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GEOTHERMAL EXPLORATION - UGA/92/002

Geophysical investigation

Preliminary summary of findings and recommendations

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February 20th 1994

1. INTRODUCTION

The project "Geothermal Exploration - UGA/92/002" is funded by the Government of Uganda, UNDP, The OPEC Fund for International Developement and the Government of Iceland. It is executed by the Department of Development and Social Management Services (DDSMS) in cooperation with the Geological Survey and Mines Department of the Ministry of Natural Resources in Uganda. The project is focused on three geothermal prospects in western Ugnad and employs geolgical and geochemical methods with the aim to select one of the geothermal areas for further surface exploration and exploratory drilling.

On the 15th of January 1994, a consultant geophysicist under the project went on a one month mission to visit the geothermal prospects, evaluate existing geophysical data and make proposals for further geophysical studies. The following is an extended preliminary version of summary of findings and recommendations resulting from the mission. Since details of the recommended survey plans are still to be worked out, some quantities stated in this document might be subject to minor changes.

2. GEOLOGICAL SETTING

The three geothermal areas under consideration are in the western branch of the East African rift system in western Uganda. The rift which opened some 20 M.y. ago has higher heat flow than the surrounding Pre-Cambrian crust. The geothermal activity is clearly related to the tectonic and volcanic activity of the rift.

The **Katwe-Kikorongo geothermal area**, the southernmost of the three areas, is located in the Queen Elizabeth National Park between Lake Edward and Lake George, SE of the Ruwenzori Massif. It is associated with Pleistocene to Holocene volcanism and micro earthquake activity in the area indicates magmatic heat source at depth. Geothermal surface manifestations are found in the crater lake Kitagata. Hot springs with temperature up to 70 °C discharge saline to brackish waters to the lake. The largest spring is found at the bottom of the lake making measurements of flow rates impossible. Saline springs at Lake Katwe have temperature slightly above annual mean temperature. Due to unusual chemistry of the fluids, geothermometry has as yet not given clear indication of expected reservoir temperatures but indicates temperatures in the range of 140 °C to 200 °C. Hydro-geological investigations indicate that permaebility in the sedimentary basin underlaying the volcanic deposits is generally low and the springs are most likely associated with tectonically induced aquifers such as faults and fissures.

The **Buranga geothermal area** is located in the Semliki-Kaiso sedimentary basin under the Bwamba Escarpment at the NW boundary of the Ruwenzori Massif. Geothermal surface manifestations are mainly found in three hot spring areas laying approximately on a 600 m long line striking N-35°-A. The total flow is at least 20 l/s with temperatures as high as 98.4 °C. The geothermal water is brackish and contains considerable amount of gases, mainly CO_2 and some H_2S as well as silica and many of the springs have deposited large travertine cones. Geothermometry applied to water samples from the Buranga field indicates reservoir temperatures in the range 120-130 °C. Even though the hot water emerges through the sedimentary layers of the

Semliki basin, it originates most likely from deep circulation along faults in the Pre-Cambrian basement associated with the Bwamba Escarpment. Heat is most likely mined from the generally high heat flow in the rift but the high concentrations of volatile gases could be taken as an indication of volcanic heat source at depth and magmatic intrusions in the sedimentary basin can not be ruled out.

The **Kibiro geothermal area**, which is the northern most of the three areas under consideration, is located on the SE shore of Lake Albert, on a narrow plane under the 300 m high Escarpment forming the SE margin of the Albertine rift. The main geothermal springs are found on a line which seams to be associated with a fault slightly oblique to the main fault of the Escarpment. The the measurable flow of the springs in Kibiro is estimated about 6.5 l/s with temperatures ranging from 33 °C to 86.4 °C. The geothermal water is brackish and geochemical analyses of the water indicate mixing of fresh and geothermal waters and that the reservoir temperature of the geothermal component is about 200 °C. Like in Buranga the most likely cause of the geothermal waters in Kibiro is deep circulation along the faults in the rift, mining heat from the generally high heat flow in the rift, but high H_2S content and native sulphur deposited near the springs might suggest magmatic heat source at depth.

3. EXISTING GEOPHYSICAL DATA

Geophysical exploration for geothermal resources in Uganda has been limited to date and existing geophysical data from the geothermal fields under consideration is sparse and inconclusive. Some geophysical work has been carried out in the Katwe-Kikorongo area, mainly aimed at hydro-geological studies and assessment of salt mining potential in Lake Katwe. This included some resistivity soundings which show that subsurface resistivity is low arond Lake Katwe but the areal extend of the survey is to limited to indicate the size of the anomaly.

In Buranga some geophysical work has been done specifically aimed at geothermal exploration, comprising magnetic and gravity measurements as well as some resistivity measurements. These data provide general ideas of some geophysical parameters in the area but are to limited and inconclusive to give any details. No geophysical work, focusing on the geothermal resource, has been carried out in the Kibiro area.

