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FINAL REPORT
GEOTHERMAL RESOURCES PROJECT-STAGE ONE

PART 3
SURFACE GEOLOGY
SAN JACINTO-TISATE-NAJO AREA

Prepared for

GOVERNMENT OF NICARAGUA
Ministry of Economy, Industry and Commerce

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PREFACE

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

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

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

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

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

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

Part 5 - GRAVITY AND MAGNETIC SURVEYS, by Mario Mazzolini

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

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

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

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

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

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Aerial view of San Jacinto fumarole area looking east, with San Jacinto village beyond.

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Vista aerea este del area fumarola de San Jacinto, con el pueblo de San Jacinto detras.

SURFACE GEOLOGY

SAN JACINTO - TISATE - ÑAJO AREA

ABSTRACT

Hydrothermally altered areas, active fumaroles and minor thermal springs occur in localized zones at the village of San Jacinto, at Tisate 2.5 km. north of San Jacinto, and at Ñajo about 4.5 km. northwest of Tisate. All of these areas are on the eastern flank of the Quaternary Volcanic Range of Northwestern Nicaragua.

Thermal activity is well developed but is not as extensive nor as intensive as at the South Volcán Momotombo fumaroles.

These thermal areas, particularly the San Jacinto-Tisate area, show favorable possibilities as a geothermal power prospect.

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

INTRODUCTION

Location

The area is located at the crest of the Quaternary volcanic Marrabios Range northeast of León in Northwestern Nicaragua (figure 1).

The village of San Jacinto, in the south part of the area, is located on the paved highway between León and Malpaisillo.

Purpose and Scope

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

The area of investigation was selected to cover a relatively compact group of thermal manifestations, some of which were previously known.

Method and Acknowledgements

This report is based to a large extent on field work and preliminary reports by F. L. Doyle of this project. The present author revised and expanded the preliminary data, and did detailed air photograph interpretation and local field

