DEPARTMENT OF THE INTERIOR
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Petroleum exploration in Malawi

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PETROLEUM EXPLORATION

IN MALAWI

by

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ABSTRACT

Sedimentary rocks, which could contain petroleum accumulations, are present in two areas of Malawi: (1) beneath the northern part of Lake Malawi and (2) in the Lower Shire Valley. The first named region encompasses an area of about 2,000 km^2 and last named region encompasses an area of about 700 km^2.

In the northern part of Lake Malawi, where the sedimentary section is 2.5 to 3.5 km thick, shallow cores (< 10 m) from the lake bottom indicate that organic-rich sediments are being deposited today under highly anoxic conditions. Seismic reflection surveys indicate that large structural features capable of trapping migrating petroleum are present. Seismic-stratigraphic interpretations and field surveys suggest that potential reservoir rock, in the form of deltaic sandstone, is being deposited locally along the lake margins and extends into the lake. At the present time, however, there is no evidence to suggest that petroleum has been thermally generated at depth. Geologic interpretations suggest that Lake Malawi is a relatively young geologic feature (less than 4 m.y.b.p.) and heat flow measurements are about average for continental areas.

In the Lower Shire Valley, there is no direct geologic evidence that indicates the presence of source rock although some authors have speculated that Cretaceous age marine shales exist at depth.

Based on the lack of geologic evidence for thermal maturity and a large areal extent of potential sedimentary rocks, the petroleum potential of Malawi must be considered poor. Industry, therefore, has not been able to justify the high expenditures (probably greater then $500,000,000 U.S.) that would be

required to test drill in the extreme water depths (greater than 500 m) of Lake Malawi.

Despite the fact that its petroleum potential is rated as poor, Malawi may decide that further exploration is warranted. The author, therefore, has outlined a low-cost, small-scale geophysical and drilling program that, although not designed to actually discover petroleum accumulations, is intended to give further insight to Malawi's petroleum potential, increase the knowledge of the subsurface geology, and, hopefully, thereby attract industry to explore further. The geophysical program is designed to be coordinated with coal exploration in the northern part of the country, water resources studies in the southern part of the country, and to develop geophysical capabilities in the Malawi Geological Survey.

INTRODUCTION

In September of 1982, the Government of Malawi requested from the United States Agency for International Development (USAID) the technical assistance of a petroleum geology consultant. The consultant was to advise the Malawi Government on its possible role in promoting and monitoring oil exploration in Malawi. In particular to look at the possibility of setting up, within the Geological Survey Department, a small petroleum geology unit to monitor company operations and provide expert advice to the government. At the time that this request was made, the Government of Malawi had signed an agreement to enable Shell Exploration B.V. to carry out an airborne geophysical survey of Lake Malawi and the Lower Shire Valley. In anticipation of further exploration and possible petroleum production, an exploration and production bill was being prepared by officials of the Malawi Government.

In February of 1983, when the author, under the auspices of USAID, arrived in Malawi, the role of the petroleum consultant was somewhat revised. By that

time, Shell had discontinued all exploration and had dropped their exclusive option to negociate further exploration rights. In discussion with officials of the Malawi Geological Survey, it was decided that the petroleum consultant should investigate the possibility of small-scale exploration projects involving foreign consultants working in cooperation with the Malawi Geological Survey - such projects would be geophysically oriented toward obtaining further knowledge of Malawi's petroleum geology and the results might attract foreign oil companies to explore further.

The suggested projects that resulted were based on discussions and field reconnaissance surveys with Malawi geologists during a three week period beginning February 1, 1983. The author wishes to thank Dr. Richard Johnson, Chief Geologist and Mr. James C. Chatupa of the Malawi Geological Survey for their helpful explanations of the regional geology, their many useful suggestions, and their assistance in obtaining transportation to visit field sites.

The author spent approximately 2 weeks at the Geological Survey in Zomba reviewing aeromagnetic, seismic, and gravity data. The remaining week's time was split between reconnaissance surveys of the northwestern shore of Lake Malawi and the Lower Shire Valley and report writting in the USAID office in Lilongwe.

PAST EXPLORATION

The history of petroleum exploration in Malawi has been reviewed by Crow (1982) and part of the following is a brief summary from his report. After completion of a regional mapping program by the Malawi Geological Survey in 1970, it was established that sedimentary rocks which could contain petroleum accumulations are present in only two areas - (1) the Lake Malawi area, where lacustrine sediments are presently being deposited and (2) the Lower Shire Valley in the southernmost part of the country. At that time, however, the petroleum industry showed little interest in Malawi because the potential

areas are of small areal extent and the sedimentary sections were thought to be relatively thin and composed of relatively young rocks.

