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Malawi Groundwater Project

UK Geophysicist: Summary of work done and results
14 October - 15 November 1980

by

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MALAWI GROUNDWATER PROJECT : U.K. GEOPHYSICIST.

Summary of work done and results, 14th October - 15th November 1980.

1. Itinerary:

13 October	arrived at Lilongwe from London
14 Oct. - 1 Nov.	based in Lilongwe, fieldwork at Chitedze and the new International airport site.
2 - 8 November	fieldwork near Ngabu, Lower Shire Valley.
9 -15 November	in Lilongwe.

2. Objectives:

The aims of the visit were:

(a) to review the geophysical methods currently in use for borehole siting, with regard to field procedure and data interpretation.

(b) to assess the value of a variety of different methods by undertaking trial surveys in selected areas representative of the main types of environment found in Malawi.

(c) to review the existing data.

(d) to make recommendations for the future use of geophysics in locating groundwater supplies.

3. Present Procedures:

The resistivity methods, using techniques developed by Cooper in the 1950's has formed an integral part of borehole siting for the past 20 years. Constant separation traverses(CST)- with a Wenner electrode configuration at 75ft spacing - and expanding arrays -with the current electrodes fixed 100ft apart and the potential electrodes beyond them at set distances up to 200ft, giving a maximum array length of 500ft -provide information on variations in conductivity. In 'hard-rock' areas, where a highly variable thickness of colluvium overlies a heterogenous basement complex, resistivity lows from the CST are considered favourable, while in alluvial areas-beside Lake Malawi and in the Shire Valley-low values are usually associated with clays and zones of higher resistivity taken to indicate more suitable prospects. In many cases siting is based on one or two CST with an expanding array centred at an anomalous zone to ensure that apparent resistivities lie within an appropriate range.

Cooper derived 2-layer master curves for his expanding array configuration to provide a means of interpreting depths and layer resistivities: Hummel's principle, assumming a third layer of comparatively very high resistivity, allows an interpretation of the 3 layer case with an intermediate layer of lower resistivity (i.e for an H type Field curve) which might be expected in the simple situation where weathered material lies between the surface layer and bedrock.

Details of expanding array data interpretation and drilling information are archived. The results are filed sequentially for each siting geologist without regard to geographic location so that it is a laborious process to review data from particular areas. A card system summarizing the information for each site and including any resistivity interpretation is now being introduced, but this does not guarantee the reliability of the data transcribed.

4. Comments on existing procedures:

As a matter of principle it would seem desirable to adopt the SI system of units as the basis for any measurements. This would cause a degree of inconvenience in that the surveying chains are 100ft and people are accustomed to working in feet; similarly the use of ohm - metres rather than kilohm - centimetres, involving a factor x 10, would require some mental adjustment.

The Cooper array and its interpretation while soundly based within its prescribed limitations must now be regarded as outdated. Its advantages in terms of simplicity in field operation and in providing relating large signals - an important consideration in areas of high conductivity when only low power transmitters are available - are more than offset by the restricted potential for using more comprehensive interpretation techniques, its limited sensitivity for a given current electrode spacing and the lack of indication of lateral variations. While better defination could be obtained by taking measurements at different current electrode spacings, this would increase the time required proportionately: in practise it is difficult to find examples in the records of a value other than 100ft being tried even between quiete different areas, although it should be related spacifically to the depth at which the horizon of particular interest is expected.

Either a Schlumberger or Wenner configuration, for which comprehensive sets of 3 - layer master curves are available, should be used: the former would normally be preferred where low signal strengths are not a problem, but in view of high contact resistances, high conductivities and the low powered equipment available at present (i.e Meggars and Terrameters) the Wenner array is more appropriate here.

