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ROLE OF BOREHOLE GEOPHYSICS IN MINERAL RESOURCES EXPLORATION IN AFRICA

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ABSTRACT

Throughout Africa numerous wells are drilled each year for domestic water supplies and irrigation purposes. The application of borehole geophysics, in which the properties of the penetrated strata are measured, could be important in the location of aquifers and in the acquisition of water quality data. In addition, borehole measurements could provide useful information on additional mineral resources such as petroleum, coal, uranium, sulphide ores, sulphur and evaporites. It is estimated that information from a total of about 5,000 Km, of borehole length is lost each year through the lack of recording of well data in Africa.

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INTRODUCTION

The term "minerals" in this paper will include metallic minerals, petroleum, water and industrial minerals (such as sulphur and phosphates).

The present knowledge of mineral resources in the continent of Africa is patchy, more so in some countries than in others. Although, the mineral wealth of Africa is unevenly distributed, and some areas are likely to remain barren despite detailed investigations, Africa should aim at obtaining a complete assessment of its mineral wealth. A lot has been written and said of the great mineral wealth of the continent. All this means nothing without quantitative evaluation of the resources. The task requires the co-operation of all the African countries, and utilization of the various exploration tools. Geological mapping has provided most of the information regarding the deposits close to the surface. Many mines have been opened based mainly on surface information. However, most of these deposits are rapidly becoming depleted. At the same time fewer surficial deposits are being discovered; whereas industrialization in most African countries is increasing. A need, therefore, arises to identify and evaluate those mineral deposits that lie at depth. The discovery of such deposits will depend on techniques such as geophysics and remote sensing.

Apart from the need to identify and evaluate mineral resources, geophysics can be useful in providing data on water quality. Many countries in Africa such as Nigeria, Zambia and Zimbabwe are geared toward promoting agriculture. Some of the farming projects in such countries will be heavily dependent on the use of big quantities of fertilizers. These chemicals find their way into the groundwater system (El-Ashry, 1980), and as the agricultural industries expand, groundwater pollution may become a big problem. Through the use of well-logging techniques, the effects of these chemicals can be monitored and early precautions taken before the groundwater supplies become "poisoned", thereby reducing the vital national domestic water supplies.

This paper is on the role that borehole geophysics can play in the mineral resources exploration programs in the African countiies.

Borehole geophysics is defined as the application of any or all available borehole measurements to determine properties of interest of the in situ materials surrounding the borehole. Such material may be petroleum, gas, water or hard minerals. Other names used in place of borehole geophysics are: Formation Evaluation, Well Logging and Electric Logging. Additional information can be obtained by geochemical studies of material recovered from the borehole including both rock fragments and groundwater.

WELL INFORMATION STRATEGY

A great deal of information about the mineral resources of Africa can be obtained from the numerous wells that have been drilled either for water or for oil exploration. The majority of well-logging activities in the world at present are directed to the search for oil and gas. Logging techniques have advanced in recent years as a result of the petroleum industry. The industry geared toward the search for mineral resources such as copper, uranium, phosphates, and water, should take advantage of the advances made in well-logging technology. Africa, in particular, can benefit from the use of borehole geophysics.

Drill holes are the only means of direct access to the subsurface and drilling is expensive. Maximum benefit should be obtained from drill holes in terms of maximum information per meter of borehole. Sampling of the rocks and fluids penetrated and geophysical well logging are the only ways information can be derived from these holes. Valid well logs, correctly interpreted, can be used to reduce future drilling costs (in case of groundwater) by guiding the location, proper drilling, and construction of test holes and production or disposal wells. Well logging enables the vertical and horizontal extrapolation of data obtained from drill holes.

Each year many more wells are drilled for water than for petroleum. Although most of the water wells are shallow, each is a valuable sample of the geologic environment, and logs of these holes can aid in the definition and development of water supplies, sand and gravel deposits, other nonmetallic and metallic minerals deposits, petroleum, and waste storage or disposal and artificial-recharge sites and can provide engineering data necessary for construction (Keys, et al., 1976).

Literally thousands of wells have been drilled on the continent of Africa for groundwater supplies. Information from the numerous water wells drilled every year could be utilized. At present most of this data is lost because of the following reasons:

1. Poor drilling techniques

2. Absence of geophysical or geological measurement made in the wells.
3. Lack of government control.

A great deal of valuable information about the mineral wealth of Africa is lost every day because of poor drilling techniques. The cheapest and most widely used drilling method for groundwater supply is that of percussion. A well is drilled by the continuous pounding action of a drilling bit. Rock samples come out of the hole in the form of small chips which are not preserved for further study.

