XN-ABK-280-B

GEOTHERMAL INVESTIGATIONS IN NICARAGUA

Report prepared for the

GOVERNMENT OF NICARAGUA

Ministry of Economy, Industry and Commerce

by

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February 1971

Abstract

Two high-temperature geothermal prospects have been recognized in Nicaragua. They are (1) the thermal area at the volcano Momotombo at the north-western end of Lake Managua and (2) the thermal areas at San Jacinto-Tisate west of Volcan Santa Clara. The possibility for thermal resources in the Managua area are also being pointed out. The thermal areas (1) and (2), mainly the Momotombo area, appear to be connected with geothermal reservoirs of an economically significant energy potential. Test drilling and further exploration in these areas is being recommended.

Acknowledgements

The writer wishes to express his thanks to the members of the Texas Instruments Incorporated staff under the leadership of Mr. L. T. Braun and to the members of the Nicaraguan Geological Survey as well as to Drs. F. Berry, G. Keller and D. E. White for the very pleasant cooperation during the work on the present project.

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(1) INTRODUCTION

The following report has been written in order to summarize the writer's results and impressions gained during his joint work with Drs. F. Berry, G. Keller and D. E. White and the staff of Texas Instruments Incorporated on the Nicaraguan Geothermal Project. The report, which is the final report on the writer's work during Stage I of this project, has been prepared for the Government of Nicaragua, Ministry of Economy, Industry and Commerce.

The present report represents the writer's personal views which were gained mainly during his three field visits to Nicaragua. Preliminary reports were written following each field visit.

(2) ECONOMICAL BACKGROUND

(2.1) Electrical Power

Central America has practically no resources of fossil fuel. Hydroelectrical resources are not abundant and are characterized by considerable seasonal variations. The annual load characteristic is therefore relatively poor. For power generation the region has consequently had to rely to a considerable degree on conventional thermal plants burning imported fuel.

The total capacity of present power plants in Nicaragua is of the order of 200 MW. During the coming one or two decades the demand for electric power may increase by as much as 20 to 25 MW/year.

Estimates of comparative costs of electrical energy in Central America, based on data from various sources, are given in the following Table 1. The data are quoted as generating costs at the plants excluding taxes, profits and other non-essential overhead.

Table 1 indicates that geothermal power, if available, has a considerable economical advantage over other sources in Central America. Since good hydroelectrical sources are relatively rare in the region, the data on the geothermal plants should be compared with the conventional steam plant under (a). The data are based on present

interest rates and fuel prices, but these may, of course, vary from time to time. The data are, therefore, only indicative.

Table I

Comparative energy costs in Central America

	mills/kWhr
(a) Conventional steam plants of modern design, capacity 50 to 100 MW, burning residual fuel oil, base load power	8-10
(b) Hydroelectrical plants, capacity 100-250 MW, data from 2 projects, annual load 2,500 to 4,500 hr/year	6-9
(c) Geothermal steam plant, capacity 50 to 100 MW, based on natural steam from an easily accessible high-temperature reservoir, base load power	4-6

Moreover, it should be noted that the data under (c) are based on the assumption of steam production from a relatively favorably located reservoir producing from depths of the order of 500 to 1,000 meters, and at a rate equivalent to 4 to 6 MW/ borehole.

One of the principal conclusions to be drawn from Table 1 is that considerably more adverse source conditions can be dealt with without losing the economic advantage of producing electrical power by natural steam. An elementary investigation shows that sources as deep as 2,000 to 2,500 meters can still compete favorably with the conventional

steam plants.

It is of interest to note that a fluid phase geothermal reservoir with a base temperature of 250°C will on the basis of natural steam plants of conventional design yield an energy of about 20 kWhr/metric ton of reservoir fluid. A plant of 50 MW power will thus require a total flow of 700 kg/sec from the reservoir. The integrated flow during a period of 25 years is thus about 1/2 cubic kilometer of reservoir fluid. Moreover, the energy conversion within geothermal reservoirs is generally rather poor. The total solid phase reservoir contact volume required for the period of 25 years will probably be of the order of 10 cubic kilometers. For a period of 100 years the reservoir volume will thus have to be about 40 cubic kilometers. This figure gives the order of magnitude of the reservoir volumes required for plants of this size.