A study has been made of the seismic activity in the rift around the Ruwenzori mountains. The rift was found to possess more ore less continuous seismic activity. This is important because tectonic movements will sustain permeability along faults and fissures in the presumably rather impervious rocks in the area.

In recent years reconnaissance studies, comprising gravity and magnetic measurements, have been carried out in the Lake Albert part of the rift. The purpose of this study has been to evaluate possible hydro carbon potentials of the sedimentary basin of the rift, but it provides valuable background information for geophysical investigations of the two northernmost geothermal fields, Buranga and Kibiro.

4. SURFACE GEOPHYSICS IN GEOTHERMAL EXPLORATION

The consultant geopysicist shares the view of the Chef Technical Adviser of the ongoing geothermal project that existing information about the three geothermal prospects under consideration is not decisive enaugh to allow selection of one of the geothermal areas for further studies. After completion of the present phase of geothermal investigations in Uganda, which is to be considered as the first (reconnaissance) phase of a systematic geothermal exploration, a well defined geophysical study of the prospect areas is the natural next step.

The purpose of the geophysical study is to assist in further assessment of the geothermal potential by adding information about the likely spatial extent and infra structure of the reservoirs as well as to aid siting of the first exploratory wells. It should be born in mind that surface geophysical exploration does generally not provide answers to questions about the temperature and permeability of the reservoir. If chemical analysis of surface springs does not give conclusive answers about expected temperature, this can only be determined by drilling. Permeability is only determined by drilling and testing of wells and geothermal prospect is in general not proven feasible for exploitation until after successful drilling.

5. RECOMMENDATIONS FOR FURTHER GEOPHYSICAL WORK

The salinity of the geothermal fluids is thought to be deeply connected to the geothermal activity. The salinity is likely due to volatile degasing of magmatic intrusions at depth and/or leaching by deeply convecting hot fluids. If the salinity of the geothermal fluid is higher than that of the general ground water, rocks hosting hot water will have lower resistivity than the surrounding rocks. Decreasing resistivity of electrolytic solutions with temperature will further amplify the resistivity anomaly. Hence resistivity surveys are recommended.

The hydrological structure of the geothermal systems under consideration is believed to be controlled by the tectonic activity in the rift. The general permeability of the sedimentary basins and the underlaying Pre-Cambrian basement rocks is considered to be low and that permeability is sustained by tectonic movements on faults. Therefore structural methods, capable of detecting buried faults and depth to basement, are of importance. Hence application of gravity and magnetic measurements is recommended.

The three different geophysical methods proposed map different physical properties of the subsurface rocks i.e. resistivity, density and magnetization. A joint interpretation of the survey results will therefore put more constraints on the resulting conceptual model of the geothermal system than would be obtained from any single method.

It is recommended that the resistivity surveys are performed by applying Central Loop TEM (Transient Electro-Magnetic) soundings. This method has been found to be in many respects superior to more conventional resistivity methods in geothermal exploration. The station spacings and the areal extent of the resistivity survey of each of the three geothermal areas should be such that the boundaries and the infra structure of the reservoirs is determined as well as possible. It is however recommended, in order to obtain efficiency, that detailed planning of the resistivity survey is kept flexible. Sounding results should be interpreted and the emerging resistivity structure continuously updated as field work progresses to ensure that soundings are sited where information is needed.

The gravity and magnetic surveys should be conventional ground surveys. For the gravity survey it is essential that the elevation of the gravity stations is determined by leveling (with accuracy of +/- 25 cm) in order to ensure sufficient resolution in Bouger gravity. It is further more important to perform careful topographic corrections to the gravity data, especially in the Buranga and Kibiro areas. The Magnetic survey should be ground survey measuring the total magnetic field corrected for diurnal variations of the external field. The areal extend and station density should be such that relevant anomalies, both of short and long wave lengths, are mapped properly. The survey lines of the gravity and magnetic surveys should be perpendicular to the geological strike. It essential, in order to avoid spatial aliasing, that pilot profiles are measured both perpendicular and along strike before desissions about of line spacings and station density along lines are made.

Sufficient expertize and equipment was found to exist at the Geological Survey and Mines Department and the Petroleum Exploration and Production Department of the Ministry of Natural Resources in Uganda, to carry out gravity and magnetic surveys. Foreign expertize and equipment is however needed to assist in carrying out resistivity surveys. It is therefore proposed that experts from Uganda carry out the gravity and magnetic part of the geophysical exploration and that foreign experts and equipments are brought in to assist with the resistivity surveys. The price of a complete set of instrumentation for central loop TEM soundings is about 80.000 USD and monthly rental rate is about

In order to minimize risk of interruption in field work it is recommended that two trained experts in application of central loop TEM soundings, preferably one geophysicist and one electronic enginer, will be in charge of the data collection. Processing and interpretation of the resistivity data should be performed by experienced geophysicist. It is recommended that the Geological Survey and Mines Department provides a geophysicist as a counterpart in the resistivity surveys, both in field work and data processing and interpretation. Practical as well as theoretical training of the counterpart in application of resistivity methods in geothermal exploration should be an integrated part of the geophysical project.