A second factor that prevents the discovery of mineral resources from wells drilled for the purpose of water is the insufficient knowledge of the drilling crew, in the fields of geology and geophysics. Percussion drilling machines are in most cases operated by personnel with education standard below high school or secondary school. This is no problem if the only aim is to obtain water from the well. However, this crew is incapable of identifying a mineralized zone, were it to be encountered, during a drilling exercise.

Most land in Africa is owned and controlled by the African governments. However, most drilling operations are performed without the knowledge and supervision of the government. Mineral resources of a nation can never be assessed adequately under these conditions.

The author is offering in this paper some suggestions that may help in providing solutions to some of the issues raised. Because most land in Africa is owned and controlled by the respective governments, land utilization and control should be easy, in principle. When any hole, deeper than about 10 meters, is drilled into the ground, some government agency such as the geological survey, or water department should be notified. The location of the well, its maximum depth, and water yield (if any), should be recorded. The location and depth should be placed on a map. Rock samples taken about every 3 meters should be presented to the geological survey or universities for analysis. Wherever possible, permanent crews of geologists and geophysicists should be available at drilling sites to collect well information. A desirable situation would be to have a number of well logging crews that would be able to run well logs before installation of water pumps or before any well is completed.

It is recommended that well logs be run in all existing wells in a country, wherever possible. Similarly, good pump tests should be carried out. All this information would then be placed in some "Data Bank".

The information in the data bank should be occassionally updated. Once in a while, maps should be prepared on the lithology, aquifer characteristics and any mineral resources discovered, in an area or region. The maps and any other relevant data would then be presented to a panel of geologists, geophysicists and geochemists for interpretation.

Hydrological and mineral maps from the various regions would then be compiled. This would then be extended for the entire continent as data become available.

It is further suggested to evolve a standard set of criteria to be recorded at a borehole as well as the standardisation of the emerging nomenclature to facilitate communication among African geoscientists engaged in the field of mineral resources.

CASE HISTORY

In 1974, the author was involved, together with Dr. Topfer (now of TAGS Limited), in about 120 water sitings in Zambia on behalf of the University of Zambia (Mdala, 1976). All of the sites were located using geophysical techniques. The sites were drilled to an average depth of 67 meters (200 feet). Few of the wells were contracted by a mining company. Some of the wells were for the water supply of townships and private companies. The majority of the 120 boreholes were for farmers. No geophysical well-logging was performed on any of these wells (to the knowledge of the author).

This case history indicates that 8,040 meters (24,120 feet) of borehole information was lost. A total of 826 water wells were sited and drilled by the Water Department and private companies in 1974 in Zambia (Water Affairs Dept., Personal Comm., 1980). It is most unlikely that any stratigraphic studies were made in any of the wells. Again by taking 67 meters (200 feet) as the average depth, a total 55,342 meters (166,026 feet) were theoretically available for geophysical and geological logging in 1974.

We now extend this example to the entire African continent. Drilling activities for water in other African countries may vary only slightly from that of Zambia. In Kenya, for example, where much groundwater is recovered from old land surfaces intercalated between sheet flows of volcanic rocks the depth to water is often the range between 100 meters and 133 meters (Lambert, 1965). We let 100 meters be the average depth of water wells. Assume that every African country drilled about 1000 wells, for water supply in 1974. This means that a total of 50,000 wells were drilled in about 50 countries of Africa. That is, in 1974, 5 million meters (15×10^6 feet) or 5,000 kilometers, in depth, of well information were available for analysis in principle.

TYPES OF LOG INFORMATION

We shall now look at the type of drill hole information that can be obtained. A major portion of well logging activities are directed towards exploration and exploitation for oil and gas. Logs are run to estimate the volume of recoverable hydrocarbon in a well. This is done by determining the hydrocarbon saturation, the porosity of the formation and the thicknesses of the producing zones--"pay zones," as they are commonly called. Although petroleum contributes a major share of well logging activities, continued interest in uranium exploration has also boosted borehole logging (Shepard, et al., 1980)

A mumber of logging techniques are employed. These include:

(a) Electrical logging
(b) Acoustic logging
(c) Radioactive logging
(d) Cores
(e) Water samples

LOGGING EQUIPMENT

The variety of geophysical logging equipment is very large. Fortunately, any well logging instrument--from the single conductor water-well unit to the seven-conductor oil-well unit--can be divided into the same basic components. Any basic measuring system consists of a sensor, signal conditioners and recorders or indicators. The sensor is contained in a watertight probe or sonde, which generally receives power from the surface and transmits a signal to the surface through logging cable. The cable also serves to position the probe in the well by means of a winch. Controls are used for regulating logging speed, power to surface and down-hole electronics, signal conditioning and recorder respons .