(2.2) Utilization of Heat

Although geothermal energy is now being used mainly for power generation, other fields of application are of interest. Natural steam and hot water are generally sources of heat at extremely low cost. It is of interest to point out that the data under (c) in Table 1 imply a steam production cost of 0.10 to 0.15 $/metric ton,* that is, in terms of sensible heat content a cost of 0.20 to 0.30 $/Gcal (One Gcal = one giga-calorie= 10^9 cal = $4x10^6$ B.T.U.). The cost of heat from residual fuel oil is of the order 2 to 3 $/Gcal. This figure indicates the extreme advantage of using geothermal steam as a

* All dollar amounts in this report represent U.S. $

source of heat.

Moreover, it is of interest to note that even very deep relatively low-temperature geothermal sources can produce heat at a low cost. To take an example, let thermal water at 150°C be available at the depth of 2,000 meters and be produced at the surface by relatively low yield pumped boreholes. If drilling costs can be kept at a reasonable level and each borehole yields 25 kg/sec, the cost of the unit heat at a temperature of 100°C will be of the order of one $/Gcal. This is still considerably below the cost of heat from fuel oil. The example shows that the utilization of low-enthalpy deep resources should be given due consideration if there is a market for the heat. Such market is likely to be in an industralized area as, for example, in the area around Managua.

(3) GEOTHERMAL RESOURCES IN NICARAGUA, RESULTS OF PRESENT INVESTIGATION

(3.1) Geological Setting

The volcanic geology of Nicaragua has been described by Weyl[1] and McBirney and Williams [2]. The results obtained during the present investigation are described in thorough and detailed reports by Thigpen (Parts 2,3 and 4 of Final Report on Geothermal Resources Project-Stage I). There is no reason to repeat the results described in these papers.

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[1]Weyl, R. 1961 - Die Geologie Mittelamericas, Beitraege zur regionalen Geologie, Bd.1, Gebrueder Borntraeger, Berlin.

[2]McBirney, A. R. and H. Williams, 1965 - Volcanic History of Nicaragua, University of California Publ. in Geolog. Sciences, Volume 55.

The most prominent volcanic and thermal feature of the geology of Nicaragua is the almost perfectly aligned chain of active volcanoes from Cosegüina in the northwest to Madera in the southeast. This chain would appear to be controlled by faults along the southwestern border of the Nicaraguan depression or graben. The depression which has a width of 40 to 70 km continues into El Salvador to the northwest and into Costa Rica to the southeast. Although the depression has the features of a graben, details of its structure are by no means clear, and its relation to the volcanism is obscure. The gravity survey over the depression carried out during the present investigations did not reveal clear results. The results obtained over the western flank of the depression in the San Jacinto area appear to indicate a number of faults with a total throw of 500 to 1,000 meters.

It is of interest to note that the structural control of the volcanism along the Central American depression appears to change gradually along the northern end of the structure. The setting of the volcanoes of Guatemala appears different from that of Nicaragua. Moreover, it is worthwhile noting that the dimensions and certain other features of the depression are reminiscent of the Permian magmatic province of the Oslo region of Norway, the Taupo volcanic zone in New Zealand and other non-orogenic volcanic zones extruding material of mixed composition.

It is quite clear that the uncertainty as to the structure of the Nicaraguan depression

is one of the main problems encountered in determining the structural control of the geothermal areas. This problem should therefore be given proper attention in any future work.

(3.2) Volcanic Explosions

The relatively great number of Krakatoan collapse calderas is a prominent feature of the Nicaraguan volcanic chain. McBirney [1] lists 8 structures of this kind. Moreover, there is a number of typical explosion craters such as the Laguna de Tiscapa in Managua and possibly also the Laguna de Asososcoa and Laguna de Nejapa a few km west of Managua. Steam-gas and pure steam explosions have no doubt been the main force in creating these structures.