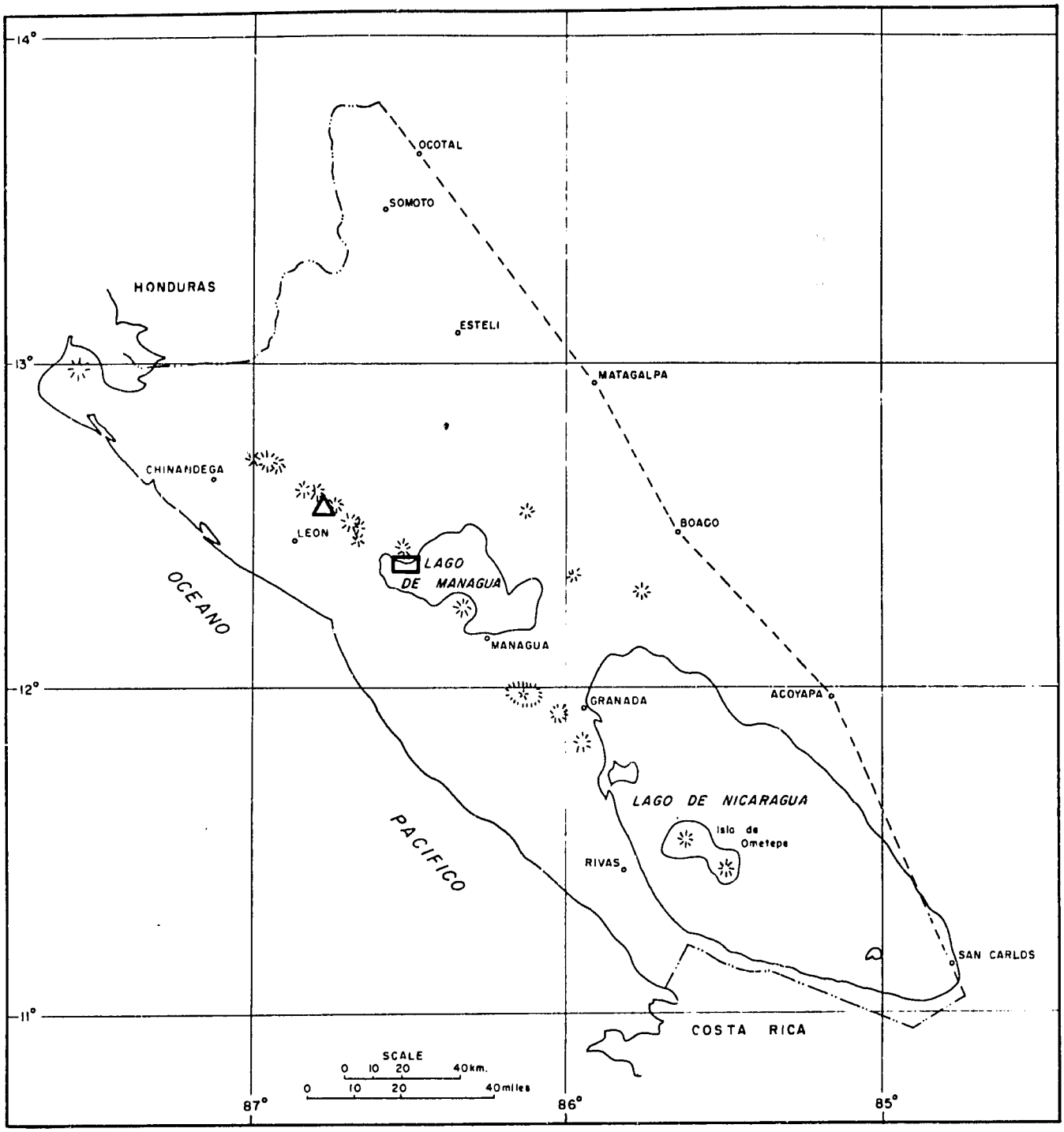

FIGURE 1 INDEX MAP

SOUTH VOLCAN MOMOTOMBO FUMAROLES

SAN JACINTO – TISATE FUMAROLES

work. Work by the present author was concentrated on structural mapping and interpretation while the stratigraphic contacts and hydrothermally altered areas are essentially those indicated by Doyle.

Much of the geological work was done in the immediate vicinity of the altered areas, especially at San Jacinto and Tisate. The surrounding area was mapped in less detail, but enough to provide a geological framework.

Exposures are poor in general except for good exposures along some of the stream channels. Much of the southern part and eastern edge of the mapped area is cultivated.

Appreciation is expressed to the Servicio Geológico Nacional for assistance provided. Petrographic analyses were made by J. Viramonte of the Servicio Geológico Nacional. Appreciation is also expressed for the cooperation of the technical coordinator and other members of the Catastro e Inventario de Recursos Naturales de Nicaragua project.

Previous Work

Local geological work was done by McBirney (1953) and Williams (1953) in a preliminary evaluation of the geothermal power prospects of the area, mostly at Tisate. The thermal activity at San Jacinto and Tisate was mentioned by McBirney

(1958). Background geological work was done by McBirney and Williams (1965) and by Kuang Sanchez (1968).

REGIONAL SETTING

The San Jacinto-Tisate-Ñajo area is on the crest and eastern slopes of the Quaternary volcanic Marrabios Range of Western Nicaragua. As discussed in the regional evaluation section (Part 2) of the project report, the volcanic range is localized along a major northwest-trending structurally weak zone, probably a major fault zone, along or near the western edge of the Nicaraguan Depression. The depression has the general surface aspect of a broad graben, but the structure is probably more complicated, involving fault block structures or downfolding.

The volcanoes which make up the Marrabios Range are mostly composite cones but scattered calderas and cinder cones are present. Several of the volcanoes, including Volcán Telica to the west of the San Jacinto-Tisate area (Part 2, fig. 6), recently have been intermittently active. At Volcán Telica this activity consists of relatively frequent short ash eruptions separated by long fumarolic periods.

Pyroclastic rocks predominate in the Marrabios Range but varying amounts of andesitic and basaltic lavas are present.

Most of the youngest lavas are olivine basalt.

Regionally, thermal activity such as hydrothermally altered areas, active fumaroles, and thermal springs and wells are concentrated in the Marrabios Range and adjacent Nicaraguan Depression.

Further descriptions of the thermal activity in Western Nicaragua are presented in the regional evaluation section of the project report (Part 2).

The San Jacinto-Tisate-Ñajo area is on the eastern slopes of Volcanes Santa Clara and San Jacinto. Older volcanic deposits occur to the east of the thermal activity and Volcán Rota is to the southeast.

It should be noted that terminology for the volcanoes has varied, i.e., the present (indicated on topographic maps) V. Santa Clara has been called V. San Jacinto and the present V. San Jacinto has been called El Listón.