To derive the maximum amount of accurate data from logging equipment, operators must understand basic log interpretation, and log analysts must understand the principles of logging-equipment operation (Keys, et al., 1976). The operator should be able to recognize equipment malfunction from a log in the field, where it is often possible to correct the problem and rerun a log If the analyst is familiar with logging equipment and procedures, he will not make lithologic interpretations of instrumental problems shown on the logs.

WELL-LOGGING APPLICATIONS IN PETROLEUM ENGINEERING

Borehole geophysics is employed in petroleum exploration and exploitation. Applications in petroleum engineering include.

1. Estimation of the volume of hydrocarbon in place.
2. How much petroleum and gas can be recovered.
3. Identification of the geological environment of deposition.
4. Rock classification

5. Locating reservoir fluid contact.
6. Water salinity determination.
7. Detection of fractures.
8. Determination of porosity and pore size distribution.

The above information is obtained from such measurements as cores, acoustic logs, radioactivity logs, SP-resistivity logs and bore-hole fluid logs.

The majority of formation evaluation programs for petroleum exploration and exploitation are designed to determine the volume of recoverable hydrocarbons (Pickett, 1978). The recoverable hydrocarbons are related to the following parameters: the thickness of the producing zones, recovery factor (that fraction of the total hydrocarbons that can be recovered economically), hydrocarbon saturation, drainage area and porosity.

Of the five parameters, hydrocarbon saturation is the most important single quantity. This is partly due to the fact that hydrocarbon saturation is closely associated with the ability of the rock to transmit fluids. When water and hydrocarbons are present simultaneously in a pore system, there exists a "cutoff" saturation. If the hydrocarbon saturation approaches this "critical" value, the ability of the rock to transmit hydrocarbons drops rapidly and the ability to transmit water increases rapidly.

ELECTRIC LOGS IN FRESH WATER WELLS

A great deal of literature in the field of borehole geophysics has been directed mostly to the use of electric logs in the search for oil and gas. Little has been published on interpretation of logs run in wells drilled for fresh water. The search for suitable sources of fresh water is very important, especially in Africa. Water problems exist in some countries in the North, East, West and Southern Africa. Only countries along the equator have adequate surface water supplies to meet the water demand for public use, irrigation and for industrial needs. In most African countries, groundwater supply is required either to supplement or meet the national needs.

In some areas, water for public use is required to have a maximum total dissolved solids (TDS) of 500 parts per million (ppm), and a maximum chloride content (Cl) of 250 ppm. The upper limit for dissolved solids in irrigation and industrial waters are determined by the crops to be irrigated or by the particular industrial needs.

An electric log known as the Self Potential (SP) curve generally provides best logging approach to determination of water quality.

The relationships between SP and water activity, resistivity and concentration are well established for oil field brines. However, these oil field relationships do not apply entirely to fresh water work (Alger, 1971). Whereas in oil-field waters the dissolved salts are predominated by sodium chloride (NaCl), divalent cations in dilute formaiion water solutions have a much stronger effect on the SP than does Na^+. Thus when Ca^{++} or Mg^{++} concentrations in formation water are significant, they affect the SP as though the water were more salty than indicated by its resistivity. In many fresh waters the predominant anion is bicarbonate (HCO_3^-). In such a case, the water resistivity (Rw) of an $NaHCO_3$ solution is 1.75 times greater than Rw of the NaCl solution having the same Na^+ concentration. The correct water resistivity (Rw) is obtained by measurement of formation resistivity (Ro), and dividing it by a formation resistivity factor (F). Rw can also be obtained from the SP curve.

The value of Rw, whether determined through SP or resistivity measurements is used to evaluate water quality. The relative ion assemblage is predictable on a local basis. Thus, empirical studies permit determination of both TDS and Cl content from computed values of Rw.

Permeability information can also be obtained from well data. There is a general progression of both permeability and formation factor with grain size. The relationship between permeability and formation factor is the reverse of that used in oil field work. For fresh water investigation, the permeability is directly proportional to the formation factor.