Lake Malawi and the Lower Shire Valley are parts of the East African Rift System which extends from the Red Sea to Mozambique. The rift system in its present form is a Tertiary feature (Crow, 1982) and individual grabens and tilted fault blocks are filled by terrestrial and lacustrine sediments. At the present time, sediments with a high organic carbon content are being deposited in those areas occupied by deep-water lakes with highly anoxic bottom conditions such as Lake Malawi and Lake Tanganyika. In Lake Albert where bitumen seepages occur (Harris and others, 1956) and in Lake Tanganyika where bitumen balls are reportedly washed ashore (Crow, 1982) petroleum apparently has been thermally generated from organic-rich rocks at depth. Lakes Albert and Tanganyika, however, probably are much older geologic features than Lake Malawi.

In 1974 the Institute of Geological Sciences of Great Britain published the results of a gravity survey that covered the land area of Malawi (Andrew, 1974). Later the Superior Oil Company (Soule, 1976) interpreted the gravity data and showed that there were possibly 3 km of sedimentary rock beneath the Lower Shire Valley. The company, however, did not follow up this study.

In 1980, Dumestre (1980) reviewed the petroleum geology of Malawi and concluded that the existence of petroleum accumulations beneath Lake Malawi and the Lower Shire Valley would depend on the presence of thermally mature source rock. The author of the present paper reached the same conclusion and estimates that the possibilities are low that thermally mature source rocks exist beneath Lake Malawi. Geologic interpretations (Crossley and Crow, 1980) suggest that the Lake Malawi graben is a relatively young feature (less the 4 m.y.b.p.). Heat flow measurements in Lake Malawi sediments (Von Herzen and Vacquier, 1967) indicate that terrestrial heat flow in southern

Africa is about average for continents; however, these authors did record higher than average heat flow measurements in the central part of the lake where shallow igneous intrusions are believed to be present. In the Lower Shire Valley, however, Dumestre (1980) speculated that thermally mature source rock, in the form of marine shales of Cretaceous age, might be present at depth in the Shire Trough. These rocks, if they exist, would be a continuation of marine, Upper Cretaceous deposits of the Urema Graben on the east coast of Mozambique where natural gas seeps and natural gas production occur. Although there is structural evidence that the Shire Trough is connected to the Urema Graben there is no direct geologic evidence to indicate that Cretaceous marine rocks are present in the Lower Shire Valley.

In early 1982 interest in Malawi's petroleum potential was stimulated by an announcement by the National Science Foundation of America that a seismic reflection survey indicated a considerable thickness of sedimentary rock beneath Lake Malawi and that shallow cores showed that the lake sediments had a high organic carbon content. The scientific expedition that collected the data was from Duke University, North Carolina and a preliminary report was filed with Malawi, by Rosendahl (1981).

According to Crow and Chatupa (1982), the Duke University seismic data were difficult to interpret because of interference from water-bottom multiples which limited stratigraphic interpretation, in general, to the upper 1 km of sedimentary rock. Water-bottom multiples result from seismic energy that is reflected more than once from the water-sediment interface. In this case these multiples are of higher amplitude than seismic waves reflected from deeper rock layers. On some profiles, however, the sedimentary section appeared to be greater than 2 km thick. Although the seismic survey could not distinguish the age of the sedimentary rocks beneath the lake, it did indicate that a complicated pattern of

faults and folds was present. Some of the larger structures appeared to form potential petroleum traps if cap rock and adequate reservoir rock were present. Seismic-stratigraphic interpretations by Rosendahl (1981) suggest that potential reservoir rock, in the form of deltaic sandstone deposits, is being deposited in areas where large rivers empty into the lake. A reconnaissance survey of the mouth of the South Rukuru River area and a review of seismic records by the author of this report confirm the interpretations of Rosendahl (1981) concerning the probable presence of reservoir rocks.