ROCKS AND DEPOSITS

Older Volcanics

Andesite and basalt lava flows with possible andesite intrusions and with minor pyroclastic deposits make up the highly

eroded hills northeast of the village of San Jacinto. These rocks are also exposed in several low hills to the east in the Nicaraguan Depression, along the eastern edge and to the east of the mapped area (Part 2, fig. 6). These low hills are remnant volcanic structures such as the probable plugs at Cerro Los Bosques, which are composed of vitrophyric andesite with characteristic diabase xenoliths, to the east of the mapped area and other nearby remnant cinder cone structures. These remnant volcanic structures are highly eroded and partially covered by Quaternary alluvium and volcanic sediments.

The Older Volcanic rocks are usually moderately to highly weathered. There are two main hills of Older Volcanic rocks northeast of San Jacinto. The north hill and much of the south hill consists of andesite, with basalt included in the south hill. Much of the andesite, particularly in the south part, has characteristic diabase xenoliths.

It is possible, if not probable, that the older deposits of Volcán Rota are of similiar age. The older deposits of Volcán Rota are of andesite with the characteristic diabase xenoliths as at Cerros Los Bosques.

Rota Volcanics

The rocks of Volcán Rota are andesite and basalt lavas with a large proportion of pyroclastic deposits, mostly lapilli

tuff.

These rocks are usually partially weathered. The cone of Volcán Rota is extensively eroded and although a summit crater can still be seen, the volcano is one of the older volcanoes of the Marrabios Range and has been inactive for a relatively long period of time. Only a few lava flows can still be distinguished by surface morphology.

The rocks and deposits of Volcán Rota were not closely studied, but it appears that the older rocks are primarily andesitic lavas with diabase xenoliths while the younger rocks are basaltic lavas. As previously mentioned, the older rocks might be of the same age and type as the Older Volcanic Rocks to the north. Undifferentiated pyroclastic deposits are included. Part of the separately mapped pyroclastic deposits are probably also of Volcán Rota age.

Santa Clara - San Jacinto Volcanics

The central part of Volcanes Santa Clara and San Jacinto is composed mostly of pyroclastics with associated lava flows of andesite and basalt. An area of predominately lava flows of andesite to olivine basalt is separately mapped around the base of Volcán Santa Clara. It was not feasible to differentiate the volcanic deposits of Volcán San Jacinto. Volcán San Jacinto is the older of the two volcanoes and has been partially

overlapped along the south side by volcanic deposits from V. Santa Clara.

In the area of separately mapped lava, the amount of lava in the stratigraphic section is high, with subordinate pyroclastic deposits, usually tuff and some volcanic sediments.

To the east the Santa Clara-San Jacinto lavas and pyroclastics abut against a fault-line escarpment along the western side of the Older Volcanic hills.

Surficial Deposits and Sediments

Considerable Quaternary pyroclastic deposits, mostly tuff and lapilli tuff, have been mapped. These deposits occur principally between the volcanic centers, where fewer lava flows are present. The age of the pyroclastic deposits probably varies, corresponding to different periods of vulcanism; i.e., some of the deposits are possibly of the same age as the Older Volcanic deposits, other deposits are younger, corresponding to the Rota Volcanics and Santa Clara-San Jacinto Volcanics.

Quaternary alluvium and volcanic sediments occur in the Nicaraguan Depression in the eastern part of the map area and beyond. These deposits, not extensively studied, partially

cover some of the Older Volcanic structures.

Minor unmapped remnants of Quaternary alluvial terraces occur along the lower part of Río Apante, west of the canyon which is located at the edge of the Nicaraguan Depression. Inclusion of hydrothermally altered boulders in the terrace deposits indicates a relatively great age for the hydrothermal alteration.

Many of the lava flows are covered with a thin layer, usually less than one meter in thickness, of pyroclastic deposits or colluvium.

STRUCTURAL GEOLOGY

There are several structural trends in the area (plate 1). A major regional northwest trend is indicated by the alignment of the Quaternary volcanoes. The probable northwest-trending fault along which the volcanoes are localized has no definite surface expression in the area, possibly due to the cover of young volcanic deposits. Several northwest-trending fractures and small normal faults were mapped in the area. A strong north-south trend is well expressed by several normal faults and fractures. A northeast trend with fractures and faults is well developed in the north part of the map area. A secondary

east-west trend is expressed by a few fractures and faults.