All of the sand characteristics desirable for water wells cause an increase in formation resistivity. The water quality (TDS) is related to Rw, the higher the value of Rw, the better is the water.

BOREHOLE GEOPHYSICS IN URANIUM EXPLORATION

Uranium, like petroleum, is one of the energy mineral resources that have received great attention in recent years. The incident at the Three-Mile Island in United States of America (1979), however, has had some "cooling" efffect on business of nuclear power plants.

Though endowed with substantial uranium resources, Africa (except for South Africa) does not utilize this resource for domestic consumption and it is not even clear which direction the African countries will take on the use of uranium. Few, if any, countries in Africa have any form of national policies directed toward the development of nuclear technology. Whether nuclear technology will be adopted or not, each nation in Africa needs to have an inventory of its uranium resources, so that they can fall on it when the need arises. This section of the paper describes how borehole geophysics can be utilized in a uranium assessment program.

The radio-metric technique most useful in the detection and assessment of radioelement resources is gamma-ray spectrometry. It involves the detection of gamma rays of varying energy by scintillation or solid-state detectors, collection, sorting, and storage of energy spectra by single or multi-channel pulse-height analyzers, and treatment of the spectral data, usually by computers, to yield abundances of the individual radioelements. Downhole radiometric logging is quicker and less expensive than coring and subsequent laboratory analysis (Killeen, et al., 1976, Wollenburg, 1977). Radiometric logging utilizes a geiger tube or Sodium Iodide detector system to furnish gross-gamm counting rates. The system is suspended on a cable which is attached to a winch and a depth counter. It is preferred that the hole be uncased for logging, and free of drilling mud or other contaminants. Where significant anomalies are solely due to uranium, measurements of total gamma activity are adequate to define the abundance of the radioelement. One must assume that secular equilibrium exists between parent uranium and its daughters. With proper calibrations, based on analyses of cores from drill holes, abundances of equivalent uranium or uranium oxide can be calculated from gross-gamma count rates. Furthermore, great progress is being made in the direct determination of uranium by delayed neutron borehole logging (Wormald, et al., 1976).

BOREHOLE GEOPHYSICS IN COAL IDENTIFICATION

Coal is a source of energy whose importance may increase with the advancement of synthetic fuel technology. Because the continent of Africa has a great deal of old rocks, coal resources are not expected to be abundant, as say, in the USA. Many sedimentary basins, however, are present in the continent which should be explored for coal deposits. This is especially important to those countries in Africa which have no known reserves of petroleum and gas.

Coal seams can be identified by a high resistivity anomaly. On an electrical survey thin coal beds can cause high resistivity readings. Occassionally an SP anomaly develops in a coal bed so that it resembles a good oil or gas pay zone (Tixier, et al., 1971).

Sonic logs can also be useful in coal identification. The logs exhibit high values of transit time opposite coal beds. The greater the compaction, the lower is the transit time value--other factors being equal.

Density logs also provide a good method for coal identification. The densities of coal range from 1.4 to 1.8 gm/cc for anthracite 1.2 to 1.5 gm/cc for bituminous, and 0.7 to 1.5 gm/cc for lignite. Because all mineral impurities of significance have appreciably higher densities than hydrocarbon coal, a density log provides an estimation of the variations in ash content for any given coal seam.

IDENTIFICATION FOR SULPHUR AND EVAPORITES

The production and use of industrial minerals within any region reflect better than those of any other mineral commodity the standards of living of that region (Money, 1980). The standards of living are improving as the African countries are geared towards industrialization. There should be a similar need to explore and exploit local industrial minerals to meet present and future demands. Furthermore, increasing energy costs will have a prohibitive effect on the importation of industrial minerals by the African countries from overseas.

Sulphur has long been commercially valuable. The demand for it continues to grow. For example, world demand rose about 5% over the record levels of 1978 (Baker, 1980). Most sulphur is produced from wells, and usually occurs in the interstices of other rock minerals. It seldom represents as much as half the bulk volume of the formation.

Two properties of sulphur are particularly useful: the sonic interval transit time is exceptionally large; the density is low (Tixier, et al., 1971). Thus either sonic or density log measurements offer a means of evaluating sulphur deposits.