In 1981, Shell Exploration B. V. explored the Lake Malawi and Lower Shire Valley areas with an aeromagnetic survey. In 1983, the company submitted to the government of Malawi a report of their results which has added much to the knowledge of the general geology of the rock layers buried beneath Lake Malawi. The data indicate that basement rocks lie at relatively shallow depths over much of the surveyed area. However, in the lake area between 10°30'S and 11°30'S latitudes, the sedimentary section is interpreted to be 2.5 to 3.5 km thick over an area of approximately 2,000 km^2. The area of thick sedimentary rock coincides approximately with Lake Malawi's deepest water depths--in excess of 500 m. Similar thicknesses of sedimentary rock may also be present in parts of the Lower Shire Valley although, in this area, the presence of a thick intra-sedimentary layer of volcanic rock precluded accurate depth estimations. Following submittal of their report, Shell dropped their exclusive option to negotiate futher exploration rights. The company apparently felt that the quantities of oil and gas likely to be discovered in the Lake Malawi area did not justify the high expenditures (probably greater than $500,000,000 US) required to test drill in the extreme water depths of Lake Malawi. At the present time, the deepest water depths from which oil is produced is about 330 m; however, the technology

is available to test drill from large ocean-going vessels in water depths in excess of 2,000 m. The extreme high costs of drilling in Lake Malawi would be associated with costs of transporting a drill ship to the land-locked lake.

FUTURE EXPLORATION

The fact that large oil companies, at the present time, essentially are not interested in test drilling leaves Malawi facing a dilemma. On one hand, the import of petroleum, their derivatives, and nitrogenous fertilizer that can be made from natural gas is straining the economy of Malawi. On the other hand, to actually test Malawi's petroleum potential, drilling eventually will have to be done in deep water at extremely high costs. Malawi presently does not have the economic resources to undertake such a project and the possibility of its obtaining grants or loans of sufficient amounts for deep-water drilling is highly unlikely considering that petroleum, if discovered, will probably occur in relatively small quantities. Although low-cost techniques for subsea production in deep water may be available in the next few years, the cost of initial test drilling in deep water is not expected to decline. In fact, if oil prices continue to fall over the next 10 years as predicted by some economists, deep-water drilling worldwide will probably be limited to fields of super-giant size. However, if there is any chance of discovering oil and gas accumulations, Malawi may decide to pursue such possibilities.

In light of the above discussion, it may be in the best interest of Malawi to undertake small-scale geophysical and drilling operations, possibly with the help of foreign aid, in land areas immediately adjacent to Lake Malawi and in the Lower Shire Valley. Although it is unlikely that these operations will actually discover petroleum accumulations, the increase in knowledge gained of the subsurface geology could induce industry to explore further. For instance, if such small-scale projects were to show that sedimentary rocks of Miocene age

underlie Lake Malawi, the area would become much more attractive to industry from a viewpoint of petroleum potential. Similarly, if marine Cretaceous rocks exist in the Lower Shire Valley, the prospects for the occurrence of natural gas would be greatly echanced. Another possibility is that coal measures or black shale facies of the Karroo System may prove to be relatively thick at depth beneath Lake Malawi--such beds could provide rich source rock for the generation of natural gas.