The northwest trend is the oldest, since it controls the location of the volcanoes. The north-south trend is somewhat younger, since it affects the Older Volcanics as well as the Santa Clara-San Jacinto Volcanics. The northeast trend is possibly the youngest in the area. These age relationships are only estimates of when activity first started along a trend, since it is probable that fracturing and minor faulting have occurred more or less contemporaneously and until relatively recently along each of the trends, probably along established zones of weakness.

This structural activity is of Quaternary age, affecting Quaternary deposits. Relatively recent faulting and fracturing is demonstrated by the well expressed escarpments (in easily eroded deposits) and lineaments, but no current activity on any of the faults is postulated.

The north-south, apparently normal, faults are interesting because they are the best developed structural features, but also because displacement along these faults is predominantly downthrown to the west. This is contrary to the expected displacement downthrown to the east toward the Nicaraguan Depression. Well developed topographic scarps are present along several of the faults indicating the direction of movement along the fault. There is no evidence in the area to assume

compression on any except a very local scale, so all of the faults are assumed to be normal faults. It is possible that some of the faults, especially those to the west, high on the side of Volcán San Jacinto, are related to collapse because of magma withdrawal. An additional, unfavored, possibility is that intrusions with subsequent doming effects have caused some of the faults. It is the writer's opinion that most if not all of these faults can be explained as due to local tension along the margin of the Nicaraguan Depression, a regional tensional feature. If the postulated regional eastward-dipping fault or fracture zone exists at depth beneath the volcanoes, the seemingly anomalous direction of displacement on the surface faults could be explained as an antithetic relationship, with minor normal faults dipping toward an opposing major fault. Additional north-south structural alignments include the two probable andesite-dacite plug domes at Cerros Los Bosques (Part 2, fig. 6), as well as a volcano-tectonic depression and aligned cinder cones near Volcán Cerro Negro south of Malpaisillo.

The north-south fault which practically connects the San Jacinto and Tisate areas is topographically expressed as an eroded fault-line escarpment which marks the western side of the Older Volcanic hills. This fault is relatively old since lava flows from Volcanes Santa Clara and San Jacinto have flowed eastward down to and partially ponded against this

escarpment to create a steep stratigraphic unconformity. Between the two Older Volcanic hills, where no escarpment exists, the fault has been completely covered by later volcanic deposits but the zone of weakness can be traced as a pronounced lineament which connects the scarp segments. This fault is probably the main controlling factor for the thermal activity at San Jacinto and Tisate as further discussed later in this report.

The thermal areas at San Jacinto and Tisate are in lava flows and pyroclastic deposits which dip slightly eastward. At Ñajo the volcanic deposits dip moderately to the northeast, generally parallel to the topographic slopes (see contours of fig. 6, Part 2).

Numerous lineaments were mapped from air photographs in order to try to improve the structural framework of the area. These lineaments are probably the surface expressions of fractures, fracture zones, or small faults. On the air photographs the lineaments are expressed as linear drainage, vegetation, or tonal alignments. Only the more pronounced lineaments were mapped. The mapped faults, some of which are from air photographs, were differentiated from lineaments by topographic displacement which is associated with most of the faults.

GEOMORPHOLOGY

Most of the topography of the area is of constructional origin due to volcanic activity. Erosional topography is minor except that associated with the Older Volcanic deposits.

The center of Older Volcanic activity has been extensively eroded so that no original volcanic structures can be detected except those along the eastern edge of the map area.

Volcán Rota is extensively eroded but still retains its general volcanic form. A partially eroded summit crater exists and a few lava flows are still expressed topographically.

Volcanes Santa Clara and San Jacinto are essentially uneroded composite volcanoes with the form well preserved. Volcán San Jacinto, the older of the two, is a rather broad, massive volcanic pile with a well preserved summit crater complex, but the flanks of the volcano have been partially eroded. This erosion has accentuated structural lineaments. A few lava flows can be seen by surface morphology. Volcán Santa Clara is a symmetrical, well preserved composite volcano, which was last reported active in the XVI century (McBirney, 1958). This is the most recent volcanic activity in the map area, according to McBirney (1958). Pyroclastic deposits with characteristic steep slopes predominate near the center of the volcanic activity, while farther away from the volcanic center,

gradually sloping lava flows predominate.

The gorge of Río Apante, in the east-central part of the map is an interesting geomorphic feature. With little study, it appears that the stream was superimposed over a resistant ridge of Older Volcanic deposits from a probable higher surface of pyroclastics, but there is no hard evidence for this postulation.

Local, usually minor unmapped stream terraces, both erosional and depositional, occur along Río Apante. These terraces are probably associated with the incision of the Río Apante gorge.