Regardless of the array adopted every effort should be made to ensure that the field data are reliable and where necessary interpretable. Thus some care is required to minimize contact resistances, particularly at wider separations; potential electrodes should normally be the inner pair to reduce the effects of spontaneous potential and telluric noise at the receiver; current wires should be kept apart from potential wires and electrodes to reduce compling; expanding arrays sited on narrow zones of anomalous conductivity cannot be interpreted on the basis of uniform horizontal layers - orthogonally oriented arrays should indicate the presence of marked lateral anisotropy.

Information given by a single CST can be misleading in that there is little indication of the depth at which any anomalies might originate: the idea that the depth of investigation is equivalent to be electrode spacing almost invariably overestimates its effectiveness, sometimes grossly. Changes in the character and thickness of the near-surface layers are often significant. CST at different electrode separations or expanding arrays are required for more reliable interprietations; preliminary expanding array data should be obtained to indicate suitable spacings for subsequent reconnaissance CST in a given area.

5. Assessment of Resistivity Data:

The effectiveness of the resistivity method for borehole siting here tends to be regarded as axioimatic. The fact that the resistivity method is almost invariably used, combined with a low threshold, less than 0.3l/s, for defining the yield from a successful borehole leads to a circular argument when considering its usefulness in that there is evidence that yields of this magnitude could probably be obtained in many areas by more empirical siting procedure: it is less obvious that the resistivity method leads to significantly higher yields when compared against improved well designs.

Comparisons of resistivity interpretations with drilling information have failed to bring out any systematic relations either with borehole yields or lithology although in particular cases a close correspondence is seen.

This is due in part to the limitations of the interpretation method and also to the problems arising from the nature of the environment. The bedrock itself is not homogeneous and this variability is reflected in the overlying weathered material. The presence of graphitic formations will have a significant effect on the resistivity data, as will the development of laterite within the overburden; lateral variations over the length of the array will distart expanding array data, and their interpretation.

It is important to consider the electrical properties of the colluvium and bedrock in relation to the occurrence of groundwater and aquifers. In plateau areas where the colluvial cover and weathered bedrock are thicker than 15m it seems unlikely that zones of higher permeability would be large enough to be resolved by resistivity methods. In alluvial areas the existing data indicates that the depth of investigation of resistivity surveys has been too shallow to delineate potential aquifers; the siting procedure has almost certainly been based on variations in clay/sand content at higher levels which are unlikely to reflect the disposition of permeable horizons at depth. Borehole lithology shows that the alluvium is made up of a sequence of relatively thin bands of varying clay content which will not be resolved by resistivity data. There is evidence from the work of O'Conner (1975) that layer resistivities can be used to outline areas where the overall sand content is higer and so more farourable for drilling. Data are limited from the escarpment where siting is especially difficult. Depths to bedrock are shallower and the potential of developing groundwater from the weathered zone is much reduced in terms of both storage and extraction so that the location of fracture zones is important. Again the main problem for geophysical methods arises from the variability of the bedrock itself and each area can only be considered individually in the light of the available information. It is quite common for the bedrock to be more conductive than the colluvium - probably a result of the advanced state of oxidation and leaching within the weathered material - and CST data need to be carefully controlled by expanding arrays and borehole information where possible if they are to be interpreted meaningfully. As a general consideration it should be remembered that a thin intermediate layer of relatively high resistivity within about 10m of the surface will affect apparent resistivity values at much greater electrode separations and tend to suppress the response from any potential aquifer between it and bedrock.

6. Results from Fieldwork:

Induced polarization/resistivity, VLF electromagnetic, magnetic and hammer seismic instruments were brought to Malawi on a temporary basis as part of the assignment in order to assess their usefulness in this environment. In the limited time available the objective was to try out the different methods rather than to take up any specific siting problems: data have been obtained from two areas of "typical" plateau country near Lilongwe and from hard rock and alluvial areas of the Lower Shire.

A. Induced polarization/resistivity

Resistivity data were collected using the Schlumberger array with maximum current electrode separations of 200m on the plateau and 1000m in the Shire Valley: in neither area was it possible to obtain clear evidence of a resistivity basement i.e with a significantly higher resistivity that produced an expanding array curve slope of about 1.