It should be noted that volcanic explosions of this kind constitute just another form of releasing geothermal energy--although in a rather violent manner. In the case of the smaller craters, at least, such as the Laguna de Tiscapa, the exploding medium may be water having a temperature of only 250 to 300°C. An elementary computation shows that water at 250° can by expanding to atmospheric pressure and 100°C release a total of 1.4×10^5 joule/kg of mechanical energy. Theoretically this energy suffices to lift the water 14 km above the surface of the earth. Of course, explosions of this kind have a very low mechanical efficiency, perhaps of the order of a few per cent only. If

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[1] McBirney, A. R. 1956 - The Nicaraguan Volcano Masaya and Its Caldera, Trans. Am. Geophys. Union, 37, 1.

the ejecta are thrown a few hundred meters into the air, these results indicate that the mass of water involved in a pure steam explosion may very roughly be of the same order as the mass of the solid phase ejecta if the heat content of the solid phase is ignored. In the case of the Laguna de Tiscapa, the total volume of ejecta may have been of the order of 5×10^7 cubic meters. Allowing for some of the heat content of the solid phase the volume of thermal water involved is estimated at the order of 2×10^7 cubic meters, that is, about 1/50 cubic kilometer. In accordance with the data given in paragraph (2.1) this amount of water at 250°C would be able to produce about 4×10^8 kWhr of electrical energy, that is, operate a power plant of 2 MW for a period of 25 years. Of course, the energies involved in the Krakatoan explosions are many orders of magnitude greater than the case of Laguna de Tiscapa. In 1835 the Coseguina in Nicaragua threw out several tens of kilometers of pumice and ash. Even allowing for high temperatures, the amount of water involved must have been of the order of many cubic kilometers.

It is well known that the relaxation time for subsurface thermal anomalies is quite long. The data given about therefore indicate that the most recent explosion craters and calderas should not be overlooked as indicators of sources of geothermal energy. It is rather likely that each explosion throws out only a part, perhaps a small part, of the thermal water available.

(3.3) Main Geothermal Resources

The geothermal areas in Nicaragua discovered during the present survey are described in the reports by Thigpen (Parts 2, 3 and 4). There is no reason to repeat details of his findings.

Two main geothermal prospects have been recognized; these are (1) the geothermal area at the southern flank of the volcano Momotombo and (2) the geothermal area at San Jacinto-Tisate.

In view of the present writer, both of the above areas appear to be typical high-temperature prospects. Both are characterized by quite extensive surface display of thermal activity of the type which is generally found in areas having base temperatures above 200°C. There is extensive thermal alteration, hot ground and a considerable number of fumaroles and mud-pots. Moreover, there are typical deposits of elemental sulphur.

The surface display is more prominent and extensive in the Momotombo area. In this connection it should be noted, however, that the Momotombo is an active volcano and the thermal activity therefore appears to be of a syn-volcanic nature, that is, it may be directly connected with the active neck of the volcano. Activity of this type may possibly be rather localized.

Comparing observations in Nicaragua and other Central American countries, the writer is of the opinion that the Momotombo and the San Jacinto-Tisate thermal areas

compare quite favorably with other thermal areas in the region. Their geological setting and elevation are favorable. There is no doubt that both areas should be regarded as good geothermal prospects.

The surface display at Tipitapa and San Luis is not indicative of high-temperature conditions beneath the areas. At this juncture, these areas are, therefore, of less practical interest.

The thermal area at Volcan Casita is no doubt of a syn-volcanic nature. The location and altitude are unfavorable.

To these findings, the writer would add that there appear to be prospects for hyperthermal conditions along the entire western flank of the Nicaraguan depression. This is indicated by the present volcanism and the many explosion craters as discussed in paragraph (3.2) above. Thermal waters of moderate to high temperature may be available at some depth within the western sections of the depression.

(3.4) Geophysical and Geochemical Results

The field data obtained during the present investigations have been described and discussed in the reports by Bennett, Harthill, Keller and Mazzolini (Parts 7 and 8, 6 and 5, respectively). Again, there is no reason for repeating their findings.

Only a few comments will be made.

Geoelectrical results. A considerable effort has been devoted to the measurement of subsurface electrical conductivity in the San Jacinto-Tisate and Momotombo areas. Moreover, EM measurements have been performed along a profile across the Nicaraguan depression extending from Poneloya at the coast to Los Zarzales at the eastern flank of the depression.

