5	532.4	600	Numerous active fumaroles in summit crater with white and yellow sublimates, sporadic ash and lava flow with minor tenorite, halite, and (?) sublimates.
V. El Hoyo	high	small	1380.3	536.3	975	Abundant steam from vent on fissure developed in 1952 eruption near summit, apparently considerable alteration in summit area.
V. Momotombo	high	small	1373.3	550.1	1100	Abundant steam and fume from summit crater, conspicuous white and yellow sublimates, last lava eruption 1905.
V. Santiago	high	medium	1324.8	590.7	450	Moderate to abundant steam and fume from small spatter cone on lava covered floor of crater, occasionally amount of noxious gases increases and kills vegetation downwind, also scattered fumaroles on walls of crater. Recently cracks with steam and associated hot ground have occurred on the slopes of adjacent V. Masaya. Santiago is one of cluster of volcanoes in Masaya caldera.
V. Concepción	high	small	1275.7	650.2	1600	Moderate to abundant steam and fume from summit crater, not closely investigated.