Well logging techniques are well suited to locating and identifying commercial evaporite deposits. They are characterized by very high values on the resistivity logs. Furthermore, because some evaporites are quite soluble in water-base drilling fluids and lead to enlarged holes, the caliper is an important adjunct in the logging program. The evaporites most commonly encountered are halite (rock salt), anhydrite and gypsum. Another important evaporite mineral is trona. Of the radioactive evaporites, potash minerals are the most sought for evaporites. The radioactivity is due to an isotope (K^{40}) which comprises a constant fraction of the total amount of naturally occurring potassium. Thus the gamma ray log is an important tool in the potassium prospecting program.

APPLICATION OF BOREHOLE GEOPHYSICS TO ORE BODIES

Borehole geophysics has an application in the exploration for metallic orebodies such as sulphides. By utilizing electromagnetic and resistivity methods, it is possible to detect the presence of massive sulphides in a well.

The electromagnetic method consist of either a vertical or horizontal loop transmitter coil and detector coil. A detector coil is lowered into the borehole and readings are taken at different depths. At each depth, the transmitter coil is tilted until a minimum reading is obtained on a voltmeter connected to the detector coil (Salt, 1966). The dip of the transmitter is measured and the minimum voltage is recorded. The readings on the voltmeter are proportional to the out-of-phase component of the induced field. A plot of the voltmeter readings versus depth is made. Another plot consists of the tilt angle versus depth. Any tilt anomaly on the dip angle curves and the high out-of-phase component are indicative of the presence of a conducting mass. On the resistivity log, a low value would also be indicative of a conducting mass.

CONCLUSION

Borehole geophysics as described here has a very important role to play in the exploration for mineral resources in Africa. By applying the various well logging techniques in present and future borehole drillings on the continent, a great deal of information could be obtained regarding mineral resources, such as petroleum, water, coal, uranium, sulphide ores, sulphur and evaporites.

REFERENCE

Alger, R. P., 1971, Interpretation of Electric Logs in Fresh Water Wells in Unconsolidated Formation. Society of Petroleum Engineers of AIME, No. 1, p. 246-270.

Baker, J. M. and Cochran, D. E., 1980, Sulphur: Mining Engineering, May, 1980, p. 585.

El-Ashry, N. T., 1980, Ground-water Salinity Problems Related to Irrigation in the Colorado River Basin. Groundwater Vol. 18, No. 1.

Keys, W. S. and MacCary, L. M., 1976, Application of Borehole Geophysics to Water-Resources Investigations: Techniques of Water-Resources Investigations of the United States Geological Survey, Book 2, Chapter El.

Killeen, P. G., Bristow, Q., 1976. Uranium Exploration by Borehole Gamma-ray Spectrometry Using Off-the-Shelf Instrumentation: Proceedings of a Symposium, Vienna, 29 March - 2 April, 1976 (IAEA), p. 393-414.

Lambert, H. H. J., 1965, The Groundwater Resources of Zambia: Republic of Zambia, Ministry of Lands and Natural Resources, Department of Water Affairs.

Mdala, C., 1976, Geophysical Exploration for Groundwater in Limestone Aquifers of the Republic of Zambia: M.Sc. thesis, University of Zambia.

Money, N. J., 1980, A Review of Exploration Philosophy for Industrial, Precious and Gem Minerals in Zambia: Symposium on Industrial Minerals, precious metals and gems (26 April, 1980); Geological Society of Zambia.

Pickett, G. R., 1978, Formation Evaluation. Colorado School of Mines, Golden.

Salt, D. J., 1966, Tests of Drill Hole Methods of Geophysical Prospecting on the Property of Lake Default Mines Limited, Dufresnoy Township, Quebec: Mining Geophysics, Vol. 1, Case Histories, SEG: p. 206-220.

Shepard, W. M., Schnepfe, R. N., Kleinkopf, M. D. and Callahan, J., 1980, Exploration: Uranium Holds the Spotlight; Mining Engineering, May, 1980, p. 499.

Tixier, M. P. and Alger, R. P., Log Evaluation of Non-metallic Mineral Deposits; Society of Petroleum Engineers of AIME, No. 1, p. 368-388.

Water Affairs Department, 1980, Personal communication.

Wollenburg, H. A., 1977, Radiometric Methods: p. 5-34 in Nuclear Methods in Mineral Exploration and Production by J. G. Morse; Elsevier Scientific Publishing Company.

Wormald, M. R. and Clayton, C. G., 1976, Some Factors Affecting Accuracy in the Direct Determination of Uranium by Delayed Neutron Borehole Logging: Proceedings of a Symposium, Vienna, 1976 (IAEA), p. 427-470.