Much of the drainage is structurally controlled with linear streams caused by fractures or faults in most cases.

THERMAL ACTIVITY

Hydrothermally altered areas, often with associated active fumaroles, occur in localized zones at the village of San Jacinto, at the Tisate area about 2.5 km. north of San Jacinto, and at the Ñajo area which is about 4.5 km. northwest of Tisate (plate 1). Volcán Telica, which is currently in a fumarolic stage of activity with occasional ash eruptions, is located 7.0 km. west of Tisate (Part 2, figure 6). Several

thermal springs occur, mostly between San Jacinto and Tisate with a large spring near Ñajo.

Thermal activity is well developed, but not as much as at the South Volcán Momotombo fumaroles (Part 4). Active fumaroles, with steam vents and mudpots, and moderate alteration occur at San Jacinto. At Tisate fumarolic activity was considerably more extensive in the past but current activity is restricted to minor fumaroles and hot ground with moderate to severe alteration. At the Ñajo area, thermal activity is variable, but usually restricted to scattered minor fumaroles and hot ground with moderate alteration.

There is a close relationship between the hydrothermally altered areas and areas barren of vegetation. This relationship is not so well expressed at San Jacinto due to the nearby settlement and cultivated fields which have changed the natural vegetation patterns. The altered areas at Tisate and Ñajo occur in spots barren of vegetation in an area which otherwise has a thin to moderately thick scrub vegetation cover of trees and shrubs.

In the vicinity of hydrothermal alteration, the margins of the zones barren of vegetation appear to correspond closely to the maximum extent of surface and near-surface alteration due to soil chemistry changes caused by the alteration. There is also a relationship with direct thermal effects, with

elevated soil temperatures, but the relationship is not well understood since a shallow (one meter depth) temperature survey was not included in the project plans due to questionable value of such a survey. Preliminary work by McBirney (1953) at the San Jacinto altered area did show a close correspondence between the area of hot ground and the area barren of vegetation, with normal ground temperatures occurring near the tree line.

In the thermally active zones, especially around active fumaroles, alteration is often severe with considerable argillization of basaltic and andesitic rocks to form soft, moist clays with admixed sublimate products. The highest soil temperatures are usually found in these soft, moist zones, with current thermal activity, which indicates the moisture is probably resulting from hydrothermal fluids or steam condensation. The now visible highly and severely altered rock was probably altered relatively recently in most cases, since this soft clayey material is easily eroded and removed from the area by stream action. After thermal activity ceases in a particular spot the remaining altered rock usually becomes dry and hard.

Unfortunately, sufficient facilities were not available for precise determinations of alteration and sublimate products.

All geochemical aspects such as analyses of fumarole gases,

sublimates, and thermal waters is discussed in the geochemical part of the project report (Part 7).

Preliminary geothermal power investigations were conducted on a limited scale in the San Jacinto-Tisate area in 1953. This work, by A. R. McBirney, was under the direction of Cía. Minería La India and D. E. Spencer. The Tisate thermal area was selected as the site of three shallow inclined test holes which were drilled with mining-type equipment to a maximum vertical depth of 287 feet. According to available records (written communication, A. R. McBirney, 1953) the Tisate area was selected primarily for logistical reasons because of easier land availability. Results of these studies are further discussed later in this report. These investigations were terminated primarily because of lack of proper drilling equipment (oral communication, D. E. Spencer, 1969).

SAN JACINTO THERMAL AREA

This hydrothermally altered area with active fumaroles is located (UTM coordinates 1390.7N, 524.0E) on the northwest side of the small village of San Jacinto which is located on the paved highway between León and Malpaisillo.

This thermal area is rather limited in size with about 200 square meters of surface alteration at an elevation of about

190 meters above sea level. The thermal area is in a depression, which has been eroded in the altered rock, and which is practically surrounded by nearly fresh, young, essentially flat-lying basaltic lava flows, which have originated mostly from Volcán Santa Clara.

Thermal activity consists of several active fumaroles with a moderate amount of steam, several active mudpots, and hot ground over most of the area. The amount of alteration and subsequent erosion indicates that alteration has been occurring for at least several centuries. The earliest known reference to the area is Fröbel (1859), who also mentions thermal activity at Tisate, but his reports of "mud volcanoes" may reflect undue influence by the mud pots. The small mound (about two meters high) in the San Jacinto thermal basin and the larger mound at the Tisate area may possibly have originated from mud volcano activity but, more likely, they are residual features.