It is well known that there are particular difficulties in deriving subsurface conductivity values on the basis of surface data. Moreover, there is a considerable ambiguity involved in interpreting the conductivity data in terms of subsurface temperature fields. Rock conductivity is far from being a unique function of the temperature. As a matter of fact, the conductivity may depend to a greater extent on various other physical and chemical rock parameters than on the temperature. These difficulties are most clearly demonstrated by the Poneloya-Los Zarzales profile. This profile crosses the San Jacinto thermal area, but there is no clear conductivity anomaly connected with the region of surface thermal manifestations.

On the other hand a local dipole DC survey at San Jacinto (Part 6, Fig. G7) indicates a clear quite localized anomaly. The surface area within the 0.16 mho/m isoconductivity line is about 3 km^2, and the area within the 0.11 mho/m line is about 6 km^2. Moreover, the local EM soundings (Fig. G18) indicate a surface layer of 400 to 600 meters thickness having a conductivity of a few hundred millimho/m resting on a basement having a conductivity of 30 to 50 millimho/m.

The dipole DC survey at Momotombo is incomplete since no closed contours could be obtained. EM soundings at Momotombo (Fig. G19) indicate a surface layer having a conductivity of several hundred millimho/m resting on a basement at 1,400 to 1,600 meters having a conductivity of about 2 mho/m.

The electrical results in both San Jacinto-Tisate and Momotombo areas indicate clear local anomalies, but the results differ considerably in magnitude. The basement conductivity at Momotombo is about 50 times higher than at San Jacinto-Tisate. This difference is no doubt caused by petrological and chemical factors. The basement at San Jacinto is probably crystalline whereas the basement at Momotombo may be composed of tefras, tuffs and sediments invaded by saline waters.

Gravity and magnetic results. The gravity and magnetic field data have apparently no direct bearing on the geothermal conditions in the areas under investigation, with the possible exception of the gravity high observed at San Jacinto. However, at this juncture, we have no ways of interpreting the gravitational data in terms of the geothermal situation at San Jacinto.

Geochemical results. From a global point of view, both thermal waters and gases in the main Nicaraguan thermal areas appear to display some abnormalities.

The amount of SiO_2 in water samples from natural springs in the various thermal areas is quite uniform despite the fact that the areas differ considerably in terms of surface display. Thus, samples from San Luis, Tipitapa, Momotombo and San Jacinto all

contain 100 to 200 p.p.m. of SiO_2. On the other hand, Cl varies from about 15 p.p.m. in the McBirney drill hole at San Jacinto to 3,500 p p.m. at Momotombo. Tipitapa and San Luis have Cl in the amount of 100 to 300 p.p.m.

Almost all gas samples taken from fumaroles and natural springs appear to indicate atmospheric contamination. Disregarding totally abnormal samples, the amount of CO_2 in the gases at San Jacinto and Momotombo varies from about 10 to 45 vol. %. The H_2S at San Jacinto is found to be only 80 p.p.m. of the gases. Tisate has considerably higher values of up to 4,600 p.p.m. and Momotombo has values up to 10,000 p.p.m. Since the total gas content of the natural steam was not measured, no data are available on the absolute gas content of the steam.

The chemical composition of the thermal gases in Nicaragua displays a certain similarity to results obtained in El Salvador. The natural steam in the Ahuachapan area in El Salvador contains unusually small amounts of CO_2 and H_2S. Moreover, H_2 appears almost absent in both countries. In the case of Nicaragua it is possible that the atmospheric contamination may partially account for the relatively small amounts of H_2S found in the samples.

Borehole data. The most significant borehole data were obtained from hole MT-1. A temperature of 209°C was measured at the depth of 220 meters in this hole. Moreover, a water sample taken from the hole turned out to contain 210 p.p.m. of SiO_2. It is significant that this SiO_2 content is considerably below the value of about 300 p.p.m. which

should be expected if the water had obtained equilibrium with quartz at 209°C. On the other hand, the temperature of 209°C is quite close to the temperature of boiling of water at a depth of 220 meters. Despite the low SiO_2 content of the water it therefore appears unlikely that the temperature measured represents the base temperature of the area.