At Chitedze, near Lilongwe, where a continuing drilling programme provides lithological control, the curves showed near-surface layers of variable thickness and resistivity (relatively high-possibly lateritic) underlain by an intermediate layer of 50-100 ohm-m to a depth of 20m-50m. Interpretation of the lowest interface was subject to large errors as the final turning point and resistivity were ill-defined: orthogonal arrays rarely agreed at the larger separations indicating lateral variations and there was a degree of consistency between sites suggested anisotropy within dipping bedrock formations. Although in order of magnitude agreement with the drilling information the results could not be regarded as diagnostic.

In the Shire Valley conductivities over the alluvial deposits are high but even here the final part of the curves rose with some reluctance from apparent resistivities of below 3 ohm. metres. A projected deep drilling site almost certainly lies in an area of predominantly low permeability, saline, clay-rich deposits to a depth of about 200-250m with the only obvious possibility of fresh water in more sandy near surface material to a maximum of 20m below surface (NB the effect of subordinate bands of sand which might be present at depth would be suppressed on the resistivity curve). The lowest interface provides an estimate for the minimum thickness of the alluvium but as none of the rock types -Karoo basalts and sandstones, or basement complex-expected to underlie the alluvium had a distinctive resistivity when measured near surface the nature of the bedrock cannot be inferred. IP values are generally low as might be expected: highest values should be given by thin clay layers or sand/clay mixtures, lower readings from thick clay layers and little or no response from clean sands and gravels. (O'Canner's data suggested that some variations could be detected but they were of little use for defining aquifers.) Analysis of the decay curve shape for a Wenner array spacing of 67m and a cycle time of 8 secs did not show excessive coupling effects and it should be possible to obtain reliable data for delay times greater than 300ms if signal strengths are large enough.

B. VLF Electromagnetic

The main application of this technique would be to locating shallow fracture zones in escarpment areas. It is hoped that such an area will be visited in the next month when the method can be tested more thoroughly but trials locally indicated that none of the standard transmitting stations provided a strong signal. Approximate values could be obtained from the US Maine station but even these signals deteriorate rapidly after about 0900 hours.

C. Magnetic

Members of the ilmenite-magnetite series are mentioned as accessory minerals in varying degree in descriptions of many of the basement complex rocks so that magnetic traverses could help in mapping local variations in lithology, structural features and provide depth estimates. Surveys at Chitedze showed a complex anomaly pattern with a range of about 100nT. Interference from wire fences and power lines and instrumental problems meant that the noise level was higher than would be expected elsewhere but interesting features were brought out which appeared to relate to the foliation of the bedrock and cross-cutting joint trends. The extent to which magnetite concentrations in the colluvium are altered by the weathering process is uncertain.

Traverses near the new Lilongwe airport across a possible NNE fracture zone or joint controlled valley picked out from aerial photographs showed a broad positive anomaly which swung away from the head of the valley on a more easterly bearing and so could not be attributed solely to residual magnetite concentration. It is apparent that magnetic data provide another means of mapping sub-surface features which could be used to complement resistivity surveys. When airborne magnetic coverage of the country is available the context and significance of the anomalies should be more apparent.

D. Seismic Refraction

As the water yield tends to be linked to the depth of weathering a definitive means of locating bedrock would be helpful for which seismic refraction is the obvious method to use providing the logistical problems are not too great. With this in mind an enhancement seismograph with a hammer as energy source was tested to see if arrivals from the bedrock could be detected. In practise energy transmission through the colluvium at Chitedze proved to be poor and although marked changes in the near surface layers were apparent with velocities ranging from 0.5km/s to 1.5km/s the bedrock refractor was too deep to be mapped with maximum shot point to geophone separations of less than 60m-100m. The bedrock interface itself is probably not well defined and there was evidence of energy loss within thin near-surface bands (? lateritic) of higher than average velocity. In better circumstances in the Lower Shire good records were obtained over a distance of 150m although it may have been a second arrival that was detected.