Alteration of primarily basaltic lava of varying vesicularity and probably minor admixed pyroclastic deposits is generally high to severe with considerable argillization in the central part of the area. White and yellow sublimates and efflorescences, as yet unidentified, occur scattered over the more active part of the thermal area. Minor pyritization is associated with the most altered rock.

Preliminary heat flow measurements by McBirney (1953) indicate a value of about 3300 x 10^5 gm. cal/min. His shallow soil temperature measurements have indicated high but irregular temperatures with higher temperatures in water saturated areas and lowest temperatures over hard, unaltered rock. A conclusion that can be drawn from this data is that the heat is carried by hot water or steam with insignificant conduction. McBirney (1953) mapped three more or less concentric zones in the San Jacinto thermal areaas follows, from the center outward: (1) hot, muddy water; (2) small steam vents; and (3) hot ground without steam vents; with the zone boundaries changing with change of water level. The present situation is quite similiar except that it should be noted that active mudpots are present in zone (1) and the pools of water practically disappear during the dry season. Also, all except one of the "residual mounds" mapped by McBirney in 1953 have now disappeared.

There is no surface water discharge from the thermal area except during heavy rainfall. The level of water in the thermal pools, mud pots, etc. varies widely according to rainfall. This indicates that most of the water is probably meteoric with a probable perched water table.

The thermal activity appears to be controlled by fractures. Most of the mudpots and steam vents have a northeast alignment,

but there is no hard evidence to prove fracture control. The altered area occurs in practically flat-lying lava flows with extensive consolidated pyroclastic deposits occurring a short distance to the east of the thermal area. Control of thermal activity is further discussed later in this report.

Thermal water (40°C) occurs in a 128 m. deep water well (UTM coordinates 1389.5N, 523.0E) at a cotton gin about 1.5 km. southwest of the San Jacinto fumaroles. Thermal springs (32-46.5°C) occur north of San Jacinto.

This area is easily accessible, with close proximity to a paved highway. Accessibility problems are concerned with the fact that the fumaroles occur on the edge of a small village and are in a cultivated area.

TISATE THERMAL AREA

This hydrothermally altered area with a few active fumaroles is located (UTM coordinates 1393.3N, 524.2E) about 2.5 km. north of the San Jacinto area. There is about 600-800 sq. meters of surface alteration but current thermal activity is very scattered and localized with a few patches of hot ground and feeble fumaroles. The current thermal activity is not nearly as impressive as that at San Jacinto.

The thermal area is in a country rock of primarily andesitic lava with a varying amount of pyroclastics, mostly lapilli

tuff. Relatively small andesitic intrusions are possibly present but exposures are insufficient to prove whether such intrusions exist. Hydrothermal alteration is variable but often severe, with considerable argillization and silicification. The more severe alteration varies from bleached, clayey rocks with variable silicification, in which some original textures can be seen, to other more severely altered rocks which are composed almost entirely of clay and secondary silica with no remnant textures to be seen.

A large mound of altered rock about 50 meters long and up to 6 meters high is present in the southwestern part of the thermal area. This particular part of the thermal area is locally called Hervidero Ciego. This mound appears to be a residual feature, representing the end of a ridge which has been severely altered. Many rounded boulders of andesite and basalt occur in this mound, but these same boulders are currently being formed in the vicinity by spheroidal alteration of blocks of lava.

A minor fault with strike N50°E and dip 50°SE occurs at the north end of the above described mound. Several possible andesite dikes with northeast and north-south trends are also present but are poorly exposed. The north-south alignment of active vents described below probably represents fault or fracture control.

Thermal activity and associated shallow soil temperatures vary, but in several of the hot ground areas soil temperatures of 50-60°C are common. In the more active areas, which are concentrated in a north-south zone along the southwest edge of the thermal area (plate 1), shallow soil temperatures in the 90-100°C range are common, with steam temperatures near or at 100°C at the active vents. Very sparse native sulphur sublimates occur as very small crystals at most of the more active vents. Other typical white to yellow sublimates and efflorescences are scattered over the surface of the more active areas. McBirney's (1953) preliminary heat flow measurements indicate about 120 x 10^5 gm. cal/min., somewhat insignificant as compared to San Jacinto. As at San Jacinto, there is no surface flow of water from the area. Soil moisture is restricted to the immediate vicinity of the active fumaroles. Thermal water (38°C) occurs in a shallow water well at Finca El Tisate (UTM coordinates 1392.9N, 524.3E), immediately south of the thermal area.