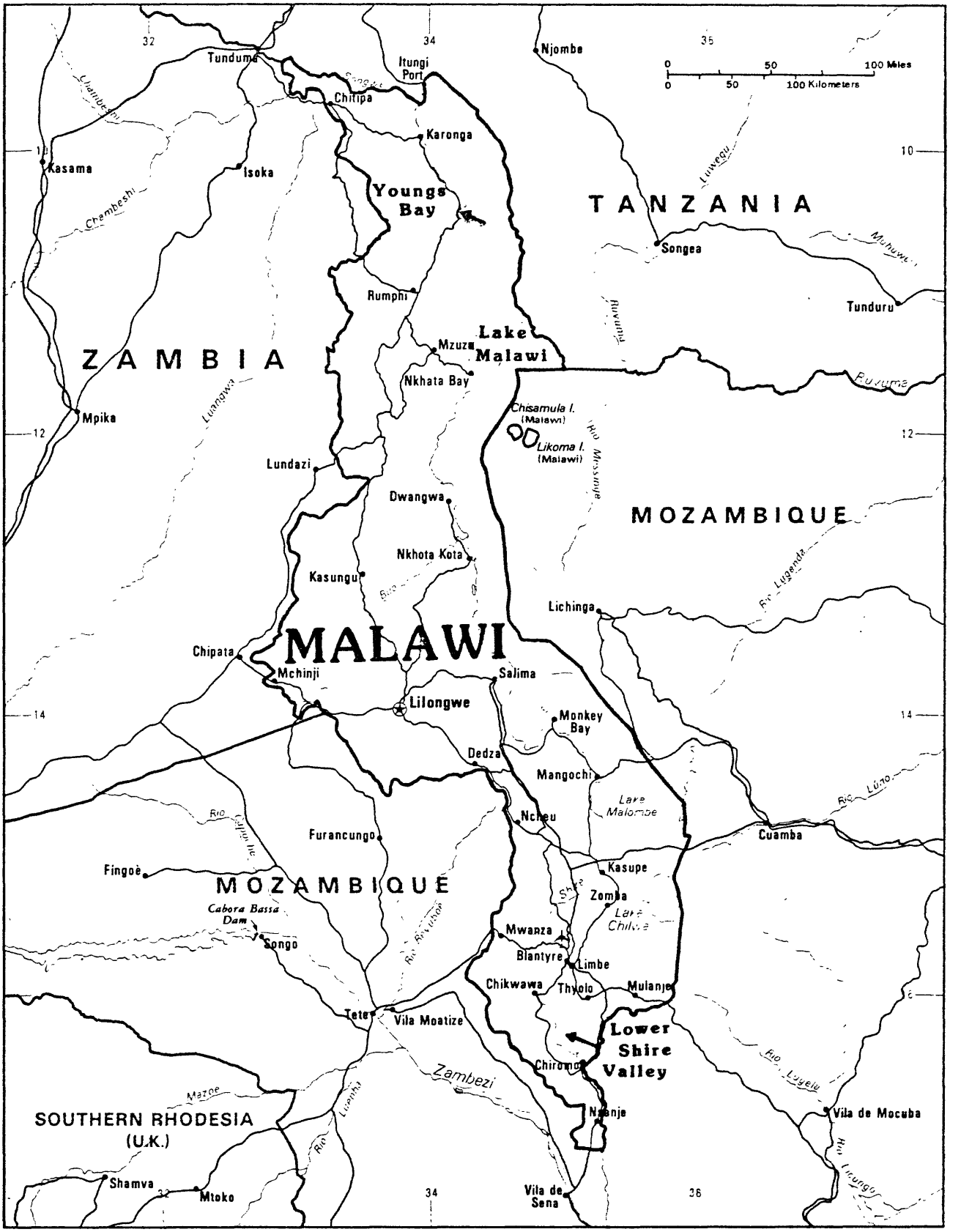
In addition to providing insight into the subsurface geology of local areas, small-scale geophysical operations performed by foreign consultants in cooperation with the Malawi Geological Survey would provide a much needed learning experience for Malawi geologists in the techniques of obtaining and interpreting geophysical data. The Malawi Geological Survey at present has no capabilities for geophysical exploration. Furthermore, judical planning of such surveys could be done so that work would be performed in conjunction with further exploration for coal and water resource studies.

In the following sections of this report, suggested low-cost projects are discussed for the Lake Malawi area and the Lower Shire Valley.

NORTHERN LAKE MALAWI AREA

The results of the aeromagnetic survey flown by Shell indicate that significantly thick sections of sedimentary rock in the Lake Malawi graben are limited to two centers: one north of 11°00'S latitude and other south of 12°00'S latitude. It is reasonable to hypothesize, as was done by Crow and Chatupa (1982), that these depositional centers represent early stages of the graben's history and that they contain the oldest lake sediments. Therefore, if petroleum accumulations underlie Lake Malawi (fig. 1), they more than likely would occur in the vicinity of the depositional centers and it is in these areas that further studies should be concentrated.

Malawi



502727 9-77 (542163)
Lambert Conformal Projection
Standard parallels 6° and 30°
Scale 1 4,400,000

Figure 1.--Map of Malawi and adjacent areas.

Railroad
Road
Airport

In addition to the seismic refraction survey on land, at least one seismic refraction profile should be recorded on the lake where aeromagnetic data indicate the thickest section of sedimentary rocks. Here again the objective should be to map the thickness of post-Karroo and Karroo rocks. This data would greatly supplement the Duke University seismic reflection data which did not differentiate post-Karroo from Karroo rocks. It is suggested that this survey be done in cooperation with future work by the university and possibly corrdinated with heat flow measurements on the lake to locate present-day hot spots in the northern part of the lake.

Thought should be given to coordinating onshore seismic refraction surveys for petroleum purposes with surveys designed for coal exploration in the nearby Karonga area. Such surveys should be designed to measure the dip and changes in thickness of Karroo beds beneath coastal-plain sediments.