5.1 The Katwe-Kikorongo geothermal area

Accessibility in the area is fairly good. Topography is generally gentle except for the craters, many of which are deep and with steep walls. The fact that the Katwe-Kikorongo geothermal area is situated in the Queen Elisabeth National Park needs a special attention and close consultation and cooperation with the relevant authorities is needed. Vegetation is mainly grass with scattered trees and bushes, except that many of the craters have fairly dense forest. Only minor cutting of forest is expected to be necessary but off-road driving will be needed.

It is estimated that a geophysical survey in the Katwe-Kikorongo area will cower an area of about 10x20 km^2, comprising about 70 - 80 resistivity soundings and about 600 - 800 gravity and magnetic stations. The time needed for field work in the resistivity survey is estimated 2.5 - 3 months and data processing and interpretation is estimated to take 2 - 3 months. The time needed for gravity and magnetic surveys is estimated to be similar to that of the resistivity survey and the surveys could be performed simultaneously. A joint interpretation of all survey results and reporting is estimated to take about 1.5 - 2 months

5.2 The Buranga geothermal field

Accessibility is rather difficult because the survey area is located in rain forest and swamps under steep hills of the Ruwenzori mountains. Field work can only be carried out in the dry season. Survey equipment will have to be carried through most of the survey area which will slow fieldwork down and some cutting of forest will be necessary.

The geophysical survey is expected to cover an area of about 5x10 km^2 comprising about 50 - 60 resistivity soundings and about 400 - 500 gravity and magnetic stations. Field work is estimated to take about 2 months and data processing and interpretation about 1 - 2 months. This applies to both the resistivity and the gravity and magnetic surveys and they can be carried out simultaneously if considered practical. About 1 month is needed for joint interpretation of survey results and reporting.

5.3 The Kibiro geothermal field

Geophysical surveying at Kibiro is made somewhat difficult because of the limited space on land, under the Escarpment of the Lake Albert rift. The survey should preferably cover an area extending some 10 km along the Escarpment and some 3 km to each side of it. Accessibility on the landwards side of the Escarpment is relatively good, with gentle topography and vegetation characterized by grass and scattered trees and bushes. Most of the lake ward side of the preferred survey area is found to be in Lake Albert, except for the narrow planes under the Escarpment.

Resistivity soundings on the lake are possible in calm weather but they might turn out to be difficult. Water born gravity measurements need specialized and expensive equipment and should not be considered but there is no problem in conducting magnetic survey on the lake. It is therefore recommended that an area of about 6x10 km^2 be mapped by magnetic measurements and the on land part of the area covered with gravity measurements. Resistivity survey should be carried out on land and extended as possible to the lake.

Field work is estimated to take about 2 months for the resistivity survey and a similar time for the gravity and magnetic survey. Data processing and interpretation is estimated to take about 1 - 2 months and joint interpretation and reporting about 1 month.

6. SUMMARY AND CONCLUSIONS

The consultant geopysicist shares the view that the information privided by the ongoing geothermal project is not decisive enaugh to allow selection of one of the three geothermal areas under consideration for further studies. They must all be considered as potential prospects and hence a surface geophysical study is proposed for all the three fields. The recommended geophysical surveys comprise resistivity, gravitiy and magnetic measurements. Adequate expertize and equippment is found in Uganda to carry out the gravity and magnetic part of the surveys but foreign expertize and equippment is needed for the resistivity part.

A survey plan is proposed for each of the three areas and associated relvant numbers regarding work and time span are summarized in the following table:

	Katwe	Buranga	Kibiro	Total
Surveyed area (km^2)	200	50	60	310
Resistivity (months)				
Field work	2 - 3	2	2	6 - 7
Interpretation	2 - 3	1 - 2	1 - 2	4 - 7
Gravity and Mgnetics (months)				
Field work	2 - 3	2	2	6 - 7
Interpretation	2 - 3	1 - 2	1 - 2	4 - 7
Joint interpreation and reporting (months)	1 - 2	1	1	3 - 4
Durtion of survey (months)	5 - 8	4 - 5	4 - 5	13 - 18
Foreign experts (man-months)	7 - 11	6 - 7	6 - 7	19 - 25

The time given for the total duration of the surveys is a minimum time supposing that the resistivity and the gravity and magnetic surveys are carried out simultainously. The price of instruments for resistivity survey is about 80,000 USD and monthly rental rate about 8,000 USD.