It should be noted that Ahuachapan in El Salvador has a measured base temperature of 228°C and the thermal waters there contain 550 to 650 p.p.m. of SiO_2. The low SiO_2 values observed at Momotombo may be the result of an unrepresentative sample and/or it may display a significant chemical disequilibrium in the system. The latter case would be of practical significance. Unfortunately, no deep borehole was drilled in the San Jacinto area and no deep water samples have therefore been available from this area.

(4) OUTLOOK PRO TEMPORE

(4.1) Field Conditions for Large Scale Power Generation

In brief terms, the following conditions appear to be required in order to sustain with reasonable certainty an economical generation of electrical power on the basis of geothermal heat involving a total energy production of the order of 10,000 MW years or more.

(1) High base temperature, preferably above 200°C.

(2) Large active permeable reservoir volume, preferably of the order of

hundred cubic kilometers or more.

(3) Adequate supply of recharge water.

(4) Relatively shallow ground water surface.

(5) Acceptable chemical quality of the reservoir water.

(6) Adequate drillability of the reservoir rock.

In the present case of Nicaragua, the main concern centers around items (1) and (2). Due to relatively favorable geographical, geological and meteorological conditions, items (3), and (4), and (6) are less likely to be of concern. There is some uncertainty as to item (5) since no reliable deep water samples have been available. However, in view of the possibility of disposing effluent waters by reinjection, an adverse chemical composition of the reservoir water is not likely to be a decisive factor.

(4.2) The two main prospects, San Jacinto-Tisate and Momotombo

Due to inadequate temperature data, mainly the lack of data from depths greater than 500 meters, we are at this juncture unable to come to definite conclusions as to the base temperature in these two areas. However, in the case of Momotombo, the temperature data from hole MT-1 indicate a base temperature at or above 209°C. Moreover, the present writer is under the impression that the surface display of thermal activity at both San Jacinto-Tisate and Momotombo indicates base temperatures in excess of 200°C. These semi-quantitative conclusions are, of course, not supported by the water

chemistry in both areas, but the present writer wishes to underline that no deep samples have been obtained in the areas. Moreover, there are indications of chemical disequilibria.

The situation as to the reservoir volumes is considerably more uncertain. In the case of Momotombo, the electrical conductivity data indicate a lower limit of a few cubic kilometers, but the data are incomplete and the active volume may be considerably greater. Moreover, as already stated, the high conductivity values can be interpreted as indicating thick layers of tefras, tuffs and sediments.

The problem at San Jacinto centers around the nature of the basement indicated by the electrical conductivity data to be within 400 to 600 meters of the surface. This is probably a crystalline basement of an intrusive or extrusive nature. Since there is no escape from the fact that the thermal activity at San Jacinto-Tisate must have its origin deep in the basement, it is by no means unlikely that the basement complex is the host of a large geothermal reservoir. Only deep exploratory drilling can lead to definite conclusions.

Comparing the two thermal areas, there is apparently not much doubt that Momotombo appears to be a more favorable geothermal prospect than San Jacinto-Tisate. However, as expressed in previous reports, the present writer wishes to emphasize the syn-volcanic character of the Momotombo area. Its close connection with the active volcano Momotombo can possibly be interpreted as indicating a relatively transient and localized phenomenon around the active neck of the volcano.

Summing up his observations and impressions, the present writer is of the opinion that in spite of a number of uncertainties both the San Jacinto-Tisate and the Momotombo areas should be regarded as favorable geothermal prospects which warrant further investigation by deep drilling.

(4.3) Geothermal Heat for Industrial Purposes in the Managua Area

The possibilities for hyperthermal conditions along the entire western flank of the Nicaraguan depression have already been discussed above. Moreover, an estimate has been given of the production cost of heat from low-enthalpy waters from depths as large as 2,000 meters.