As originally mentioned by Williams (1953), numerous north-south and northwest-trending vertical or near vertical banded zones occur with varying proportions of secondary silica, such as opal and chalcedony, and secondary clay minerals, such as kaolinite. Similiar zones were found in the three shallow core holes drilled in 1953. Also, the highest temperatures and steam flows detected while drilling these holes appear to have originated from fractures (Williams, 1953). This evidence indicates

that most of the heat flow is by steam or hot fluids along fractures, and also helps explain the sporadic surface distribution of the thermal activity. As discussed by Williams (1953), probably most of the channelways along fractures are only temporary features, at least in the near surface part, because of deposition of secondary minerals and swelling during alteration, both of which tend to close off the fractures to form vein-type structures. With this type of feeder system, surface thermal activity is likely to frequently change position as changes occur in the fracture feeder system.

Three test holes were drilled in the north-central part of the thermal area in 1953 as already mentioned. The first of the holes was stopped at a shallow depth but No. 2 and No. 3 were drilled toward each other at an angle of 30° from vertical, with No. 2 oriented southward (vertical depth 287 ft.) and No. 3 oriented northward (vertical depth 230 ft.). A maximum steam pressure of 42 lb/sq. in. (closed) was measured at a vertical depth of 184 ft. in hole No. 2. Maximum temperatures observed were 287°F at a vertical depth of about 180 ft. in hole No. 2, and 240°F at a vertical depth of about 210 ft. in hole No. 3. The above data is summarized from McBirney (written communication, 1953) and Williams (1953).

The general stratigraphic section encountered by the above holes is as follows (D. E. Spencer, written communication, 1953):

0-65 feet	Clay consisting of chalcedony, limonite, kaolin, and decomposed andesite devoid of relic structure.
65-90 feet	Hard fresh andesite
90-130 feet	Altered lapilli tuff consisting of opal, chalcedony, kaolin, and pyrite.
130-220 feet	Fairly solid chalcedony, opal, pyrite, and montmorillonite clay with small veins of calcite and quartz.
220-230 feet	Silicified andesite with quartz and calcite veins.
230-287 feet	Altered lapilli tuffs (same as 90-130 feet).

Hole No. 2 (UTM coordinates 1393,42N, 524.23E) is currently still blowing a small quantity of steam with a small quantity of normal temperature water blown out at short intervals of less than one minute. The low temperature of the water indicates it is probably recirculated meteoric water.

Accessibility to the Tisate area is poor since only a rough cart-track connects the area to the village of San Jacinto. Within the area itself, accessibility is relatively good, especially since most of the surrounding land is unused, with only scrub vegetation.

ÑAJO THERMAL AREA

Two main hydrothermally altered areas and other smaller altered areas, most of which have associated fumaroles, occur

at and southeast of the place called Ñajo (UTM coordinates 1396.6N, 520.8E), which is about 4.5 km. northwest of Tisate. The thermal activity here seems to be separated from that at San Jacinto-Tisate, with apparent closer connections with the North Volcán Telica fumaroles which are located about 2.0 km. southwest of Ñajo (see fig. 6, Part 2).

Each of the two main altered areas is about 100 meters in diameter and is at a general elevation of about 300 meters above sea level. The northerly altered area has moderate alteration of andesitic lava with scattered argillization and minor fumarolic activity, with a soil temperature of about 80°C. Two small thermal springs, one with a flow of about 5 gpm at 67°C and the other with a flow of about 1 gpm at 61°C, occur in a northeast-trending gully alongside the altered area.

The southerly altered area, at a slightly higher elevation to the southwest of the above described area, has considerably more thermal activity and more intense alteration of basalt and andesite with considerable argillization, especially near current thermal activity. The thermal activity consists of several small mudpots and small fumaroles, most of which are in a northeast-trending gully. One very small thermal spring, with a flow of less than 1 gpm at 59°C, occurs in the same gully at the downslope edge of the altered area.

These two altered areas are in a zone of well developed northeast-trending lineaments, but, in particular, are both

associated with a probable fault trending N 50°E along the gully mentioned above. Indications are that the hydrothermal solutions and gases are rising along faults and fractures.