7. Provisional Conclusions:

A. the use of resistivity methods at present is essentially qualitative and their principal value lies in rejecting areas where fresh rock may be close to the surface: any positive contribution to locating zones of better yield and specific capacity is less apparent

B. it seems likely that for rural supplies in plateau areas where depths to bedrock exceed about 15m resistivity surveys are superfluous as weathered zone aquifer is essentially continuous and in any case the mapped conductivity variations cannot easily be equated with aquifer properties;

C. resistivity surveys should be concentrated on specific problems and not undertaken for routine borehole siting unless the occurrance of shallow bedrock- which cannot reasonably be avoided by a visual inspection- is suspected;

D. before siting on the basis of CST data it has to be possible to identify anomalies which relate to the aquifer (ie usually in terms of depth to hard bedrock) and to differentiate these from effects of changes in near-surface or bedrock conductivities; even in the simplest 2-layer case resistivity values from two electrode spacings are needed to define the bedrock profile; the electrode spacings used have to be sensitive to changes in near-surface resistivities and bedrock depth and should be chosen on the basis of expanding array data using the same electrode configuration i.e. a Wenner array; the possibility that the bedrock itself may be a conductive formation has also to be considered before siting on resistivity lows in preference to zones of intermediate value;

E. existing data within say 10km of anew site should be reviewed to give an indication of the local environment; in order for this to be practical the existing files would have to be recorganized on a more logical basis to provide easy access; the best way to do this would be to use grid references - putting the kilometres reference on each data sheet and grouping the sheets in blocks of 10x10km squares;

F. present siting techniques in alluvial areas seem to be unrelated to aquifer conditions; to be of any use it, is necessary that the depth of investigation is at least as great as that of the potential aquifer - which does not seem to have been the case - as it is unlikely that the presence of clay or sand zones closer to the surface can be used as an indicator; where the sequence is finely banded or poorly sorted the average resistivity probably reflects the proportion of clay and hence the likely permeability and salinity; whether or not a discrete sand/gravel bed can be picked out depends upon its transverse resistence in relation to its depth of burial;

G. where detailed surveys are required for high yields or in difficult areas an integrated approach should be used and in this connection there seems to be a case for acquiring a proton magnetometer and a more powerful resistivity set to give greater depth penetration and flexibility of approach; if possible exploratory drilling should be regarded as a part of the survey so that an interim assessment of the data can be made and the programme adjusted to obtain the maximum relevant information; - for example to avoid following up a fracture zone infilled with clays; the objective of the survey should also be clearly defined and electrode spacings, line directions and separations chosen accordingly - the same parameters are not suited to locating both near-surface fractures and deeply buried gravel beds; narrow fractures below colluvium are almost certainly undetectable;

H. a more positive effort should be made to review the geophysical surveys in terms of drilling results- which may be delayed by several months - in order that problem areas can be isolated, interpretations reassessed and statistics assembled on the range of resistivities attributable to different localities and lithological units as a guide to future surveys;

I. the possibilities for borehole logging are limited by the drilling techniques which result in casing being used throughout most of the holes;

J. the application of geophysics in the future should be dependent upon local policy; there are at present no Malawian geophysicists working here although the potential fields of study in groundwater, exploration for minerals and other natural resources, problems in engineering geology and more academic structural geology would seem to exist: specific problems could be dealt with by short term consultants but a longer term advisory visit should be considered only in the context of establishing local expertize in the form of a small autonomous unit which would provide assistance on all questions related to geophysics.

8. Future Programme:

Fieldwork will be continued in the plateau, escarpment and lakeshore areas, and the assessment of existing data completed. About 3 weeks - from the middle of December - will be spent at the Geological Survey, Zomba to review the available information and to consider future prospects for geophysical work. A provisional report covering groundwater aspects should be completed before the end of the visit.

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