There may be some market for heat for small-scale industry in a rather densely populated area such as in and around the city of Managua. The city happens to be located just on the main axis of volcanism along the western flank of the depression and should therefore have close access to hyperthermal sources. As a prospective market for the geothermal heat, we may mention,

(a) water purification and sterilization,

(b) water for industrial cleaning, washing and boiling,

(c) cooling and refrigeration on the basis of the absorption principle,

(d) processing of pulps,

(e) sugar refining.

The list is most probably incomplete. The writer is of the opinion that the possibilities in this field should not be overlooked. They may turn out to be of some economical importance. A further investigation of thermal resources in the Managua area may therefore be warranted.

(5) FUTURE EXPLORATION AND DRILLING

(5.1) Outstanding Field Problems

The apparently favorable outlook for economically exploitable geothermal resources in two or three locations in Nicaragua calls for an open-minded planning of future research and exploration. It is important to recognize problems at an early stage and to take the necessary steps to solve them. A number of important problems which future geothermal investigations in Nicaragua will have to cope with are listed below. Progress in the solution of these problems will be of economical importance for the future exploitation of the resources. Work on the problems listed below should therefore be included in Stage II of the geothermal investigations.

(1) Reliable estimations of main geothermal parameters such as the base temperature and the active reservoir volume in the case of the Momotombo and San Jacinto-Tisate areas. These data have to be obtained mainly by exploratory drilling. Further geoelectrical work is also warranted.

(2) Uncovering of the geological setting of the areas with regard to the regional volcanism and the structure of the depression, including depth to the regional crystalline basement. Further geological mapping and seismic field work will supply important data.

(3) Derivation of the structural control and hydrology of the main thermal areas. Local microearthquake surveys and a regional survey of hydrogen and oxygen isotopes in waters will be of importance to uncover the main pattern of ground water flow.

(4) Finding of the optimum way of disposing of effluent thermal waters from boreholes and power installations. The effluent waters are often loaded with components such as fluorine and boron which are harmful to flora and fauna. Reinjection of the waters into suitable subsurface formations offers an attractive possibility. However, this method involves the danger of a thermal contamination of production zones and has therefore to be applied with care. The design of reinjection systems has to be based on sufficient field data which have to be obtained by special investigations.

(5.2) Exploration and Initial Production Drilling

The purpose of further exploratory drilling has already been outlined in the preceding paragraph. In order to obtain sufficiently detailed and complete data on the base temperature and other field conditions, the exploratory boreholes should be 1,000 to 1,500 meters deep. Although base temperatures below 250°C can be established with boreholes

which are not deeper than about 600 meters, we are also interested in detecting temperature inversions which are often of considerable diagnostic importance. In the case of the Momotombo area, such deep temperature profiles would have a direct bearing on the volcanic relations of the area.

As to the initial production drilling, we may envisage the construction of a 50 MW power plant as a proper initial step in the exploitation of geothermal resources in Nicaragua. The thermal area at Momotombo may be the site of this plant. Assuming a wet reservoir with a base temperature of, for example, 250°C, the total flow of reservoir water required for the operation of this plant would be about 700 kg/sec. Assuming a flow reserve of 30%, that is, a total integrated capacity of the boreholes of 900 kg/sec, and a relatively low average capacity of each borehole of 75 kg/sec, we find that the total number of active boreholes would have to be about 12. To this we have to add an estimated number of unsuccessful or "dry" boreholes. Taking a somewhat pessimistic point of view, let this number be 6, that is, the total number of boreholes required for the 50 MW plant be 18. As already stated in (2.1) above, the total output of these holes during a period of 25 years would be of the order of 1/2 cubic kilometer.

As a first step in proving the necessary geothermal resources for this project we may envisage the drilling of 1/3 of the required number of holes, that is, a total of 6 boreholes. The completion of these holes will have to be followed by a test period of not less than one year. Following successful tests, the drilling for the 50 MW plant will be

completed and all boreholes tested for another minimum period of one year before going ahead with plant construction. As stressed above, at least one of the initial boreholes should be drilled to a depth of not less than 1,500 meters. The depth of the production holes may range from 500 to 1,000 meters, but it appears advisable to plan for an average depth of 1,000 meters.

Due to the limited amount of field data available, the siting of the initial boreholes appears somewhat problematic. This is a common situation in geothermal work. The pertinent problems have been discussed at the consultants' meetings with the Texas Instruments staff and joint recommendations have been worked out.