Several smaller altered areas, with or without current thermal activity, are located east and southeast of Ñajo (plate 1). One of these altered areas (UTM coordinates 1395.4N, 521.1E), south-southeast of Ñajo, is localized for about 65 meters along a youthful, probable fracture-controlled gully. Alteration of colluvium and possible pyroclastic deposits is moderate with localized partial argillization, including minor pyritization. Several small fumaroles with a representative temperature of 98°C occur along the gully.

Another altered area about 100 meters long and 30-40 meters wide is located (UTM coordinates 1395.8N, 521.6E) southeast of Ñajo at the northeast end of a ridge, at a slightly higher elevation than the other thermal activity. This altered area is located along a mapped lineament, probably a fracture. There are several small, feeble fumaroles with a zone of highly altered, partially argillized rock (originally basalt) around each fumarole. Shallow soil temperatures in the more active spots are about 99°C.

Accessibility to the Ñajo thermal area is very poor. Only a few very rough cart-tracks exist. Local relief is considerable.

OTHER THERMAL ACTIVITY

At Hda. Santa Clara (UTM coordinates 1396.9N, 522.5E) east of Ñajo, a large, apparent lava-contact spring area, with several sources in a localized area, has a total flow of about 1500 gal/min. at 42-46°C. An area marked "Fuentes de Aguas Sulfurosas" on the 1:50,000 topographic map of the area, with a map position about 1 km. northeast of Hda. Santa Clara, was searched for but no sulfurous water was found. The reference apparently is to the Hda. Santa Clara springs.

Several thermal springs were located between San Jacinto and Tisate. The warm springs (32-46.5°C) are localized along a north-south tributary of Río Apante. Only one highly mineralized spring, with a temperature of 66.5°C and very low flow, was located (UTM coordinates 1392.6N, 524.6E) in the area. This spring is along a mapped probable fault about one km. south of Tisate. All of the other thermal springs are also near to or along the major north-south fault as shown on plate 1. Some of the springs are lava-contact type but probably actually originate from fractures. Normal temperature springs are mostly located to the west of the thermal spring alignment, usually at lava contacts.

Further information on the thermal springs and wells is tabulated in Part 2 of the project report.

LOCALIZATION OF THERMAL ACTIVITY

There seems to be little doubt that in the three thermal areas discussed, the thermal activity is localized by fractures and faults. The Ñajo thermal areas, in slightly dipping lava flows, are very probably localized by a fault and associated fractures. The Tisate area, in practically flat-lying lava and pyroclastic deposits, is, at least for the most part, localized along fractures and faults with some possible control by questionable dikes. The thermal springs between San Jacinto and Tisate are located along or near a mapped major fault, while the thermal springs at Hda. Santa Clara are very probably associated with nearby faults. At the San Jacinto thermal area, in essentially flat-lying lava flows with minor pyroclastic deposits, evidence is less strong but fracture control of activity is likely.

The north-south major fault which practically connects San Jacinto and Tisate probably serves as the conduit from depth for the hydrothermal solutions and gases (plate 1 and figure 2). This fault has been partially covered by younger volcanic deposits from Volcanes Santa Clara and San Jacinto, but the fault still exists as a weak zone, which has probably been propagated upward into overlying deposits as a fracture zone. At some depth beneath the surface, this fault is inferred to extend south of its presently mapped termination north of San

Jacinto, to and beyond the thermal area at San Jacinto. Subsurface geophysical data to help substantiate this extension is presented in Part 6 of this project report. The intersection of other fractures and small faults with the major fault is thought to be especially important for localization of thermal activity along the major fault. This last relationship appears to be important at all of the thermal areas discussed.

SUMMARY AND CONCLUSIONS

Three thermal areas were studied. The San Jacinto thermal area is quite compact but has intensive thermal activity. The Tisate thermal area covers a more extensive area but much of the area is "dead" with scattered minor fumaroles. The Ñajo thermal area consists of several scattered altered areas with variable thermal activity.

The San Jacinto-Tisate thermal areas are possibly connected at depth; they are very probably along the same fault conduit system. The Ñajo thermal area appears to be a separate area of less immediate interest.

The San Jacinto-Tisate area shows favorable indications for possible geothermal power development but the thermal activity at the three areas is considerably less extensive and intensive

than at the South Volcán Momotombo area. This indicates a probable secondary rating for a geothermal power prospect as compared to the South Volcán Momotombo area.

Additional investigations involving geophysics, both resistivity and gravity-magnetics, geochemistry, and drilling of 200 ft. depth temperature gradient holes is warranted. Most of these investigations have been completed and are described in other sections of the project report.

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