Following the geophysical surveys, a hole should be drilled to test post-Karroo rocks. The primary objectives of the drilling should be:

(1) micropaleontological and palynological studies to establish the age of the oldest lacustrine sediments,

(2) temperature measurements to establish the geothermal gradient, and

(3) geochemical analysis of potential source rocks. These analyses can probably be performed on drill cuttings and continuous cores would not be required unless coal measures are penetrated. Thought should be given to obtaining a suite of geophysical logs from the test -- costs, however, may be prohibitive.

LOWER SHIRE VALLEY

The main objectives of further studies in the Lower Shire Valley (fig. 1) should include at least the following: (1) map the top and base of rocks of the Karroo system, (2) map the thickness of Cretaceous sedimentary rocks and determine their environment of deposition (marine, lacustrine, or terrestrial), (3) measure the geothermal gradient, and (4) map the extent of basalt flows.

Basement rocks, Karroo rocks, and post-Karroo rocks more than likely have large differences in velocity so that the top and base of the Karroo system can be mapped by simple seismic refraction techniques. The possibility of mapping the thickness of Cretaceous rocks and basalt flows will depend on measurements made during the actual field surveys.

It is suggested that at least 3 seismic refraction profiles be recorded--2 perpendicular to the regional strike of the graben and one along the graben axis. Good road systems and easy access for cross-country profiles during the dry season would facilitate such profile orientation. In addition velocity measurements should be made on outcrops of the Cretaceous Lupata series, the Karroo system, and the basalt flows. The actual length of profiles and shotpoint locations should be determined as field work progresses.

Following completion and interpretation of the geophysical surveys and depending on the results of the survey, a test hole should be drilled with the objective of testing Cretaceous deposits, determining their environment of deposition, measuring the geothermal temperature gradient, and analysing samples of potential source rock. These analysis probably can be performed on drill cuttings and would not require more expensive coring.

Thought should be given to coordinating all geophysical work done in Lower Shire Valley with deep aquifer studies. Adequate water supply for irrigation in the valley is a serious problem and any knowledge of deep aquifer systems that

might be gained through geophysical work would be of great help to Malawi in formulating water resources programs.

ADDITIONAL WORK

In addition to the geophysical surveys outlined above, it is suggested that measurements of crustal thickness be made across the entire Malawi Graben. Such measurements would involve a single seismic refraction profile oriented approximately east-west across the entire country. Through such measurements, knowledge would be gained of the overall geologic structure of the Malawi Graben and provide information pertaining to past and present thermal regimes. This survey could be performed with the same equipment used in the other seismic refraction surveys.

The geophysical system employed should use geophones independent of cables or wires. This would involve the use of radio controlled geophones or systems with internal clocks that could measure travel times (shotpoint to geophone) with an accuracy of at least 2 milliseconds. Employment of such equipment would facilitate field work and allow access to regions otherwise inaccessible by roads.

In order that Malawi receive maximum benefit from a geophysical program the following suggestions are offered:

(1) Prior to the start of field work, a short course in theory and field techniques of seismic refraction methods should be given to the Malawi Geological Survey.

(2) Provide the opportunity for at least one Malawian geologist to work on data interpretation.

(3) Coordinate geophysical work for petroleum exploration with coal exploration in the northern Lake Malawi area and with water resources studies in the Lower Shire Valley.

(4) Take advantage of Malawian technical expertise as far as logistics, surveying, explosives technicians, labor, etc. when planning geophysical exploration.

(5) The Malawi Geological Survey should obtain field tapes from any future seismic reflection surveys done on the lake. Reprocessing of the data, such as removal of water-bottom multiples, could prove useful in further petroleum exploration.

SUMMARY

A relatively low-cost program aimed at increasing Malawi's knowledge of its petroleum potential should contain the following:

1) Onshore seismic refraction surveys in the Youngs Bay area and the Lower Shire Valley with the objective of mapping at least the top and base of Karroo rocks.

2) A single offshore seismic refraction profile in the northern part of Lake Malawi also to map the top and base of Karroo rocks.

3) An east-west oriented seismic refraction profile across the width of the country to measure crustal thickness.

4) Following interpretation of the geophysical data, it may be decided to drill test holes in the Youngs Bay and Lower Shire Valley areas. The objective of the Youngs Bay drilling would be to document the age of earliest Lake Malawi sedimentation and to measure the geothermal gradient. The objective of the Lower Shire Valley drilling would be to test for the presence of marine Cretaceous rocks.

5) The program, as outlined, should be coordinated with coal exploration in the Karonga area and water resources studies in the Lower Shire Valley. Such small-scale additional surveys, while the equipment is available within the country, would be useful to coal and groundwater studies in these areas.

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