(5.3) Drilling Equipment and Casing Program

The deep exploratory and production drilling will preferable have to be carried out with a rotary drilling rig having a capacity of not less than 1,500 meters with a 4-1/2 inch drill pipe. The rig will have to be equipped with an adequate pumping capacity, safety equipment for pressure control and cementing gear.

Casing program would involve shallow surface casing, then about 100 meters of 13-5/8 inch O.D. pipe and finally a few hundred meters of 9-5/8 inch O.D. pipe. The main production hole would have a width of 8-5/8 inches.

(5.4) Comments on an Initial Light-Rig Drilling Phase

The question arises whether it would be economical to carry out some of the initial exploratory drilling with a shot-hole or a slim-hole rig. This initial phase could be completed before the decision is made to move in the larger rig, and could thus act as a precautionary step.

The present writer is of the opinion tha e only alternative which comes into consideration would be to continue some drilling with the Mayhew 1500 drilling rig which was used during Stage I. There is no economical or technological advantage in moving in a special slim-hole rig.

As a matter of fact, it might be advisable to initiate the drilling at San Jacinto-Tisate by drilling one or two slim holes of 600 meters depth with the light rig

However, the field work at Momotombo appears to have furnished such positive results that further work with the light rig appears superfluous. Moreover, due to reasons already discussed, the exploratory boreholes in this area have to be drilled to greater depths than 600 meters. The drilling program in this area therefore requires full scale drilling equipment which would then also be used at San Jacinto-Tisate.

(6) RECOMMENDATIONS AS TO STAGE II OF THE NICARAGUAN GEOTHERMAL PROJECT

Based on the discussion above, the writer recommends the following procedures for Stage II of the project.

Drilling should be initiated at Momotombo and should involve the drilling of one or

two deep wells, at least one of them to a depth of 1,500 meters. Following this, one deep well should be completed at San Jacinto-Tisate. Further drilling in one of the areas should be carried out in accordance with the results obtained as to reservoir temperatures, permeability and chemical quality of the water. A total of 6 wells should be completed in the area selected for production drilling. The drilling program should include contingency plans for the drilling of two additional boreholes, for example, one in the Managua area. The total program is estimated to include the drilling of 3 boreholes to the depth of 1,500 and 6 boreholes to the average depth of 900 meters, that is, a total of about 10,000 meters. The unit cost of a completed borehole is estimated at U.S.$110/meter. Recommendations as to the initial drilling sites are presented in a joint report of the consultants to the project.

Moreover, it is being recommended that Stage II involve an adequate program for testing the continuity of the steam production obtained for a minimum period of one year. These tests will have to include the monitoring of the mass flow, temperature and chemistry of waters and gases.

Finally, Stage II should involve further geological, geophysical and geochemical work as indicated under (5.1) above. This will include the following special investigations:

(1) Further detailed geological mapping with special emphasis on the structure of the Nicaraguan depression.

(2) Further geoelectrical work as recommended by the consultants.

(3) A seismic refraction survey of the active areas.

(4) Local microearthquake surveys at selected stations.

(5) Isotope survey on meteoric, ground and thermal waters.

(6) Contingency plans as to further gravity, microgravity, magnetic and other geophysical methods.

Based on the assumption that Momotombo will be selected as the main geothermal prospect, the financial plans for Stage II appear as follows:

Drilling

Momotombo	6 boreholes = 6,000 meters	U.S.$0.66x10^6
San Jacinto	1 " 1,500	0.17
Contingency, San Jacinto and/or other areas	2 " 2,500	0.27
		1.10

Testing, Exploration and Research

Testing, piping, disposal, geology, geochemistry, logging	0.25
Geophysics	0.15
	U.S.$1.50x10^6

The figures, which are based mainly on experience in El Salvador, include overhead costs and salaries.

Permanent or almost-permanent personnel:

One drilling engineer

One petrologist

One geologist

One geophysicist

One "steam" engineer (for testing)

One geochemist

Office personnel

Special field work will have to be carried out under the supervision of specialists brought in from time to time.